

**NEW ZEALAND DEFENCE FORCE ANTHROPOMETRY
SURVEY: VARIATIONS IN KINANTHROPOMETRY AND
IMPLICATIONS FOR THE NEW ZEALAND DEFENCE FORCE**

Stephven Kolose
BSc, PGDipErg, MSc

A thesis submitted to the Auckland University of Technology
in fulfilment of the degree of Doctor of Philosophy

March 2021

Supervisors:
Professor Patria A. Hume
Professor Grant R. Tomkinson
Dr Tom Stewart

Thesis Abstract

The aim of this thesis was to conduct an anthropometric survey of the New Zealand Defence Force (NZDF) and to explore potential implications and applications of 3D anthropometric data in a military clothing context.

Anthropometric data are traditionally captured by trained measurers using basic tools such as tape measures and callipers. However, these measurements can be time consuming and limited in their ability to capture true human body size and shape. The emergence of 3D body scanning can reduce measurement time while increasing the volume of measurements collected. Anthropometric datasets are beneficial to the military in terms of health, design, ergonomics, engineering, and in particular, clothing applications. Although numerous countries have conducted anthropometric surveys, research on the application of 3D anthropometric data for military clothing is limited. The New Zealand Defence Force had never had an official 3D anthropometric dataset but expressed an interest in its application to their clothing processes.

This thesis is structured into eight sequential chapters dedicated to developing and delivering a quality 3D survey methodology and protocol (Chapters 2–4), implementing the survey and building the 3D database (Chapter 5), and exploring the applications of this database to the military (Chapters 6–8).

The dataset collected in Chapter 5 consisted of traditional and 3D anthropometric measurements for 1,003 (791 male: 212 female) NZDF uniformed personnel. The final scan database contained 3,009 body scan images and 84,252 body measurements. Furthermore, the study produced a comprehensive protocol consisting of measurement and landmarking instructions for all 84 measurements collected in the survey, in addition to their respective summary statistics.

Chapter 6 identified whether there was sexual dimorphism in the NZDF by examining the absolute and proportional differences in anthropometric measurements between males and females. The findings showed that males had significantly greater absolute and proportional measurements compared to females for most measurements, except waist and thigh girth. Additionally, a combination of waist girth, hip girth, bicep girth, and biacromial breadth, could classify sex with 95% accuracy. These results could be used to guide the design of male and female variants for clothing and other military equipment.

The purpose of Chapter 7 was to determine how well decision tree models could predict tailor-assigned combat uniform sizes (the current unisex shirt and trouser in the NZ Army), and whether automatic, post-processed, or physical anthropometry measurements led to the most accurate model. The findings showed that classification was more accurate when based on the 3D automated measurements and was higher for trousers (62.8% accuracy) compared to shirts (54.9%). Body weight and waist girth were identified as the most important variables in the decision tree models. Despite the modest accuracy, these findings demonstrate that 3D anthropometric measurements, when used with decision tree models, show promise for classifying unisex clothing sizes. If refined, this system could increase the efficiency of the uniform sizing process for future military recruits.

Chapter 8 attempted to elucidate the modest prediction results in Chapter 7 by determining how anthropometric characteristics could be clustered into distinct groups and examining the characteristics of each cluster. Principal Component Analysis was used to identify key body dimensions for upper (waist girth and body height) and lower body (waist girth, hip girth, and inseam length) clustering. A combination of two-step and k-means cluster analysis resulted in six and 10 distinct clusters for female and males, respectively. Body scan images representing each cluster centroid were presented to show the variation in body shapes. The resulting cluster information could be used to develop gender-specific sizing systems.

This body of work demonstrates how traditional and 3D body scanning measurements can be used in a comprehensive anthropometric survey, measurement protocol, and database for the NZDF. This thesis illustrates that 3D anthropometric data can be applied successfully to the military. More specifically, 3D anthropometric databases have been shown to be useful for (1) identification of sex-related differences within a military population, (2) prediction of military clothing sizes using automated measurements, and (3) identification of body size groups or ‘clusters’ that can be used to develop sex-specific sizing systems. It is hoped the original information contained within this thesis will help military organisations to conduct large-scale 3D anthropometric surveys and to develop 3D anthropometric databases, which, in turn, can help provide solutions to real-world clothing-, ergonomics-, engineering-, and health-related problems.

Table of Contents

Thesis Abstract	ii
Table of Contents	iv
List of Figures	xiii
List of Tables	xvi
Attestation of authorship	1
Co-authored works	2
Research chapter contributions	5
List of abbreviations	7
Acknowledgements	8
Chapter 1 Introduction	11
Background	11
Thesis Rationale	12
Statement of Purpose	14
Thesis Organisation	15
Candidates Contributions	17
Delimitations	18
Chapter 2 An Overview of Kinanthropometry Standards and Protocols	19
Preface	19
Overview	20
What is Kinanthropometry and Anthropometry?	20
Measurements	21
Measurement protocol	22
Traditional anthropometry standards and protocols	24
Advantages and disadvantages of traditional anthropometry	28
Summary	31
Chapter 3 An Overview of 3D Body Scanning Technology	32
Preface	32
Overview	33

Introduction	33
Applications.....	34
3-D body scanners	36
Validity.....	42
Challenges	43
Postures	43
Missing data due to shading	45
Landmark extraction.....	45
Security and confidentiality.....	45
Summary	46
Chapter 4 An Overview of Military Anthropometry Surveys 2000–2020	47
Preface	47
Overview	48
Introduction	48
History	49
Notable surveys	51
Challenges and trends.....	53
Combined variable list.....	55
Summary of military surveys 2000 to 2020	59
Summary	67
Chapter 5 New Zealand Defence Force (NZDF) Kinanthropometry Survey Development	69
Preface	69
Overview	70
Anthropometry in New Zealand.....	70
New Zealand Defence Force	71
Aim.....	72
Methods	73
Sampling.....	76

Measurement extraction tools	82
Logistics and supply plan	85
Communications plan.....	86
Survey site assessment	87
Survey protocol	87
Privacy and data management.....	95
Analysis	95
Results	104
Summary	106
Chapter 6 What Absolute and Proportional Anthropometric Variables Distinguish Between Male and Female Military Personnel	109
Preface	109
Abstract	110
Introduction	111
Method.....	113
Results	119
Discussion	124
Conclusions	126
Chapter 7 Prediction of Military Combat Clothing Size Using Decision Trees and 3D Body Scan Data.....	127
Preface	127
Abstract	128
Introduction	129
Method.....	132
Results	138
Discussion	142
Conclusions	145
Chapter 8 Cluster Size Prediction for Military Clothing Using 3D Body Scan Data ...	146
Preface	146

Abstract	147
Introduction	148
Method.....	150
Results	155
Discussion	164
Conclusions	166
Chapter 9 Discussion	167
Research Summary.....	167
Significance of findings.....	168
Limitations.....	171
Future directions.....	173
Conclusion.....	174
References	175
APPENDIX I Ethics confirmation letters	195
NZDFAS Study	195
NZ Army Study	196
Ethics completion 2019	197
APPENDIX II Participant information sheet and consent forms	198
NZDFAS data collection participant information sheet.....	198
Participant informed consent NZDFAS form.....	203
Participant information sheet for NZ Army clothing study	205
Participant informed consent NZ Clothing study form.	208
APPENDIX III NZDF Uniform Size Prediction Model and Application Development: Technical Report to New Zealand Defence Force (NZDF)	210
Acknowledgements	212
Contributor’s statement	212
Research team.....	212
Overview	213
Background	215

Methods	215
Results	223
Discussion	235
Future research	237
Conclusions	238
Recommendations	238
References	239
APPENDIX IV International military survey variable comparison	244
APPENDIX V Measurements and Normative Data	256
Abdominal extension depth sitting - Post-processed measurement (mm)	259
Abdominal extension depth sitting summary statistics - Post-processed measurement (mm)	260
Acromiale height sitting - Post-processed measurement (mm)	261
Acromiale height sitting summary statistics - Post-processed measurement (mm)	262
Acromiale height - Post-processed measurement (mm)	263
Acromiale height summary statistics - Post-processed measurement (mm)	264
Acromiale-radiale length - Post-processed measurement (mm)	265
Acromiale-radiale length summary statistics- Post-processed measurement (mm)	266
Ankle girth - Automatic measurement (mm)	267
Ankle girth summary statistics- Automatic measurement (mm)	268
Arm span - Physical measurement (mm)	269
Arm span summary statistics - Physical measurement (mm)	270
Axilla height - Post-processed measurement (mm)	271
Axilla height summary statistics - Post-processed measurement (mm)	272
Biacromial breadth - Post-processed measurement (mm)	273
Biacromial breadth summary statistics - Post-processed measurement (mm)	274
Bicep girth flexed - Physical measurement (mm)	275
Bicep girth flexed summary statistics - Physical measurement (mm)	276
Bideltoid breadth sitting - Post-processed measurement (mm)	277
Bideltoid breadth sitting summary statistics - Post-processed measurement (mm)	278
Bitrignon mandibular arc - Physical measurement (mm)	279
Bitrignon mandibular arc summary statistics - Physical measurement (mm)	280

Bizygomatic breadth - Physical measurement (mm)	281
Bizygomatic breadth summary statistics - Physical measurement (mm)	282
Body height - Automatic measurement (mm)	283
Body height summary statistics - Automatic measurement (mm)	284
Breast height - Automatic measurement (mm)	285
Breast height summary statistics - Automatic measurement (mm)	286
Bust chest girth - Automatic measurement (mm)	287
Bust chest girth summary statistics - Automatic measurement (mm)	288
Buttock depth - Post-processed measurement (mm)	289
Buttock depth summary statistics - Post-processed measurement (mm)	290
Buttocks girth - Automatic measurement (mm)	291
Buttocks girth summary statistics - Automatic measurement (mm)	292
Buttock-heel length - Physical measurement (mm)	293
Buttock-heel length summary statistics - Physical measurement (mm)	294
Buttock height - Automatic measurement (mm)	295
Buttock height summary statistics - Automatic measurement (mm)	296
Buttock-knee length sitting - Post-processed measurement (mm)	297
Buttock-knee length sitting summary statistics - Post-processed measurement (mm)	298
Buttock-popliteal length sitting - Post-processed measurement (mm)	299
Buttock-popliteal length sitting summary statistics - Post-processed measurement (mm)	300
Calf girth - Automatic measurement (mm)	301
Calf girth summary statistics - Automatic measurement (mm)	302
Cervicale height sitting - Post-processed measurement (mm)	303
Cervicale height sitting summary statistics - Post-processed measurement (mm)	304
Chest breadth - Post-processed measurement (mm)	305
Chest breadth summary statistics - Post-processed measurement (mm)	306
Chest depth - Post-processed measurement (mm)	307
Chest depth summary statistics - Post-processed measurement (mm)	308
Chest height sitting - Post-processed measurement (mm)	309
Chest height sitting summary statistics - Post-processed measurement (mm)	310
Crotch height - Post-processed measurement (mm)	311
Crotch height summary statistics - Post-processed measurement (mm)	312

Crotch length - Automatic measurement (mm)	313
Crotch length summary statistics - Automatic measurement (mm)	314
Crotch waist preferred anterior - Post-processed measurement (mm)	315
Crotch waist preferred anterior summary statistics - Post-processed measurement (mm)	316
Crotch waist preferred posterior - Post-processed measurement (mm)	317
Crotch waist preferred posterior summary statistics - Post-processed measurement (mm)	318
Elbow girth - Automatic measurement (mm)	319
Elbow girth summary statistics - Automatic measurement (mm)	320
Elbow grip length - Physical measurement (mm)	321
Elbow grip length summary statistics - Physical measurement (mm)	322
Elbow rest height standing - Physical measurement (mm)	323
Elbow rest height standing summary statistics - Physical measurement (mm)	324
Eye height - Post-processed measurement (mm)	325
Eye height summary statistics - Post-processed measurement (mm)	326
Eye height sitting - Post-processed measurement (mm)	327
Eye height sitting summary statistics - Post-processed measurement (mm)	328
Foot ball circumference - Physical measurement (mm)	329
Foot ball circumference summary statistics - Physical measurement (mm)	330
Foot ball length - Physical measurement (mm)	331
Foot ball length summary statistics - Physical measurement (mm)	332
Foot breadth - Physical measurement (mm)	333
Foot breadth summary statistics - Physical measurement (mm)	334
Foot length - Physical measurement (mm)	335
Foot length summary statistics - Physical measurement (mm)	336
Forearm-fingertip length - Post-processed measurement (mm)	337
Forearm-fingertip length summary statistics - Post-processed measurement (mm)	338
Forearm-forearm breadth - Physical measurement (mm)	339
Forearm-forearm breadth summary statistics - Physical measurement (mm)	340
Grip reach - Physical measurement (mm)	341
Grip reach summary statistics - Physical measurement (mm)	342
Hand breadth - Physical measurement (mm)	343
Hand breadth summary statistics - Physical measurement (mm)	344

Hand circumference - Physical measurement (mm)	345
Hand circumference summary statistics - Physical measurement (mm)	346
Hand length - Physical measurement (mm)	347
Hand length summary statistics - Physical measurement (mm)	348
Head breadth - Physical measurement (mm)	349
Head breadth summary statistics - Physical measurement (mm)	350
Head girth - Automatic measurement (mm)	351
Head girth summary statistics - Automatic measurement (mm)	352
Head length - Physical measurement (mm)	353
Head length summary statistics - Physical measurement (mm)	354
Hip breadth sitting - Post-processed measurement (mm)	355
Hip breadth sitting summary statistics - Post-processed measurement (mm)	356
Hip breadth standing - Post-processed measurement (mm)	357
Hip breadth standing summary statistics - Post-processed measurement (mm)	358
Hip girth maximum - Post-processed measurement (mm)	359
Hip girth maximum summary statistics - Post-processed measurement (mm)	360
Iliocristale height - Post-processed measurement (mm)	361
Iliocristale height summary statistics - Post-processed measurement (mm)	362
Index finger breadth distal - Physical measurement (mm)	363
Index finger breadth distal summary statistics - Physical measurement (mm)	364
Index finger breadth proximal - Physical measurement (mm)	365
Index finger breadth proximal summary statistics - Physical measurement (mm)	366
Index finger reach - Physical measurement (mm)	367
Index finger reach summary statistics - Physical measurement (mm)	368
Interpupillary breadth - Physical measurement (mm)	369
Interpupillary breadth summary statistics - Physical measurement (mm)	370
Knee circumference - Post-processed measurement (mm)	371
Knee circumference summary statistics - Post-processed measurement (mm)	372
Knee height - Automatic measurement (mm)	373
Knee height summary statistics - Automatic measurement (mm)	374
Knee height sitting - Post-processed measurement (mm)	375
Knee height sitting summary statistics - Post-processed measurement (mm)	376

Medial malleolus-hallux length - Post-processed measurement (mm)	377
Medial malleolus-hallux length summary statistics - Post-processed measurement (mm)	378
Neck girth base - Automatic measurement (mm)	379
Neck girth base summary statistics - Automatic measurement (mm)	380
Palm length - Physical measurement (mm)	381
Palm length summary statistics - Physical measurement (mm)	382
Popliteal height sitting - Post-processed measurement (mm)	383
Popliteal height sitting summary statistics - Post-processed measurement (mm)	384
Radiale-styilion length - Post-processed measurement (mm)	385
Radiale-styilion length summary statistics - Post-processed measurement (mm)	386
Seated height - Physical measurement (mm)	387
Seated height summary statistics - Physical measurement (mm)	388
Shoulder-elbow length - Post-processed measurement (mm)	389
Shoulder-elbow length summary statistics - Post-processed measurement (mm)	390
Sitting elbow rest height sitting - Post-processed measurement (mm)	391
Sitting elbow rest height sitting summary statistics - Post-processed measurement (mm)	392
Sleeve outseam - Post-processed measurement (mm)	393
Sleeve outseam summary statistics - Post-processed measurement (mm)	394
Suprasternale height - Automatic measurement (mm)	395
Suprasternale height summary statistics - Automatic measurement (mm)	396
T2 height - Post-processed measurement (mm)	397
T2 height summary statistics - Post-processed measurement (mm)	398
Tenth rib height - Post-processed measurement (mm)	399
Tenth rib height summary statistics - Post-processed measurement (mm)	400
Thigh clearance - Post-processed measurement (mm)	401
Thigh clearance summary statistics - Post-processed measurement (mm)	402
Thigh girth - Automatic measurement (mm)	403
Thigh girth summary statistics - Automatic measurement (mm)	404
Thumb tip reach - Physical measurement (mm)	405
Thumb tip reach summary statistics - Physical measurement (mm)	406
Tibiale laterale height - Post-processed measurement (mm)	407
Tibiale laterale height summary statistics - Post-processed measurement (mm)	408

Trochanterion height - Post-processed measurement (mm)	409
Trochanterion height summary statistics - Post-processed measurement (mm)	410
Vertical trunk circumference - Post-processed measurement (mm)	411
Vertical trunk circumference summary statistics - Post-processed measurement (mm)	412
Waist breadth - Post-processed measurement (mm)	413
Waist breadth summary statistics - Post-processed measurement (mm)	414
Waist circumference preferred - Post-processed measurement (mm)	415
Waist circumference preferred summary statistics - Post-processed measurement (mm)	416
Waist depth standing - Post-processed measurement (mm)	417
Waist depth standing summary statistics - Post-processed measurement (mm)	418
Waist girth - Automatic measurement (mm)	419
Waist girth summary statistics - Automatic measurement (mm)	420
Waist height preferred - Post-processed measurement (mm)	421
Waist height preferred summary statistics - Post-processed measurement (mm)	422
Weight body mass - Automatic measurement (kg)	423
Weight body mass summary statistics - Automatic measurement (kg)	424
Wrist girth - Automatic measurement (mm)	425
Wrist girth summary statistics - Automatic measurement (mm)	426

List of Figures

Figure 1—1 Overview of thesis themes and chapters.....	16
Figure 2—1. Examples of length measurements using 1D (Radiale-stylion length), 2D or photograph-based anthropometry (Acromiale-radiale length, radiale-stylion length and hand length) and 3D (acromiale-radiale length) data collection methods. Centre photo courtesy of Mellow, Hume [57].	22
Figure 2—2. Differences in chest circumference (top) definitions when taken at the level of the scye (CAESER) or nipple (ANSUR and ISO 7250). Waist girth (bottom) is taken at the level of the narrowest point of the waist between the lower costal (10th rib) border and the iliac crest in ISAK[59], at the point of the uppermost lateral border of the right ilium (in line with the midaxillary plane) in NHANES[61] and the level of the Omphallion (navel) in ANSUR [63].	23
Figure 2—3. Common traditional anthropometry measurement tools.	26

Figure 2—4. Boney landmarks used to help identify measurements in the full ISAK level 2, 3 and 4 profile.	26
Figure 2—5. Differences in Harpenden and Slim guide skinfold callipers and an example of a broken segmometer.	30
Figure 3—1. Typical layout of a 3D body scanner. The light source and camera are both mounted on a pole system. This is an example of a laser line system.	36
Figure 3—2. Headus' <i>CySize</i> TM output. Landmarks are placed physically, then identified and labelled digitally.	40
Figure 3—3. ScanWorX (Anthroscan TM) output showing the automatic measurement function.	41
Figure 3—4. An example of a scan posture within the Vitus XXL. Body postures vary from participant to participant and if not controlled, is a potential source of measurement error.	44
Figure 5—1 A summary of the key activities during each phase. Each activity is explained in more detail throughout this book. POC refers to 'Point of Contact'.	74
Figure 5—2. NZDFAS Measurement selection and testing process.	82
Figure 5—3. Measurement room equipment layout.	83
Figure 5—4. Anthroscan TM automatic measurement software.	84
Figure 5—5. <i>CySize</i> TM (Headus Ltd) measurement software. [Top] The user can select any region of the body (green) then use the various <i>CySize</i> TM tools to determine the maximum depth within the region (using the 'x' caliper function). [Bottom] <i>CySize</i> TM contains various landmark, measurement extraction tools and image enhancement functions to obtain clear measurements.	85
Figure 5—6. NZDFAS landmarks required for physical measurements. These measurements have a dual-purpose of they can also be used for digital measurements except for menton, sellion, submandibular, tragon (right and left) and trapezius.	90
Figure 5—7. Some of the physical landmarks are converted to 'digital' landmarks (purple dot) which in turn, are used to identify and record digital measurements during post-processing.	90
Figure 5—8. NZDFAS physical measurements. All 25 physical measurements were measured with traditional anthropometric tools.	91
Figure 5—9. Body scanning process (left to right) posturing, body scan and checking and processing. Note that the lights are turned off during an actual scan. Light clothing is also desired, if not available than dark clothing will suffice.	93

Figure 5—10. The three scanning postures: Posture 1 (left), Posture 2 (centre) and seated Posture 3 (right). The black stickers represent the stickered landmarks required for the digital measurements.....	94
Figure 5—11. Output of Anthroscan™ automatic measurement based on scan posture 2.	96
Figure 5—12. Examples of measurements which required checking, adjustments, or in extreme cases, removal. In photo A the yellow line should be horizontal, in B the yellow line is drawn around the hair bun, in C the yellow line does not conform to the base of the neck, and in D the loose-fitting shorts prevented an accurate crotch measurement.	97
Figure 5—13. Common artefacts with CySize™ analysis: webbed skin (A), holes on the surface (B) or unknown objects (C).	101
Figure 5—14. The NZDFAS CySize™ measurement process.	102
Figure 5—15. Final check procedures for the NZDFS data.	103
Figure 6—1. Body scanner postures based on previous body scanning surveys (Furnell et al., 2012; Tomkinson et al., 2012b). Scan posture 1 (left), posture 2 also known as the standard posture (middle), and posture 3, seated (right).	115
Figure 6—2. Comparison of girths, breadths, lengths, and heights of NZDF personnel through the Phantom (vertical line on 0-axis). All values are mean Zp-scores. The right side of the panels shows the Cohen's d effect size for sex differences (the darker shaded boxes indicate large differences.	122
Figure 7—1. NZ Army MCU shirt and trouser (courtesy of New Zealand Defence Force).	131
Figure 7—2. Body scan posture (standard posture) used in the NZDFAS. The labels identify the 17 automatic measurements that were captured.	134
Figure 7—3. Overview of methods and analyses. Decision trees models were developed from the NZDFAS 2016-18 dataset and tested on the NZ Recruit datasets.	137
Figure 7—4. Shirt size classification for the NZ Army.	140
Figure 7—5. Trouser size classification for the NZ Army.	141
Figure 8—1. NZDFAS cluster analysis process for female-shirt, female-trouser, male-shirt and male-trouser datasets.	154
Figure 8—2. [Top] Scatter plot showing the different clusters for females shirt (body height vs waist girth) and body shape images representative of each cluster centroid [Bottom]. Scatter plot showing the different clusters for female trousers (Inseam length vs hip girth)	159

Figure 8—3. [Top] Scatter plot showing the different clusters for male shirt (body height vs waist girth) and body shape images representative of each cluster centroid [Bottom]. Scatter plot showing the different clusters for male trousers (Inseam length vs waist girth) and body shape images representative of each cluster centroid.....	161
---	-----

List of Tables

Table 4-1. A chronological review of military anthropometric surveys.....	50
Table 4-2. Summary of selected anthropometric surveys conducted between 2000 and 2020 showing sample, measurement, demographic, and technology descriptives.	57
Table 5-1. NZDFAS data collection team.	75
Table 5-2. NZDFAS full support team (including data collection team).	76
Table 5-3. NZDFAS target sample by demographics.	78
Table 5-4. NZDFAS automatic measurement validation results.	81
Table 5-5. Automatic measurements analysis challenges and solutions.....	97
Table 5-6. Part of the physical measurement's spreadsheet used during data collection.	98
Table 5-7. CySize™ challenges and solutions.....	100
Table 5-8. Basic descriptive statistics (n=84) by gender and service.	104
Table 6-1. New Zealand Defence Force Anthropometry Survey (NZDFAS) Phantom.	118
Table 6-2. Frequencies for the 1003 NZ Defence Force Personnel across five demographics of age, ethnicity, service, years of service, and trade.	120
Table 6-3. Absolute body dimension values (mm) for the 1003 NZ Defence Force Personnel.....	121
Table 6-4. Logistic regression model results showing the best variables for predicting a person's sex.....	123
Table 7-1. NZDFAS measurement methods description.	135
Table 7-2. Descriptive characteristics of the NZDFAS and NZ Army recruit samples.	138
Table 7-3. Classification results for shirt and trouser size for measurements obtained from cross-validation.	139
Table 7-4. Classification results for shirt and trouser in the recruit dataset.....	142
Table 7-5. Confusion matrix for shirt and trouser predictions in the recruit dataset. ...	142
Table 8-1 NZDFAS measurement methods description.	152

Table 8-2. Descriptive characteristics of the NZDFAS sample.	155
Table 8-3. PCA results by gender and clothing type. An asterisk “*” depicts the greatest loading factor within the associated component. Square boxes depict variables selected for clustering.	158
Table 8-4. Female shirt cluster number, measurement variable (mm) and descriptives by clothing type.	160
Table 8-5. Male cluster number, measurement variable (mm) and descriptives by clothing type.	162

Attestation of authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the award of any other degree or diploma of a university or other institution of higher learning, except where due acknowledgement is made in the acknowledgements.

Chapters 2, 3, 4 and 5 of this thesis represent four chapters that have been published in an eBook. Chapters 6, 7 and 8 represent three papers that have been submitted to peer-reviewed journals for consideration for publication. In each of these eBook chapters, submitted and accepted papers, I completed at least 80% of the manuscript while the remaining 20% was contributed by the various co-authors. All co-authors have approved the inclusion of the joint work in this doctoral thesis.

Stephven Kolose

Monday 22nd March 2021

Co-authored works

Journal manuscripts published

Kolose, S., Stewart, T., Hume, P.A., Tomkinson, G.R. (2021). Prediction of Military Combat Clothing Size Using Decision Trees and 3D Body Scan Data. *Applied Ergonomics*. 95. <https://doi.org/10.1016/j.apergo.2021.103435>.

Kolose, S., Stewart, T., Hume, P.A., Tomkinson, G.R. (2021). Cluster Size Prediction for Military Clothing Using 3D Body Scan Data. *Applied Ergonomics*. 96. <https://doi.org/10.1016/j.apergo.2021.103487>.

Journal manuscripts currently under peer review

Kolose, S., Stewart, T., Hume, P.A., Tomkinson, G.R. (2021). What Absolute and Proportional Anthropometric Variables Distinguish Between Male and Female Military Personnel? [Annals of Human Biology]

Published eBook entitled “Three-dimensional physique assessment in the military: New Zealand Defence Force Anthropometry Survey protocols and summary statistics”.
<https://doi.org/10.24135/TOAB.7>.

Kolose, S., Hume, P.A., Stewart, A. (2021). Chapter I - An overview of kinanthropometry standards and protocols, in *Three-dimensional physique assessment in the military: New Zealand Defence Force Anthropometry Survey protocols and summary statistics*. Kolose, S., Hume, P.A., Tomkinson, G.R., Stewart, A., Stewart, T., Legg, S.J. Editor. 2021, JELCKC SPRINZ: Auckland, New Zealand.

Kolose, S., Hume, P.A., Stewart, A. (2021). Chapter II - An overview of 3D body scanning technology, in *Three-dimensional physique assessment in the military: New Zealand Defence Force Anthropometry Survey protocols and summary statistics*. Kolose, S., Hume, P.A., Tomkinson, G.R., Stewart, A., Stewart, T., Legg, S.J. Editor. 2021, JELCKC SPRINZ: Auckland, New Zealand

Kolose, S., Hume, P.A., Stewart, A. (2021). Chapter III An overview of military anthropometry surveys 2000-2020, in *Three-dimensional physique assessment in the military: New Zealand Defence Force Anthropometry Survey protocols and summary statistics*. Kolose, S., Hume, P.A., Tomkinson, G.R., Stewart, A., Stewart, T., Legg, S.J. Editor. 2021, JELCKC SPRINZ: Auckland, New Zealand.

Kolose, S., Stewart, T., Hume, P.A., Tomkinson, G.R. (2021). Chapter IV New Zealand Defence Force (NZDF) anthropometry survey development, in *Three-dimensional physique assessment in the military: New Zealand Defence Force Anthropometry Survey protocols and summary statistics*. Kolose, S., Hume, P.A., Tomkinson, G.R., Stewart, A., Stewart, T., Legg, S.J. Editor. 2021, JELCKC SPRINZ: Auckland, New Zealand.

Kolose, S., Hume, P.A., Tomkinson, G.R., Stewart, A., Stewart, T., Legg, S.J. (2021). Chapter V Measurements and Normative Data for the New Zealand Defence Force (NZDF) Kinanthropometry Survey, in *Three-dimensional physique assessment in the military: New Zealand Defence Force Anthropometry Survey protocols and summary statistics*. Kolose, S., Hume, P.A., Tomkinson, G.R., Stewart, A., Stewart, T., Legg, S.J. Editor. 2021, JELCKC SPRINZ: Auckland, New Zealand.

Book chapter

Njoku, C.O., Stewart, A.D., Hume, P.A., Kolose, S. (2018). Non-imaging Method: 3D Scanning, in *Best Practice Protocols for Physique Assessment in Sport*, P.A. Hume, D.A. Kerr, and T.R. Auckland, Editors. 2018, Springer Singapore: Singapore.

Technical reports

Kolose, S., T. Stewart, and P.A. Hume, (2019). NZDF Uniform Size Prediction Model and Application Development: Technical Report to NZDF. Auckland University of Technology.

Presentations

Kolose, S. (2011). *NZDF Anthropometry Survey*. Workwear Group. Auckland. New Zealand. 11 October 2011.

Kolose, S. (2015). *NZDF Anthropometry Survey*. RNZAF Psychology Conference. May 2015.

Kolose, S. (2018). *NZDF Anthropometry Survey- Preliminary results*. Workwear Group. Auckland. New Zealand. 15 May 2018

Kolose, S. (2019). *Predicting Combat Uniform Sizes Using 3D Body Scanning*. NZDF Clothing and Logistics Directorate. 27 September 2019.

Kolose, S. and Rodrigues, S. (2018). *Safety: The Role of Kinanthropometry in the NZDF*. New Zealand Defence Industry Association – General Meeting. 15 March 2018.

Kolose. S. and Rodrigues, S. (2018). *New Zealand Defence Force Anthropometry Survey*. DTA Symposium. 2018.

Kolose. S. and Rodrigues, S. (2018). *New Zealand Defence Force Anthropometry Survey: Results Brief*. NZDF Capability Branch. 26 June 2018.

Research chapter contributions

Chapters 2–5 and Appendix V of this thesis are published in an eBook. Chapters 7–8 of this thesis have been published in peer reviewed journals. Chapter 6 is currently under peer review. The percentage contribution of each author is presented below.

Chapter 2: An overview of kinanthropometry standards and protocols.

Stephven Kolose	80%
Patria Hume	15%
Arthur Stewart	5%

Chapter 3: An overview of 3D body scanning technology

Stephven Kolose	80%
Patria Hume	6%
Arthur Stewart	7%
Grant Tomkinson	7%

Chapter 4: An overview of military anthropometry surveys 2000-2020

Stephven Kolose	80%
Patria Hume	10%
Grant Tomkinson	10%

Chapter 5: New Zealand Defence Force (NZDF) anthropometry survey development.

Stephven Kolose	75%
Patria Hume	10%
Grant Tomkinson	5%
Tom Stewart	10%

Chapter 6: What Absolute and Proportional Anthropometric Variables Distinguish Between Male and Female Military Personnel?

Stephven Kolose	80%
Patria Hume	5%
Grant Tomkinson	5%
Tom Stewart	10%

Chapter 7: Prediction of Military Combat Clothing Size Using Decision Trees and 3D Body Scan Data.

Stephven Kolose	80%
Patria Hume	5%
Grant Tomkinson	5%
Tom Stewart	10%

Chapter 8: Cluster Size Prediction for Military Clothing Using 3D Body Scan Data.

Stephven Kolose	80%
Patria Hume	5%
Grant Tomkinson	5%
Tom Stewart	10%

Appendix V: Measurements and Normative Data for the New Zealand Defence Force (NZDF) Kinanthropometry Survey:

Stephven Kolose	60%
Patria Hume	15%
Grant Tomkinson	5%
Tom Stewart	10%
Arthur Stewart	5%
Stephven Legg	5%

We, the undersigned, hereby agree to the percentages of participation to the chapters identified above:

Stephven Kolose:

Tom Stewart:

Patria Hume:

Arthur Stewart

Grant Tomkinson:

Stephven Legg:

List of abbreviations

1D	One-dimensional
2D	Two-dimensional
3D	Three-dimensional
C2	Cervicale
CA	Cluster Analysis
DOD	Department of Defence
DTA	Defence Technology Agency
NZ Army	New Zealand Army
NZDF	New Zealand Defence Force
NZDFAS	New Zealand Defence Force Anthropometric Survey
PCA	Principal Component Analysis
RNZAF	Royal New Zealand Air Force
RNZN	Royal New Zealand Navy
T2	Second thoracic vertebrae

Acknowledgements

First, I give all praise to God for all that he has done for me and my family along this journey. Thank you, Lord, and bless those who have helped me on this journey.

Thank you to my three amazing supervisors who I often refer to as my ‘dream team’. Thank you, Patria, for all that you have taught me over the past six years. It has been an honour to be your favourite student and part time chef. Thank you so much for believing in me. You have an amazing heart – God bless you and the family. To Grant, thank you for all the encouragement and support. You have done so much for me and this survey. I hope one day we will finally meet in person and spin a good yarn or three. Tom, although you came in late to the supervisory team, thank you for guiding me through the latter half of this journey. I am blessed to have you as my supervisor, mentor, friend, and unsuccessful fishing buddy. I also would like to thank my career mentors Stephen Legg, Allan Keefe, and Arthur Stewart for their contributions to the eBook. Although you are all retired, you have left a lasting impression on the next generation of anthropometrists and ergonomists. I am honoured to call you my friends. Thank you to my wonderful examiners Professors Deepti Gupta and Frances Joseph; and convener Professor Welby Ings for their valuable contributions. Thank you so much for appreciating the significance of this research, bless you.

Thank you to the Defence Technology Agency (DTA) for the support, resources, and funding for this survey. I have many fond memories of my time at DTA. Thank you to the group directors, OAHS group and support staff for giving me the opportunity to lead this ground-breaking survey for the NZDF. I would also like to acknowledge the NZDF Vice Chief of Defence (and individual service chiefs) and the NZDF Capability Branch whose funding, resources and support were also fundamental to this project’s initiation, implementation, and completion. A special thank you to all the NZDF survey participants, whose body shapes have contributed to our new data resource and sizing standard. It is not easy being measured by a stranger, but you all participated knowing that the output will bring positive change to the organisation. Thank you to Col. Stephen Piercy, Mary Roberts, Ewan Henderson, (Solider Systems, Logistics Command, Land), Maree Henderson, Armelle Leprou, Margie Browne, Wilhelmina Pou, Patricia Goddard (Workwear Group), WGCDR Gus Cabre, Baz Belzile, Colin Eddie, Louise Beattie (Aviation Medicine Unit), Jo Hughes (Org Research), Peter Coleman (OCDF) and Peter

Vasbenter (Defence Security) for their use of facilities, resources, administrative, professional, and moral support for this study.

Thank you to my hard-working NZDF data collection team especially Meagan Beaumont, Varshti Willis, Brooke Hammond and Henare Peta. We spent the best part of six months on the road together and it was a lot of fun! To Adam Dooley, thanks for your hard work during the survey. We were both away from our families for at least 3 months and never once did you complain. The success of this survey is as much yours as it is mine. Thank you to Hugh Terry, Tina Williams, and Stuart Junge for supporting the project and my studies. Sam Rodrigues and Savannah Purcell, thanks for your hard work during the analysis and your friendship. I also acknowledge the hard work done by Luke Selway, Deon Nathan, and Graham Fordy. Thank you to the individual base and camp senior leadership teams for assisting and facilitating the participant recruitment process; and providing messing facilities for our data collection team during the survey.

Thank you to my international colleagues, Nathan Daniel, Mike Dale, Tod Wachowicz (UniSA), Alistair Furnell, Jenna Coleman, Peter Blanchonette (DSTG), Brian Corner (USAFRL), Tim Guenzel (Human Solutions Ltd), Phil Dench (Headus Ltd), Hein Daanen (Vrije Universiteit) and my fellow panel members for NATO HFM panel 266 and TTCP for their endless support and training regarding CySize™ and 3D body scanning. Your training, mentorship, resources, and friendship were extremely valuable.

Thank you to the models used in this document: Adam Dooley and Edward Ashworth, Anja Zoeller, Tom Stewart, Darrell Bonetti and most importantly- myself.

I would like to thank my dear parents, Lemalu Tise and Sina, and my siblings, Esmay and Simon, for their endless love and support. I love you and thank you for being an amazing source of strength. Thank you for the sacrifices you have made, God bless you.

I personally dedicate this thesis to my four children, Alaane, Nathaniel, Oliver and Keanan. You mean the world to me. Thank you for being yourselves and filling my life with joy and purpose. Thank you for looking after mum when dad was away. May this journey of mine encourage you to follow your dreams and aim as high as you possibly can. Love you kids. I also thank my nieces Menorah, Rialani, Christabelle and Demielle for being wonderful babysitters.

Finally, if I dedicate this thesis to my children, then I share all its success with the love of my life, Gloria. Words cannot express how thankful, grateful, and lucky I am to have you in my life. Thank you for always being there for me and looking after the children when I was hardly around. You have sacrificed so much so that I can follow my dreams. When I left the NZDF in 2019 to concentrate fully on this final stretch, you helped me get through it. You deserve all the best things in life and more. I love you and I cannot wait to see where the future takes us next.

Background

Traditionally, the human body has been measured by hand using basic tools such as tapes, rulers, and callipers. Traditional anthropometry is widely considered the ‘gold standard’ method of obtaining anthropometric data [1, 2]. However, traditional anthropometry measurements can be subjective [3] and susceptible to human error. Even if the anthropometrist is experienced, obtaining measurements using traditional measurement tools can be time consuming (e.g., 40 minutes for a full ISAK profile comprising 42 measurements) and at times, invasive for the participant [4-6]. While measurement precision and accuracy has improved over time, traditional tools are limited and are unable to provide a 3D perspective of the body. The recent development of 3D whole body scanners considerably expands the repertoire of traditional anthropometry by allowing measurements of volumes, cross-sections and surface areas, and shape contours. While scanners vastly increase the range of possible measurements, they also reduce participant burden, are non-invasive, and create a permanent record of body size and shape which can be archived and revisited.

Up to date anthropometric data is particularly important for the military. Knowing the body size and shape of military personnel is critical to correctly specify, evaluate, develop, and acquire military equipment [7]. For example, aircraft, land vehicles, tanks, submarines, and weapons systems [8]. Compared to other industries, the military has one of the most extensive track record of large-scale anthropometric surveys dating back as far as the US civil war in the late 1800s [9]. Countries with a consistent history of conducting surveys are the United States [10], Canada [7], United Kingdom [11], Australia [12], and more recently, Iran [13], Brazil [14], India [15], and Ethiopia [16]. Despite the many surveys conducted, there is no universally accepted military anthropometric protocol. As such, comparisons of anthropometric measurements or data across time and populations is challenging.

Thesis Rationale

The New Zealand Defence Force (NZDF) is “part of New Zealand’s broader national security system and works closely with the New Zealand Ministry of Defence and other agencies to protect and advance New Zealand’s national security interests” [17]. The NZDF ($n = 12,297$) comprises three services, the New Zealand Army (NZ Army; 38% of NZDF), Royal New Zealand Navy (RNZN; 18%), and the Royal New Zealand Air Force (RNZAF; 20%), as well as a civilian population (24%) based on 2019 data [18]. Between 2016 and 2018, the Defence Technology Agency (DTA) — the science, research, and development agency for the NZDF — and the AUT University Sports Performance Research Institute New Zealand (SPRINZ), conducted the first tri-service 3D anthropometric survey in New Zealand.

The NZDF has never had an official anthropometric dataset. Previous large-scale anthropometric surveys in the NZDF have been limited to aircrew in 1974 [19] and soldiers in 2011 [20]. The aircrew survey had limited demographic representation (e.g., NZ European male pilots only) while the soldier survey concentrated on foot measurements only (e.g., foot lengths, breadths, and circumferences). A limited anthropometric profile is collected annually by the Royal New Zealand Air Force as part of their pilot selection process and in-cockpit assessments [21]. Anthropometric data for the NZDF civilian population are also limited. In the absence of these data, studies have estimated measurements based on overseas data. For example, Slappendel and Wilson [22] used the ratio scaling method by combining British data [23] with NZ stature data from the Life in New Zealand Survey [24]. A new military anthropometric dataset will provide the NZDF with accurate information that can inform health, engineering, ergonomics, design, and clothing research.

Despite numerous military anthropometric surveys worldwide, and the increasing prevalence of 3D body scanning technology, there is still limited application of 3D anthropometry data in the military. For example, a survey of subject matter experts in military clothing [25] found that: only 30% of respondents utilised 3D body scanning for clothing specification and issuing; only 63% indicated that their current sizing systems were adequate for their needs; 74% received frequent complaints about fit and sizing of clothing; and 85% wanted better guidance on how to translate body dimensions into an effective and optimised sizing system. This culminated in a report by the NATO task group that recommended more countries procure 3D body scanners to record the shape

and dimensions of their personnel, train staff to use and validate scanning systems, as well as encouraging the international sharing of anthropometric data [25].

The high levels of dissatisfaction with clothing fit observed in the NATO survey may be attributable to sex differences. In the military, the number of females is increasing worldwide [26, 27] yet military uniforms and garments are traditionally designed from male body dimensions. Rather than creating a separate female variety, military uniforms have largely remained unisex with females having to ‘put up with’ garments originally designed for the male form. There have been various attempts to better understand and accommodate females, including producing sizes that are scaled down versions based on male proportions [27-30]. However, this is problematic because proportional differences between genders might mean that scaled down versions are inadequate. Although literature exists on the sex-related differences in body dimensions between males and females [31-42], little is known about the role that absolute and proportional differences between sexes play in clothing sizes. One reason why the NATO respondents requested more guidance on the application of anthropometric data to sizing systems is because anthropometric datasets are usually high-dimensional datasets; meaning, they can comprise more than 100 body dimensions [43, 44]. Fortunately, various statistical and data mining techniques have recently been used to understand anthropometric data (both traditional and 3D) for the purposes of classifying clothing size and developing sizing systems [45-48]. However, this area of research is still in its infancy.

This thesis intends to examine how 3D anthropometric surveys are conducted, as well as exploring the practical application of these data in the military. This thesis reviews recent military anthropometric surveys to develop, test, and implement the first 3D anthropometric survey for the NZDF. The application of these data will be explored within a clothing context, with the intention of improving military sizing processes. It is hoped these studies will make novel contributions to research, but also have wider implications in the design of military equipment.

Statement of Purpose

The overall aim of this thesis was to conduct an anthropometric survey in the New Zealand Defence Force and explore potential implications and applications of 3D anthropometric data in a military context. To achieve this aim, the thesis is organised into several chapters, where the primary objectives were to:

- Conduct a 3D anthropometric survey of the NZDF, by:
 - ❖ Reviewing existing literature, with a focus on traditional anthropometry (Chapter 2), 3D body scanning (Chapter 3) and anthropometric surveys in the military (Chapter 4);
 - ❖ Developing a survey methodology and conducting the survey (Chapter 5);
 - ❖ Presenting a summary of the data using descriptive statistics (Appendix V).
- Examine how 3D anthropometric data could benefit military clothing by:
 - ❖ Examining how absolute and proportional body measurements vary between males and females, and the implications for clothing garments (Chapter 6);
 - ❖ Determining whether statistical models can predict tailor-assigned combat uniform sizes, for the purpose of streamlining existing sizing processes (Chapter 7);
 - ❖ Exploring how anthropometric characteristics of the NZDF population cluster, to inform the development of new sizing systems (Chapter 8).

Thesis Organisation

Thesis Structure

Chapters 2–5, and Appendix V of this thesis are published as a standalone eBook titled “*Three-dimensional physique assessment in the military: New Zealand Defence Force Anthropometry Survey protocols and summary statistics*”. This provides a summary of the survey development and protocols. The original research chapters in this thesis (Chapters 6–8) focus on the application of the survey data. These are presented as they have been submitted to, or accepted in, the target journals. Therefore, some repetition of information occurs. Each chapter begins with a preface to provide the logical link between chapters. The themes of each chapter follow a sequential progression that culminates in a cohesive whole. Each paper was reviewed and authorised for publication by the New Zealand Defence Force. The present thesis is organised into six chapters (Figure 1—1).

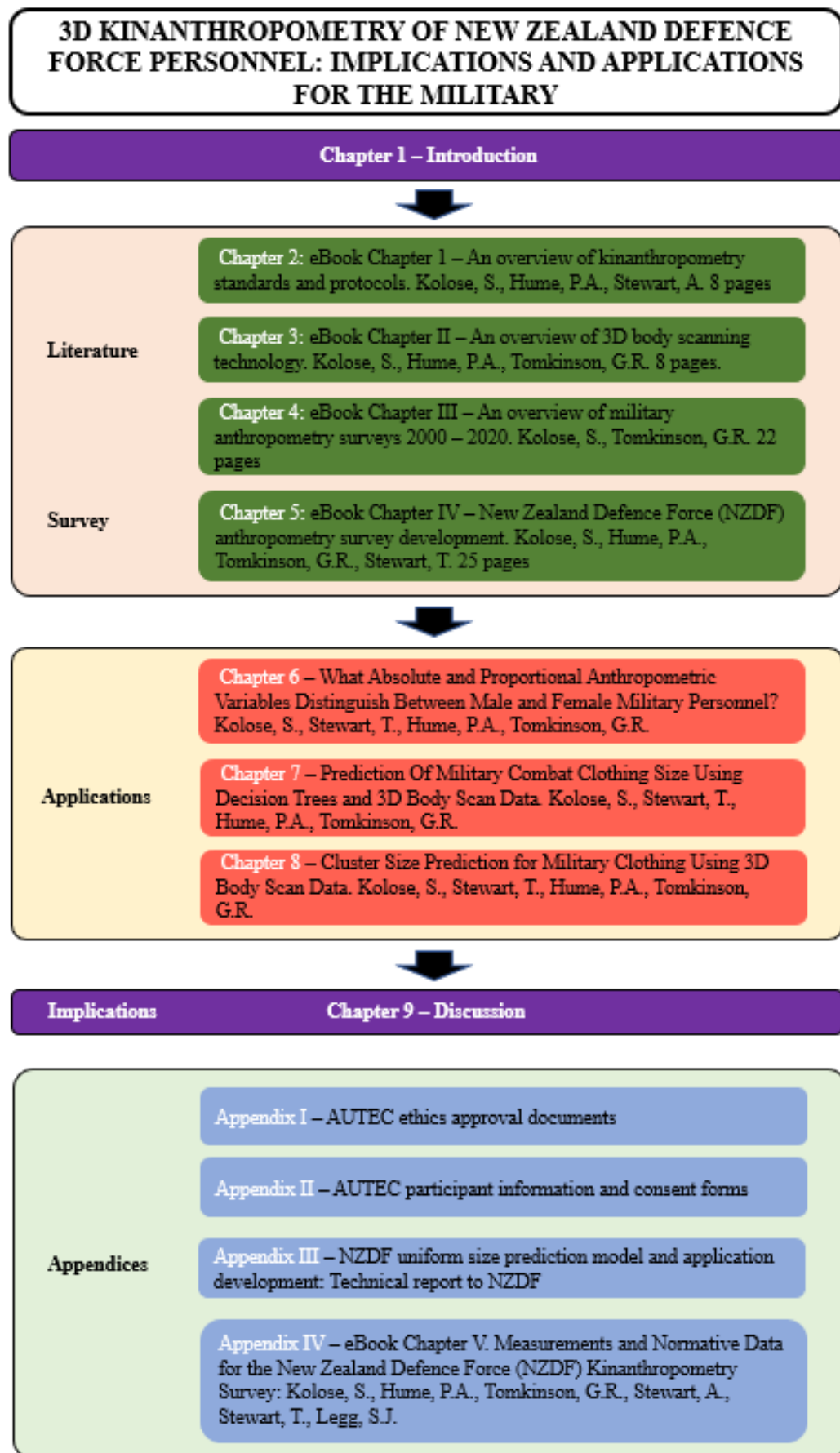


Figure 1—1 Overview of thesis themes and chapters.

Candidates Contributions

This thesis fulfils the requirements of an Auckland University of Technology Doctoral degree through a significant and unique contribution to this field; the development of 3D anthropometric-based models to classify, and help develop, sizing systems for the military. The research questions in this thesis were developed by me in collaboration with my supervisors. Through this process, I have developed research skills and attitudes necessary to operate in the academic sphere.

Although this body of work was nested within the New Zealand Defence Force anthropometry program, I played a critical role as the project lead for both the NZDF (employed as a science researcher) and AUT (principal investigator and doctoral student). I participated in all data collection sessions, was responsible for introducing new accredited anthropometrists to the NZDF; and designed, tested, and developed the survey procedures. I trained staff and contractors to use the CySize™ software to obtain the post-processed measurements. I provided key feedback which led to new design features added to the CySize™ software. The preparation of all survey (traditional and 3D body scanner) equipment, protocols and calibration tests were my responsibility for all data collection activities. I led the data analysis for the survey with assistance from Dr Tom Stewart, Dr Sam Rodrigues, Mrs Savannah Purcell, Mr Luke Selway and Mr Deon Nathan. I was responsible for writing the eBook parts and manuscript documents for journal publication with oversight from the supervisory team and other co-authors, including international subject matter experts and advisors. I led the NZ Army recruit clothing study in Waiouru with support from Professor Patria Hume, Dr Tom Stewart, Mr Hugh Terry, Dr Sam Rodrigues and the NZDF Clothing and Logistics Directorate. I conducted various presentations and briefings to promote and share the study findings both within New Zealand (DTA symposium, Navy engineering conference, New Zealand Defence Industry Association annual conference, Solider Systems HQ and ISAK accreditation courses) and abroad (The Technical Cooperation Programme, NATO technical panel).

Delimitations

The following are the delimitations of the research projects presented in this thesis.

- ❖ The NZDFAS sample excluded civilian and reservist population as the focus was on regular force personnel.
- ❖ The NZDFAS sample population excluded participants on deployment or outside the main military camps and bases in New Zealand.
- ❖ This research focussed on anthropometry and 3D body scanning in the military clothing industry. There is a substantial amount of research in the commercial clothing industry with regards to this topic. However, we had insufficient time and funding to purchase and review these systems. As a result, we chose to use a more cost-efficient option by way of data mining methods to interrogate our dataset. In the future, we would like to conduct a more thorough review of these ‘off-the-shelf’ systems and their comparisons to traditional methods in more detail.
- ❖ Specific measurements in the measurement validation study did not achieve acceptable limits. However, they were still included in the automated (derived from the 3D scan) measurements protocol to (a) reduce participant measurement time (e.g., head, ankle, and bust chest girth) or (b) they were deemed too invasive to measure physically (e.g., vertical trunk circumference or crotch length).
- ❖ Sitting height was originally an automatic measurement. However, after a review of the first data collection activity, it was derived physically for the remainder of the survey. Therefore, the survey at the first camp contained no data for sitting height.
- ❖ The validation of post-processed measurements in the CySize™ software could not be performed due to funding restrictions during the survey protocol testing period. To assist, subject matter experts from the University of Australia provided guidance on the suitability of using CySize™ through (1) one-to-one training in Adelaide, and (2) measurement review meetings in Auckland.

Stephven Kolose, Patria Hume, Arthur Stewart

Preface

Traditionally, anthropometric data are captured physically by trained anthropometrists, using various tools and in strict accordance with defined protocols. This chapter briefly reviews the literature on the key concepts of kinanthropometry and anthropometry. It also describes different physical measurement protocols and the advantages and disadvantages of traditional anthropometry. An understanding of these concepts is vital for large-scale anthropometric survey planning, especially since most surveys to date have relied largely on traditional anthropometric measurement. This is the first of four eBook chapters presented in this thesis.

Overview

There is no universally accepted protocol for three-dimensional (3D) human body scanning. This book has been produced as a call for international standards in 3D body scanning. Initial 3D body scanning protocols were lodged with the J.E. Lindsay Carter Anthropometry Archive in 2014 [49].

Throughout this book, 3D body scanning is discussed as a tool that captures, measures, or records anthropometric data. Three-dimensional body scanning uses laser, light or infra-red technologies to determine surface anthropometry characteristics such as body volume, segment lengths and girths. Body posture during scanning is important to ensure accurate measures can be made from the scan images. The images vary depending on the configuration, resolution, and accuracy of the scanner.

Scanning technology is expensive given the hardware and software required, and only provides surface anthropometry characteristics. For physique assessment including estimates of body composition, body size, and shape, the International Society for the Advancement of Kinanthropometry (ISAK) protocols should be followed. The advantages of the ISAK surface anthropometry methods are that assessments take approximately 10 minutes for a restricted profile, up to 40 minutes for a full profile, and the equipment is readily available, less expensive, and easily calibrated. The ISAK methods are valid and reliable if ISAK training is undertaken to ensure correct landmarking is performed.

What is Kinanthropometry and Anthropometry?

Kinanthropometry is the study of human size, shape, proportion, composition, maturation, and gross function. Kinanthropometry can also be defined as a process of measuring a body in motion; or measurements that capture the change in dimensions of body parts or the range of movement of body joints (also termed ‘functional’ or 4D measurements) [50]. The term is named from the Greek root words *kinein* (to move), *anthropos* (human) and *metrikos* (the act of measuring) [51]. Anthropometry is part of the field known as kinanthropometry, which can be defined as: “The academic discipline which involves the use of anthropometric measures in relation to other scientific parameters and/or thematic areas such as human movement, physiology or applied health sciences” [52].

A pioneer of anthropometry, Quetelet in 1870 attempted to obtain measurements of the ‘average’ man to provide better-fitting uniforms for Napoleon’s army. In the 1950’s anthropometrics became a recognized scientific discipline. Today a more contemporary definition of anthropometry is: “The scientific procedures and processes of acquiring surface anatomical dimensional measurements such as lengths, breadths, girths and skinfolds of the human body by means of specialist equipment” [52].

Anthropometry is associated with measurements of body size, shape, strength, mobility, flexibility, working capacity [53] and the study of body dimensions (e.g., lengths, breadths, girths skinfolds) that utilize surface landmarks for reference [54]. Anthropometry is used in the design of vehicles, work sites, equipment, aircraft cockpits, clothing [5], sports science and ergonomics [55]. Anthropometric data provide designers with the physical and functional characteristics of potential end-users which can be applied to many design solutions. Poor quality, or a lack of anthropometric data, can result in failure to accommodate individuals in the workplace, customer dissatisfaction, and may lead to discomfort, accidents and injury [56].

Measurements

Anthropometric data comes in many forms that include one-, two- and three-dimensional data (Figure 2—1). One-dimensional (1D) data is identified easily as there is only one number (e.g., body height = 1670 mm) [56]. One-dimensional data are often captured using traditional anthropometry or ‘direct’ measurements obtained by a skilled anthropometrist. The measurements are captured using tools such as tapes, callipers, or a stadiometer. Two-dimensional (2D) anthropometry data have two dimensions (i.e., x and y) which can be extracted from a two-dimensional source such as a photograph. Digital photogrammetry is a method of measuring limb segment dimensions from photos [57]. Three-dimensional (3D) anthropometric data have three dimensions (i.e., x, y, z) which can be extracted from a 3D body scanner [58].

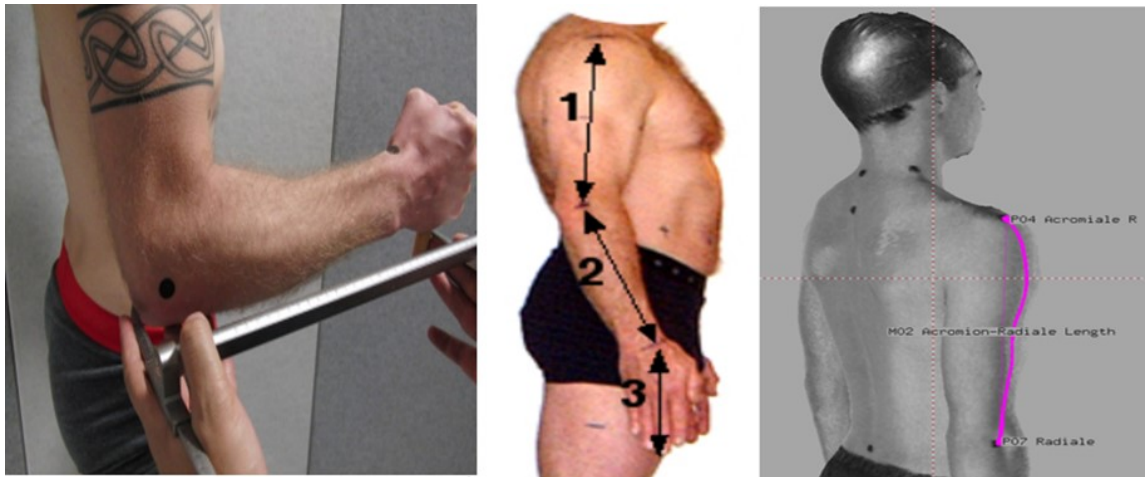


Figure 2—1. Examples of length measurements using 1D (Radiale-styilion length), 2D or photograph-based anthropometry (Acromiale-radiale length, radiale-styilion length and hand length) and 3D (acromiale-radiale length) data collection methods. Centre photo courtesy of Mellow, Hume [57].

The three types of anthropometric data rely on several important factors. The measures are acquired by skilled anthropometrists who are trained to use specialised equipment. All participants must be minimally clothed or wear tight fitting garments. Most measurements require the location and placement of bone landmarks (especially for segment lengths). Measurements are generally conducted on one side of the body because fat patterning is largely symmetrical within measurement precision, however, muscle development can show marked asymmetry, especially in the upper limb. The survey purpose may require both, left, right, preferred, or non-preferred limb sides to be measured.

Measurement protocol

An anthropometric protocol or measurement profile (also referred to as a landmark profile) refers to instructions or guidelines on how to conduct anthropometric measurements. There are many anthropometric protocols in use today, each having bony landmark sites and measurement definitions [54]. The most well-known civilian and military protocols are:

- ❖ Military Handbook: Anthropometry of the U.S. Military Personnel [8]
- ❖ International Society for the Advancement of Kinanthropometry (ISAK) [59]
- ❖ Civilian American and European Surface Anthropometry Resource (CAESAR) [60]
- ❖ National Health and Nutrition Examination Survey (NHANES) [61]

- ❖ ISO 7250 standard [62]
- ❖ US Army Anthropometry Survey (ANSUR) [10]

We describe military anthropometry protocols and measurements later in this book. Despite the number of protocols there is no ‘universal anthropometric’ protocol. Such a title would be difficult as many existing protocols differ with respect to measurement and landmark terminology, definition, and implementation. For example, measurements such as height are also known as stature, sitting height can also be called seated height, and weight is also referred to as body mass. Stature can be ‘stretched’, via upward traction of the mandible by the measurer, which minimises diurnal height loss, or not stretched. Chest girth (or circumference) is defined by some protocols as the circumference around the scye or armpit (CAESER) or at the level of the thelion or nipple (for males) (ANSUR and ISO 7250) (Figure 2—2). Chest circumference measurements can vary with the ISAK protocol – chest girth is recorded at end-tidal (fully exhaled breath) while other protocols [59] take the maximum circumference value.

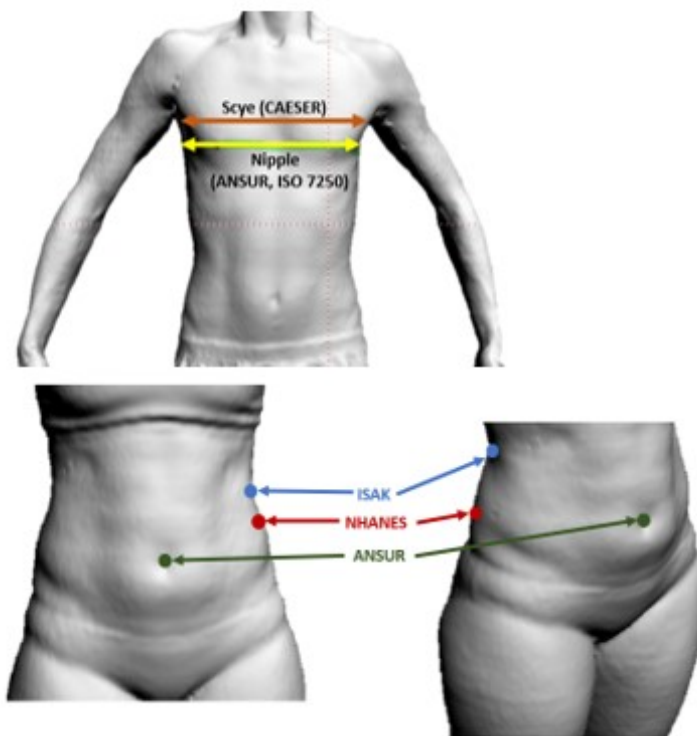


Figure 2—2. Differences in chest circumference (top) definitions when taken at the level of the scye (CAESER) or nipple (ANSUR and ISO 7250). Waist girth (bottom) is taken at the level of the narrowest point of the waist between the lower costal (10th rib) border and the iliac crest in ISAK[59], at the point of the uppermost lateral border of the right ilium (in line with the midaxillary plane) in NHANES[61] and the level of the Omphallion (navel) in ANSUR [63].

Protocols such as ISAK and ISO 7250 are examples of internationally recognised, stand-alone anthropometric standards. However, a large proportion of the ISAK and ISO 7250 measurements (based on the civilian population) do not feature in various military anthropometry survey protocols such as ANSUR and vice-versa. The same can be said for measurements between ISAK (with origins in the field of human biology sport and exercise science) and ISO 7250 (an ergonomics-orientated protocol). For example, ISAK does not include ISO 7250 measurements such as popliteal height and elbow height which are critical to ergonomics workstation design [64]. Furthermore, the same issue of ambiguity of measurement names, landmarks and definitions persist. The differences between various protocols measurement terminology or definitions are likely discipline related.

Literature comparing existing anthropometric measurement protocols and standards is limited. Researchers have provided commentary on how future anthropometric protocols should be theorised, written, implemented, and shared. The book chapter “Towards a generalised anthropometric language” [65] provides a Generalised Anthropometric Language (GAL) mechanism by which future protocols should be designed. It was recommended that the GAL would entail landmarks being defined by using a description of anatomical terms and sites, and a combination of dimensions would make up an anthropometric protocol. It was envisaged that the GAL would help establish links between protocols and therefore between studies. A well-defined GAL with syntactic rules would help instruct researchers to refine and explicitly record their techniques. It would also decrease the incompatibility and confusion that exists between researchers using different anthropometric protocols. We support this approach and have therefore produced this book as a call for international standards in 3D body scanning.

Traditional anthropometry standards and protocols

This next section discusses the most widely used traditional anthropometric measurement and landmarking protocols and standards for measuring civilians (i.e., military anthropometric protocols are covered in a later section).

The International Society for the Advancement of Kinanthropometry (ISAK)

The International Society for the Advancement of Kinanthropometry was formed in 1986 by experts in the fields of sport, exercise science and human biology seeking methods to standardise practice. This was a collective effort to limit vague and ill-defined definitions

of previous protocols which did not allow for exact landmark location, delineation and a systematic approach to quality control [66].

The ISAK scheme became highly popular due to (at the time) several innovative features. For example, ISAK was one of the first schemes to introduce a teaching and practice structure based on a 4-level hierarchy of practitioner licensing, based on competency as assessed by a practical exam. As part of this process all measurers were required to pass error control targets in terms of reproducibility in a standardised setting.[66] While other schemes focus on the reproducibility of measurers within a single lab setting, the ISAK's inter-measurer and intra-measurer reliability protocols enabled comparisons of measurers across different lab settings. The ISAK scheme has a strict focus on identifying landmarks consistently and accurately to enable accurate measurements. ISAK was one of the first schemes to utilise raw data scores (as opposed to conversion into % fat values) as a result of strict protocol definitions and quality assurance of individual measures [66]. Compared to other anthropometric protocols, ISAK is very descriptive and is specific with regards to measurer, client and equipment positioning and recording. The accreditation or license period is 4 years plus an additional 6 months aside for levels 2 to 4 to complete their 20 practical profiles. The extension period is only 4 months for level 1 students to complete their profiles (as their profiles contain less measurements).

There are some disadvantages with the ISAK system. For example, measurers with little to no background in human biology may struggle with the anatomical terminology and the identification of landmark sites. The teaching structure in level 1 (beginner level) provides theory and practical sessions to ensure adequate understanding of anatomical bony locations and performance of measurements based on the landmarks. Success during the course comes down to practical experience and a firm grasp of terminology and fundamental skills.

Courses can be perceived as costly given the need for the limited number of ISAK level 3 or 4 instructors to travel for delivering courses. There is a substantial cost associated with purchasing anthropometry equipment for a full profile set of measurements. The standard anthropometry kit consists of small and large bone callipers, small and large sliding callipers, a segmometer, skin fold callipers and a metal girth tape (Figure 2—3). Weight scales, anthropometry box and stadiometers are purchased at additional cost to the standard anthropometry kit.

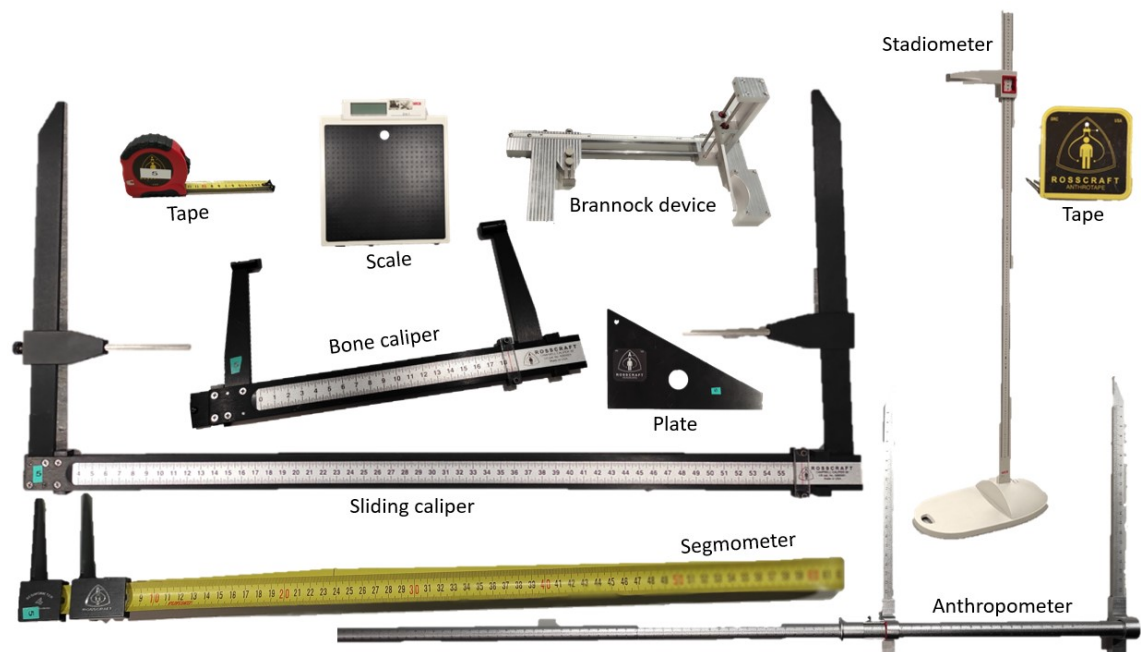


Figure 2—3. Common traditional anthropometry measurement tools.

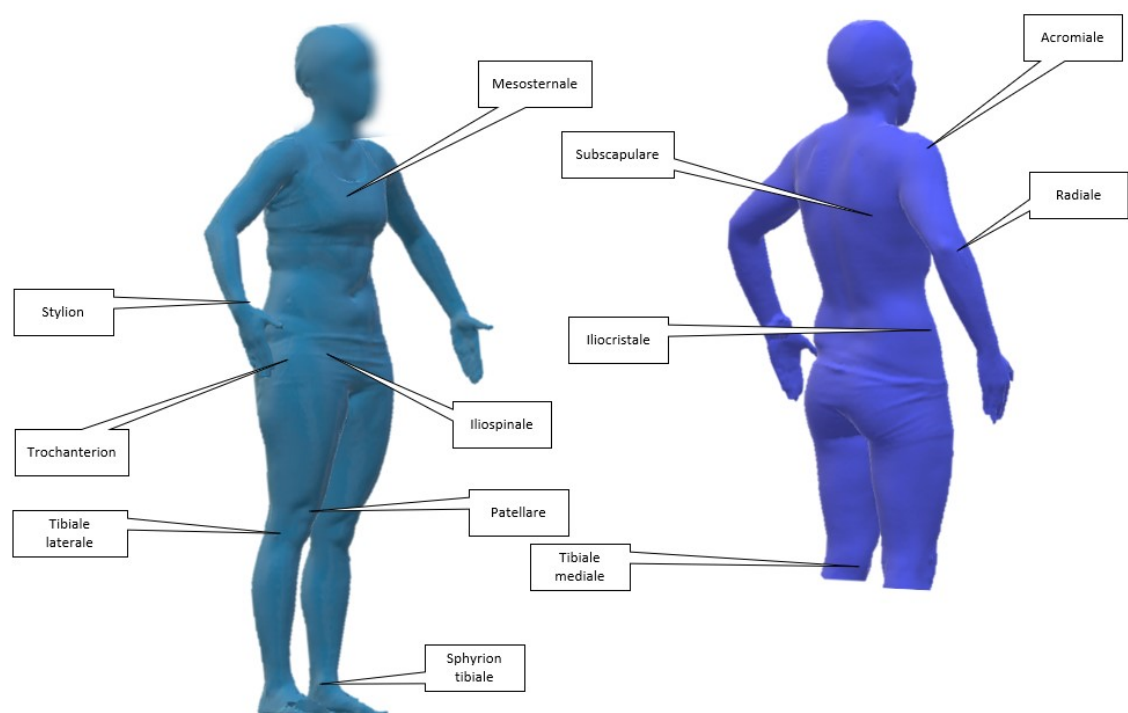


Figure 2—4. Boney landmarks used to help identify measurements in the full ISAK level 2, 3 and 4 profile.

The ISAK protocol consists of restricted (18 measurements taught in the level 1 course) and full (43 measurements taught in the level 2 course) profiles [67]. Both profiles consist of basic (mass, stature and sitting height, arm span), skinfolds (triceps, subscapular, bicep, iliac crest, supraspinale, abdominal, front thigh and medial calf), girths (arm flexed and tensed; waist gluteal and calf), and breadths (humerus and femur). The additional measures in the full profile include girths (head, neck, forearm, wrist, chest, thigh-gluteal,

mid-thigh, ankle), breadths (biacromial, biiliocrystal, bi-styloid, transverse chest, anterior-posterior chest, anterior-posterior abdominal), lengths (acromiale-radiale, radiale-styilion, midstyilion-dactyilion, trochanterion-tibiale laterale, tibiale mediale-sphyrion tibiale, foot) and heights (iliospinale, trochanterion, tibiale laterale). The ISAK full profile consists of 12 bony landmarks that are used to assist the measurement process (Figure 2—4).

Currently there is no publicly available database from ISAK that is accessible for comparison of body composition data.

Civilian American and European Surface Anthropometry Resource (CAESAR)

CAESAR was the first 3D whole-body surface anthropometry survey [68] of three civilian populations (United States of America, the Netherlands and Italy) conducted by the U.S. Air Force, Syntronics Inc, the Netherlands Organization for Applied Scientific Research (TNO) and a consortium of companies under the Society of Automotive Engineers (SAE) [69].

The CAESAR database consists of approximately 12,000 body scan images taken between 1998 and 2000 of over 4,000 men and women, aged 18–65, covering various weights, ethnic groups, geographic regions, and socio-economic status.

World Anthropometry Engineering Report (WEAR)

The WEAR web-portal was set up by experts in engineering anthropology to unify 145 anthropometric databases across 10 countries and six continents [70]. The web-based database of 3D size, shape, fit and performance data is maintained by members of the WEAR organisation [71].

The WEAR database includes 250,000 participants (men, women, and children, from civilian and military populations) with approximately 50 traditional anthropometric dimensions collected on each individual making over 12 million individual datum. Datasets date from the 1950s, with most post-1970, and more than 20 large datasets collected post-1990 [70].

The WEAR portal contains checklists for measurement validity (sampling, subject population, and secular change), comparability (definition of measurements), and accuracy (before, during, and after measurement capture), lessons learned, fit and accommodation maps, human size and shape information, 3D visualisation, statistical analysis tools and fit prediction models.

International Standards Organization (ISO)

The International Standards Organization describe anthropometric measurements, instruments, standard postures, clothing, and measurer training. ISO guidelines enable practitioners (especially ergonomists) to apply their knowledge to the geometric design of workplaces, tools, apparel and to enable comparison of anthropometric data from different international populations [72]. Example ISO standards with respect to anthropometry include:

- ❖ “ISO 15535: 2012 General requirements for establishing anthropometric databases” describes the general requirements for establishing anthropometric databases, their associated reports and measurements taken in accordance with ISO 7250-1. It provides information such as characteristics of the user population, sampling methods, measurement items and statistics, to make international comparison possible across various populations.
- ❖ “ISO 7250-1: 2017 Basic human body measurements for technological design - Part 1: Body measurement definitions and landmarks” serves as a basis for extracting one- and two-dimensional measurements from three-dimensional scans (specified in ISO 20685). It provides guidance on how to take anthropometric measurements and gives information to the ergonomist and designer on the anatomical and anthropometrical bases and principles of measurement, which are applied to design tasks. The standard is intended to be used in conjunction with national or international regulations or agreements to ensure coherence in defining population groups and to allow comparison of anthropometric data among member samples.

Advantages and disadvantages of traditional anthropometry

The advantage of traditional anthropometric protocols such as ISAK, ISO and CAESAR are that they have been developed by experts in the field. The protocols have been refined over time to increase accuracy and establish competency and efficiency when taking and recording measurements (for instance the technical error of measurement).

Traditional methods use measurement equipment that is easy to transport. Although the equipment can vary in design and build quality, accurate measurements can be obtained if the equipment is routinely maintained and calibrated, and the measurer is skilled and experienced in its use.

Traditional measurements require only enough space (e.g., a small office) to enable the participant and measurement technician to complete the anthropometric profile. The traditional anthropometrist is trained to utilise various structural features of a room to make measurements efficient. For example, utilizing the corners of a room as a ‘zero’ point for arm span measurements. Seated leg length measurements (e.g., buttock to heel) can be made with the participant sitting against a wall. The room ceiling can be used to conduct standing arm reach measurements. These room ‘features’ such as the location of windows or doors can influence how the anthropometrist sets up the equipment, or the order in which to take body measurements and landmarking. Whatever the environment, it is important that measurements can be made consistently with minimal changes between settings. Although the precise protocols are robust the timing is flexible.

With international accreditations like ISAK, accredited anthropometrists are trained to identify, implement, and record measurements consistently. This ensures that measurements are acquired in the same way with confidence.

There are, however, disadvantages of traditional anthropometry. Measurements can be subjective [3] and susceptible to human error. The experience, expectations, training, and accuracy of the measurer can influence the results [73]. Traditional measurements are subject to observer error in landmark location, participant positioning and instrument applications [74].

Traditional measurement surveys are also expensive to plan and conduct [54]. Costs include equipment hire or purchase, booking of the testing location, accommodation facilities and travel. Costs will vary depending on the sample size required, the number of landmarks and measurements required, and the availability and locality of participants and measurement personnel.

Despite the precision of a skilled anthropometrist, the use of traditional measurement tools to obtain measurements is time consuming (e.g., 40 minutes for a full profile) and at times, invasive for the participant [4]. Equipment has varying levels of precision with Harpenden skinfold callipers (Figure 2—5) enabling readings to 0.1 mm versus 0.5 mm for SlimGuide skinfold callipers. Tools such as the tape-based segmometer (Figure 2—5) can be fragile and bend or break after prolonged use. Tool-related maintenance tasks are required such as checking springs (coil properties may change with time or be affected by contaminants, including rust), lubrication of joints, bolt, or screw tightness.



Figure 2—5. Differences in Harpenden and Slim guide skinfold callipers and an example of a broken segmometer.

The high variability in intra and inter-observer traditional measurements [75] is increased for atypical body types [34, 76]. For example, in a study of intra-abdominal bleeding [77] there was a 6 cm difference in patient waist girth measurements across 10 measurers. Inter-observer variability using traditional measurements of thigh girth has been reported as 8.27% (4 cm difference)[78]. This was in contrast to errors of 0.2–0.5 cm reported for the same measurement [73, 79, 80]. To minimise these errors, protocols such as ISAK suggest using multiple measurements with calculation of the mean or median. The differences between measurements must lie within an acceptable measurement limit depending on the type of measurement performed. In ISAK, these limits are <5% for skinfolds and <1% for all other measurements (e.g., breadths, girths, and lengths). Furthermore, the real virtue in tight error control is to become capable of detecting small changes in measurements which are real. The main disadvantage of taking multiple measurements is that it is time consuming [5, 6, 73, 81].

Traditional anthropometric protocols, while providing good accuracy for linear and circumference measurements, provides limited information for volume, area, body size and shape [4, 7, 73]. The use of anthropometry has stagnated [82] with static or one-dimensional measures. While the Whole-Body Surface Area (WBSA) equation [83] was based on one dimensional measurements, the three-dimensions of the body should be measured using techniques that provide three-dimensional outputs [4].

Summary

Kinanthropometry is a scientific field that is traditionally associated with physical or ‘hands on’ measurements conducted by experienced anthropometrists. No universal anthropometric protocol exists as many disciplines such as ergonomics, sports science, clothing design, and manufacturing have developed their own set of standards targeted to their own industry. Traditional methods have been tested, validated, and quantified to a point where measurement skills are taught internationally to practitioners. Despite their historical success in many larger-scale surveys, traditional anthropometric measures do possess shortcomings, many of which can be addressed with modern day technology. Chapter 2 of this book outlines the advantages and disadvantages of 3D body scanning and the implications for kinanthropometry.

Stephven Kolose, Patria Hume, Arthur Stewart, Grant Tomkinson

Preface

The preceding chapter described the key concepts of traditional anthropometric measurement. While this method has remained the ‘gold standard’ for population surveillance for many decades, a new technology has emerged that has the potential to revolutionise the way anthropometric data are measured. The purpose of Chapter 3 was to introduce 3D body scanning by focusing on different scanning technologies, 3D measurement validity, its applications, and a summary of the potential challenges. Knowing the strengths and limitations of this technology is crucial for 3D anthropometric survey planning. This is the second of four eBook chapters in this thesis.

Overview

Throughout this book, 3D body scanning is discussed as a tool that captures anthropometric data. This chapter summarises what 3D body scanners are, the applications, types of body scanning systems, associated software, validity, reliability, and challenges.

Introduction

What is 3D body scanning?

A whole-body scanner is an optical 3D measuring system that produces a digital copy of the surface geometry of the human body. The purpose of the 3D scan is to capture an outside surface of the body using optical techniques in tandem with light sensitive devices without the need to touch the body.

Commercially made full-body 3D body scanners were available since the late 1990s [84]. They were initially made for anthropometric research, the clothing industry (individual and tailored clothing) [85], the entertainment industry (special effects in movies), computer animation and medicine (e.g., prosthetics and plastic surgery) all with the purpose of measuring the human body [86]. As the technology developed, it was used by western countries for systematic anthropometric population measurement for clothing and textile design. Current 3D body scanning systems, designed by different manufacturers, differ in the number (and quality) of cameras, scanning range, light sources, and also in the sophistication of the accompanying computer programs used for visualization and measurement analysis [71].

Many large-scale (national) anthropometric surveys have utilised 3D body scanning in countries such as the USA [87], North America [88], Thailand [89], India [90], Spain [91], Belgium [92], Mexico [93], Romania [94], Brazil [95], Italy [96], Portugal [97] and China [98]. Most of these studies focussed on apparel and automotive industries where accurate anthropometry are required for well-fitted clothing and ergonomic cars [99].

Why Measure Physique Using 3D Scanning?

The introduction of 3D scanning reduced the need to have consistent physical contact with the body. However, surface markers can be placed on the body as reference points to check. Scanners vastly increase the range of possible measurements and create a permanent record of body size and shape that can be archived and revisited. This is advantageous for traditionally ‘uncomfortable’ measurements such as crotch height (where some anthropometric protocols require the measurer to place an anthropometer on the inferior-lateral aspect of the male genitalia). Even if participants are scanned in tight fitting garments, the measurements can still incur a systematic bias.

The availability of 3D whole body scanners provides the ability to take rapid simultaneous measurements, and automated data extraction and analysis. It has the potential to revolutionise surface anthropometry [100]. With these new capabilities, it is possible to easily quantify dimensions such as projected frontal areas, limb volumes, limb cross-sectional areas, and abdominal cross-sections and volumes. It is also possible to quantitatively describe shapes and shape changes. The main driver behind 3D scanner development has been the apparel industry. The technology can enable the possibility of creating garments on demand, tailored to optimize fit for each individual.

Three-dimensional body scanning has synergies with human factors, where humanoid manikins can be rescaled using the extracted measurements and animated to perform specific tasks and to interact with the built environment. For example, using 3D manikins in engineering software suites such as SolidWorks[®] (Dassault Systems, Vélizy-Villacoublay, France). These techniques are already being employed in military research and in the design of transportation and operator workspaces [100].

Applications

Clothing and apparel

The clothing and apparel industry invest heavily in the development and improvement of 3D body scanning technology, due to its many implications. For example, 3D body scanning can be used to record many clothing measurements such as sleeve in-seam and waist girth [93, 101]. The measurements can then be matched to existing clothing size characteristics, allowing clothing manufacturers and retail outlets to choose appropriate inventories for their target population [93, 101].

Health and medical

The health and medical sector regularly use 3D scanning and modelling technology. The 3D scanner can be used to create implants, gloves, body shape, and prosthetics[102], holograms for human body imaging and garment creation [103]; detecting scoliosis in patient's back shape or scanning human feet to detect anomalies [104-106]. Body scanning technology is useful for measuring body surface area [107, 108] which is useful for determining dosages of many drugs (e.g., anticancer drugs [109]), the design of restraints [110] and developing shape indexes to monitor secular trends in body shape and limb volumes [111].

Ergonomics and human factors

The use of 3D body scanners is widely used in the field of ergonomics and human factors. Body scan images can be imported, via human modelling programs, into virtual environments which have been scanned or created in computer-assisted design (CAD) applications, or in hybrid environments. With appropriate motion capture or task descriptions, the virtual bodies can be animated to perform specific tasks in a naturalistic way in a digital environment [112]. The user can also simulate whether the actions or tasks can lead to physical injury due to working in uncomfortable or awkward postures. Examples of popular DHM software are CATIA Human Builder (v5, Dassault Systems, Vélizy-Villacoublay, France), JACK (SIEMENS, Munich, Germany), V5 HUMAN and Realistic Anthropological Mathematical System for Interior comfort Simulation (RAMSIS, Human Solutions, Kaiserlauten, Germany) [113].

Sports science

Previous studies have shown that 3D body scanning is a useful tool in sports science research. The technology enables researchers to take multiple measurements of a larger number of athletes at any given time [4, 114] before various sports events. It also helps sports and exercise scientists to understand the physique specialisation for specific sports.

Other sports applications exist. For example, body scanners have been used to assess principal moments of inertia in elite athletes from gymnastics to ski jumping [115, 116], investigate how females' breast area measurements change, when wearing compression sports bras during running [117], inform 3D design and development of swimwear [118], develop sizing systems for football boots in the National Football League (NFL) [119] and assess performance errors in a golf swing [120]. It is also possible to quantify

dimensions such as projected frontal areas (a critical factor in aerodynamic sports such as cycling and skiing) [121], limb volumes (which are strong predictors of sprint performance), limb cross-sectional areas (proportional to strength), and abdominal cross-sections and volumes (predictors of risk of diabetes and cardiovascular disease[122]) [123, 124]. It is possible to quantitatively describe shapes (and hence facilitate garment and equipment design) and shape changes (and hence describe what happens to the body during dietary and exercise interventions) [125].

3-D body scanners

Typically, 3D whole body scanners consist of at least one light source that projects a line or pattern on to the participants' body. Cameras record the image of the reflected light. On fixed laser scanners, the light source and camera both move in tandem (vertically) on the scanner pole. The images are then processed by computer software that is specifically designed to analyse the depth structure of the body surface (Figure 3—1).

There are five common types of body scanners: laser line, structured pattern, multiview camera systems, millimetre wave systems and infrared systems. Each of these systems are discussed below.

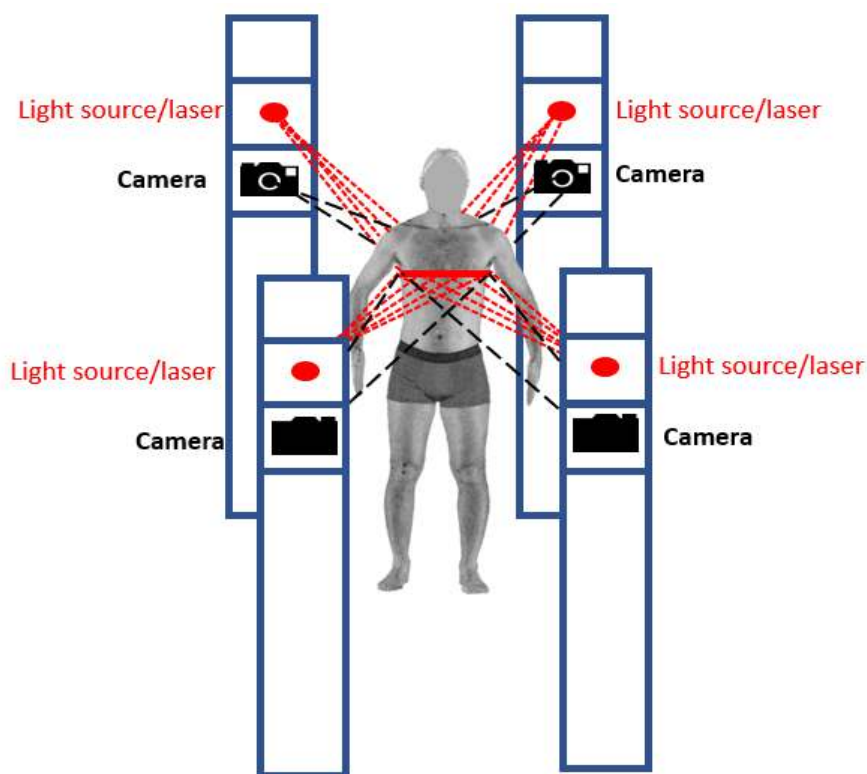


Figure 3—1. Typical layout of a 3D body scanner. The light source and camera are both mounted on a pole system. This is an example of a laser line system.

Laser line systems

Laser-based scanners use class 1 (eye safe, non-ionising) lasers to project light in an array beam onto the body surface from different sides. Multiple digital cameras capture the position of the projected light and software reconstructs the body contour of the acquired image via a mathematical algorithm which is based on triangulation. The system captures a series of surface points (typically between 700,000 and 1,000,000) with Cartesian coordinates.

Most systems house the sensor (laser) and cameras in four columns which are synchronized to scan the body from head-to-toe [100]. The column system is then enclosed in a curtain or fabric area for participant privacy.

The most popular laser line systems are the WBX or WB4 (Cyberware, California. U.S.), Vitus Smart XXL (Human Solutions Ltd, Kaiserlauten, Germany) and the Bodyline Scanner (Hamamatsu Photonics, Hamamatsu, Japan) systems. The Cyberware WBX system shows good reliability and notably used in the movie industry as well as the Civilian American And European Surface Anthropometry Resource (CAESAR) survey which is often regarded as the first and largest civilian anthropometry survey to date [126].

The Vitus Smart XXL system is made in Germany and advertised as a portable device containing 4 poles (each with a laser scanning unit). These systems are often used in the Garment industry but are also used extensively by the US, Canadian, Australian and New Zealand Defence Forces.

Structured light

A cheaper alternative to laser scanning is white-light scanning. This technology is based on the use of projectors. They project a sequence of white-light stripes consisting of dots, bars, or any other light patterns on to the participant. The light pattern deforms as it falls on the body, and the resulting deformation is captured via cameras.

Structured light scanning systems are generally faster than laser line systems but take longer to process or extract measurements [93, 127]. The laser line system could also be considered a structured light pattern, but it has a strong time component because of its line sweep and therefore considered as a different class of light system. Compared to laser line, structured light systems have less moving parts which increases the life cycle of the scanning system while also being safer for the participant [128] and more portable.

Some scanners in this category are fully automatic and autonomous. For example, the NX-16 (TC², North Carolina, U.S.) system can be operated by the participant or person inside the scanner who presses a button located on holding levers inside the scanning cabin. Recorded messages and video presentations inside the cabin give additional information and instructions [129]. The TC² system utilises multiple optical lenses to produce a 3D surface geometry of the body. It can scan the whole body in approximately 8 seconds and produces 140 body measurements [3].

The Triform or TriBody™ (Wicks and Wilson-Crowley Company, Hampshire, UK) uses white light to capture the 3D scan data in 12 seconds using 8 camera views. Multiple stripes of white light are used to capture the 3D shape of the participant. The light contains no visible rays, lasers, or other radiation. The resulting images are analysed automatically using the TriBody software that produces a 3D point cloud model containing approximately 1.5 million Cartesian (XYZ) co-ordinates [3]. Other popular models include the Mephisto EX-pro and Gotcha systems (4ddynamics, Antwerp, Belgium), 3D Mega Capturor II (InSpeck 3D, Montreal, Canada), Cartesian (SpaceVision, Tokyo, Japan) and SYMCAD (TELMAT, France) systems. More recent models include the Size Stream® (TAL Group, North Carolina, US), Fit3D ®(Fit3D, Inc, California, US), the hand-held portable Artec L scanner (Artec Group, Luxembourg) and the home-based Naked Labs® Scanner (Naked Labs, San Francisco, US).

Multi-view cameras

Multi-view systems produce a 3D image that is acquired from two or more cameras. A stereo-camera records two images at the same time from a different viewpoint. Next, sophisticated matching algorithms determine corresponding points in the two images to compute their 3D coordinates, resulting in a dense 3D points cloud [129]. The advantage of a stereo-camera system is that no laser line or light pattern is transmitted, and no sunlight or extraneous light artefacts can disrupt the pattern. However, using the line or patterns enables a 3D image with higher resolution and accuracy [128, 130]. An example of a system that uses this technology is Flex 8 (3dMDbody, Atlanta, U.S.).

Millimetre wave

This class of body scanning technology is like X-ray machines found at various airports around the world. For increased privacy, the participants are not required to remove any clothing.

Active scanners use the reflection patterns of millimetre waves that have been projected on the body [128, 130]. The ultra-high frequency radio waves penetrate participants clothing, reflects off the body, and are then collected by a transceiver and processed [129]. Passive scanners process the millimetre (or radiation) waves that are emitted by the human skin [128, 130]. Millimetre waves pass through most clothing ensembles but not the skin. Thus, the shape of the body can be captured without undressing. This offers an advantage in time and effort, but may introduce an ethical problem because of the explicit nature of the resultant image which views the body as naked [128, 130].

Infrared depth sensing technology

Infrared (otherwise termed as depth sensing) body scanners use nonvisible wavelengths. This technology is relatively new compared to previous body scanner models. Some infrared systems utilise what is known as ‘Time of Flight’ technology. This refers to the time that an infrared ray takes to travel to the nearest object in its field of view, and back to its sensor [131]. This technology is more cost effective and portable compared to other scanners. Research suggests that this technology is not as accurate as larger, more expensive fixed scanners [84]. However, models such as the recent Styku® S100 (Styku, Los Angeles, US) model demonstrated nearly perfect reliability with negligible systematic and random errors in a recent study [124]. The earliest (and most recognisable) form of this technology is the Microsoft Kinect sensor on the Microsoft Xbox console (Microsoft Corporation, Redmond, WA, US). The technology is currently being used in today’s high-end smartphones for taking depth-sensing photographs. For example, portrait mode which ‘blurs’ images in the background while accentuating the image of the object in focus.

Measurement extraction software

In addition to the hardware required to capture 3D scans, there must also be software dedicated than can interpret and extract body measurements. Some of the more commonly used systems are Cyberware’s DigiSize, Headus’ CySize™ (manual digital extraction) (Figure 3—2), Hamamatsu’s BodyLine Manager (discontinued), and Human Solutions’

ScanWorX (offers both manual-digital and automatic-digital extraction). These programs can extract a large number of traditional measurements based on a known landmarking system or algorithm [67, 93]. These types of software can also measure contour distances, cross-sectional areas, surface areas and volumes [132].

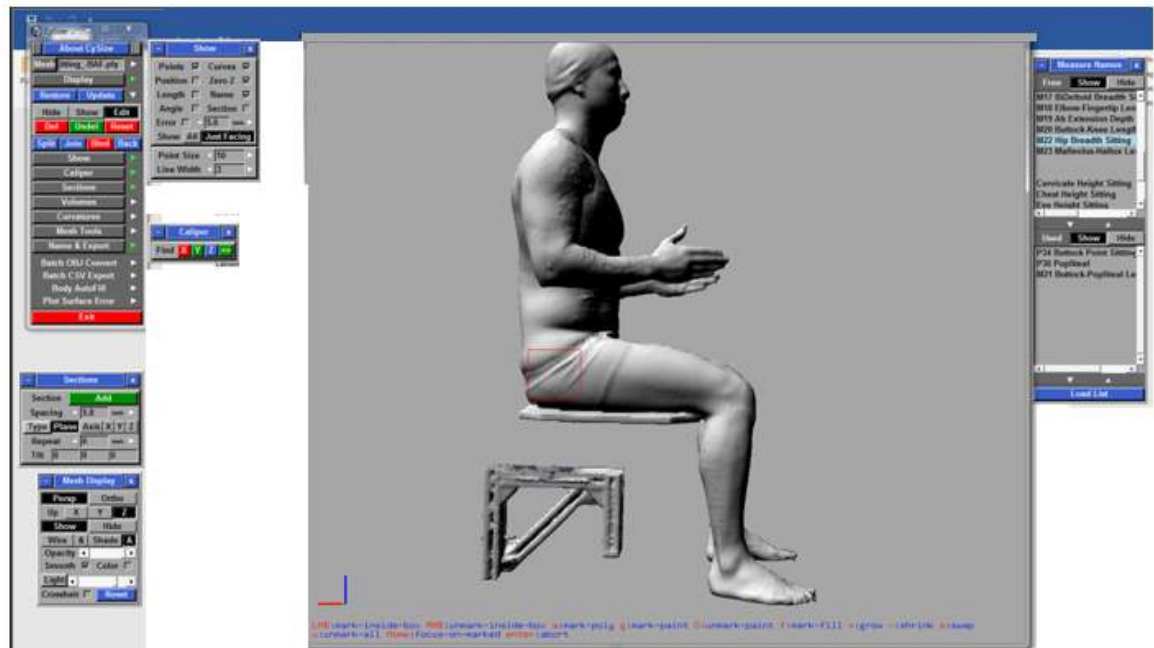


Figure 3—2. Headus' CySize™ output. Landmarks are placed physically, then identified and labelled digitally.

Like traditional anthropometry, 3D body scanning measurement extraction software requires landmarking. It would be sensible for all software to have a universal standard for identifying landmarks. Unfortunately, this is not the case as most software suites use different or ill-defined landmarks [67].

With regards to measurement extraction software, manufacturers may provide information about 'what' landmarking systems they use, but the process of 'how' the algorithms create measurements in line with those standards remain unclear due to commercial sensitivities. For example, the measurements in the automatic measurement function within ScanWorX (Figure 3—3) is based on a combination of ISO 7250:2010 and ISO 8559:1989 standards. Unfortunately, there is no validation research available assessing how well this software performs these measurements or what body types provide optimal landmark recognition and measurement accuracy.

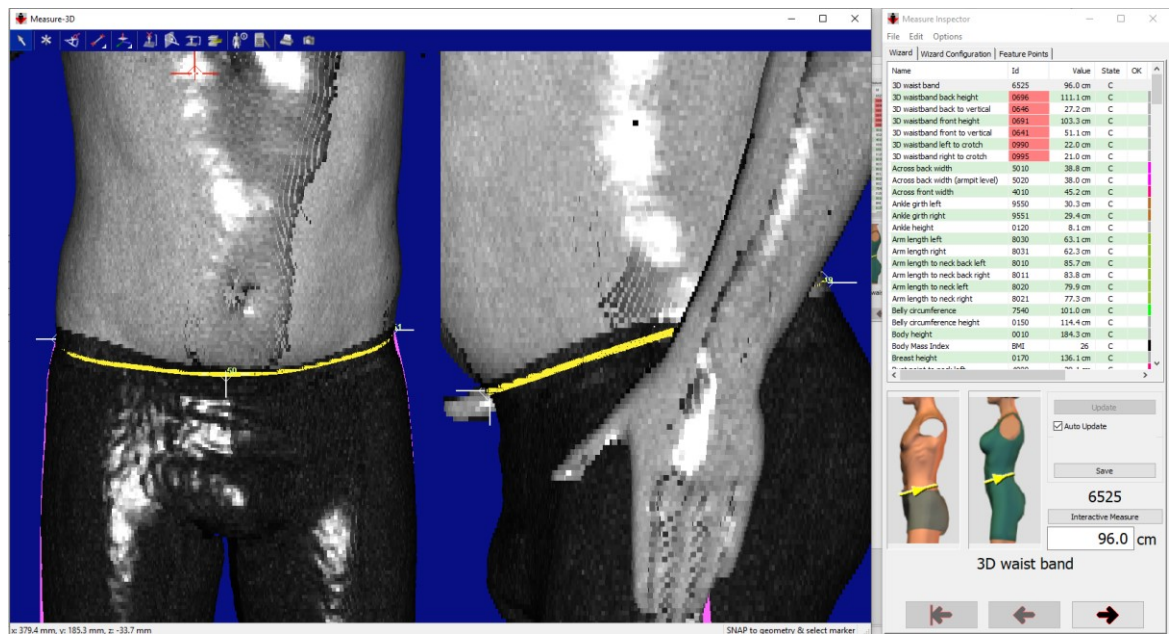


Figure 3—3. ScanWorX (Anthroscan™) output showing the automatic measurement function.

Whatever system is used, it is imperative that the software can identify landmarks correctly. According to Buxton, Dekker [133] landmarks can be identified in three ways:

- ❖ Automatic landmark recognition (ALR) – this refers to extraction without human intervention using two methods:
 - Template matching – The software creates a base template with all known measurements marked out. The template is then deformed to match the scan data. The system then extracts the XYZ co-ordinates of the known measurements.
 - Curvature matching – The software detects known measurements based on surface shape. An area of the scan is isolated then a search is performed to identify a point based on slopes and gradients.
- ❖ Digital landmark recognition (DLR) – this refers to a user identifying locations and placing landmarks on the completed scan.
- ❖ Physical landmark recognition (PLR) – the user places landmarks (adhesive balsa triangles or reflective discs) on the participant before they are scanned. Using colour and texture recognition capabilities, the software can automatically identify these landmarks in XYZ space. The software can also be programmed to ‘zone in’ on special landmarks by recognizing features of the landmarks (e.g., zoom in on all objects that are 30 mm in diameter).

Validity

Many studies have investigated the reliability and/or validity of scan-derived measurements compared to more traditional (e.g., ISAK) systems. Body scanners have been shown to measure body volumes, circumferences and lengths more rapidly and accurately than traditional techniques [134]. Jaeschke, Steinbrecher [135] discovered strong correlations between automatic and traditional measurements for body height; however, the automatic measurements generally ‘overestimated’ most other measurements. Choi and Ashdown [136] demonstrated that automatic-derived measurements provided significantly larger values using traditional measurements for waist circumference. However, the differences in waist circumference may be the result of skin compression experienced during the traditional measurements [135]. Wells, Treleaven [6] found that traditional measurements were more accurate at predicting buttock girth and hip girth, while Glock, Vogel [111] found that body height, waist, upper arm, calf and hip circumference showed high validity for both traditional and body scanner methods. Zhang, Zheng [137] compared measurements obtained from the NX-16 TC2 scanner with the equivalent tape measurements for the mid-arm, thigh, and ankle circumferences. All showed relatively high correlations (0.89, 0.90, and 0.93, respectively).

Wells, Stocks [138] compared the NX-16 (TC2 scanner) with traditional measurements for chest, waist girth, waist width, waist depth, knee girth and calf girth on 1,484 children. All traditional measurements were successful, but the 3D scans were successful in only 71% of the children. The unsuccessful scans were attributed to body movement (inside the scanner during scanning) or the lack of calibration at the start of each data collection day [81].

The accuracy of the body scanned measurements can be influenced by procedural and postural issues. For example, Kuehnepfel, Ahnert [139] observed systematic differences for body height, waist girth and hip girth measurements. This was attributed to measurement errors with regards to participant posture and movement artefacts. Lu, Wang [140] found that scanning participants with their palms facing backwards reduced the differences between scan-derived measurements and equivalent traditional measurements. Lu and Wang [141] also found that the scan-derived measurements can achieve satisfactory accuracy and precision if the variation caused by the participants scan posture is controlled. Adding supporting devices within the scanner helped ensure

the participant maintained a consistent posture during the scan. The anthropometrist should be skilled in posturing the participant and prompting the participants with regards to breathing during the scan (e.g., hold their breath).

Challenges

The following will discuss several shortcomings of 3D body scanning with respect to collecting anthropometric data.

Cost

Compared to traditional techniques, body scanning systems are expensive. The costs of various scanning systems in 2013 ranged from US\$10,000 to US\$240,000 [128]. In comparison, a standard Anthropometry kit cost US\$1,539 (e.g., RossCraft Centurion Kit <http://www.thehumansolution.com/centurion-kit.html>).

Identification of bone landmarks

Some landmarks will not show on digital scans as they may be obscured by skin, adjacent limbs, and superficial tissue. Examples are the acromion and the tibiale laterale, particularly in participants with significant muscular build. To help with identification, bone landmarks stickers or specialised markers are placed on the selected site to aid in post scan analysis [142].

Size, portability, and space requirements

Most whole-body scanners are bulky systems which require an area to suit its dimensions. The Vitus XXL scanner, for example, requires a height clearance of almost 3 m and a floor area of approximately 2.5 m² x 2.5 m². This is not ideal for typical office workspaces. In general, when compared to traditional techniques, 3D body scanners need a larger space to set up, take longer to physically set up, require competent trained scanner operators (unless the participant controls the scan like the TC² system), and time is needed for calibration and re-calibration.

Postures

Traditionally, anthropometric measurements are taken when the body is in anatomical position or like this position (Figure 3—4). For example, placement of the participant's head in the Frankfort plane, having arms relaxed by their side, both palms facing anteriorly, fingers extended towards the ground, and thumbs facing away from the body.

This technique may not be useful for 3D scanning as the posture may obscure certain parts of the body from being scanned [4].

Many systems have a strict requirement for adopting certain postures in the scanner. Participants are required to adopt a static posture for a short amount of time. Automatically derived measurements can be dependent on the quality of the posture within the scanner. For example, some measurements are calculated based on Cartesian (XYZ) co-ordinates on the body. An incorrect posture can lead to a shift in these co-ordinates. A classic example is body height. When standing in the Frankfort plane, the system may define height as the highest point on the head. If the participants posture was too far forward, then this point on the head may change, resulting in a different measurement.



Figure 3—4. An example of a scan posture within the Vitus XXL. Body postures vary from participant to participant and if not controlled, is a potential source of measurement error.

Missing data due to shading

There are points on the body where the laser cannot detect. Examples include the armpit and crotch area, sides of the torso, and inside of the arms and legs [4]. There are problems with defining a person's correct height due to the amount of hair that rises above the scalp. Some scanners cannot differentiate between the hair and head [142]. Parts of the head can appear missing if reflected light from hair is not captured by the cameras, potentially making it impossible to identify the vertex, and therefore capture height.

Landmark extraction

Earlier we presented three methods in which landmarks can be identified using measurement extraction software (ALR, DLR and PLR). All have their limitations which must be considered prior to developing a survey protocol or procedures:

- ❖ The ALR method does not recognize variations in shapes and sizes [143] and only has pre-set measurements (e.g., it is difficult to add ad-hoc measurements) [133]. It is also difficult to locate landmarks accurately without palpation [4].
- ❖ With DLR, is the difficult to identify bony landmarks (e.g., acromion) on participants who may have a lot of adipose tissue or musculature on that area [133].
- ❖ With PLR, some landmarks require additional features to make them stand out in the scan. For example, one cannot use a flat disc landmark to identify the left-acromion, but instead, opt for a raised land marker to highlight this point to the user [143].
- ❖ PLR has additional time burden, feasibility issues, and the invasive nature of touching the participant.

Security and confidentiality

Another shortcoming of 3D body scanning revolves around the security and confidentiality of the participants scan images. For example, scan images are stored on computers which, if not appropriately protected, is potentially open to 'cyber-attack (e.g., 'hacked') through various connections to the internet [127]. People are also potentially identifiable from facial/bodily features or unique markings such as tattoos.

Summary

There are many uses for 3D body scanners today. From an anthropometric data collection perspective, 3D scanners can collect more measurement information on participants in much less time. The accuracy of 3D scanning is improving over time as the level and sophistication of technology increases. Furthermore, 3D body scanners are becoming more portable and accessible to the public (e.g., hand-held scanners). Despite several shortcomings, 3D scanners still deliver functionality that is simply not possible with traditional techniques, such as recording shape and volume information, and the ability review measurements retrospectively for verification and error control. The next chapter will focus on how 3D body scanners contributed to various military anthropometric surveys.

Stephven Kolose, Patria Hume, Grant Tomkinson

Preface

The preceding chapter described how the introduction of 3D body scanning has changed the way in which anthropometric data are collected. Although traditional anthropometric data have been collected since the 1860s, and 3D body scanning technology was commercialised in the late 1990s, very few military anthropometric surveys have used the technology. The purpose of Chapter 4 is to provide both a historical overview and a summary of contemporary anthropometric surveys in the military. This summary includes a comparison of sample methods, measurements (traditional and digital), 3D scanning technology, and key demographics. Importantly, the key challenges and future considerations for anthropometric military surveys are discussed. This is the third of four eBook chapters in this thesis.

Overview

The military has an extensive track record of conducting anthropometric surveys. This chapter discusses the importance of anthropometry for the military and summarises military anthropometric surveys. Measurements from these surveys were used to create a combined military anthropometric profile.

This review provides an overview of international military anthropometric surveys that have been conducted over the past two decades. The final reports, methods, and statistics and in some studies, the complete data set, are available online. However, some studies are not readily available due to confidentiality or proprietary reasons. Where information was available, we have described the 3D body scanning technology that was used, summarised the corresponding measurements and procedures, and summarised the findings in tables.

Introduction

Anthropometry in the military has a long and comprehensive history. The combination of anthropometry, health and physical performance are still the primary focus in many military organisations today. These form the foundation of many military standards for selecting and retaining military personnel.

Anthropometric data is important for both military individuals and military populations. In the past, basic anthropometric measurements were used for accession, retention, and occupational assignment for ‘individual’ soldiers [144]. Therefore, an individual’s occupation or trade within the military was partly determined based on their physical attributes. Of equal importance, for the successful design and fit of military clothing, personal protection equipment, workstations, anthropometric data of the ‘whole population’ is more important.

Anthropometry is potentially more important to the military than civilian populations. Due to the strict and sometimes dangerous operational requirements, incorrect anthropometric data can have a more direct and immediate effect on safety (e.g., poor ballistic or body armour coverage of vital body organs), performance (e.g., poor fitting footwear causing lower limb injuries during a pack march), and job performance for military personnel (e.g., long term injuries and neck pain in drivers and pilots).

Anthropometry is also important as equipment and technology must keep up with secular trends or ‘growth’ of humans over time and can be used to estimate future body size and shape of successive generations of military personnel.

This has important implications for the design and acquisition of new military vehicles and the design of protective body equipment and clothing. Therefore, it is vital that regular anthropometric surveying of military personnel is conducted [145].

History

The first military survey was conducted during the American Civil War. The survey concentrated on stature, weight and body mass index to help identify recruits who may be malnourished, have tuberculosis, or simply to identify factors that explain why soldiers may be unfit for military service [146].

In World War I, measurements such as chest circumference, body mass index (BMI), height, and weight were considered key indicators of soldier fitness for load-carrying, marching and fighting [147]. Men and women in the US Armed Forces were measured as early as 1942. At the end of World War II, the collection, analysis, and applications of anthropometric data were used increasingly for military research and development [147].

There have been numerous anthropometry surveys (mainly conducted in the US) in the military (Table 4-1) but not all are widely available.

Table 4-1. A chronological review of military anthropometric surveys.

Year	Population	Sample size	Source	No. of measures
1861–65	US Volunteers	1,232,256	Gould (1869) [148]	(# not stated)
1863–65	US Draftees	501,068	Baxter (1875) [149]	(# not stated)
1917–18	US Draftees	1,961,692	Davenport & Love (1921) [150]	(# not stated)
1919	US Separates	103,909	Davenport & Love (1921) [150]	(# not stated)
1946	US Army Men	105,062	Newman & White (1951)[151]	66
1946	US Army Women	8864	Randall & Munro (1949) [152]	66
1950	US Air Force Flyers	4063	Hertzberg et. al (1954) [153]	132
1959	US Army Aviators	500	US Defense handbook [8]	(# not stated)
1964	US Navy Aviators	549	[154]	98
1965	US Ground Personnel	3869	US Defense handbook [8]	161
1966	US Army Men	682	[8]	73
1966	US Marines	2008	White & Churchill (1978) [155]	73
1966	US Army Basic Trainees	2639	US Defense handbook [8]	70
1967	US Air Force Flyers	2420	Grunhhofer & Kroh (1975)[156]	189
1968	US Air Force Women	1905	Clauser et al. (1972) [157]	139

1970	US Army Aviators	1482	Churchill et al. 88 (1971)[158]
1977	US Army Women	1331	Churchill et al. (1977) (# not stated) [159]
1988	US Army Men	1774	US Defense handbook [8] 240
1988	US Army Women	2208	US Defense handbook [8] 240
1989	US ANSUR I	3982	Gordon et. al (1989)[160] 108

Notable surveys

The 1946 US Army men survey was the first extensive anthropometric survey to be conducted. The purpose was to provide body size information for the design, sizing and tariffing of military clothing and personal equipment. The data were difficult to process as punch cards were used to store data.

The 1946 US Army women survey consisted of 5216 Women's Army Corps (WAC), officers, and enlisted woman, and 3648 army nurses. Data were collected using punch cards. At the time, no statistical analysis could be performed on the original data set until 1972 (when the data were transferred to magnetic tape and subsequently analysed by computer programs). The final number of participants for the survey was reduced to 8100 due to errors that were discovered in the original punch cards [8]. This is possibly one of the earliest examples of when computer processing power was used to assist the analysis of anthropometric data. It highlights a shift in technology, and the notion of measurement error, as evident in the punch card system [8].

The 1950 US Air Force flying personnel survey measured 4063 men across 14 Air Force bases. The survey consisted of 132 body measurements. The data for the survey were analysed before the introduction of modern computer facilities.

The 1966 US Basic Trainees Survey was the first to focus solely on new recruits. There are many advantages of measuring new recruits as analyses can be made on how their body shape can change through intensive military training. The disadvantage of measuring new recruits is that they do not represent the typical military body shape for those in service [8].

The 1970 US Army Aviators survey consisted of crew chiefs, door gunner mechanics, warrant officers and warrant officer candidate trainees, commissioned trainees and commissioned rated pilots. It was one of the first surveys to include both fixed-wing and rotary-wing pilots [8].

The 1988 US Men and Women surveys were the first major anthropometric survey in the US. Collectively, they consisted of over 132 body measures on 5499 males and 3485 females. This study deliberately over-sampled underrepresented demographic groups to predict increased number of personnel projected over several years. This was the first anthropometric database with completely commensurate data for men and women. It was also the first survey to use oversampling and statistical matching procedures to create working databases (those which can evolve with new data) to assess both present and future army populations [8]. Several observations can be made from these previous surveys. Over time:

- ❖ Anthropometric measurements progressed from individual (basing roles on physical attributes) to benefiting the wider population with regards to clothing and equipment
- ❖ Data collection and analysis has become increasingly sophisticated allowing for more in-depth analysis.
- ❖ Sample size has steadily declined as measurements become more defined and complex (potentially due to power analyses designed to detect meaningful differences between groups). Furthermore, the original surveys were based on basic height and weight measurements only.
- ❖ The number of females and ratio of females-to-males has steadily increased.

To date, there has been little research that has focussed on comparing the methodology, results and lessons learnt from the various international military anthropometry surveys. Most of today's surveys are based on measurement protocols developed in the past (e.g., ANSUR II). Many surveys use a different set of tools (e.g., body scanners, traditional anthropometric tools or anthropometry measurement rigs) which makes inter-survey comparisons challenging. The surveys were conducted in different eras and possibly limited to technology and body of knowledge of that time (e.g., punch cards vs. magnetic tape vs. 3D scanning). Most of all, many reports and publications are not openly available due to copyright, confidentiality, security classification or age.

Challenges and trends

To address contemporary issues in military anthropometry and understand where the field is heading in the future, the International Ergonomics Association (IEA) congress and Defence Science and Technology Group (DST group) organised a workshop in 2015 [161].

The panel consisted of content experts in military anthropometry. The panel were also survey leaders for their respective countries. A summary [161] of the key findings were:

- ❖ ‘What to measure’? Some surveys required an excessive number of measurements (despite the measurements being requested by the stakeholders in the consultation phase).
- ❖ All panel members agreed that anthropometric datasets required standardized measures and methods to promote interpretability within and between military forces.
- ❖ Research was needed to accurately describe encumbered soldiers. Many military organisations have their own clothing correction factors but the methods to obtain the measurements and the results are inconsistent between countries.
- ❖ Due to the continued advances in personal equipment and clothing, it may be more feasible to conduct smaller and more targeted surveys as opposed to large-scale surveys.
- ❖ There are many logistical challenges involved with capturing a representative sample. Oversampling is frequently used, but participants were often chosen based on their immediate availability.
- ❖ Measurement bookings required senior support at the outset of the survey, ideally from a uniformed and high ranking official.
- ❖ The panel discussed alternative sampling methods such as continuous sampling. That is, basing a body scanner at recruitment centres to capture body’s during intake periods. Unfortunately, this would lead to an over representation or skew towards younger personnel.
- ❖ The ability to freely disseminate anthropometric data is difficult due to privacy concerns of the 3D scan data. Some surveys openly share their data (e.g., ANSUR) but only with a few countries. The panel believed that the availability (or lack) of such data directly impacts of the development of tools.

- ❖ More research should be concentrated on dynamic anthropometric data as opposed to data in a static position. However, this was deemed too difficult in terms of balancing multiple interactions between the participant (their shape and what they are wearing), their environment and tasks.
- ❖ There is difficulty translating anthropometric data into a usable medium for the designer or engineer. For example, some designers know that they need anthropometric data, but do not necessarily know how to use it. It was agreed that more tools are needed to address this issue. For example, basic software that looks at virtual fit testing versus standard anthropometry parametric model- based programs to represent 3D.
- ❖ There is a need to develop digital human modelling packages which are more realistic and offer more than just comparing linear or 1D measurements (e.g., girths, lengths, and breadths).
- ❖ There is a need to have anthropometric data incorporated into biomechanical models. Alternatively, it would be advantageous if digital modelling software can utilise data from different surveys or countries.

Secular trends of body dimensions are important to the military. Historically, these have focused on weight and height [162]. The most visible expression of the secular trend is the increase in adult height. To put things into perspective, the Netherlands is one of the tallest nations in the world. Between 1860 and 1990, the mean height of the Dutch population (men and women) increased by 16 cm (from 165 cm to 181 cm). By the year 2000, the average height for young men and women were 184 cm and 171 cm respectively [12, 162] . By comparison, people from South-east Asian countries (e.g., Indonesia) are regarded as some of the shortest in the world [163]. For example, the mean height for male Indonesian Army soldier was 169 cm while 90 percent of the Indonesian military were between 165 cm and 176 cm in height [164]. There have been limited studies looking at the secular trends for military personnel for measurements other than height and weight [145]. Tomkinson et al [145] identified positive secular trends in several absolute measurements related to platform fit and ergonomic design (e.g., stature, sitting height, buttock-knee length, and hip breadth). These changes have implications for military procurement.

In the military, certain platforms, vehicles, and aircraft can operate in service for decades. For example, the F-111 Aardvark (Royal Australian Air Force), B-52 fixed wing (United States Air Force) and Sea King helicopter (UK armed forces) were in service for 34 years,

55 years, and 40 years, respectively [165]. Over time, the anthropometric profile of people who operate such equipment can change. Ideally, the planning process for long-term military acquisitions (e.g., upgrading an Air force C-130 Hercules fleet, naval frigate or army tanks) should consider changes in the operator's body measurements over the lifetime of the platform or product. However, identifying secular changes is difficult for several reasons.

This section describes the measurements, technology and demographics used in eight international military anthropometric surveys conducted between 2000 and 2019. The surveys represent the few studies that are available to the public. The surveys covered are:

- ❖ 2006–7 Anthropometry Survey of UK military personnel
- ❖ 2010 Anthropometric Survey of Iranian Military Personnel
- ❖ 2012 Anthropometric Survey of U.S. Army Personnel (ANSUR II)
- ❖ 2012 Australian Warfighter Anthropometry Survey (AWAS)
- ❖ 2012 Canadian Forces Anthropometric Survey (CFAS)
- ❖ 2014 Anthropometric Survey of Brazilian Air Force
- ❖ 2015 Anthropometric Survey of the Royal Australian Navy (ASRAN)

The surveys are summarised according to purpose, sample size, measurement combination and demographic information in Table 4-2.

Combined variable list

All measurements used in the surveys (except for the Iranian survey) were recorded and condensed (according to nomenclature) in Appendix IV. This is not an official list — it is an interpretation of what a combined military measurement profile may look like. To the best of the authors' knowledge, the combined measurement list in Appendix IV is the first published attempt at combining measurements from different military surveys over the past two decades.

The list also considers the Civilian American and European Surface Anthropometry Resource (CAESAR) dataset. Whilst not a military survey per se, CAESAR was added as a civilian comparison and because it is widely considered as the first and largest anthropometry survey to use 3D body scanning [68]. The demographic information for CAESAR will not be covered.

The following observations were made during the development and interrogation of the list in Appendix IV. Measurement names and definitions varied from dataset to dataset. For example, foot breadth horizontal (ANSUR and AWAS) versus foot breadth (CFAS). Furthermore, nomenclature is inconsistent, and measurements were not standardized between surveys:

- ❖ Dimension units such as girths and circumference differed amongst the datasets. For example, elbow girth (CFAS) versus elbow circumference (ANSUR).
- ❖ Most datasets take measurements from the right-hand side of the body. Some datasets took measurements on both the left- and right-hand side of the body (e.g., CAESAR and UK). This ultimately increased the number of measurements in their respective profile.
- ❖ Whilst body scanning technology was used, the measurement profiles still consisted of predominately physical measurements.

With the introduction of new, more advanced 3D body scanner systems, even more measurements may be conceived in the future. This will undoubtedly make it difficult to compile a universal military anthropometric measurement profile as covered earlier in this book. Based on this evidence, the composition of future anthropometric measurement profiles (protocols) may continue to be ‘stove-piped’ within each country.

Table 4-2. Summary of selected anthropometric surveys conducted between 2000 and 2020 showing sample, measurement, demographic, and technology descriptives.

COUNTRY	SAMPLE CHARACTERISTICS	#; LM; P; DIGITAL (A, P, D)	ETHNICITY	TRADE	SCANNER
2002	4431	99; 72;	<u>North America:</u>	(# not stated)	Cyberware (US, ITA)
Civilian American and European	18 to 65 years	40; (-, 99, -)	77% White		WB4 Whole Body Scanner Laser
Surface Anthropometry	2094 Male		11% Black		
Resource - CAESER	2332 Female		12% Other		<2mm
	54% North America		<u>Netherlands:</u>		Human Solutions, Vitus Pro Laser
	28% Netherlands		82% White		<2mm
	18% Italy		18% Other		
			<u>Italy:</u>		
			96% Italian		
			4.0% Other		
2006-7	2470	96; -; 18;	<u>Only minority groups presented</u>	(# not stated)	Textile Clothing Technology Corporation [TC] ²
Anthropometry	17 to 55 years	(71, -, 6)	1.5% Black		KX-16
Survey of UK	2160 Male		1.0% Caribbean		Cyberware Laser Head Scanner
Military Personnel	311 Female		0.9% Black African		Infrared Laser 1 mm
Tri-service	44% Army		0.72% Fijian		
	26% Air Force		0.2% Indian		
	30% Navy		0.16% East African		
			8.0% Gurkas		
2010	12635	90; -; 90;	(# not stated)	(# not stated)	MANUAL ONLY
Anthropometric	18 to 30 years	(-, -, -)			
Survey of Iranian	Male (# not stated)				
Military Personnel	Female (# not stated)				
2012	7435	135; 53;	62% White	27% Quartermaster supply	Cyberware WBX and PX and INFOOT foot scanner Laser
Anthropometric	17 – 58 years	94; (-, -, 41)	21% Black	15% Signal, COMS & Info systems	<2mm
Survey of U.S. Army Personnel - ANSUR II	7435 Male		11% Hispanic	10% Medical	
Army only	3922 Female		3.0% Asian	8.0% Intelligence Ordinance/Mechanical	
	64% Active Duty		1.0% Native American		
	33% National Guard		1.0% Pacific Islander		
	3% Reserves				
2012	2138	84; 25;	Country of birth	24% Rifleman	Human Solutions, Vitus XXL Whole body scanner Laser
Australian	18 to 40 years	40; (-, 44, -)	92% Australia	7.6% Driver	27 cm ³
Warfighter	1861 Male		1.3% New Zealand	5.9% Combat Engineer	
Anthropometry	277 Female		1.3% Other	5.7% Crewman ASLAV	
Survey - AWAS			1.1% South-East Asia	5.0% Operator Supply	
Army only			1% Europe (ex. UK)	3.5% Operator Admin	
			1% UK	3.4% Gun Number	
			0.7% Pacific Islands		

2012	2205	47; -; 46;	Racial distribution	8.8% Pilot	Human Solutions,
Canadian Forces	17 to 60 years	(-, -, 1)	92.7% Caucasian	8.4% Infantry	Vitus XXL Whole
Anthropometry	38.4% Army		2% Other	6.1% Aviation	body scanner Laser
Survey - CFAS	21.9% Navy		1% Black	Technician	27 cm ³
Tri service	39.7% Air Force		0.8% Filipino	5.8% Combat Engineer	Human Solutions,
	1890 Male		0.7% Latin American	4.7% Crewman	VITUS aHead
	315 Female		0.6% Metis	Armoured	Head Scanner
			0.6% Chinese	4.1% Resource Support	Laser 30 cm ³
				Clerk	FootIn3D Scanner
				3.9% Supply Technician	Laser 35 cm ³
				3.4% Air Combat	VisImage Inc
				Officer	BoSS XXI Body
				2.9% Avionics System	Sizing system
				Tech	Photo
2014	2339	39; -; 39;	Racial distribution	<u>Officers (top 4 only)</u>	MANUAL ONLY
Anthropometric	16 to 52 years	(-, -, -)	72% White	14.5% Transport	
Survey of Brazilian	Brazilian Pilot population		22.3% Brown	6.5% Fighter	
Air Force	44% Potential pilots		4.4% Black	5.7% Helicopter	
Air Force only	56% Current pilots		1% Asian	4.1% Instructor	
	2133 Male		0.22% Indigenous	<u>Cadets and students</u>	
	206 Female		0.08% Other	20.5% Trainees	
				8.7% Students	
				7.1% Admin	
				3.5% Infantry	
2015	1332	87; 69;			Human Solutions,
Anthropometric	18 to 54 years	43; (-, 44,			Vitus XXL Whole
Survey of the Royal	1090 Male	-)			body scanner Laser
Australian Navy -	232 Female				27 cm ³
ASRAN					
Navy only					

Key: MEASUREMENTS: (#=total sample number, LM = landmarks, P = physical measures, D=digital measurements. *Digital* (A=Automatic, P = Post-processed, D = Derived). SCANNER (RES=Accuracy in mm or point cloud distance as points/per cm²).

Summary of military surveys 2000 to 2020

2004–5 Australian Defence Anthropometric Personnel Testing (ADAPT) project

In 2004, the Australian Defence Force in conjunction with the University of South Australia (UniSA), Sinclair Knight Merz, Permian, the University of Ballarat, and the Australian Institute of Sport (AIS), conducted the Australian Defence Anthropometric Personnel Testing (ADAPT) study as part of the wider Australian Defence Force Aircrew (ADF) and Crewstation Anthropometry Project MIS 872 [166].

The project comprised three phases: (1) capturing 3D scans of crew stations using a seven-axis FARO ScanArm later used in CAD design programmes, (2) UniSA and AIS obtaining anthropometric data from current ADF aircrew and potential aircrew from young civilians from around Australia, using principally 3D measures plus several physical measures, and (3) and integrating the crew station scan images with the 3D body scans in a software program called JACK. The JACK software animated the virtual bodies to simulate flight tasks in the cockpit [4].

The dataset was used to identify recruitment guidelines for aircrew, to optimise cockpit human-machine interface and improve the fit of clothing and equipment [85]. Prior to the ADAPT project the most recent ADF anthropometric survey was conducted in 1977, which comprised 30 measurements on 3,000 male military (across Air Force, Navy and Army) personnel.

The project used a Vitus XXL 3D whole body laser scanner (Vitus XXL, Human Solutions) with a resolution (point density) of 27 points/cm². Each scan took approximately 12 seconds resulting in 32 digital measurements with the aid of Physical Landmark Recognition (PLR; see PART II for a description of PLR). Four additional measurements (stretch stature, sitting height, buttock-knee length, and weight) resulted in 36 total measurements.

The project captured measurements for 1,510 male and female civilians (who were potential aircrew recruits or students or in their final year of high school between 18 to 30 years) and 255 current aircrew personnel from the RAAF (aged between 20 and 56 years). The survey took 45 to 60 minutes to process each participant, with approximately 30 participants were processed each day. Each participant completed a questionnaire, including a section on clothing sizes [shoe size, dress and bra size (females) and shirt size (males)]. Participants then changed into form-fitting underwear and a latex swimming

cap before their physical measurements were recorded. Next, 23 landmarks were placed on the body (these landmarks could not be accurately located by looking at the scan) [167, 168]. The participants were then scanned in the middle of the body scanner with their legs slightly spread apart and their arms slightly abducted away from their torso [168]. Digital measurements were extracted from the scans using specialist software tools (e.g., CySize™ and Anthroscan™) such as girths (using a simulated tape measure or contour), cross-sectional areas, volumes and distances between landmarks [168, 169].

2006–7 Anthropometry survey of UK military personnel

The survey was conducted by the QinetiQ Human Protection & Performance Enhancement Group on behalf of the Haldane–Spearman Consortium (H–SC) for the Ministry of Defence (MOD) Research Acquisition Organisation (RAO) [11].

Prior to this survey, the previous published dataset was the Defence Standard 00-25 Part 17 developed from surveys conducted between 1970 and 1995 [11]. The UK Ministry of Defence (MOD)-Industry Human Factors Integration (HFI) group planned to use this dataset to update Defence Standard 00-25 Part 17. DEF STAN 00-25 provides human factors design guidance (including anthropometric data) for use in the UK defence industry. The dataset was also designed to be used internally and by contractors designing and building military equipment (e.g., Human Factors Integration, development of Systems Requirements Documents (SRD), forecasting clothing purchases). It was envisaged that this information would reduce costs and post-production adaptations for equipment and vehicles by specifying adaptations prior to acceptance [11].

Two Textile Clothing Corporation [TC]² 3D body light scanners were used. The scanners used infrared as opposed to laser technology (see chapter II for more information on this technology). Hundreds of thousands of data points were captured to produce a 3D representation of the body at an accuracy of ± 1 mm. Each scan took 3 seconds in duration.

The survey comprised 96 measurements, 18 of which were collected physically, 71 using digital measurements and six were derived. The measurements were based on physical measurements used in a previous UK survey [170] and from ISO 8559 [171]. Several measurements were modified to meet scanner technology limitations. For example, the scanner could not detect bony landmarks unless they were pre-landmarked by the scan operator. Head measurements were taken using a Cyberware Laser Head Scanner) as the 3D body scanner took limited head measurements [11].

Each scanning day consisted of eight, 1-hour sessions. Six participants were briefed at a time. At the brief they were required to fill in a demographic proforma. Next, participants were processed in pairs by two body scanner teams. At least one of each pair was head-scanned. Physical measurements were only taken when a scan could not extract the required measurement or when a scan-derived measurement was unobtainable. Participants were scanned once in a standing and once in a sitting position, with males wearing light grey briefs and females wearing a grey sports bra and skin-tone pants which were supplied by the project team. All data were validated before being entered onto the anthropometric database [11].

The survey of 2,470 personnel consisted of 2,160 male and 311 females. The sample was 44% Army, 26% Air Force and 30% Navy personnel ranging from 17 to 55 years of age. The sample also consisted of 188 Gurkas who were considered a significant ethnic group with known anthropometric differences from the general UK army [11].

The final report did not provide a full breakdown of the participants by ethnicity or race. However, numbers were provided for minority ethnicities such as Black Caribbean, Black African, Fijian, Indian and East African. The report presented sample numbers for three groups that present different anthropometric data from rest of the armed forces. These groups were Aircrew (n = 126), Gurkas (n=188) and Royal Marines (n=181).

The report concluded with measurement profiles that included an illustration of the body scan output, descriptive statistics, and frequency tables by gender and service.

2010 Anthropometric Survey of Iranian Military Personnel

In 2010, the anthropometric characteristics of Iranian military personnel (aged 18 to 30 years) were reported [13]. The measurement protocol and definitions were based on the 2008 National Health and Nutrition Examination Survey (NHANES) [172]. The survey did not utilise a 3D body scanner, but rather 90 physical measurements using the NHANES protocol. The 12,635 participants were armed forces personnel with a minimum of 10 years' experience. Participants were selected using systematic random sampling stratified by age. Further information relating to gender, trade and ethnicity was not provided. No measurement profile was provided. The report included summary statistics (mean, standard deviation, 5th to 95th percentiles) for each measurement and a multi-country (Iranian versus US, Australian and UK army) comparison table for stature, sitting height, upper limb and lower limb measures.

The first research on anthropometry and design in Iran's army was conducted in 1971 [173], where 7,784 Iranian soldiers were measured for military shoes and clothes. The next survey was conducted in 1995, with 2,130 personnel measured. The 2010 survey was to be the latest study focussing on ergonomics and anthropometric measures in the current military forces [13].

2012 Anthropometric Survey of U.S. Army Personnel (ANSUR II)

The 2012 Anthropometric Survey of US army personnel (ANSUR II) [10] is one of the most comprehensive anthropometric surveys in the military. Conducted by US Natick Soldier Research, Development and Engineering Centre (NSRDEC) between October 2010 and April 2012, the survey acquired anthropometric data for 1,090 males and 232 females to serve the Army's design and engineering needs. The sample represented the US Army Active Duty, Reserves, and National Guard. The dataset was also intended for equipment design, sizing, and tariffing applications with potential commercial, industrial, and academic applications.

The US army's previous anthropometric survey was conducted in 1987–88 which is commonly known as the U.S. Army Anthropometric Survey (ANSUR) or ANSUR I. ANSUR I consisted of 132 anthropometric dimensions on 8,997 personnel (5,506 male and 34,921 female). The processing time for one individual was up to four hours to enable a large number of measurements to be taken [160]. The ANSUR I measurements were all captured physically with no 3D body scanning system. However, a device known as the Automated Headboard Device (AHD) was used to capture head and facial measurements.

The ANSUR II survey consisted of 94 physical measurements, and 39 derived measurements from 3D whole body (Cyberware WBX), INFOOT foot, and PX head scans (from I-WARE Laboratory, Osaka, Japan). The measurements were based on 51 physical landmarks. Both systems are laser scanners. The whole-body scanner was accurate to ± 1 mm. Each scanner took approximately 15 to 20 seconds to complete. The whole-body scanner was controlled using the CyScan software in conjunction with an Enhanced Anthropometric Rating System (EARS) program. EARS was used as an evaluation step that would assist the scan operator with capturing high quality scans. Scan data were transferred to the system server through a local network, and were later backed up to DVD [43].

The 11,357 participants included 7,435 males and 3,922 females. The sample included Active Duty, National Guard, and Army Reserve Soldiers. Participants were between 17

to 58 years old. Sample breakdown by race consisted of White (62%), Black (21%), Hispanic (11%), Asian (3%), Native American (1%) and Pacific Islander (1%) respectively. Sample breakdown by trade or occupation (by order of most prominent) consisted of Quartermaster Supply (27%), Signals, Communications, and Information systems (15%), Medical (10%) and Intelligence (8.0%) (Table 4-2).

2012 Australian Warfighter Anthropometry Survey (AWAS)

The Australian Defence Force (ADF) Australian Warfighter Anthropometry Survey (AWAS) was run by the Defence Science and Technology Organisation (DSTO) Land Division in conjunction with the Australian Defence Test and Evaluation Office (ADTEO) and the School of Health Sciences at the University of South Australia between 2010 and 2012 [174].

The previous anthropometric survey was the Australian Tri-Service Anthropometric Survey in 1977 [175] which consisted of 3000 male ADF personnel aged 17-50 years. The survey also consisted of 1044 male Army personnel and utilised a total of 31 physical measurements [165].

The purpose of the AWAS survey was to gather comprehensive anthropometric data on a broadly representative sample of the (active forces) ADF Army personnel. It was envisaged the data could be used to optimise the design of clothing and protective equipment for sea and air vehicle platforms [166].

The AWAS used a 3D whole-body scanner (Vitus XXL, Human Solutions) to help collect digital anthropometric measurements. A total of 84 physical and digital measurements were collected per individual. The Vitus XXL scanner is a laser scanner with a scan resolution (point density) of 27 points/cm² and takes approximately 12 seconds to for a single scan.

Forty measures were taken physically, and the remainder were extracted from the digital scans. The 25 surface landmarks were placed on the participants skin (by the anthropometrists) using palpation of the skin. The measurement profile was derived from a review of Australian and international military anthropometric surveys, input from Australian clothing industry experts and the results of a validation trial [176].

Prior to undergoing measurements, all participants were given a brief where they were required to provide informed consent and complete a demographic questionnaire before they were assigned a 4-digit coding convention to anonymise their data. Participants were

then escorted to a landmarking area and reminded of the procedures used for landmarking, physical measurement and/or 3D scanning [174].

At the body scanner, participants wore a swim cap to help locate the vertex and other reference points on the head. Once inside the scanner, participants were positioned in two standing postures and one sitting posture. The scan time was approximately 12 seconds per posture. The physical measurements were taken by ISAK Level 2 trained anthropometrists using traditional anthropometric measurement equipment. The anthropometrists had extensive training in the survey measurements [176].

The 2,138 participants included 1,861 males (87%) and 315 females (13%). In terms of country of birth, 92% of the sample was born in Australia, followed by New Zealand (1.3%), South-East Asia (1.1%), Europe-except UK (1%), UK (1%), and Other (1.3%). The main trades or occupations represented by the sample were Riflemen (24%), Drivers (7.6%), Combat engineers (5.9%), Crewmen (5.7%), Operator supply (5%), Operator admin (3.5%) and Gunners (3.4%).

2012 Canadian Forces Anthropometric Survey (CFAS)

The Canadian Forces Anthropometric Survey (CFAS) was conducted in 2012 by the Defence Research and Development Canada (DRDC) and Human Systems Incorporated. Prior to 2012, the Department of National Defence (DND) lacked up to date, accurate and representative anthropometric data of the Canadian Forces. The purpose of the survey was to update the anthropometric dataset and use it for the specification, evaluation, development, and acquisition of military equipment [7].

Prior to the 2012 survey, the two most recent anthropometric surveys in Canada were the Royal Canadian Air Force (RCAF) survey in 1985 (taking 73 physical measurements on 519 aircrew) and the Canadian Land Forces Survey in 1997 (140 measurements on 708 participants). The measures in 1997 consisted of a combination of physical measurements, 2D digital images of the foot and hand and 3D laser scans of the head[7].

The CFAS used four different types of scanning technology in addition to traditional methods to capture measurements for their respective protocol. The VITUS XXL Whole body scanner which has an accuracy of ± 1 mm at a point density of 27 points/cm², the VITUS AHead Scanner (± 1 mm accuracy at a point density of 30 points/cm²) and the FootIn 3D (± 1 mm accuracy at a point density of 35 cm points/cm²). A BoSS XXI Body sizing system was used to capture 2D whole body dimension data. The BoSS system used

two digital cameras that take simultaneous pictures from the frontal and sagittal planes. Proprietary algorithms then interpreted the images to identify landmarks to make linear and circumferential measurements of the participant.

The total CFAS sample was 2,205 personnel (38.4% Army, 21.9% Navy and 39.7% Air Force) and consisted of 1,890 male and 315 female participants. The demographics in terms of race consisted of 92.7% Caucasian, 2% other, 1% Black, 0.8% Filipino, 0.7% Latin American, 0.6% Metis and 0.6% Chinese. The main trades represented were Pilots (8.8%), Infantry (8.4%), Aviation Technicians (6.1%), Combat Engineers (5.8%), Crewman (4.7%), Resource Support Clerks (4.1%), Supply Technicians (3.9%), Air Combat Officers (3.4%) and Avionics Technicians (2.9%).

2014 Anthropometric Survey of Brazilian Air Force

In 2014, researchers from the Brazilian Air Force University, New York University and Arizona State University conducted the first anthropometric survey on Brazilian Air Force pilots. The data were used for optimising aircraft cockpit design, uniform design, pilot accommodation, protective gear and digital human modelling [14].

There was previously no published anthropometric dataset for the Brazilian military. Only two anthropometric databases from Brazil were recorded in the literature both of which were based on the civilian population. The first database was developed in 1988 based on male industrial workers from Rio de Janeiro. The second database is from 2008 and based on eight anthropometric measurements taken from Aviation Transport Users (common passengers) [14].

The 2014 survey did not use a 3D whole-body scanner and was based on physical measures only. The survey consisted of 39 measurements that were adapted from Hotzman, Gordon [177]. The measurements were specifically relevant to the design of aircraft cockpits, protective gear, uniform sizing, and computerised digital human modelling [14]. The measurements were conducted by Brazilian military personnel who were responsible for administering the anthropometric measurements in the annual fitness test.

The survey procedure consisted of four independent measuring stations and two anthropometrists per station (alternating as measurer and recorder). Each team consisted of 12 people, with one 'substitute measurer' per station. The four measuring stations consisted of the following activities: a) landmarking, b) standing and seated

measurements (depths, breadths, and lengths) conducted using a Beam calliper. The station included foot measurements using the modified Brannock device, standing and sitting measurements (heights and lengths) using the anthropometer, and circumferences and hand measurements using a Poech sliding calliper.

Seated measurements were taken on a table (70 cm in height) using two wooded boxes as a footrest, styrofoam pieces (to adjust feet up and down) and a wooden buttock plate. All measurements were taken on the right side of the body and recorded to the nearest millimetre. Measurements were recorded on a laptop and hand-written tables for back up. Outliers were determined in Excel™ using a filtering process based on previous studies and standards [8, 62].

The 2,339 aircrew (2,133 males and 206 females) were aged 16–52 years. With respect to distribution by race, 72.0% of participants were White, 22.3% Brown, 4.4% Black, 1.0% Asian, 0.2% Indigenous, and 0.8% Other. In terms of trades, the top four Officer trades represented were Transport (14.49%), Fighter (6.54%), Helicopter (5.69%) and Instructor (4.11%) pilots. Cadet and Student trades represented were Trainees (20.48%), Students (8.72%), Administration (7.14%) and Infantry (3.46%) personnel.

2015 Anthropometric Survey of the Royal Australian Navy (ASRAN)

The Anthropometric Survey of the Royal Australian Navy (ASRAN) was conducted in 2015 by the Maritime and Land Divisions of the Defence Science and Technology Group in conjunction with the University of South Australia. The purpose of ASRAN was to capture relevant (and update previous) Royal Australian Navy (RAN) anthropometric data to support the Australian Defence Force Maritime Procurement Programme and inform the development of a new habitability standard for the RAN [178-180].

The previous Royal Australian Navy anthropometric data were obtained in 2000, which consisted of 302 personnel (251 male and 51 females). As part of the scoping plan for the ASRAN, the 2000 RAN reference data were compared against international standards [181]. The findings showed that the 2000 reference data were inappropriate for the design of future marine platforms as well as several other issues. For example, the data were outdated, the female sample was small, and the data were not generalisable to the current RAN population (e.g., no submariners were included and the sample was not representative of all trades and age groups). Furthermore, the survey was conducted using physical measurements and presented results in only three percentile categories (5th, 50th, and 95th). The limited percentile data would not be helpful for designing equipment

or platforms for a section of the population outside these values [178, 180]. For example, 99th percentile may be required by specialized populations such as aircrew or special forces. Outside of the 2000 RAN reference data the most recent anthropometric survey in the Australian Defence Force was the AWAS conducted in 2012 as described earlier in this chapter.

The technology used in ASRAN is identical to that used in the AWAS in 2012. Two Vitus XXL whole-body scanners (Human Solutions, Kaiserslautern, Germany) were used in conjunction with a team of anthropometrists for the physical measurements. The measurements used in ASRAN were similar but not the same to those used in the AWAS. The AWAS measurements were based on measurements that were in-line with clothing and body armour design; the ASRAN measurements were prioritised on habitability and platform design. Stakeholder interviews, consultation and published reviews were used to select the final measurement list. This resulted in a total of 87 measurements per participant, comprising 43 physical and 44 digital measurements from 69 physical and digital landmarks [179].

The 1,332 personnel (1,090 males and 232 females) were aged 18 to 54 years. No further information regarding the participant or study demographics were available at the time of this review.

Summary

This chapter provided a summary of eight military anthropometric surveys that were conducted over the past 20 years. To the best of our knowledge, these represent the most recent and publicly available military surveys.

It was apparent that equipment, clothing, platform, and workstation design were the driving force for these surveys. Many military organisations also wanted to ‘update’ their existing anthropometric datasets according to current best practise, in preparation for future equipment acquisition, and to support design, engineering, and human factors research.

Two surveys did not utilise 3D body scanning technology but instead used ‘traditional’ measurement profiles and protocols. Several used the same body scanning technology (e.g., Vitus XXL or TC²) each with their own protocols and procedures for measuring data. Despite the rapid increase in the development of 3D technology, anthropometric surveys appear to be still dominated by physical measures (as opposed to digital) and the

surveys at the start and end of the decade still use similar body scanning technology (Vitus XXL or similar variation). This is further evidenced in Appendix IV where most of the measurements in these survey protocols are physical. Surveys used a mixture of measurement definitions from different protocols (e.g., ANSUR II, NHANES, ISO 7250) or developed their own protocols. Even when 3D body scanning was used, measurement definitions were still based on physical (or 1D) measurement definitions (despite known issues with the accuracy of scanning technology). As a result, traditional 1D measurements captured by traditional survey protocols are not suitable for today's real-world problems. The use of 3D data may be more suitable and flexible to solve many contemporary design issues (e.g., using human 3D models to simulate real-world tasks in a virtual environment).

Some measurement teams have undergone extensive training by way of international accreditation (e.g., ISAK qualification/training) while others have learnt through internal training from senior anthropometrists. Some also conducted validation trials and assessed test-retest reliability of measurers before and during the surveys. There is no universal anthropometry qualification recommended by the military.

There was a greater number of males sampled in the surveys despite attempts to oversample female participants. This is most likely a reflection of the male and female ratio in the military in general. The reporting of participant trades, ethnicity or racial distribution is not fully described in all survey reports that are publicly available. These characteristics are important (especially ethnicity) as they help describe the anthropometric differences of their respective population. The information can also be used to compare different surveys or better estimate temporal trends.

The next chapter describes the methodology of the 2016–2018 New Zealand Defence Force Anthropometry Survey.

Chapter 5 New Zealand Defence Force (NZDF) Kinanthropometry Survey Development

Stephven Kolose, Patria Hume, Grant Tomkinson

Preface

The preceding chapter summarised previous military anthropometric surveys. Many countries have a long history of conducting anthropometric surveys, with few using 3D body scanning technology until this past decade. The knowledge obtained from Chapters 2 to 4 provided a foundation for developing and implementing a modern 3D anthropometric military survey. The purpose of Chapter 5 is to report on the development, methodology, implementation, and analysis of the New Zealand Defence Force Anthropometry Survey (NZDFAS), currently one of the most recent tri-service, 3D anthropometric surveys in the world. The resulting measurement protocols and summary statistics are presented in Appendix V. This is the last of four eBook chapters presented in this thesis.

Overview

This chapter is a culmination of the material covered in Parts I to III of this book. We will discuss how the New Zealand Defence Force Anthropometry Survey (NZDFAS) was initiated, how the survey was designed, and how it was implemented. This was the first study of its kind in New Zealand. The purpose of this section is to document the methodology used for the NZDFAS and provide the reader with information on how to conduct a large-scale anthropometric study.

Anthropometry in New Zealand

Prior to this study, data relating to the anthropometric dimensions of New Zealand Defence Force personnel (and New Zealanders in general) was limited. A comprehensive survey suitable for human engineering design and ergonomic applications had never been undertaken, despite unsuccessful attempts in the 1980s and 1990s [24]. Two previous New Zealand-based studies helped shape the current NZDFAS. Researchers previously relied on overseas data (e.g., Australian, US, or UK) due to the lack of NZ data. Slappendel and Wilson [22] derived anthropometric estimates for New Zealanders by applying ratio-scaled data from the British population [23] to NZ stature data collected during the 1990 Life in New Zealand (LINZ) Survey. The LINZ survey comprised 1,610 females and 1,405 males who were randomly selected from the electoral roll. The ratio-scaling technique was a proven method for obtaining anthropometric data at the time; however, the use of international data can result in inaccuracies due to the differences in body size and shape of the respective populations.

Prior to the NZDFAS, two highly regarded anthropometric studies were conducted in the NZDF, one in 2011 on the New Zealand (NZ) Army and the other in 1973 for the Royal New Zealand Air Force (RNZAF). In 2011, Baxter and Baxter [20] conducted a survey to obtain a preliminary dataset of the anthropometric characteristics of the feet of soldiers within the NZ Army. The sample consisted of 807 military personnel from two NZ Army camps, with an average individual measurement time of eight minutes. No demographic data (e.g., gender, trade) were recorded as the sole purpose of the data collection was to obtain as many participants as possible. The data consisted of boot sizes and foot measurements (breadth, width, circumference, and arch height) measured by a single researcher using a seamstress' tape measure. Data were entered into Excel (Microsoft) and analysed for descriptive statistics. The results were insightful as one in six soldiers were not provided with a boot that fit properly. This may have been attributed to the boots

having designed for soldiers of European descent, who were anecdotally considered to have a ‘narrow’ profile foot compared to participants of Maori and Pacific Island descent. One in seven soldiers wore boots that were larger than required (in some cases up to three sizes bigger) to obtain a boot wide enough to fit. The average foot length (26.3 cm) was shorter than the average comparable boot dimension. The NZ Army had lower arch heights than the general NZ population which was attributed to the higher proportion of Maori and Pacific Islanders in the soldier sample (30%) compared to the NZ general population (15%). This study highlighted important findings: (1) the NZDF requires an anthropometric dataset that is representative of its population; and (2) anthropometric data are useful for understanding issues of fit (for current inventory and for estimating future inventory) and helping identify clothing and equipment that is both functional and fit for purpose (e.g., specific to the population body sizes, soldiers trade etc).

Perhaps the largest New Zealand military anthropometric survey (in both measurement and sample number) was conducted by Toulson in 1971 [19] for the Royal New Zealand Air Force Aviation Medicine Unit (AMU) in Auckland. The study was based on 238 male Aircrew between the ages of 18 and 49 years, with the purpose of improving procurement of flying clothing size ranges and to compare New Zealand anthropometric data to international military populations. The study captured 62 measurements per participant. Despite the large participant sample size and number of measurements, few were aware of this study’s existence because it was published as an internal AMU report [19]. Nonetheless, the study by Toulson fulfilled much of the criteria described in Part I of this book. That is, the study was conducted on a specific population (NZ Air Force crew), by experienced anthropometrists using proven methods and technology. Unfortunately, the data are now nearly 50 years old and may not be representative of the current NZDF.

New Zealand Defence Force

The NZDF, in partnership with the Ministry of Defence, is responsible for delivering Defence in New Zealand. In 2019, the NZDF had 9474 regular force (active or uniformed) personnel, and comprised three services—the New Zealand Army (n=4705), the Royal New Zealand Air Force (n=2525), and the Royal New Zealand Navy (n=2244) [18].

In 2008, the NZ Army requested that the Defence Technology Agency (DTA) initiate an anthropometric survey of its personnel. DTA, through Massey University, conducted an anthropometric pre-scoping study [24]. The main recommendations from the study were to i) form an anthropometry project scoping team to advise the NZDF on the development

of a NZ Army anthropometry project, and ii) consider the purchase of a 3D body scanner to help automate data collection.

It was apparent that anthropometric data in the NZDF were required not just for the NZ Army, but for all three services. For example, anthropometric data for Naval lifeboat, bridge console, and bunk bed design; for RNZAF aircrew selection and helicopter seating; and for NZ Army vehicle design and uniform sizing.

The lack of NZDF (or NZ civilian population) data to inform these requests highlighted the need for a current anthropometric database. Knowing the current body size and shape of NZDF personnel helps to ensure that current and future military equipment can be identified and selected more accurately.

The NZDFAS was initiated and conducted by the Defence Technology Agency (DTA) which is the main provider of research, science, and technology support to the NZDF and Ministry of Defence. The survey was endorsed by the NZDF Vice Chief of Defence, Chief of Army, Chief of Air Force, and the Chief of Navy in 2015. Ethics approval for this work was provided by the Auckland University of Technology Ethics Committee (AUTEC). The funds to conduct the survey, including domestic travel and meals for the data collection team, were provided by the DTA. The study utilised a Vitus XXL 3D body scanner (Human Solutions Ltd, Germany) and associated software funded by NZDF Capability Branch in 2012.

Aim

The aim of the NZDFAS was to create a tri-service anthropometric body scan and measurement database to inform the size and fit of military clothing and equipment (personal protection devices and tools), and to support design and engineering decisions regarding operator fit within platforms (aircraft cockpit, land vehicle cabin, or ship control rooms) and other working areas (office space, classrooms, or individual workstations).

Methods

In 2016, a survey site scoping exercise identified suitable data collection facilities around New Zealand. The project involved four phases, which spanned from December 2013 to December 2019:

- ❖ Phase 1 (February 2014–August 2015): A suitable sample size, measurement profile, data collection team, body scanning process, and survey logistics (including travel and survey site) were identified.
- ❖ Phase 2 (September 2015–January 2016): A suitable data collection procedure was drafted and tested, measurements were validated, and the data collection team (anthropometrists) were trained.
- ❖ Phase 3 (February 2016–September 2016): Data collection activities were performed at nine NZDF locations throughout New Zealand. Additional data were collected in May 2018.
- ❖ Phase 4 (November 2016–August 2018): Data were processing, analysed, and reported.

Figure 5—1 provides a summary of the key activities during each phase. Each activity is explained in more detail throughout this part.

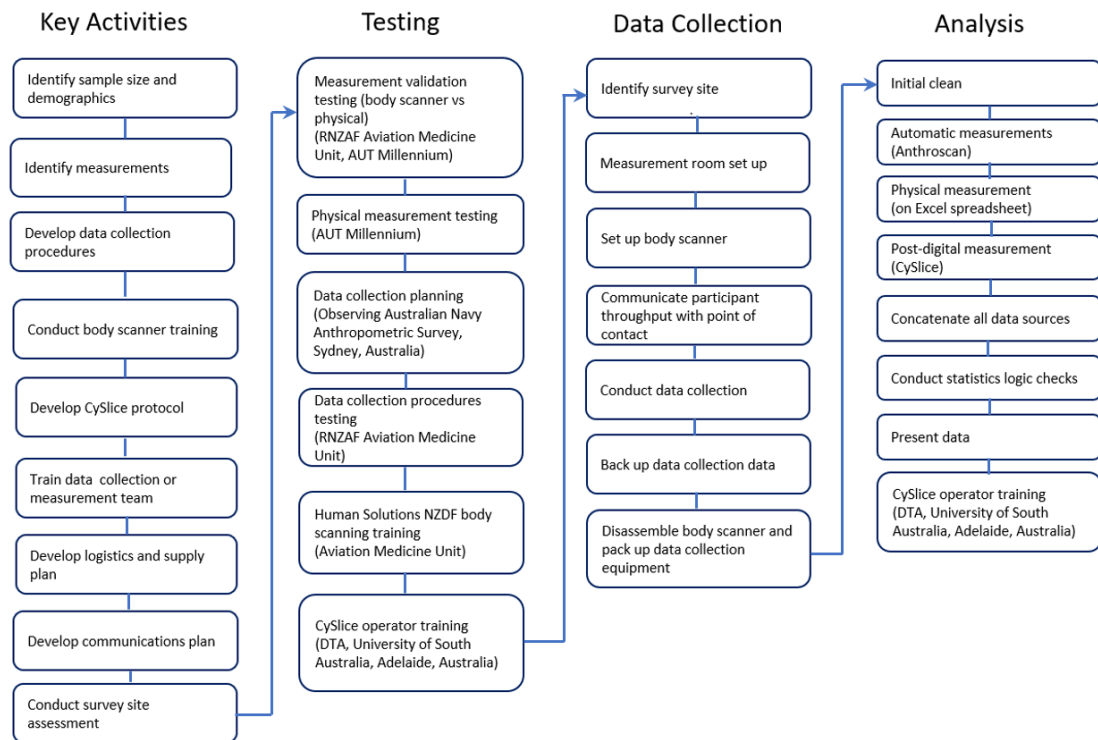


Figure 5—1 A summary of the key activities during each phase. Each activity is explained in more detail throughout this book. POC refers to ‘Point of Contact’.

To ensure participants completed the scanning requirements in as short a time as possible, while maintaining data integrity, a team of personnel with specific responsibilities were used at each data collection session. These roles and responsibilities are presented in Table 5-1.

Table 5-1. NZDFAS data collection team.

Role	Responsibilities
Team leader	• The survey protocol conduct • Data sampling site logistics (e.g., liaison and coordination with data collection site manager) • Overseeing transport, un/packing, dis/assembly, and calibration of scanner and all equipment. • Recording any incidents on a Serious Events Register • Timekeeping for workflow • Ensuring that all data files are backed up regularly. • Assisting other team members when required
Participant receptionist	• Greeting and briefing participants • Administering informed consent forms and demographic questionnaires • Collecting and filing all hard copies of paperwork • Assigning participants an ID number
Anthropometrists	• Locating and placing physical landmarks on participants • Taking physical measurements • Recording all measurements • Observing other anthropometrists to minimise mistakes. • Escorting participants to the scanner technician
Scanner technicians	• Positioning participants in the correct postures for scanning • Operating the scanner system • Verifying the scanned images for correct posturing, landmark positioning and checking scan image quality. • Saving the scan

In addition to the data collection team the survey was supported by 61 NZDF staff (Table 5-2).

Table 5-2. NZDFAS full support team (including data collection team).

Role	N	Responsibilities
Data collection team	21	Trained anthropometrists (i.e., 19 were trained at ISAK Level 2 and two were accredited at ISAK Level 1). • 16 were volunteers from the NZDF (e.g., science researchers from DTA, Medics and Personal Training Instructors) • 5 were contracted from the Auckland University of Technology (AUT) Sports Performance Research Institute New Zealand (SPRINZ).
Logistic support staff.	30	Logistic support staff: • 18 were points of contact (POC) at the nine NZDF establishments (consisting of members of the base leadership team, unit commanders, and Events and Human Resources staff). They were responsible for facilitating survey site bookings and managing participant throughput for the survey. • 6 were receptionists and scribes. • 2 were contractors employed to assist with data cleaning and analysis. • 3 were from the DTA Business services team responsible for travel bookings, supplies and logistics support. • 1 member provided specialist statistical support.
Subject matter experts	10	International subject matter experts who assisted with various stages of the study: • Measurement/protocol development, validation, refinement, and CySize™ training (University of South Australia, Defence Science and Technology Organization, Australia), • Body scanner training, troubleshooting and hardware support (Human Solutions Ltd, Germany), • CySize™ analysis and software support (Headus Ltd, Australia). • Body scan file conversion and general project support (Defence Research and Development Canada).

Sampling

The minimum sample size to ensure valid statistical representation of body dimensions across the NZDF was determined using a power analysis equation from ISO 15535:2012 [182]. The equation was based on the probability that the survey population would provide sufficient fidelity to represent the true population between the 5th and 95th percentiles, with 95% confidence and 1% accuracy [182]. This is a common method applied by international military organizations in Australia [166] and Canada [7].

An internal validation trial in 2014 identified waist height as having the greatest coefficient of variation (12.9%). This coefficient was entered into the equation resulting

in a minimum sample size of 1504 personnel. International military anthropometry experts recommended that the sample size should be 10% of the population, which equated to 947 given the NZDF population of 9474. The targeted sample size was then inflated to 15% (1421) personnel to oversample specific demographics such as females. Approximately 1421 personnel were randomly selected from a pool of 9474 in the NZDF personnel register. The data were then filtered according to participants who (1) resided at anyone of the nine main NZDF camps and bases, (2) were active service personnel, and (3) were regular force (or uniformed) personnel only (excludes civilian or reserved forces). These filters in addition to errors in the personnel database (e.g., personnel who either resigned or retired from the NZDF were still marked as ‘active’) resulted in a revised target of 1096 personnel or 11.5% of the current uniformed population.

A stratified sampling strategy was used to select the NZDF personnel to maintain an adequate balance among the three services and across gender and ethnicity groups (while purposive sampling occurred during the survey). To achieve this, the current proportions of Army (49%), Navy (27%), and Air Force (24%) personnel among the 9474 active uniformed population were applied to the survey sample of 1096. This resulted in target samples sizes of 535, 297, and 264 personnel from Army, Navy, and Air Force, respectively. Demographic proportions by trade, ethnicity, and gender were applied in a similar manner, resulting in the following initial survey targets (Table 5-3).

Most role descriptions within the NZDF can be categorised into 10 major trade categories. The trade and sub-trade (e.g., Combat and Armourer) category definitions were obtained from the NZDF Defence careers website (www.defencecareers.mil.nz). The ethnicity categories were based on the New Zealand Census [183] (except for Pacific Islanders and Maori, which were combined in this study). Cross-referencing the census ethnicity categories with the 2015 NZDF personnel database identified six main ethnic groups within the NZDF. Of note, ‘NZ Europeans’ were classed as ‘European’ while ‘New Zealanders’ were categorised in the ‘Other’ category. The demographic targets were then applied to the nine NZDF base/camp locations to determine how many participants were required from each data collection location.

Table 5-3. NZDFAS target sample by demographics.

NZDF Service by Gender								
Trade	Ethnicity	Army		Air Force		Navy		TOTAL
		Male	Female	Male	Female	Male	Female	
Combat	European	49	0	8	0	1	5	63
	Pacific	57	1	4	1	19	2	84
	Asian	4	0	0	0	9	0	13
	Latin Am	1	0	0	0	0	0	1
	African	2	0	0	0	1	0	3
	Other	45	0	6	2	34	6	93
Specialist	European	14	3	4	1	0	1	23
	Pacific	8	1	0	0	10	0	19
	Asian	1	0	0	0	0	0	1
	Latin Am	0	0	0	0	0	0	0
	African	0	0	0	0	0	0	0
	Other	9	4	4	2	0	1	20
Medical	European	9	6	2	1	3	3	24
	Pacific	4	2	0	0	3	1	10
	Asian	0	0	0	0	1	0	1
	Latin Am	0	0	0	0	0	0	0
	African	0	0	0	0	0	0	0
	Other	5	4	2	4	1	4	20
Apprentice	European	2	0	0	0	0	0	2
	Pacific	11	0	0	0	0	0	11
	Asian	1	0	0	0	0	0	1
	Latin Am	0	0	0	0	0	0	0
	African	0	0	0	0	0	0	0
	Other	14	0	0	0	0	0	14
Engineering/	European	24	0	62	3	30	1	120
	Pacific	7	1	8	2	23	1	42
	Asian	1	0	3	0	13	0	17
	Latin Am	0	0	0	0	3	0	3
	African	1	0	0	0	0	0	1
	Other	19	0	44	3	25	2	93
Intelligence	European	15	0	8	4	0	3	30
	Pacific	6	6	1	0	20	7	40
	Asian	0	0	1	0	0	0	1
	Latin Am	0	0	0	0	3	0	3
	African	1	0	0	0	2	0	3
	Other	11	1	7	0	0	4	23
Hospitality	European	9	3	0	1	0	3	16
	Pacific	5	3	0	0	16	7	31
	Asian	0	0	0	0	4	0	4
	Latin Am	0	0	0	0	0	0	0
	African	0	0	0	0	0	0	0
	Other	5	2	0	1	10	4	22
Logistics and	European	22	5	11	5	0	3	46
	Pacific	18	7	2	2	0	3	32
	Asian	1	0	1	0	0	0	2
	Latin Am	0	0	0	0	0	0	0
	African	1	0	0	0	0	0	1

	Other	18	5	8	12	0	4	47
Aviation	European	0	0	15	2	0	0	17
	Pacific	0	0	2	0	0	0	2
	Asian	0	0	0	0	0	0	0
	Latin Am	0	0	0	0	0	0	0
	African	0	0	0	0	0	0	0
	Other	0	0	11	3	0	0	14
Other	European	35	5	0	0	0	0	40
	Pacific	10	1	0	0	0	0	11
	Asian	1	0	0	0	0	0	1
	Latin Am	0	0	0	0	0	0	0
	African	0	0	0	0	0	0	0
	Other	24	5	1	0	0	1	31
Gender total		470	65	215	49	231	66	
Service total		535		264		297		
Target total		1096						

Measurements

A systematic approach was used to identify measurements of interest for the NZDF. First, measurement profiles from the most recent large-scale military anthropometry surveys (United Kingdom, United States, Canada, and Australia) were extracted and recorded (n=255).

Next, duplicate measurements were removed based on inconsistencies in nomenclature or measurement description (n=155). A criterion was applied in which measurements common to three or more country protocols were automatically selected (n=60). Sixteen additional NZDF measurement profiles (currently in use within the NZDF) were added. For example, measurements used in RNZAF Personnel and Selection (PERSEL) assessments; and measurements equivalent to the NZDF clothing (shirt and trouser specifications) for recruitment clothing sizing activities. Ten measurements were later added from standards such as ISO 7250 [182, 184-187] and DEF STAN 00-250 leaving a draft list of 86 measurements for the NZDFAS profile.

The draft list of measurements was reviewed by content experts. The physical (traditional) measurements were peer-reviewed by an ISAK Level 3 criterion anthropometrist from the J.E. Lindsay Carter Kinanthropometry Clinic and Archive (JELCKCA) at AUT. To determine the most valid, reliable, and feasible method of obtaining the body measures in the NZDFAS, a content expert in 3D body scanning from the University of South Australia (UniSA) advised the project on the best method to collect each measurement (automatically using the body scanner software, physically using traditional tools or post-

processed using a third-party software). Measurements identified as potential automatic measurements were taken forward for subsequent validation.

It was important that the NZDFAS profile incorporated as many automatic measurements as possible to reduce participant burden and limit the number of physical measurements. Anthroscan™ has the ability to obtain 160 automated measurements [188], however, only 23 of the 160 measurements were common within the 86 identified initially. The remaining 63 measures were derived by either physical or post processed methods. The accuracy of the 23 measurements required a separate validation. Measurements that did not pass validation were either derived physically, post-processed, or removed from the study entirely.

Measurement validation

Two validation studies were conducted to assess the accuracy of automatic measurements derived from the body scanning process. The first utilised 3D body scan data from a population of UniSA students (n = 90). The measurements were processed using the Anthroscan™ automated measurement software. The results were then compared to physical measurement data captured by ISAK Level 2 and 3 accredited anthropometrists (UniSA). The second validation study involved comparing additional automatic measurements with their equivalent physical measurements in 12 NZDF and AUT personnel. The validation criteria were as follows, if the mean percentage difference between automatic and physical measurements were <5% then the automatic measure was considered acceptable.

Of the 23 measurements validated, 12 passed the 5% criteria while 11 measurements were still accepted due to special circumstances (Table 5-4). Head circumference and bust chest girth was not within the <5% threshold (7.7% and 5.4% mean difference) but was still added as an automatic measurement to reduce participant burden. Crotch length was not validated but was included in the automatic measurements as it was deemed too intrusive for physical measurement. Ankle girth, while <5% threshold during the validation testing activities, was added to the automatic measurement list to reduce participant measurement time. Weight was measured by the SECA scale that is built into the scanner platform and was calibrated with a 20 kg weight prior to each testing session. Neck girth (opting to use neck girth base instead), shoulder length (no relevant design application), and waist height omphalion (opting for waist girth) were removed from the

list. Vertical trunk circumference was measured using post-processing methods as it was deemed too invasive for physical measurement.

Table 5-4. NZDFAS automatic measurement validation results.

Measurement (mm)	N	% difference	Decision
1. Body height	12	1.0	Validation pass
2. Breast height	12	1.4	Validation pass
3. Buttock girth	20	2.7	Validation pass
4. Buttock height	12	0.1	Validation pass
5. Calf girth	45	0.2	Validation pass
6. Elbow girth	12	3.0	Validation pass
7. Knee height	12	1.5	Validation pass
8. Neck girth base	40	0.8	Validation pass
9. Suprasternale height	12	1.2	Validation pass
10. Thigh girth	38	1.8	Validation pass
11. Waist girth	12	3.1	Validation pass
12. Wrist girth	12	2.0	Validation pass
13. Ankle girth	N/A	N/A	Not validated – accepted to reduce measurement time.
14. Crotch length	-	-	Not validated – accepted as not practical for physical measurement.
15. Weight	N/A	N/A	Not validated – 100% accuracy compared to SECA manual scale.
16. Bust/chest girth	12	5.4*	Validation fail – accepted to reduce measurement time.
17. Head circumference	12	7.7*	Validation fail – accepted to reduce measurement time.

Based on the validation results (Table 5-4), a draft measurement list and protocol was peer-reviewed by content experts from the AUT SPRINZ and UniSA. This consultation led to a refined measurement protocol outlining how each measure was to be conducted using a body scanner, traditional anthropometry techniques, or advanced 3D processing software. To assist with the decision-making process, the project focussed on deriving as many measurements using the body scanner (whether automatic or post-processed) as possible to reduce participant throughput and increase participant numbers.

Measurements that could not be performed consistently (e.g., the Vitus XXL produces low resolution images for hands, fingers, and feet therefore) or practically (e.g., arm span, reaches or buttock to heel length extend limbs outside the available scanning range) with the body scanner were conducted physically (n=25). The remaining 38 measurements, three (discarded) automatic measurements and a late addition (shoulder elbow length) formed the final 42 measurements to be derived at the post-processing stage. The final NZDFAS measurement profile consisted of 84 measurements. See Figure 5—2 for a breakdown of the measurement identification, validation, and selection process.

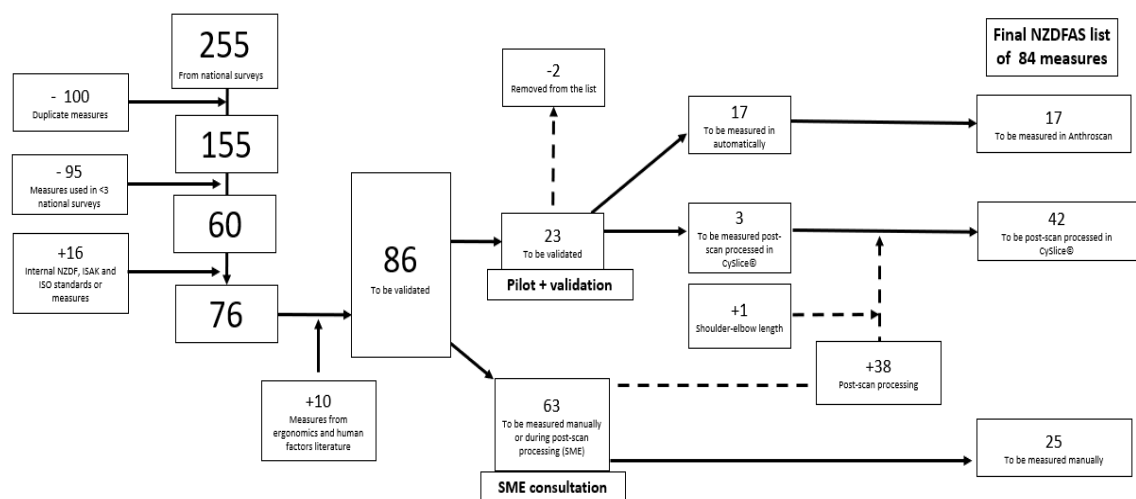


Figure 5—2. NZDFAS Measurement selection and testing process.

Measurement extraction tools

The survey consisted of three important measurement extraction tools and methods.

Physical (traditional) anthropometry measurements

The physical measurements utilised a stadiometer, anthropometry box, tapes, rulers, and various callipers following 2001 International Society of Kinanthropometry (ISAK), 2012 Australian Warfighter Anthropometry Survey (AWAS), 2012 Canadian Forces Anthropometric Survey (CFAS), 2011 UK military ISO 7250-1, Human Solutions and JIS Z 8500:2002 [189] protocols and standards. Anthropometrists were members of the NZDF and AUT who were trained to ISAK Level 1, 2, and 3 standards.

The measurement equipment was loaned from the AUT SPRINZ and calibrated before each data collection exercise. Figure 5—3 shows an example of how the measurement room was arranged, although the layout varied depending on the location constraints.

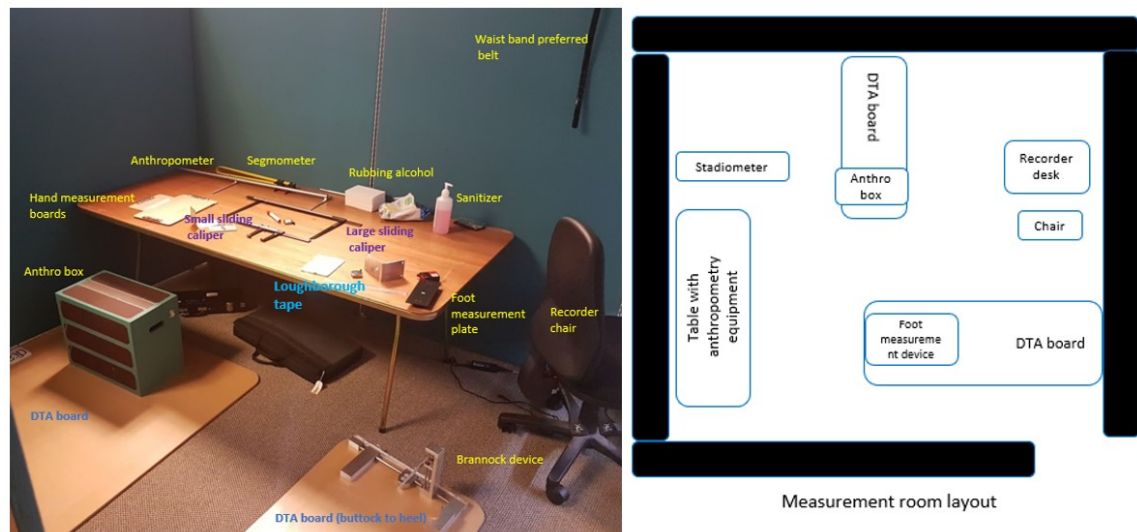


Figure 5—3. Measurement room equipment layout.

Automatic measurement (using Anthroscan™ software)

A Human Solutions Vitus XXL whole body laser scanner was used to scan each participant. The scanner projects non-ionising laser light onto the body with the reflection captured by cameras as a series of points (between 700,000 and 1,000,000), each with cartesian coordinates which are sewn together to create a ‘digital statue’. The scanner is an eye-safe Class 1 visible non-ionising red laser light and was manufactured in compliance with the regulations of the U.S. Food and Drug Administration pertaining to laser safety (21CFR1040.10 and 21CDR1040.11) [190].

The scanner was calibrated at the start of every data collection day. The weight scale (built into the platform) was calibrated each day using a 20 kg weight. Individual laser height alignment was calibrated during the setup at each new location.

Seventeen automatic measurements were extracted using software called Anthroscan™ (Figure 5—4). After extraction, the scan operator checked each scan image to confirm that the measurements were successfully captured. Examples of automation errors are a circumference line height that is higher or lower than the intended location (e.g., thigh girth) or a circumference line around both left and right thighs as opposed to one. These errors can be fixed by the operator post-scan using various Anthroscan™ software tools.

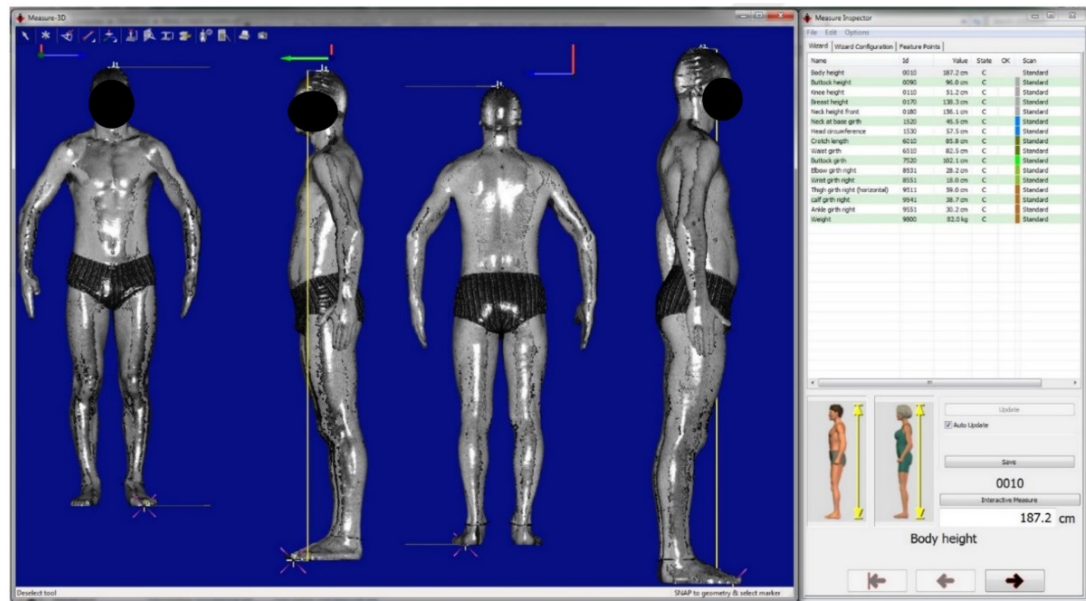


Figure 5—4. Anthroscan™ automatic measurement software.

Digital measurements (using CySize™ software)

CySize™ is a third-party software used by various military research organizations such as the Defence Science Technology Group in Australia (Figure 5—5). CySize™ is a powerful and accurate tool for analysing 3D data. It provides more in-depth measurement functionality (and tools) than Anthroscan™ and can be used to make almost any measurement on the body providing the scan image quality is clear. The NZDFAS CySize™ measurement process is primarily based on the AWAS Landmarking and Measurement manual [190]. The 42 measurements extracted using CySize™ are those which cannot be performed with acceptable accuracy automatically; or too slow to measure physically (e.g., some measurements may require pre-requisite landmarks further increasing measurement time such as vertical trunk circumference). This method allowed the operator to extract these measurements post-survey.

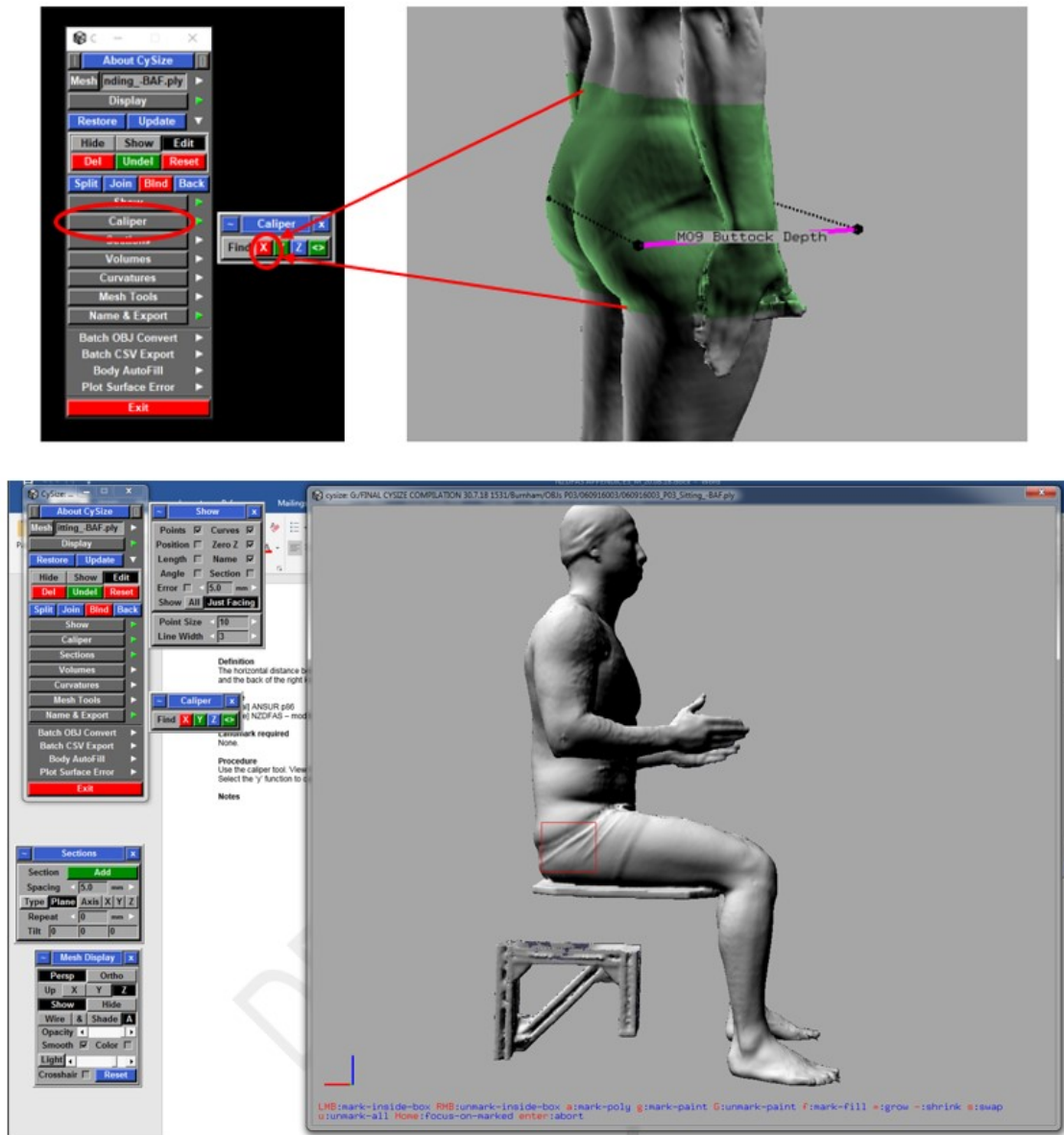


Figure 5—5. CySize™ (Headus Ltd) measurement software. [Top] The user can select any region of the body (green) then use the various CySize™ tools to determine the maximum depth within the region (using the ‘x’ caliper function). [Bottom] CySize™ contains various landmark, measurement extraction tools and image enhancement functions to obtain clear measurements.

Logistics and supply plan

The NZDFAS data collection activities occurred between February and September 2016. The measurement team was selected based on their geographical posting (as opposed to having one dedicated team for all survey locations). This was designed to minimise travel and accommodation costs. It also meant that the measurement team had a representative who was familiar with the base/camp surroundings and their peers (participants). The

measurement team stayed on site at either the Officers' Mess or transit barracks. Two project leads travelled to all the survey locations by van. All trial equipment (physical measurement tools and the body scanner) was transported in this van. Supplies, such as disinfectant wipes, landmarking stickers and stationery was delivered to pre-selected bases ahead of time.

Communications plan

Prior to the study, an NZDFAS administration order was sent to all site (Point of Contacts) POCs. This order formally documented the dates, participant targets and site requirements needed for each survey.

Two weeks prior to the survey, the project lead and site POC liaised to confirm target participants numbers, and that the site, accommodation, meals, and IT requirements were ready for the survey team. Within 7 days of the survey, the participant was given an information sheet relating to the survey. Participants were able to volunteer through an expression of interest to their unit commander, or by making a booking using an online system that was based on the defence force intranet. The participant list constantly changed, as some participants volunteered on the day, while others withdrew due to operational priorities in advance. This made achieving the sampling targets very challenging and managing these required a high degree of flexibility with respect to planning participant and survey team rosters. There were occasions when available time slots could not be filled, despite regular communication with the POC. Sampling methods worked for better for some services better than others. For example, the online booking system (where participants picked and chose times based on a live booking system managed by the POC) was more popular with Air Force personnel compared to Navy personnel. Purposive sampling (e.g., relying on POCs to identify participants within their line of command who met specific demographic targets) achieved a greater response rate for Army participants compared to Air Force and Navy. Overall, the most challenging service to survey was the Navy because (1) there is only Naval base in New Zealand and (2) a large proportion of Naval personnel are based on ships that are away from the base for months at a time hence the Navy achieving 44% of its original target.

The project lead and site POC were in regular communication throughout the survey to manage any issues. Post-survey, the POC and base commander were emailed a summary of the survey operation, results achieved (e.g., numbers surveyed) and gratitude for their

cooperation and support. The relationship between the survey team and the POC is the most critical aspect for the survey.

Survey site assessment

Prior to data collection, the survey lead travelled to each base, and identified the most suitable location to conduct the survey. It was important that the physical measurement rooms had no windows (or at least had the ability to cover windows), be private (free from normal walking traffic), be near the body scanner and briefing rooms, have sufficient space (2.5 m x 2.5 m minimum) for three people including the measurer and scribe, and have appropriate heating or cooling devices. The body scanner room required a ceiling height of at least 3 metres to accommodate the scanner poles, have a floor space of 3.5 m x 3.5 m, provide enough room for a desk and chair, and have lights that can be turned off.

Data collection took place within offices, hangers, training centres, conferences centres, and gymnasiums across nine bases and camps throughout New Zealand. Changing room facilities are important but not crucial as participants were able to get changed inside the body scanner. Ideally, all rooms (one briefing, two physical measurement, and a body scanner facility) are close together to facilitate throughput.

Survey protocol

Data collection consisted of five stages that took between 35 and 45 minutes to complete per participant.

Stage 1: Briefing and informed consent (10 minutes)

Prior to their visit, all participants were issued with an information sheet and consent form via email. This contained information about the study aims and methods, and pre-testing instructions (e.g., instructions on level of hydration and food intake, clothing, and pre-testing exercise). Upon arrival, the receptionist greeted the participants at the reception desk. Hard copies of the information sheet and consent form were also available at the reception desk. The brief was conducted ‘one-to-one’ or in large groups depending on the participant numbers per session.

Each participant was verbally informed of the measurement procedures and their rights as volunteers. Participants informed of their right to withdraw at any time without prejudice. Participants were given the option to be measured by a male or female anthropometrist. Participants were also given the opportunity to have a support person

with them during measurement. Participants were assured that their personal information (demographic or body scan) will be kept private in a secure location, and not shared with their peers, commanding officers, or other parties without the participant's explicit permission.

After providing written informed consent, participants completed a short demographic questionnaire and were assigned a unique identification number using a 6-digit coding convention. The consent form was the only document linking each participant's identification number to their name. Records and scan images for personnel in the NZ Special Air Service (SAS) were stored separately with defining features (tattoos) altered for privacy.

All participant demographic information in NZDFAS was recorded electronically using a complementary software program for Anthroscan™ called Personal Data (PEDA). The demographic information from PEDA was later integrated with the participants body scans according to their 6-digit ID number.

Stage 2: Change to form-fitting clothing (5 minutes)

Participants were then shown to a private changing area so they could change into light coloured sports or undergarments (tight-fitting briefs for men, and high-rise underpants and stretch midriff tops for women). Participants wore their own underwear, provided it was deemed acceptable for scanning by an anthropometry team member. It was recommended that light coloured clothing (e.g., white, silver, light shade) was worn with minimal thickness to follow the natural contours of the body. The light colours provide optimal reflection during the scanning process. While the colour of the clothing was strictly enforced in the information sheet, not all participants adhered. Participants were not turned away if they wore the incorrect coloured or slightly incorrect fitting undergarments for scanning. In our study, dark coloured undergarments did not affect the measurement results (automatic or post processed) if the scan image showed the appropriate location of the landmarks (in which white stickered landmarks were used on dark clothing). Shoes, socks, and jewellery were removed, and if necessary, participants tied up their hair. All participants wore a tight swim cap on their head. All personal belongings were stored in a large plastic container for safekeeping (one container per participant).

In locations where changing rooms and measurements rooms were far apart, the anthropometrists would work together ensuring that no non-surveying team members

were in close vicinity. Participants were not permitted to enter or leave the changing area, measurement room or scanning area until they were authorised by their anthropometrist. If there were any delays, then they wore their Personal Training (PT) gear until it was time to move station.

Stage 3: Landmarking (8 minutes) and physical measurements (20 minutes)

Next the participants were landmarked (see Figure 5—6 and Figure 5—7). The landmarks served two purposes for the NZDFAS: (1) to aid identifying and recording physical measurements, and (2) for identifying and implementing digital measurements after the scan. Prior to landmarking, all participants were reminded of the procedures via a series of photos describing the landmarks and the three postures they were required to assume during landmarking, physical measurement, and 3D scanning.

The required landmarks were marked on participants by trained anthropometrists. The anthropometrist were either an accredited ISAK Level 2 anthropometrist or have received suitable training from a qualified Level 3 or 4 anthropometrist or senior staff member [191]. Participants were given the option of being measured by an all-female or all-male measurement team if required. For optimal results and to minimise measurement error, a pair of anthropometrists were assigned to one participant. One was the designated landmarker and measurer, the other an observer. Printed instruction booklets (containing all the landmarking and measurement procedures) were provided for reference for the survey team. The measurement room also had a poster describing the appropriate scan posture for the participant. To identify each skeletal reference point, each landmark was physically located by palpation on the body surface. They were then marked as a ‘cross’ using a pen. When landmarking was complete, anthropometrists re-checked the placement of their landmarks before ticking the corresponding box on the datasheet to signify that the landmarks have been located.

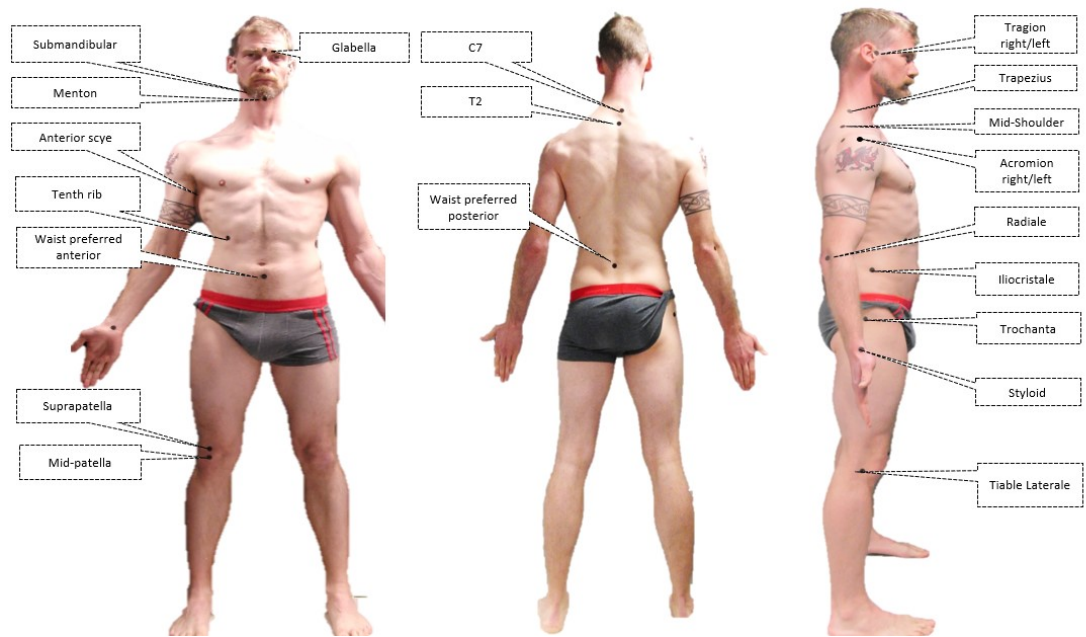


Figure 5—6. NZDFAS landmarks required for physical measurements. These measurements have a dual-purpose of they can also be used for digital measurements except for menton, sellion, submandibular, tragon (right and left) and trapezius.

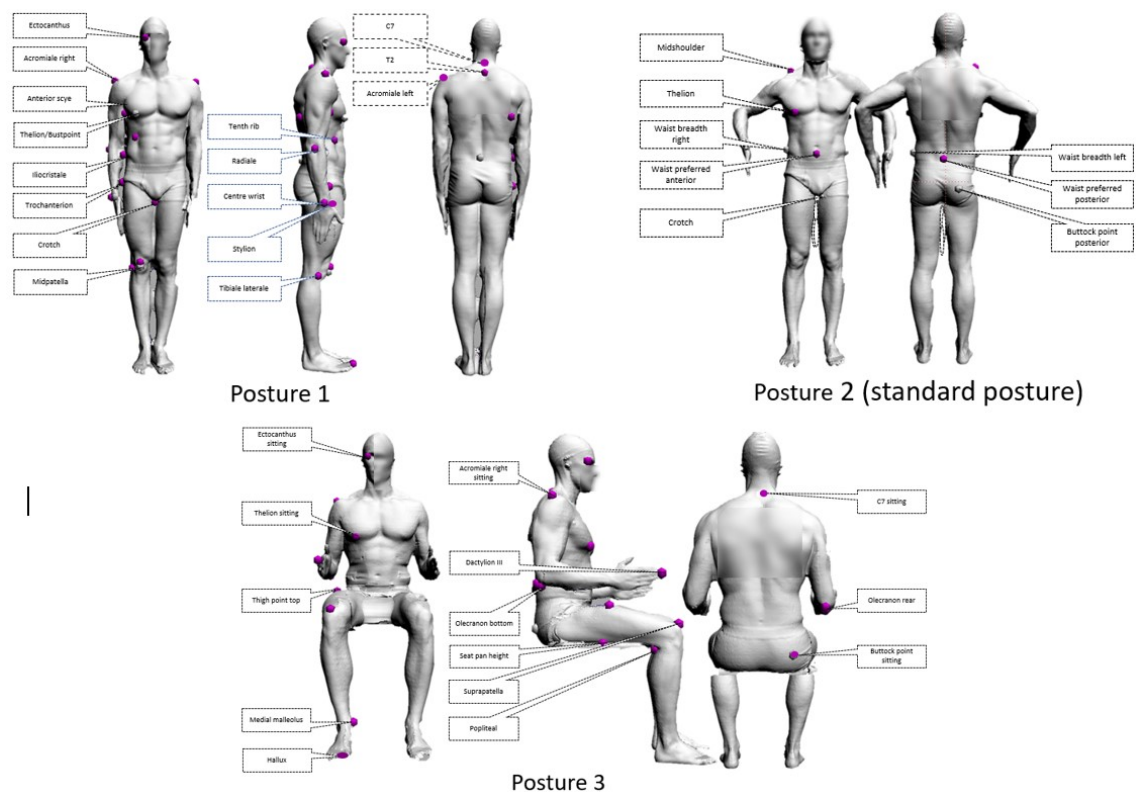


Figure 5—7. Some of the physical landmarks are converted to 'digital' landmarks (purple dot) which in turn, are used to identify and record digital measurements during post-processing.

Next, the anthropometric team conducted the physical measurements (Figure 5—8). One anthropometrist acted as the recorder. Each measurement was repeated twice and entered an Excel spreadsheet. Following the completion of all 25 physical measurements, a review of the datasheet was conducted. Measurements falling outside of normative bounds were re-checked by the anthropometrist, with a third measurement taken if the first and second measurements differed by more than 1%. Note, a higher tolerance of 5% was used as the test-retest difference for index finger reach, thumb tip reach, grip reach, elbow-grip length, elbow rest height standing, bicep circumference flexed, and arm span.

All measurements were taken on the right side of the body only as per ISAK protocol [67]. If the participant had an injury on the right side, then the measurement would be taken on the left side, and a note explaining this change was recorded in their data sheet. Due to time restrictions, no skinfold measurements were taken during the NZDFAS. After the measurements, the recorder disinfected all equipment in preparation for the next participant.



Figure 5—8. NZDFAS physical measurements. All 25 physical measurements were measured with traditional anthropometric tools.

Stage 4: Scanning (15 minutes)

After the physical measurements, participants proceeded to the scanning area (Figure 5—9). Participants were shown three postures to adopt during the scan. Posture 1 required participants to stand erect (with head in the Frankfort plane) with feet together, arms straight and relaxed to the side with palms facing medially with fingers fully extended and thumbs facing anteriorly at right angles to the fingers. Posture 2 required participants to stand in the same position but with feet shoulder width apart, and the arms abducted away from the area with a 45° bend in the elbow and forearms vertically positioned (i.e., perpendicular to the ground). Posture 3 required participants to be seated, in an erect seating posture and the head in Frankfort plane. The arms were bent to 90° at the elbow with the base of the forearm in line with the thighs. Fingers were extended at 90° to the thumb. Feet were flat against the ground with both feet facing anteriorly at less than shoulder width apart. The seat was adjusted at a height that facilitated a 90° knee bend.

For optimal scan results, the timing of the prompt must be clear, consistent, and accurate. Movement during the scan can result in inaccurate automatic and digital measurements [100]. The most obvious errors in post-processing occurred when participants were standing in an asymmetric stance (altering the x,y,z coordinates) with an offset vertical back and neck alignment.

At the start of the scan, participants were asked to breathe in, breath out slowly, and then hold their breath for 10 seconds. The breath was held (after fully exhaled) when the laser was between the shoulders and the mid-thigh region, to minimise movement artefacts. Normal breathing resumed after the scan was completed.

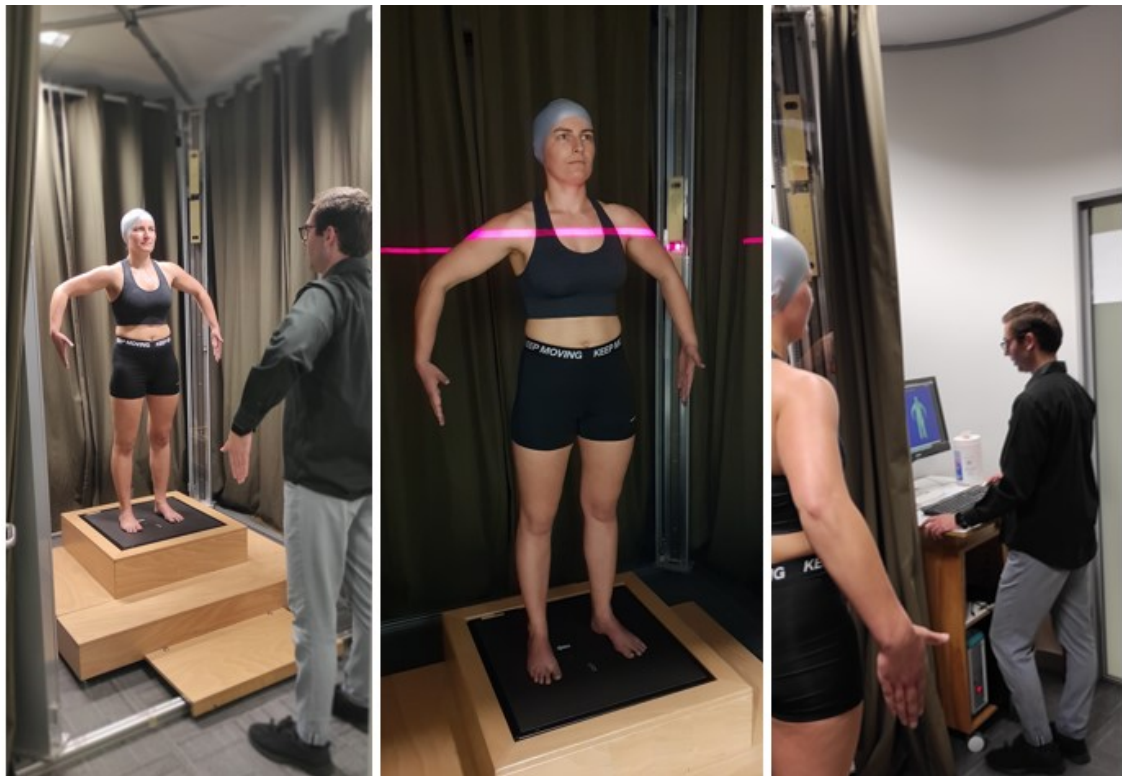


Figure 5—9. Body scanning process (left to right) posturing, body scan and checking and processing. Note that the lights are turned off during an actual scan. Light clothing is also desired, if not available than dark clothing will suffice.

The first two scan postures were from a standing position (Figure 5—10). The final scan, in a seated position, was taken using the body scanner platform seat. The seat was height adjustable and could be removed from the platform. Participants were positioned so that their buttocks and upper thighs were completely on the seat surface. The technician ensured that their knees were bent to 90° with both feet flat on the floor and facing forward. Foot stools were available but were rarely required. It was important that there was enough distance between the elbows and the lateral side of the torso. A 3D phenomenon known as ‘webbing’ may appear on the body scan if the elbows are too close to the body. Scanning only commenced when the technician was satisfied with the posture. Each scan lasted approximately 12 seconds and produced a 3D image of the participant. After each scan, participants relaxed their posture while the technician visually inspected their scan image. The operator checked each individual scan for a) presence of all stickered landmarks, b) correct posture, and c) that all necessary scan files (e.g., weight file from the in-built scale). If the technician was not happy with the scan results, then the scan was repeated.

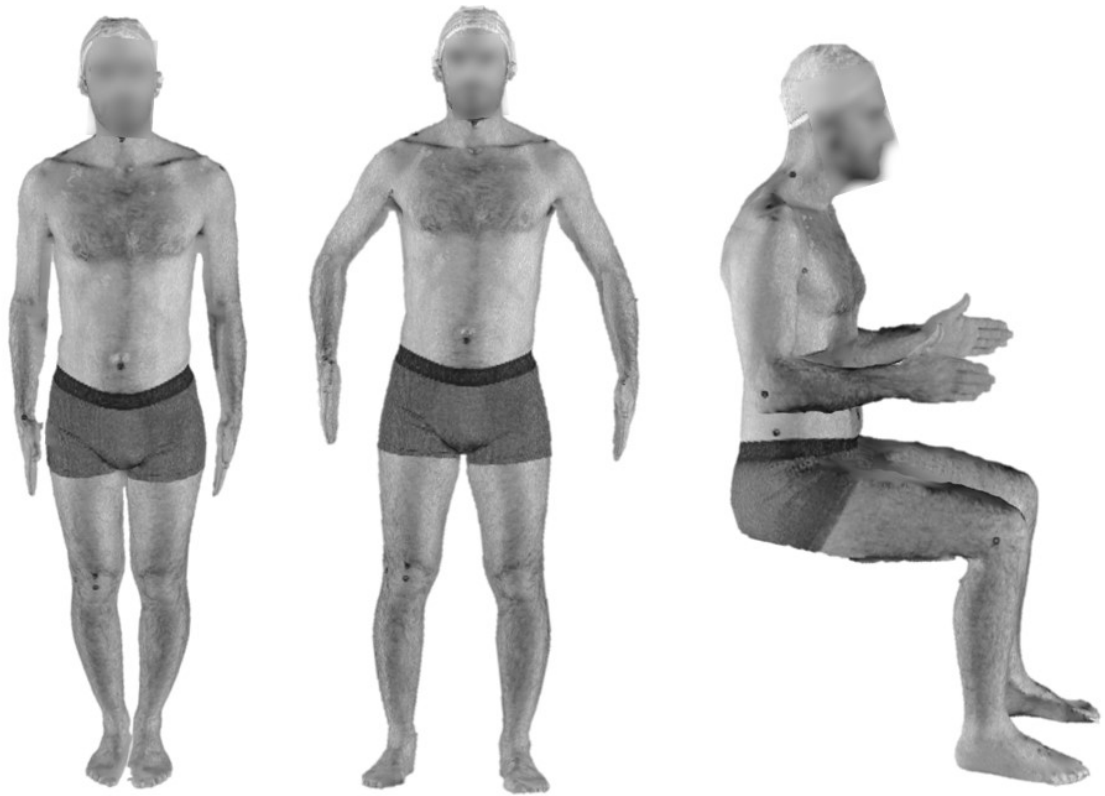


Figure 5—10. The three scanning postures: Posture 1 (left), Posture 2 (centre) and seated Posture 3 (right). The black stickers represent the stickered landmarks required for the digital measurements.

Figure 5—10 shows the three scanning postures. From left to right: Posture 1 (feet together, arms straight at the side, fingers flat and extended with palms facing towards the inner thigh), Posture 2 or standard pose (feet shoulder width apart while pointing forward, arms out to the side with a 45° elbow bend, both forearms vertical, fingers extended and palms facing the thigh), and Posture 3 or sitting pose (elbows and knees bent to 90°, back erect, both knees are aligned vertically above feet, knees slightly apart, both palms facing medially, fingers fully extended, and thumbs towards the ceiling). All three postures required the participant's head to be in the Frankfurt plane.

Stage 5: Participants get changed back into their regular clothing (5 minutes)

After scanning was complete, the survey team would remove and dispose of the landmark stickers and wipe the penned landmarks with skin appropriate alcohol wipes. Participants were ushered back to the changing area where they changed back into their clothes. The participant was then directed back to reception area with their completed datasheet and belongings, and then released from the data collection process.

Privacy and data management

Participant names were replaced with the identifier code administered during the brief. This code was used to label all data associated with the participant. The project lead was the only individual with the master spreadsheet linking the participant's name, service number and identifier code. During the project, only the project lead and named investigators had access to the data collected.

All electronic data were stored on password protected computers at AUT and will be held for 10 years. Paper-based data (informed consent forms) were stored in a secure location at DTA. Following the 10-year storage period, all hard copies of data will be destroyed (shredded).

At the completion of each data collection day, the raw body scan data and digital demographic data was copied to three 3 TB external hard drives. Each individual participant file was approximately 400 MB. This consisted of body scan data (bsf, obj, ply, and demographic files), excel files (physical measurements and outputs from the Anthroscan™ automatic measurement function). Survey data were not transmitted over the internet.

Analysis

Initial clean

After the completion of the survey, all raw data (e.g., demographics in PEDAs format, physical excel data and raw body scan data) were saved into folders (based on the unique identifier code) and by survey site (e.g., Whenuapai). An audit was conducted to ensure all necessary files were present. Any missing files were investigated further. Examples of errors were misspelled participant service numbers, identifier numbers, the absence of the weight file, or files being misplaced (saved in another participant's folder).

Automatic measurement

The body scan images were uploaded to a Human Solutions Anthroscan™ scan database. Anthroscan™ utilises proprietary algorithm and measurement definitions derived from ISO 7250 and ISO 8559 to automatically detect the required 17 measurements. All three scan postures (postures 1 to 3) were uploaded along with the demographic (PEDAs) information for each participant. To extract the automatic measurements, the operator followed Section 6.5 (Running an Automated Measurement) of the Anthroscan™ User

Manual[192]. Note, the automatic measurements are conducted on scan posture 2 only (Figure 5—11). Scan postures 1 and 3 were uploaded for reference only. The operator then checked each scan for measurement errors, such as the positioning of the hair bun during head circumference measurements. Table 5-5 shows common issues and how they were rectified. All measurements were then exported to an Excel spreadsheet using the export function. This was combined with their corresponding demographic information that included participant ID, service number, location, gender, trade, ethnicity, age, service, handedness, years of service, and uniform sizing information.

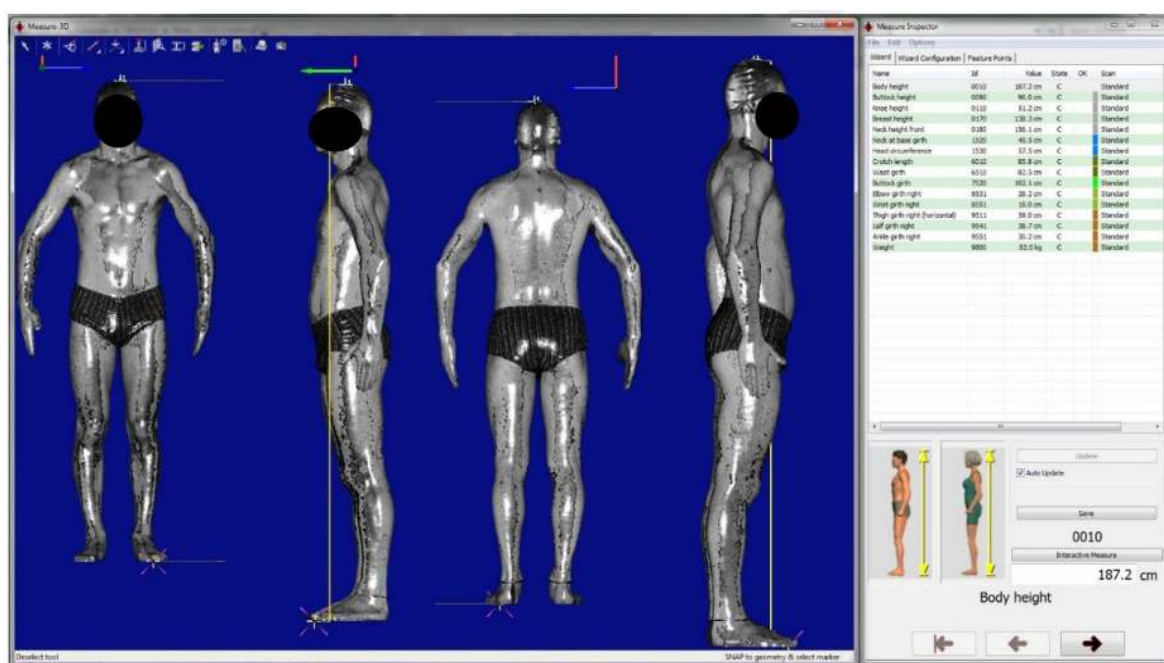


Figure 5—11. Output of Anthroscan™ automatic measurement based on scan posture 2.

Table 5-5. Automatic measurements analysis challenges and solutions.

Issue	Solution
Head circumference – for many of the female participants the head circumference line was drawn around a hair bun. This exaggerated their head circumference results. The line may also be crooked (see photos A and B in Figure 5—12). Neck base girth – the line drawn by the software does not follow the natural curvature of the base of the neck (see photo C in Figure 5—12). Crotch length – if participants are wearing loose fitting shorts it will affect the accuracy of this measurement. Close fitting undergarments were recommended but not all participants wore these during the assessment (see photo D in Figure 5—12).	• Skip this measure as moving the line above or below the hair bun will render this measure inconsistent with the definition. • If the line is crooked, then adjust by moving the front or back of the line until it is horizontal to the ground. • For future data collection ensure the hair bun is below eye height. • Adjust by moving the measurement line until it conforms to the shape of the neck. • If the shorts are too loose then skip this measure. • For future data collection, ensure participants are wearing the appropriate undergarment.

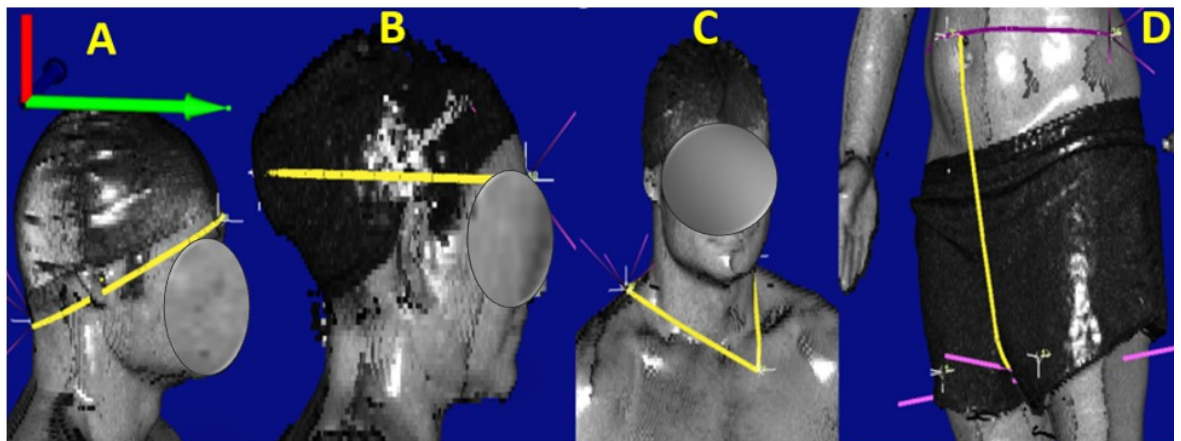


Figure 5—12. Examples of measurements which required checking, adjustments, or in extreme cases, removal. In photo A the yellow line should be horizontal, in B the yellow line is drawn around the hair bun, in C the yellow line does not conform to the base of the neck, and in D the loose-fitting shorts prevented an accurate crotch measurement.

Physical measurements

Participants' individual physical measurements were recorded in an Excel spreadsheet (example in Table 5-6) displays the percentage difference between the first and second measurements. If this was outside the respective tolerances, then the '3rd measure required?' column read "Yes" (and a median is calculated as opposed to a mean). The tolerances and correction factors were reviewed and approved by a Level 3 anthropometrist from AUT.

Table 5-6. Part of the physical measurement's spreadsheet used during data collection.

ID Code:	Req.				%	3rd	Media	Median+
Measurer initials:		1	2	3				
1	Seated height	1%	96.9	96.8	-0.1%	No	96.9	96.9
2	Head length	1%	20.1	20.3	1.0%	No	20.2	20.2
3	Head breadth	1%	15.5	15.6	0.6%	No	15.6	15.6
4	Bizygomatic	1%	13.2	13.2	0.0%	No	13.2	13.2
5	Bitrignon	1%	31.8	32.2	31.	1.3%	Yes	31.8
6	Interpapillary	5%	5.8	5.7	-1.7%	No	5.8	5.8
7	Index finger reach	5%	88.4	90.2	2.0%	No	89.3	90.4
8	Thumb tip reach	5%	85.9	84.0	-2.2%	No	85.0	86.1
9	Grip reach	5%	79.3	78.7	-0.8%	No	79.0	79.4
1	Elbow-grip length	5%	38.4	37.6	-2.1%	No	38.0	37.3
1	Elbow rest height	5%	70.3	70.3	0.0%	No	70.3	110.6
1	Forearm - forearm	1%	55.3	58.2	53.	5.2%	Yes	55.3
1	Bicep	5%	38.5	37.9	-1.6%	No	38.2	38.2
1	Arm span	5%	192.	192.	-0.2%	No	192.5	192.5
1	Buttock-heel	1%	107.	108.	0.6%	No	107.7	107.7
1	Index finger	1%	1.6	1.6	0.0%	No	1.6	1.6
1	Index finger	1%	2.0	1.9	2.0	-5.0%	Yes	2.0
1	Hand breadth	1%	8.5	8.5	0.0%	No	8.5	8.5
1	Palm length	1%	12.7	13.0	2.4%	Yes	12.9	12.9
2	Hand length	1%	21.8	22.1	1.4%	Yes	22.0	22.0
2	Hand	1%	20.9	21.1	1.0%	No	21.0	21.0
2	Foot length	1%	27.4	27.7	27.	1.1%	Yes	27.5
2	Ball of foot length	1%	20.0	19.8	-1.0%	No	19.9	19.9
2	Foot breadth	1%	10.2	9.9	9.8	-2.9%	Yes	9.9
2	Ball of foot	1%	25.4	24.9	24.	-2.0%	Yes	24.9

Digital or post-processed (CySize™) measurements

Extensive research has been conducted on finding the most suitable scan posture to extract each CySize™ measure. Each measurement and associated landmark are recorded in one of three scan postures (Posture 1, 2, or 3). This is to ensure that the measurements are made in the most logical position. For example, buttock to knee length can only be found when the participant is in a sitting position (Posture 3) and not standing as in Postures 1 and 2. Ectocanthus (an indicator for standing eye height) is recorded in Posture 1 where both feet are together. In Posture 2, feet are shoulder width apart which is not consistent with this measurement definition. For consistency, each measure is only recorded from one posture. Some landmarks such as ectocanthus can be used in multiple measurements (e.g., Eye height standing or sitting). The 42 measurements represent measurements that could not be recorded either accurately or quickly using physical or automatic methods (Table 5-7).

Table 5-7. CySize™ challenges and solutions.

Issue	Solution
Difficulty in seeing all landmarks clearly. Some landmarks are obstructed from view due to a digital phenomenon or artefact known as ‘webbing’. Webbing occurs when two points of the body are too close together and the software connects the two with a ‘web’-like feature as a by-product of the surface reconstruction (see items labelled A in Figure 5—13)	• Re-calculate the automatic body auto-fill function. Modify starting position from a different point on the slice. • Zoom in on the webbing, sometimes there are small ‘holes’ where the digital tape can still pass through unimpeded providing it is still in the approximate vicinity. • Alternatively, take the measure above or below the webbing, providing it still meets requirements in the measurement protocol definition. • If the webbing is too extensive, skip this measurement.
The surface mesh can appear to have a ‘hole’ in the skin or a ‘laceration’ type effect (see item B Figure 5—13)	• Recalculate auto body fill. • If this problem persists, skip this measure. • This is an artefact of the merging of scan patches and could be corrected in Anthroscan™.
Unknown artefact or objects in the scan. For example, see item labelled C in Figure 5—13).	• Recalculate auto body fill. • Try an alternative location. For example, the purple patch (patch C in Figure 5—13 hinders placement of the Seat pan height landmark. Try finding this on the opposite side of the seat pan. In this case, only the Y coordinate of the landmark is required – regardless of the horizontal location on the seat pan. • If in doubt, skip this measure.
Inter-operator reliability – the difference in how each operator interprets a landmarking location.	• Regular meetings (weekly or fortnightly) to communicate concerns or discrepancies. • Development of an issues register that the lead researcher will check and provide feedback on. • The lead researcher conducted regular checks of the CySize™ measurer’s landmark positioning and measurement positions.
Participant scan images are off-axis (i.e., not in an x, y, z compatible position). This can be partly due to incorrect body posturing (by the scan operator) within the scanner. For example, a participant may be facing slightly to the right, or body ‘hunched’ forward, left, or right. This often happens when participants are not placed in the Frankfort plane ¹ in the scanner.	• CySize™ has developed an x, y, z correction tool. This allows the image to be re-aligned to the correct plane prior to taking measurements. • If body posture is extremely off-axis then consider skipping this individual. This can be addressed with using a third party tool such as <i>Meshlabs</i> (ISTI-CNR, Krnataka, India).

¹The Frankfort plane refers to a straight, horizontal line between the Orbitale (bottom edge of the eye socket) and the Tragon (the notch superior to the tragus of the ear). This is the correct head position for measuring height.

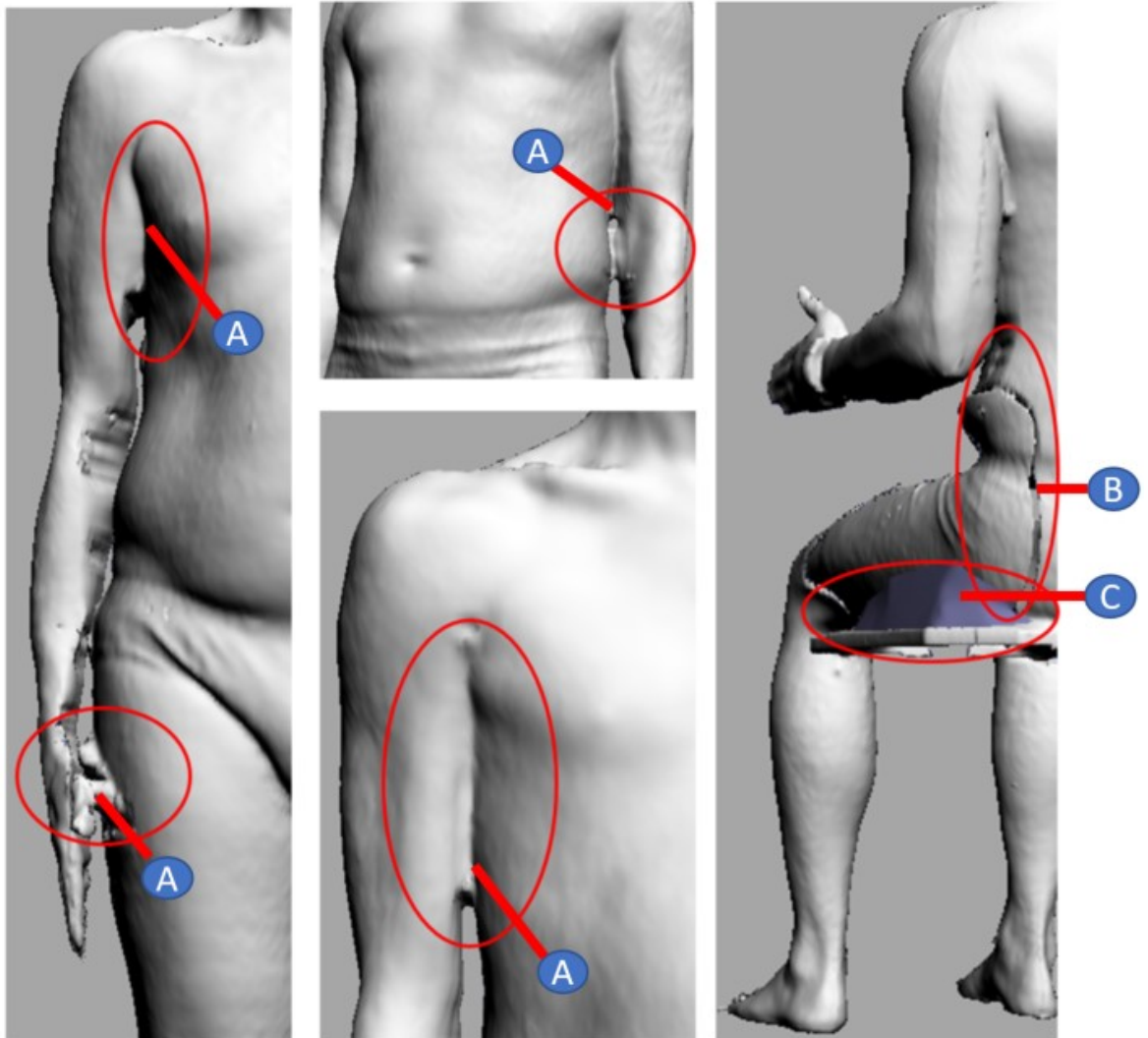


Figure 5—13. Common artefacts with CySize™ analysis: webbed skin (A), holes on the surface (B) or unknown objects (C).

A total of 42 measurements were recorded using CySize™ software developed by Headus Ltd, Australia. CySize™ has been used successfully by various international military organisations, most notably in Australia. The software has tools that can extract accurate measurements from 3D point cloud image files. Many of these tools are not part of the 3D body scanner software.

This section is designed for operators who are trained to use CySize™. For users who are new to this software, please read resources [166, 190] that provide comprehensive instructions on how to prepare data files, identify and save landmarks and measurements [166]. Before using CySize™, raw image scan files from the 3D body scanner software

(Anthroscan™) must be converted into a form that is usable in CySize™ [193]. Figure 5—14 provides a summary of the NZDFAS CySize™ process.

ANALYSIS: EXTRACTING DIGITAL (CYSLICE) MEASUREMENTS PROCEDURE

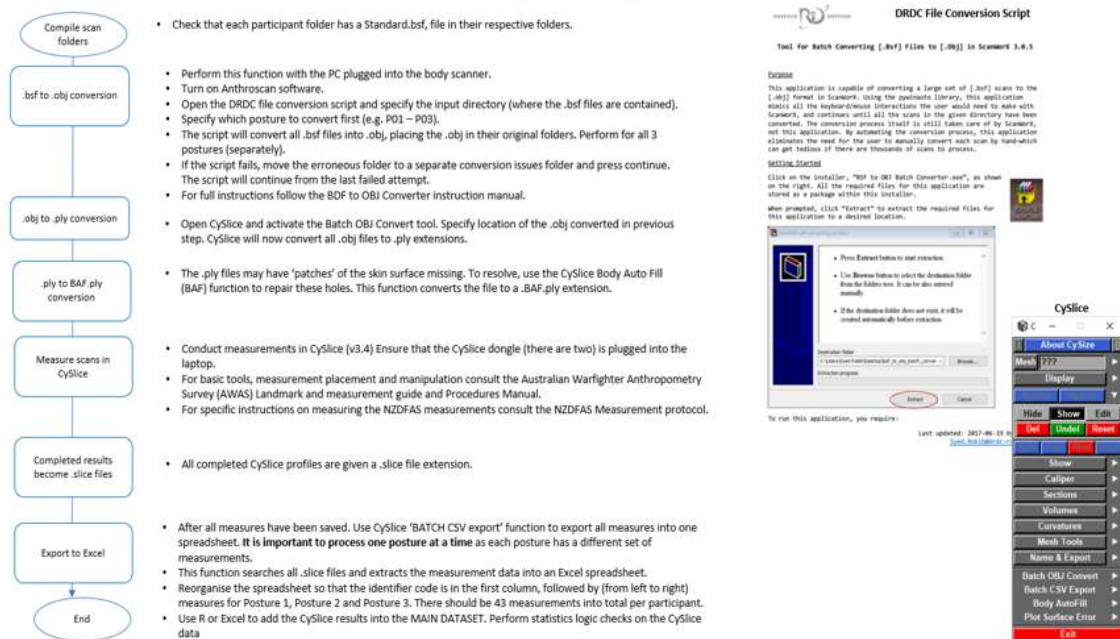


Figure 5—14. The NZDFAS CySize™ measurement process.

Concatenate all data

Once all measurements were completed, the CySize™ results were combined with the demographic, physical, and automatic data to form the full NZDFAS dataset.

Statistics and logic checks

A series of data preparation steps (Figure 5—15) were then performed using the R statistical software:

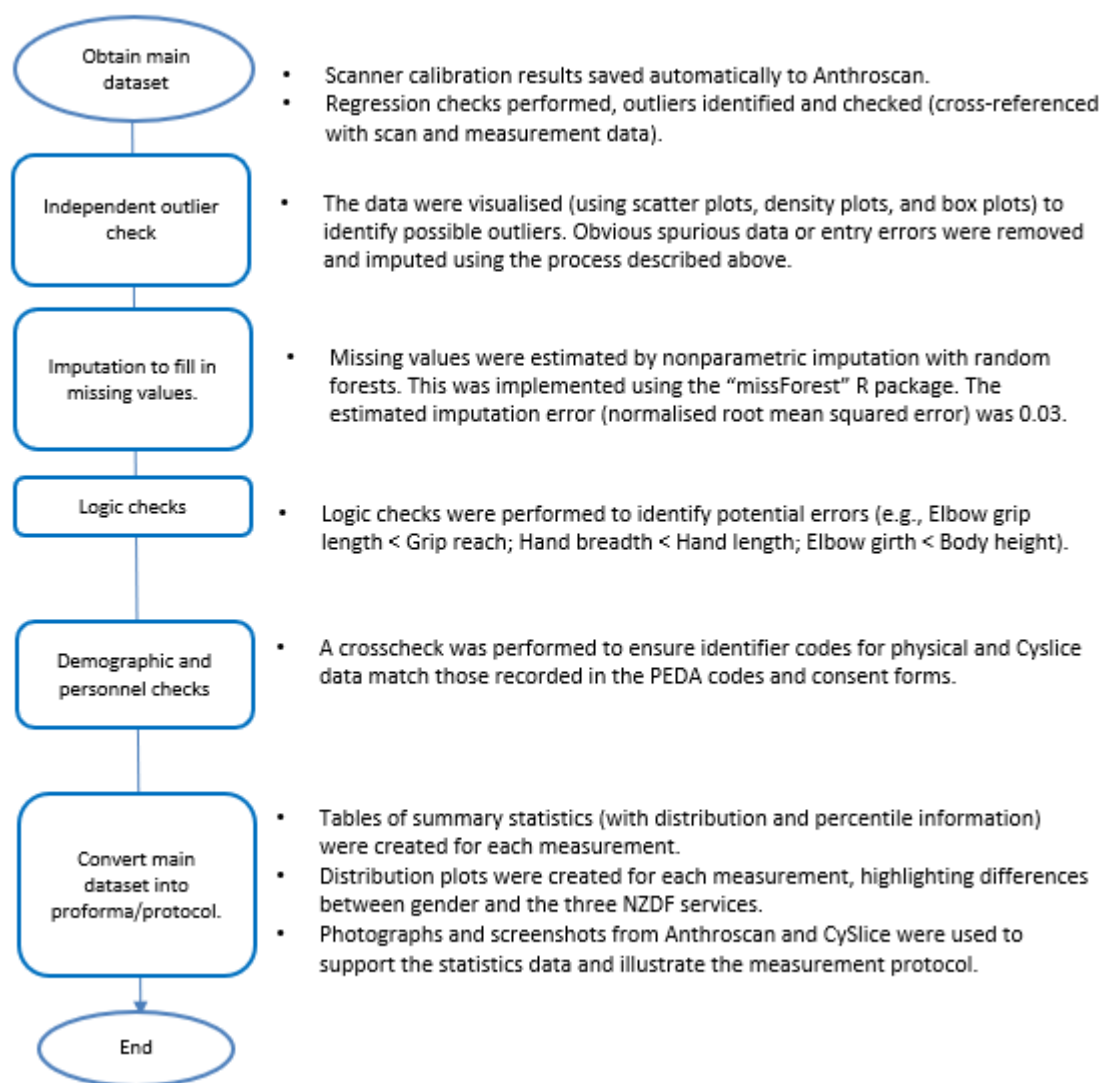


Figure 5—15. Final check procedures for the NZDFS data.

Results

Table 5-8 summarises the mean and standard deviation by gender and service. See APPENDIX V for more detailed information.

Table 5-8. Basic descriptive statistics (n=84) by gender and service.

Measures	Air Force		Army		Navy	
	Female (n=72)	Male (n=218)	Female (n=97)	Male (n=487)	Female (n=43)	Male (n=88)
Ab extension depth sitting	236.2±34.3	271.3±37.9	249.9±32.9	271.9±32.5	254.2±36.5	280.7±41.4
Acromial height sitting	592.7±29.4	625.1±28.4	600.4±28.9	623.1±30.4	588.8±25.3	615.8±27.5
Acromiale height	1362.8±50.3	1473.3±61.8	1371±50.3	1462.5±60.2	1358.6±46.8	1467±51.7
Acromiale radiale length	320.7±14.9	347.9±18.2	319.7±15.4	345.4±19.1	319.7±16.1	349.1±17.9
Ankle girth right	248.4±12.7	277.9±19.4	247.5±15.7	271.9±17.9	255.5±18.4	284.8±18.2
Arm span	1680.6±67.6	1838.6±78.2	1690.3±66.3	1835.2±75	1669.1±56	1842.6±68.5
Axilla height	1230.8±52	1330.3±55.3	1242.8±50.6	1322.3±55.7	1230±43.7	1320.5±52.8
Biacromial breadth	376.3±14.9	420.9±19.2	378.3±18.4	423.1±18.9	377.3±14.5	422.6±19.3
Bicep girth flexed	304.7±30	353.8±31	314.5±25.3	360.8±31.8	310.3±34.5	363.5±34.8
Bideloid breadth sitting	447.8±25.7	504.2±29.3	459±31	510.6±28.4	461.3±35.5	516.8±33.1
Bitragion mandibular arc	270.4±12	303.4±16.9	276.5±14.1	303.7±16.5	282.6±15.3	312.8±18.2
Bizygomatic breadth	126.7±7.3	133.9±8.3	124.2±6.7	130.3±7.8	125.2±7.4	132.2±8.2
Body height	1670.8±56.5	1794.5±66.7	1675.2±55.8	1783.2±66.1	1661.2±52.8	1783.9±55.8
Breast height	1203±47.6	1309.5±55	1211.7±50.3	1300.1±54.7	1192±48.3	1302.4±50.2
Bust chest girth	947.1±78.5	1049.4±90.5	963.6±73.2	1053±78.4	967.3±86.1	1074.6±89.3
Buttock depth	263.7±22.9	284.1±27.3	267±22.7	283.6±23.5	262.1±26.7	283.6±28.3
Buttock girth	1037.4±73.1	1043.3±73.6	1050.3±62.5	1054±70.3	1044.3±74.7	1051.6±77.4
Buttock heel length	1000.5±39.1	1075.3±50.9	1004.9±46.3	1065.8±47.5	995.1±40.4	1071±48.2
Buttock height	839.6±36	910.2±46.7	841.3±39.1	899.8±46.2	832.5±33.3	909±43.6
Buttock knee length sitting	598.7±22.5	629.2±31.5	597.6±26.3	624.3±29.1	602.2±24.4	631.4±28.7
Buttock popliteal length sitting	502.1±27.7	524.3±27.3	500.7±23.2	518.5±25	515.5±23.6	533±23.8
Calf girth right	373.8±22.5	389.1±27.3	377.1±24.7	390.6±26.2	380.1±25.1	397.9±25.1
Cervicale height sitting	653±30	692.8±29	654.6±28	689.4±29.1	651.8±26.5	687.2±24.4
Chest breadth	315.4±24.7	364.3±30.2	321.5±26.3	364.6±28.3	321.1±31	374.4±31.9
Chest depth	247.4±23.9	248.9±26.4	250.1±26	250±22.8	253.3±23.6	253.9±26
Chest height sitting	430.7±26.5	450.4±27.6	433.2±25.1	448.9±25.2	419.9±28	441±27.4
Crotch height	767.2±30.9	794.9±43.8	766.7±33.9	787.8±40.6	767.3±33.6	790.8±42.5
Crotch length	785.9±48.7	891.4±66.1	798.8±53.5	896.2±57.3	784.9±52.5	881±50.3
Crotch waist preferred anterior	253.6±36.2	293.7±29.8	259.1±36.4	291.6±32.3	242.5±41.3	281±36.5
Crotch waist preferred posterior	418.3±69.7	421.4±59.5	434.1±65.2	439.2±70.7	434.3±84	431.1±82.6
Elbow girth right	249.3±16.3	283.5±19.9	257.2±17.2	288.6±20.1	252.3±20	291±19
Elbow grip length	327.2±16	361.5±18.2	325.8±14.4	356.8±17.6	321.6±12.2	357.7±18.2
Elbow rest height standing	985.5±38.7	1064.8±47.4	998.4±39.5	1057.6±46.2	987.5±40.3	1056.7±42.9
Eye height	1549±54.3	1677.5±64.9	1551.9±53.5	1664.4±65.2	1542.8±50.1	1670.6±54
Eye height sitting	778.5±31.1	827±31.2	779.8±29.6	824.6±32.9	772.2±29.8	818.8±29.2
Foot ball circumference	232.3±12	254.8±12.5	230.5±11.6	253.8±14.3	232.6±12.3	255.6±12.5
Foot ball length	178.3±8	197.1±10	180.4±9.3	197.3±9.7	177.8±7.3	195.8±11.1

Foot breadth	93.8±5.7	102.5±5.4	93.8±5.6	102.7±6.3	93.4±5.7	102.6±6.1
Foot length	244.4±10.9	269.4±12.2	245.8±10.7	269.2±12.5	243.9±11.8	271±11.9
Forearm fingertip length	435.6±19.5	481.9±21.1	438.7±18.9	480.2±21.4	435.1±15.3	482.5±19.9
Forearm forearm breadth	469.8±39	544.1±50.1	476.3±38.1	541.3±52.9	474±42.2	558.1±51.4
Grip reach	702.3±34.5	772.2±38.8	701.1±34.2	765.4±40	689.5±29.1	770.8±39.4
Hand breadth	77.9±3.6	87.3±4.1	78.6±4.1	87.7±4.3	78.1±3.5	88.4±3.9
Hand circumference	190.6±9.3	214.7±10.3	190.8±10.2	213.7±10.5	188.4±9.8	214.7±9.8
Hand length	185.4±9.3	201.3±10.6	182.8±10.5	197.2±11.6	178.9±9.4	196.7±9.1
Head breadth	149.1±6.2	155±6.4	149.6±7.4	155.6±5.9	147.4±6	156.9±6.6
Head girth	576.1±12.2	596±16.5	579.9±11.8	600.3±14.9	575.4±12.1	595.3±14.4
Head length	194.8±5.9	202.6±7.1	195.2±5.8	202.2±6.6	193.7±6.8	200.6±6.2
Hip breadth sitting	424.8±32.7	423.4±33.6	433.6±27.5	427.1±31.4	436.1±29.5	431.6±32.6
Hip breadth standing	371.5±18.7	367.7±20.6	376.2±17.4	368.8±20.7	375.7±21.1	369±21
Hip girth maximum	1046.3±66.1	1056.3±68.9	1056.5±55.7	1063.6±64.8	1057±73.2	1059.8±82.7
Iliocristale height	995.6±44.7	1076±53.3	998.8±41.4	1067.6±50.7	993.7±40	1076.6±54.5
Index finger breadth distal	14.2±1.3	16.4±1.5	14.7±1.2	16.6±1.3	14.6±0.9	17.2±1.3
Index finger breadth proximal	16.8±1.3	19.2±1.5	17.4±1.3	19.4±1.4	17.1±0.9	20±1.1
Index finger reach	791.1±36.9	869±40.9	795.2±39	861.3±43	780.8±30.7	868.7±39
Interpapillary breadth	58.2±3.6	61.2±3.8	58.6±3.5	60.8±4.1	57.4±4	60.6±5.1
Knee circumference	368.4±23.8	387.2±24.5	371.4±21.2	387.1±23.5	378.1±22	391.9±21.4
Knee height	447.3±19.7	485.5±24.9	448.7±21.2	479.6±24.7	443.5±18.4	484.6±23.3
Knee height sitting	513.7±23	558.2±27.6	513.3±22.3	553.9±26.5	513.7±21	564.8±27
Malleolus hallax length	189.5±11.4	211±11.5	192.4±10.2	209.9±11	191.7±10.9	211.8±11.3
Neck girth base	389.9±25.8	452.7±28.2	402.6±27.2	462.8±31.9	396.3±29.6	464.4±34.7
Palm length	106.7±5.8	116.2±7.3	105.2±6.8	113.6±8.8	104.3±6	114.8±6.5
Popliteal height sitting	413±21.2	451.5±23.2	411.5±20	447.4±23.3	416±16.4	458.6±25.2
Radiale stylium length	238.8±13.6	266.9±14.9	243.1±12.7	267±14.9	233.4±12.1	267±15.2
Seated height	890.6±28.6	945.5±30.5	892.1±30.4	942.5±34.6	887.6±29.8	940.5±26.8
Shoulder elbow length	345.4±15.2	374.6±18.1	346.6±15.5	373.2±19	340.9±14.9	374.4±17.2
Sitting elbow rest height sitting	251.4±23.7	255.7±24.1	257.7±26.2	254.9±27	252.4±21.9	245.5±24.9
Sleeve outseam	566.2±24.1	620.8±30.4	569.1±24.5	617.9±30.5	558.1±23.3	620.1±27.2
Suprasternale height	1371.9±51.9	1478.4±62.4	1374±52.2	1464.6±60.6	1362.8±46.6	1470.1±52.9
T2 height	1389.5±52.3	1508.6±61.6	1402.7±54.7	1503.6±61	1398±47.9	1506.7±51
Tenth rib height	1059.1±44.7	1152.6±51.6	1063.3±41.8	1139.6±50.7	1073.3±45.3	1152.4±55
Thigh clearance	156.8±13.1	168.9±14.1	158±13.6	167.6±14.9	158.7±13.4	170.8±13.8
Thigh girth right	585.3±40.3	591.7±48.9	601.5±37.4	598.8±51.7	598.2±42.2	603.1±48.2
Thumb tip reach	756.8±36	828.9±41	758.6±38.5	821.5±41	746.8±29.2	829.7±38.1
Tibiale laterale height	442.1±23.5	483.1±25.1	441.2±19.3	479.6±26.7	430.7±16	479.3±30.5
Trochanterion height	854.9±49.2	937.7±48.7	863.3±43.3	931.1±47.9	847.2±36.8	924.1±47
Vertical trunk circumference	1623.1±65.1	1790.5±86.1	1649.2±72.5	1795.5±76.7	1633.9±78.9	1795.4±74.5
Waist breadth	318.4±31	333.9±31.8	325.9±29.6	333.6±29.8	324.2±34.1	338.1±33.6
Waist circumference preferred	861.9±76.3	935.6±105.6	878.3±94.9	932.8±98	875.3±120.3	951.9±109
Waist depth standing	228±33.9	256.4±35.5	238.5±35.5	254.8±34.4	245.5±37.5	264.2±37
Waist girth	789±90.9	897.6±108.3	814.6±89.6	894.6±99.6	813.3±110.4	917.4±122.2
Waist height preferred	998.2±53.6	1051.8±46.6	998.6±48.3	1045.6±46.8	992.3±42.4	1052.3±46.4
Weight body mass	67.9±9.7	85.4±13.8	71.6±10.9	85.8±12.1	71.4±13.5	87.7±13.2
Wrist girth	159.9±9.4	178.4±11.1	162±10.1	179.6±11.2	161.5±10.8	183.5±10.5

Summary

The following are key observations from the NZDFAS survey. It is hoped that future researchers will take these factors into consideration when planning their respective surveys.

Validating measurements is an important part of the survey planning process and should never be taken lightly. This is particularly important when attempting to use automated measurements. Despite the accuracy claims by various 3D body scanner manufacturers, it is important to conduct your own validation; that is, benchmarking the performance of the scanner output against a known ‘gold standard’ in this case, physical measurements. Furthermore, the following is recommended:

- ❖ Conduct the validation under supervision of a criterion measurer (e.g., ISAK Level 3+ or an experienced anthropometrist).
- ❖ Compare measurements that have the same measurement definitions (e.g., if the scanner system records chest girth at the lion height then the physical measurement should also be taken at this point).
- ❖ Consider the effect of scan posture in the validation process (e.g., some scanner systems capture height from a posture that requires feet shoulder width apart, while traditional definitions may require feet together).
- ❖ Incorporate redundancies should measurements fail initial validation. For example, if the automated measurement fails, consider capturing it physically or post-processed depending on how much time you have with (a) the participant (b) your survey team.
- ❖ Whilst some measurements could fail the validation, determine whether the failure criteria are meaningful in the context of the application of the measurement. For example, is 5% error for sleeve length necessarily negative from a clothing design perspective?

If possible, leverage information, techniques, and datasets from other surveys or even better, personnel who led their respective studies. The NZDFAS would not have been possible without the support from various international military organisations. Every project lead has a story to tell and developed methods that worked well for them (and can talk about those which did not). From our experience, the international military anthropometry research community is very welcoming to new and inexperienced members. While it is nice to receive, it is also important to give, share, and relay your

own findings where possible (depending on your organisation), military anthropometry is very much a team effort.

Training for data collection is very important. Depending on the organisation, anthropometry teams are either trained internally (in-house) or trained by external agencies such as ISAK. ISAK is just one anthropometric standard, which may differ from a military, fit-for-purpose standard. As part of ISAK training courses, people learn how to follow an international anthropometric standard, and they get training in haptics and proxemics. There is an in-built curriculum, examinations, and both in-course and post-course profiling thresholds to achieve for precision and accuracy. Courses are regularly and widely available across the global ISAK network. Anecdotally, more organizations are opting to train their data collection teams with ISAK. However, it must be advised that most military anthropometric measurements (e.g., ANSUR II and all protocols that are based on it) are very different to ISAK. Measurement differences aside, one of the most important benefits of training military anthropometrists through ISAK is measurement etiquette. ISAK is excellent at teaching the fundamentals of measuring (e.g., how to use calipers and tapes accurately and efficiently). The breadth of teaching material covered in the ISAK course curriculum is a must for new military anthropometrists.

In terms of selecting an anthropometry team, consider selecting individuals who are good team players with good ‘people’ skills. Like in team sport, tactics (following the anthropometric standard) and dynamics (social interactions) are very important. Sometimes these traits are just as important as measurement accuracy. From experience, I have witnessed a lot of complacency (e.g., high ‘ego’ leading to avoiding measurement duties) within our best or most accurate measurers, while other (less accurate) team members worked tirelessly and were more committed to the cause. Measurement slippage can also occur with long testing periods (with the same team) say over a fortnight. Therefore, managing these dynamics within your data collection is important for ensuring the quality of the measurement outputs while avoiding fatigue (which may lead to increased errors and reduced accuracy).

Finally, if you are new to leading anthropometric surveys, be prepared to make mistakes. In my case, I experienced a lot of ‘trial and error’ at almost every stage of the project. Therefore, when planning initial project timelines, it is vital that this ‘learning phase’ is

built in at every phase of the project (e.g., training, scanner familiarisation, analysis, measurement identification, validation).

From discussions with fellow national survey leads, the completion of a large-scale anthropometric survey (from project initiation to submission of final report) can take anywhere up to 5 to 6 years depending on funding and resources available. The NZDFAS project took approximately 5 years to complete. For a country with an active service population of around 9000 this (compared to larger nations) was relatively a slow burn. However, it was a big learning curve for all involved, which will serve the NZDF well for future surveys. Accounting for this learning phase is extremely important.

In conclusion, 3D body scanning shows enormous potential for assisting military anthropometric surveys. While many surveys still take predominately physical or traditional measurements, the uptake of 3D body scanning is steadily increasing amongst military nations and their respective surveys. The military needs to use the 2D and 3D outputs as they still more-or-less only use 1D outputs from 3D scanners.

The NZDFAS produced New Zealand's first 3D anthropometric dataset that is now available to the NZDF. It is important that we build on this body of work for future anthropometric surveys in New Zealand to ensure that anthropometric data are applied correctly to real-world ergonomic, engineering, and design problems. We hope future surveys will incorporate more 3D shape and volumetric measurements in addition to 1D measurements extracted from the 3D scans. We hope that future researchers can use this material, methods, and subsequent lessons to plan surveys for their respective organisations.

The next three chapters will look at the applications of this dataset to military clothing.

Chapter 6 What Absolute and Proportional Anthropometric Variables Distinguish Between Male and Female Military Personnel

Stephven Kolose, Tom Stewart, Grant Tomkinson, Patria Hume

Preface

Chapter 5 reported on the development, implementation, and analysis of the NZDFAS survey. This resulted in the development of a novel measurement protocol that utilised traditional anthropometric measurement in conjunction with automatic and post-processed measurements from 3D scans. Collectively, this work achieved the first part of the thesis aim — to conduct an anthropometric survey of the NZDF. Chapters 6 to 8 address the second part of the thesis aim — to explore the applications and implications of the NZDFAS dataset in a military context. More specifically, the remaining chapters focus on the application of 3D anthropometric data on military clothing.

As described in Chapter 1, there has been a global increase in the proportion of females who have joined the military. This has implications for the design and fit of existing military clothing and equipment. While some garments are unisex, specific differences in male and female body dimensions may necessitate a single-sex clothing system. To achieve this, knowledge of how body measurements and proportions differ between males and females is important. Accordingly, the purpose of Chapter 6 is to examine the absolute and proportional anthropometric differences in male and female NZDF personnel.

Abstract

Aim: The aim of this study was to identify any sexual dimorphism in human body dimensions among New Zealand military personnel using data from the 2016–18 New Zealand Defence Force Anthropometric Survey.

Methods: A total of 1003 (791 male, 212 female) New Zealand military personnel had 84 physique measurements obtained manually using surface anthropometry and digitally using a 3D whole-body scanner. The girth, breadth, length, and height variables were categorized as being either absolute (those directly measured in kg, mm, or cm) or proportional (ratio measures and those normalized using the “Phantom model” height of 170.18 cm). The most sexually dimorphic measurements were identified using stepwise logistic regression.

Results: Males had significantly larger absolute and proportional measurements compared to females for most, but not all, measurements. Using logistic regression, four body dimensions (waist girth, hip girth, bicep girth, and biacromial breadth) classified sex with 95% accuracy.

Conclusions: This study demonstrated sex-related proportionality differences in body dimensions for New Zealand military personnel, with waist, hip, and bicep girths, and biacromial breadth, the most sexually dimorphic. Sex-related differences in proportionality provide information for informing clothing decisions in the military.

Introduction

Anthropometry for fit optimisation

Anthropometry deals with body measurements, shape, strength, mobility, and flexibility in a working capacity [53]. To optimize fit, it is important to use the correct and updated anthropometric measurements for the target (e.g., the end-user) population [194]. Most anthropometric datasets are based on traditional linear measurements (e.g., lengths, breadths, girths); however, they can sometimes fail to capture the true size or shape of the human body due to large variations in body proportions [31].

Sex differences in absolute and proportional measurements

The systematic anthropometric differences between males and females, beyond the basic functional proportions of sexual organs, is called sexual dimorphism [195]. Previous studies have demonstrated sexual dimorphism for absolute (linear or one-dimensional) body dimensions such as foot length/breadth [33, 196], hip/pelvis circumference [40], and lower leg (tibial) length [35]. Sexual dimorphism has also been studied in athletes [38, 197, 198] and military personnel [31]. Despite its applications, there is limited research on how to optimally scale anthropometric data when examining sexual dimorphism. Options range from simple ratio scaling [199] to modern statistical techniques such as stepwise discriminate function [31]. Another popular method, first proposed in the 1970s to 1980s, was the ‘Phantom’ strategy [200, 201], where, using geometric similarity, body dimensions are scaled to a baseline height (or Phantom height) of 170.18 cm. The Phantom Z-scores are useful for making proportional comparisons. The differences in Z-scores can be quantified between individuals or within an individual. For example, the Phantom stratagem has been used to compare athletes [202] and to track longitudinal growth changes [203]. Most of the methods were based on linear (and not 3D) measurements from civilian populations.

Sex differences in military uniforms.

The increasing number of females in both the military and combat roles worldwide [26, 27] has future implications for military clothing sizing, especially because traditional military sizing systems were developed for the male body type. For example, garments for the upper body can be ‘baggy’ for females, while tight around the hips [28]. A poor fit can compromise safety (e.g., increased potential for loose clothing to ‘snag’ on items, impaired reach and mobility) [28]. Research comparing anthropometric measurements

between men and women has found that sex-related differences in body proportions can be too large for a single sizing system [204], and that sex-specific sizing systems can lead to issues in manufacturing, stocking, and distribution [28].

How are sex differences identified from anthropometric data?

In the past, clothing measurements were derived from body dimensions captured using linear (traditional) measurements such as lengths and breadths. Unfortunately, neither the reference points or the path of linear measures strictly follow the path of a garment plane as it moulds over the 3D body [205]. With the introduction of 3D body scanners, anthropometric data can be derived from 3D body scans and used to better examine sex-related differences. For example, using 3D anthropometric data from the Civilian American and European Anthropometry Resource (CAESAR), Fullenkamp, Robinette [31] used stepwise discriminant analyses to identify the combination of anthropometric measures that best distinguished between males and females [60, 126]. Six measurements (i.e., shoulder breadth, hip breadth sitting, bilateral femoral epicondyle breadth sitting, knee height, sitting height, and bilateral humeral epicondyle breadth sitting) accurately distinguished sex 99% of the time. Women were significantly larger than men for seated hip breadth, but significantly smaller for shoulder breadth, suggesting that male proportioned clothing, even if scaled down, will not necessarily fit females. To date, research on absolute and proportional sexual dimorphism has never been performed on a military population. Sexual dimorphism has never been studied on both traditional and 3D body scanning data for the purposes of identifying measurements informing clothing design.

New Zealand Defence Force

The New Zealand Defence Force (NZDF) has a uniformed population of 9328 personnel consisting of three services: the New Zealand Army (NZ Army; n=4655), the Royal New Zealand Air Force (RNZAF; n=2489) and the Royal New Zealand Navy (RNZN; n=2184). Women comprise 14%, 20% and 24% of these services, respectively [206]. In 2019, the NZDF set individual service gender targets to increase female participation in the RNZAF and RNZN to 25% and 30%, respectively, by 2025 [206]. The NZ Army aims to have at least 40% women entering its tertiary education scheme and commissioning courses, and gender targets of 25% for combat support, and 35% for combat service support trades, in place by 2025 [206]. This increase in females may mean that changes (or alterations) to current clothing inventory are necessary to reflect the female form.

Between 2016 and 2018 the NZDF Defence Technology Agency (DTA) in conjunction with the Auckland University of Technology (AUT) conducted the NZDF tri-service anthropometric survey (NZDFAS) of 1003 uniformed personnel, representing approximately 11% of all available personnel. During the survey, 84 anthropometric measurements were assessed using one of three methods: physical measurements (using traditional anthropometry); 3D body scanner automatic measurements (generated automatically by the body scanner software, Anthroscan™); or post-processed measurements (processed after the data collection using third-party software called CySize™).

The aim of this study was to identify any sexual dimorphism in human body dimensions among New Zealand military personnel using the NZDFAS. The objective is to examine the absolute and proportional differences between males and females in the NZDFAS dataset. We hypothesised that males would generally have larger absolute and proportional body dimensions compared to females.

Method

Ethical approval for this study was obtained from the Auckland University of Technology Ethics Committee (AUTEC #14/126). The New Zealand Defence Force (NZDF) approved the use of the NZDFAS data for research purposes.

Participant sampling strategy

The NZDFAS dataset was collected between February 2016 and June 2018 and consisted of 1003 uniformed participants from the Royal New Zealand Navy (n=131), Royal New Zealand Air Force (n=289) and the New Zealand Army (n=583). The participants were recruited across the five major military establishments throughout New Zealand using a mixture of stratified and purposeful sampling. The participants were from various service backgrounds with the majority from engineering and technical (25%), combat (19%) and logistics and administration (11%). The ethnic composition of participants was mainly European (41%), New Zealand European (37%), and Māori/Pacific (20%).

Protocol and equipment

The NZDFAS protocol [207] was based on the Australian Navy, US Marines, and Canadian Forces protocols [7, 43, 166, 208] and video resources from Defence Research

and Development Canada. The data collection activities at each survey site comprised four stages:

- ❖ Brief, where participants had the study aims explained to them and they completed written informed consent and an electronic demographic questionnaire. This questionnaire captured information such as their service type (Navy, Army, or Air Force), years of service, sex, ethnicity, trade, and questions on how they rated the fit of their uniforms and other military equipment.
- ❖ Physical landmarking, where participants had 20 landmarks physically palpated and marked by anthropometrists trained at Level 2 by the International Society for the Advancement of Kinanthropometry (ISAK). The landmarks were used to help identify and extract manual and digital measurements according to a measurement schedule [207].
- ❖ Manual measurements, where participants had 25 measurements [207] taken twice by the anthropometrist using equipment recommended by ISAK (e.g., anthropometer, large sliding calliper, small bone calliper, tape). If the first and second measurements were outside specified limits (i.e., 1% for breadths, length, and girths, 5% reach measurements) then a third measurement was taken. Measurements were recorded directly into a modified ISAK Level 2 profile spreadsheet in Excel (Microsoft Corp., Redmond, WA, USA).
- ❖ Body scan, where participants were scanned inside the Vitus Smart XXL® body scanner (Human Solutions, Kaiserlauten, Germany) [190] wearing tight-fitting underwear (e.g., briefs for males, sports bra and underwear for females) and a swim cap (to standardise head-related measures such as standing height). Each participant was scanned in three different postures (two standing and one sitting posture) as shown in Figure 6—1.

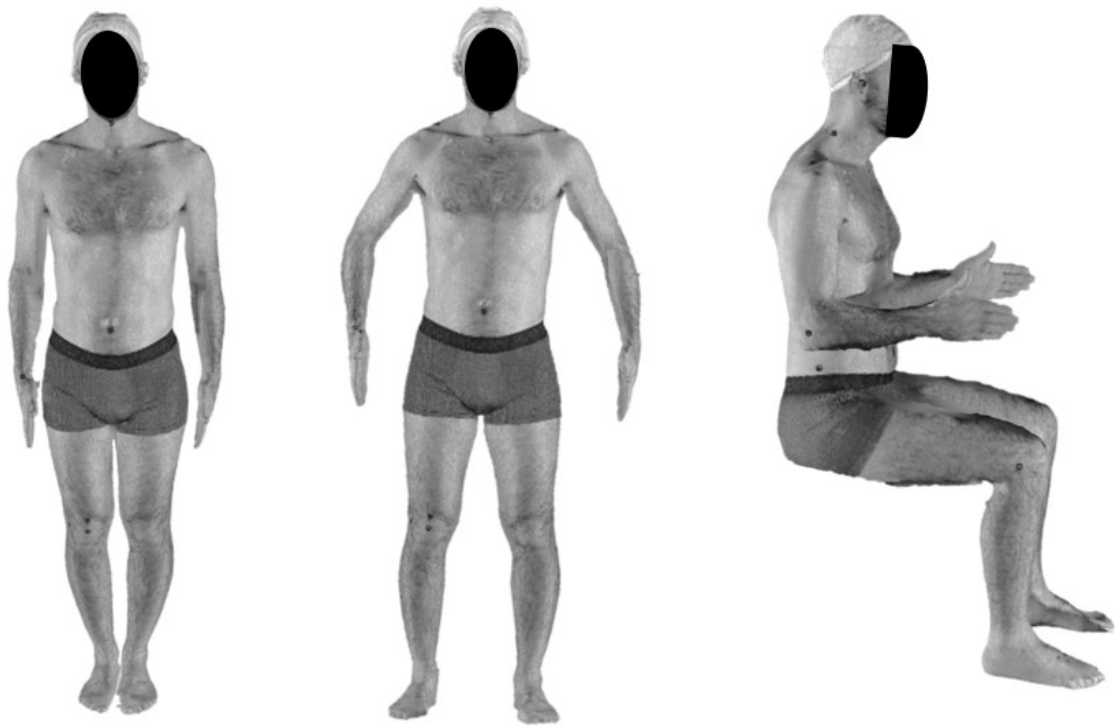


Figure 6—1. Body scanner postures based on previous body scanning surveys (Furnell et al., 2012; Tomkinson et al., 2012b). Scan posture 1 (left), posture 2 also known as the standard posture (middle), and posture 3, seated (right).

Data treatment

Body scan data were processed using the Anthroscan™ software (v6, Human Solutions, Kaiserlauten, Germany), which uses algorithms and measurement definitions derived from ISO 7250 to automatically detect key anthropometry measurements. All 17 automatically derived measurements were checked for scan errors such as the positioning of the hair bun during head girth measurements, or whether each thigh girth measurement included only the corresponding thigh as opposed to both thighs. Next, 42 digital measurements were extracted using CySize™ (v3.4, Headus, Perth, Australia). The CySize™ measurement process, including detailed instructions on how to prepare scan data and extract measurements, was based on a study-specific measurement protocol [207] and the Australian Warfighter Anthropometry Survey (AWAS) Landmarking and Measurement manual [190]. The CySize™ procedure comprised converting the native body scans into the CySize™-specific file format and applying the autofill function to remove ‘holes’ from the mesh. The process was applied to all three scan images (Figure 6—1).

Statistical analyses

To ensure the dataset was complete, missing values were estimated by nonparametric imputation with random forests. This was implemented using the “missForest” R package [209] with 100 trees. The estimated imputation error (normalised root mean squared error) was 0.0306. In total, 6.0% of the data were missing. Measurements more than 3 standard deviations from the mean were treated as outliers. Participant characteristics (age, ethnicity, service, years of service, and trade) were examined using descriptive statistics (mean, standard deviation, frequency) and compared between sexes using chi-square tests or independent samples t-tests where appropriate.

One-way MANOVA models were used (one for each group of measurements) to compare the absolute girth, breadth, length, and height measurements between males and females. Absolute body dimensions were compared between males and females using post-hoc contrasts, with p values adjusted using the Bonferroni correction. The partial eta-squared statistic was computed to indicate effect size. A full list of measurements can be seen in .

Table 6-1. To compare the proportional anthropometry of male and female personnel, the anthropometric measurements of each participant were adjusted for differences in height by normalising to a baseline or Phantom height of 170.18 cm [200, 201]. The Phantom is a unisex, bilaterally symmetrical conceptual model based on reference male and female data from large population surveys. The Z-scores (Zp-scores) for each anthropometric variable were used to determine the magnitude and direction participant characteristics varied from the Phantom [38, 210], with z-scores combined by sex to determine the standardised differences between males and females. Participant Zp-scores were calculated [201, 211] using the equation:

$$Z_p \text{ score} = \left(\frac{1}{S}\right) \left[v \left(\frac{170.18}{h}\right)^d - p\right]$$

Where:

S = Phantom standard deviation for the variable

v = NZDFAS measurement value for the variable

h = Body height of NZDF participant

d = Phantom dimensional constant where value 1 = heights, lengths, breadths, and girths

p = Phantom mean value for the variable

This equation was applied to the 35 measures that were common in both NZDFAS and Phantom reference data (Table 6-1). Nine of the 35 measures were composite measures (utilised a combination of NZDFAS measurements). The Zp-scores for each sex and NZDF service type were visualised against the Phantom to examine differences. The difference in Zp-scores between males and females were qualitatively interpreted using Cohen's d thresholds of small (0.2), medium (0.5), and large (0.8) effect sizes [212].

Binary logistic regression was used to identify which anthropometric measures best separated males and females. The Zp-scores of all 35 measures were treated as independent variables, with a stepwise variable selection process used. This method was chosen given the large number of independent variables, and the goal of optimising the predictive ability of the model. All analyses were performed in IBM SPSS Statistics© (v24, IBM Corp., Armonk, NY, USA).

Table 6-1. New Zealand Defence Force Anthropometry Survey (NZDFAS) Phantom.

Phantom terms [201]	NZDFAS terms (Physical or scan posture number) [207]	Measure (variable used in analysis)
Girths		
Chest (mesosternale end tidal)	Bust chest girth (Scan Posture 2)	Chest
Arm (fully flexed, tensed)	Bicep girth flexed (Physical)	Bicep
Abdominal I	Waist girth (Scan Posture 2)	Waist
Thigh	Thigh girth (Scan Posture 2)	Thigh
Hips	Hip girth maximum (Scan Posture 1)	Hip
Wrist I (distal styloid)	Wrist girth (Scan Posture 2)	Wrist
Knee	Knee circumference (Scan Posture 1)	Knee
Calf	Calf girth (Scan Posture 2)	Calf
Ankle	Ankle girth (Scan Posture 2)	Ankle
Breadths		
Biacromial	Biacromial breadth (Scan Posture 1)	Biacromial
Bideltoid	Bideltoid breadth sitting (Scan Posture 3)	Bideltoid
Transverse chest (mesosternale)	Chest breadth (Scan Posture 1)	Chest
Hand	Hand breadth (Physical)	Hand
Foot (standing distal I-V metatarsal)	Foot breadth (Physical)	Foot
Lengths		
Back (cervicale-gluteal arch)	Derived (cervicale height – buttock height)	Back
Upper extremity I (acromiale-dactylion)	Derived (acromiale-radiale length + radiale-styilion length + hand length)	Upper extremity I
Upper extremity II (acromiale-styilion)	Derived (acromiale-radiale length + radiale-styilion length)	Upper extremity II
Arm (acromiale radiale)	Acromiale-radiale length (Scan Posture 1)	Acromiale radiale
Forearm (radiale styilion)	Radiale-styilion length (Scan Posture 1)	Radiale styilion
Lower extremity (stature – sitting height)	Derived (stature – sitting height)	Lower extremity
Hand (styilion dactylion)	Hand length (Physical)	Hand
Thigh III (trochanterion – tibiale)	Derived (trochanterion height – tibiale laterale height)	
Foot (standing akropodian-pternion)	Foot length (Physical)	Foot
Heights		
Supersternale	Suprasternale height (Scan Posture 2)	Suprasternale
Cervicale	Derived (stature – [seated height-cervicale height sitting])	Cervicale
Height acromiale	Acromiale height (Scan Posture 1)	Acromiale
Height radiale	Derived (acromiale height – [acromiale-radiale length])	Radiale
Height styilion	Derived (acromiale height – [acromiale-radiale length + radiale-styilion length])	Styilion
Height dactylion	Derived (acromiale height – [acromiale-radiale length + radiale-styilion length + Hand length])	Dactylion
Height trochanteric	Trochanterion height (Scan Posture 1)	Trochanterion

Height tibial (lateral or medial)	Tibiale-laterale height (Scan Posture 1)	Tibiale-laterale
Height gluteal arch	Buttock height (Scan Posture 2)	Gluteal arch
Sitting height	Seated height (Scan Posture 3)	Seated
Span (dactylion to dactylion)	Arm span (Physical)	Arm span
Body mass (weight)		
Weight	Body mass (scan posture 2)	Weight

Notes: The Phantom terms Abdominal I, Wrist I, Upper extremity I etc. refer to measures from Ross and Ward [201]. These terms were paired with their equivalent measure in the NZDFAS dataset [207].

Results

Eighty-four physique measurements were obtained manually using surface anthropometry and digitally using a 3D whole-body scanner for 1003 (791 male and 212 female) New Zealand military personnel. Table 6-3 provides the absolute body dimensions.

Descriptive statistics

The most prominent ethnicities were European and Other (mainly consisting of those who identify themselves as ‘New Zealanders’). Over half of the participants (58%) were from the Army, and most participants had less than five years of full-time service. One quarter of the sample comprised participants from the Engineering and Technical trades. Significant demographic differences between males and females were observed for the proportion of personnel in services and trades (Table 6-2).

Table 6-2. Frequencies for the 1003 NZ Defence Force Personnel across five demographics of age, ethnicity, service, years of service, and trade.

Variable (P-value ^a)	Level	Male	Female	Total
Age (0.17)		31.6±10.7	30.5± 0.4	31.3±10.4
Ethnicity (0.14)	Asian	22 (2.8)	1 (0.5)	23 (2.3)
	European	327 (41.3)	81 (38.2)	408 (40.7)
	Maori/Pacific	152 (19.2)	48 (22.6)	200 (19.9)
	Other	290 (36.7)	82 (38.7)	372 (37.1)
Service (<0.001)	Army	486 (61.4)	97 (45.8)	583 (58.1)
	Air Force	217 (27.4)	72 (34.0)	289 (28.8)
	Navy	88 (11.1)	43 (20.3)	131 (13.1)
Years of service (0.67)	<5	331 (46.9)	90 (47.6)	421 (47.0)
	6–10	152 (21.5)	41 (21.7)	193 (21.6)
	11–15	61 (8.6)	22 (11.6)	83 (9.3)
	16–20	49 (6.9)	12 (6.3)	61 (6.8)
	21–25	36 (5.1)	10 (5.3)	46 (5.1)
	26–30	39 (5.5)	10 (5.3)	49 (5.5)
	30+	38 (5.4)	4 (2.1)	42 (4.7)
Trade (<0.001)	Apprenticeship	45 (5.7)	2 (0.9)	47 (4.7)
	Aviation	32 (4.0)	14 (6.6)	46 (4.6)
	Combat	170 (21.5)	21 (9.9)	191 (19.0)
	Engineering/Technical	225 (28.4)	25 (11.8)	250 (24.9)
	Hospitality	20 (2.5)	14 (6.6)	34 (3.4)
	Intelligence IT/COMS	69 (8.7)	25 (11.8)	94 (9.4)
	Logistics/Administration	56 (7.1)	56 (26.4)	112 (11.2)
	Medical/Health	31 (3.9)	29 (13.7)	60 (6.0)
	Other	54 (6.8)	19 (9.0)	73 (7.3)
	Specialist	89 (11.3)	7 (3.3)	96 (9.6)

Data are presented as n (%) except for age presented as mean±SD; ^aP value of difference between males and females (chi-square or independent samples t-test where appropriate). COMS=Communications.

Absolute body dimensions

The means for absolute body dimensions were significantly different between males and females for girths (Pillai's trace = 0.57; $F(9, 993) = 147$ $p < 0.001$, $\eta^2 = 0.57$), breadths (Pillai's trace = 0.57; $F(5, 997) = 270$, $p < 0.001$, $\eta^2 = 0.58$), lengths (Pillai's trace =

0.45; $F(4, 998) = 205, p < 0.001, \eta^2 = 0.45$) and heights (Pillai's trace = 0.45; $F(7, 995) = 117, p < 0.001, \eta^2 = 0.45$) (Table 6-3). The only two absolute dimensions that were not different between males and females were hip girth maximum ($p = 0.122, \eta^2 = 0.002$) and thigh girth ($p = 0.582, \eta^2 < 0.001$).

Table 6-3. Absolute body dimension values (mm) for the 1003 NZ Defence Force Personnel.

Group	Variables	Male	Female
		Mean (SD)	Mean (SD)
Girths	Ankle girth*	275 (18.9)	249 (15.6)
	Bicep girth flexed*	359 (32.1)	310 (29.2)
	Bust chest girth*	1054 (83.5)	959 (77.8)
	Calf girth*	391 (26.5)	377 (24.1)
	Hip girth maximum	1061 (68.2)	1053 (63.0)
	Knee circumference*	388 (23.6)	372 (22.5)
	Thigh girth	597 (50.7)	595 (39.9)
	Waist girth*	898 (104.9)	806 (94.9)
	Wrist girth*	180 (11.2)	161 (10.0)
Breadths	Biacromial breadth*	422 (19.0)	377 (16.4)
	Bideltoid breadth sitting*	510 (29.4)	456 (30.7)
	Chest breadth*	366 (29.4)	319 (26.8)
	Foot breadth*	103 (6.0)	94 (5.7)
	Hand breadth*	88 (4.2)	78 (3.8)
	Acromiale radiale length*	346 (18.8)	320 (15.3)
Lengths	Foot length*	269 (12.4)	245 (11.0)
	Hand length*	198 (11.2)	183 (10.1)
	Radiale stylium length*	267 (14.9)	240 (13.4)
	Acromiale height*	1466 (59.9)	1366 (49.7)
	Arm span*	1837 (75.2)	1683 (65.1)
	Buttock height*	904 (46.3)	839 (36.9)
	Seated height*	943 (32.7)	891 (29.6)
	Suprasternale height*	1469 (60.6)	1371 (51.0)
	Tibiale laterale height*	481 (26.7)	439 (20.6)
	Trochanterion height*	932 (48.2)	857 (44.5)
Mass	Weight (kg)*	86 (12.7)	70 (11.2)

Proportionality (Phantom)

In almost all measurements, males showed a clear difference in proportionality to female. Males had larger Zp-scores than females for upper body girths (e.g., chest, bicep, waist, and wrist), whereas females had larger Zp-scores for lower body girths (e.g., thigh, knee,

and calf). Males had substantially larger bicep ($d=1.11$) and wrist ($d=0.99$) girths compared to females, however females had substantially larger hip ($d=1.11$) and thigh ($d=0.88$) girths compared to males (Figure 6—2).

Males also had larger breadths and lengths compared to females, although sex-related differences were more varied. Males had substantially larger chest ($d=1.33$), biacromial ($d=0.94$) and bideltoid ($d=0.89$) breadths compared to females. Six out of 11 sex-related Zp-scores were negligible ($d<0.2$) six of which were height measurements.

Males had greater proportions than females across the three NZDF services except for the hip, knee, and thigh girths (all services), and back length (Navy only) (see Supplementary File 1).

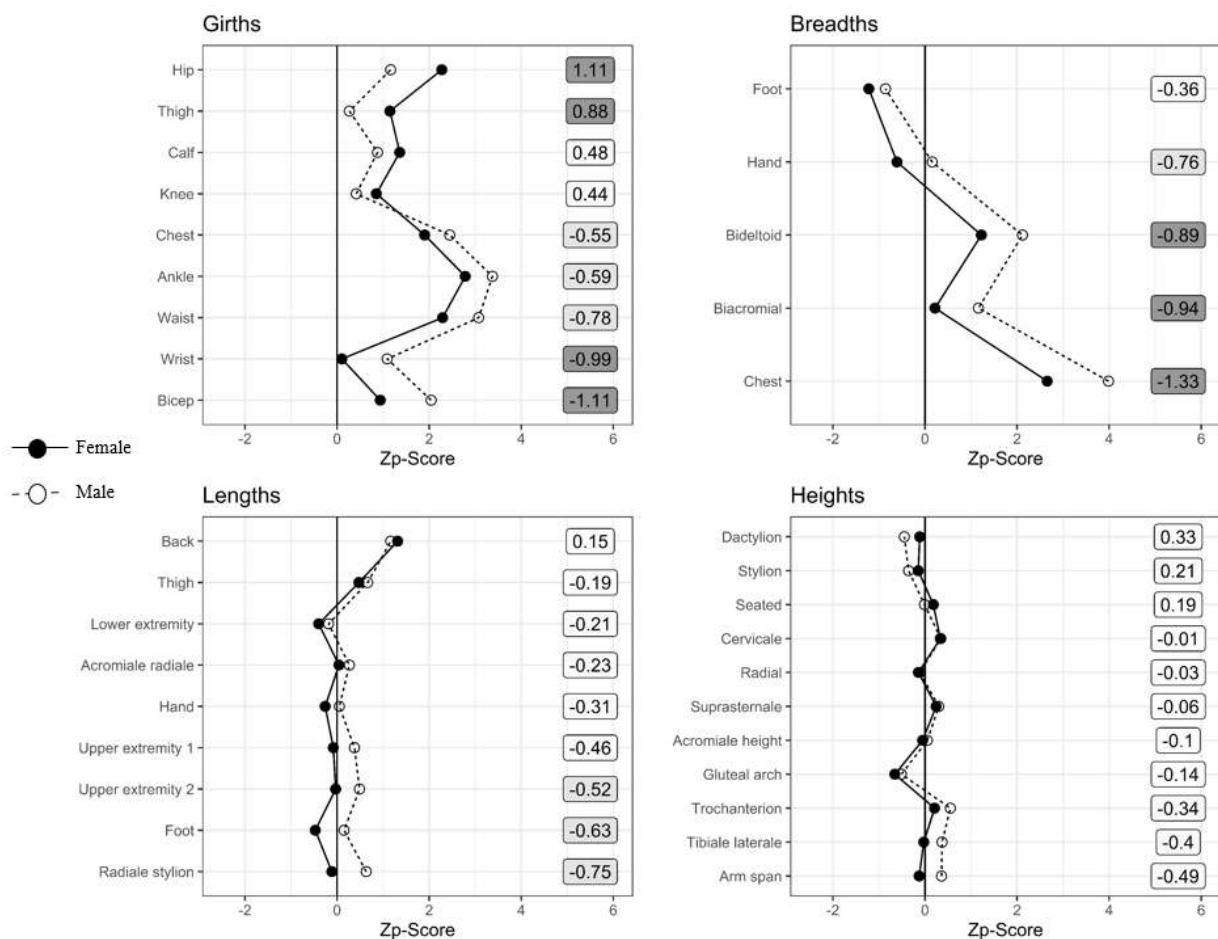


Figure 6—2. Comparison of girths, breadths, lengths, and heights of NZDF personnel through the Phantom (vertical line on 0-axis). All values are mean Zp-scores. The right side of the panels shows the Cohen's d effect size for sex differences (the darker shaded boxes indicate large differences).

Logistic regression model

The logistic regression demonstrated clear findings. The model was statistically significant ($\chi^2(8) = 17.3$, $p < 0.001$) and explained 79% of the variance in sex (Nagelkerke R²), correctly classifying 94.9% of cases. Through the stepwise variable selection process, four measurements (waist girth, hip girth, bicep girth, and biacromial breadth) best described the sex-related differences. The odds ratios in Table 6-4 can be interpreted as the likelihood of being a male, given a 1 unit (1 SD) increase in the Zp-score. For example, for every 1 unit increase in the bicep girth Zp-score, the individual is 4.11 times more likely to be male than female, when all other variables in the model are held constant. In contrast, an increase in hip girth equates to a lower likelihood of being a male.

Table 6-4. Logistic regression model results showing the best variables for predicting a person's sex.

Variable	B	SE	P-value	OR	95% CI for OR	
Waist girth	0.95	0.12	<0.001	2.57	2.03	3.26
Hip girth	-3.42	0.26	<0.001	0.03	0.02	0.06
Bicep girth	1.41	0.18	<0.001	4.11	2.90	5.81
Biacromial breadth	1.27	0.21	<0.001	3.56	2.38	5.33

OR = Odds ratio; B = log-odds coefficient; SE = standard error

Using this model, the equation to obtain the log-odds of being male is shown below. To obtain the odds of being male, the result of the equation should be exponentiated.

$$\text{Log} \left[\frac{Y}{1-Y} \right] = 1.393 + 0.945(X_1) + -3.423(X_2) + 1.413(X_3) + 1.271(X_4)$$

Where:

Y = Probability of the participant being a male

X₁ = Waist girth, in cm

X₂ = Hip girth, in cm

X₃ = Bicep girth, in cm

X₄ = Biacromial breadth, in cm

Discussion

This study utilised New Zealand Defence Force Anthropometry Survey (NZDFAS) data to examine the extent of sexual dimorphism in absolute and proportional dimensions of military personnel. Males were significantly larger for 92% (24/26) of absolute body dimensions, with hip and thigh girths not significantly different between sexes. Males were proportionally larger than females for most measurements except hip, thigh, knee, and calf girth. Proportionally, the largest differences were observed for chest breadth, hip girth, and bicep girths. Finally, four measurements best described the sex-related differences (waist girth, hip girth, bicep girth, and biacromial breadth).

Sex classification accuracy and number of predictor variables

This study was able to classify sex with 95% accuracy using four body measurements (waist girth, hip girth, bicep girth, and biacromial breadth). These results are comparable to previous studies; for example Fullenkamp, Robinette [31] classified sex with 99% accuracy using seven measurements (shoulder breadth, hip breadth sitting, bilateral femoral epicondyle breadth sitting, knee height, sitting height, and bilateral humeral epicondyle breadth sitting). Likewise, Cheng, Bruening [213] achieved 96% accuracy using three measurements (height, hip breadth, and shoulder breadth). Shoulder breadth (biacromial breadth) and hip-related measurements were common among both of these studies and the present study.

Classification accuracy was similar despite each study including participants from different racial backgrounds. Fullenkamp, Robinette [31] examined participants from North America, Italy and the Netherlands while Cheng, Bruening [213] examined participants from North America only (mainly African and white American). These results suggest that sex can be predicted using anthropometric measurements regardless of racial background.

Outside the military, the findings mirrored the results of Keogh, Hume [38] who showed that 0 males had significantly larger absolute and proportional body dimensions except for thigh ($d=0.54$) and hip girths ($d=0.57$). We found that males had significantly larger absolute hip ($d=0.12$) girths than females, but proportionally, female hip girths were larger than males ($d=1.11$). While males generally have a larger absolute body size, our findings indicate that female hip and thigh girths (at least in this military sample) are larger proportionally compared to males. This has important sizing implications for

military trouser sizing as higher girths may require more sizes and potentially increased production costs.

Implications of the main findings for the military

The sexual dimorphic measurements identified in this study have implications for clothing in the military, and the NZDF. Traditional trouser sizing is based on a combination of hip girth and inseam length (for females), and waist girth and inseam length (for males) [71, 214-216], while chest girth, hip girth, and height are crucial for upper-body garments [27]. Furthermore, hip and waist girths are also required to manufacture tight fitting garments for women [217]. As absolute hip girth was similar for both sexes, the finding can potentially support the use of a unisex trouser sizing system in the NZDF. In fact, male and female proportions were so similar regardless of grouping (girths, lengths, breadth, and heights) that unisex varieties for both upper and lower garments appear possible. Outside of clothing, the most sexually dimorphic variables identified (hip and waist girths) could be important for military ergonomics. Females possessing larger hip girths, accompanied by smaller heights and limb lengths, means that they will have a lower centre-of-gravity. While this may be advantageous for g-tolerance in the cockpit and other seated vehicle environments, it also means that the control layout will have to accommodate a larger hip area with a short sitting height [31]. Sex-related differences in hip and shoulder breadths also have design implications for crewstations in aircraft, bunk dimensions in Naval ships, and seats in Army terrain vehicles. Anthropometric measurements (e.g., waist and hip girth) also have applications for the assessment of health and disease risk (e.g., waist-to-hip ratio) [218].

Strengths, limitations, and future applications

Our findings support the results of previous civilian and military studies [31, 38] by indicating that males are generally absolutely and proportionally larger. Furthermore, our study used 3D measurements and the phantom stratagem which combined, has never been undertaken on military populations. The main limitation is that the Phantom values were based on a non-military data which limits the interpretation of the results. Future studies might consider developing a new Phantom that is based on known military population data, then compare subsequent datasets (from the same population) over time for longitudinal research into proportionality. Other iterations would be to compare the Phantom against more contemporary methods on proportionality that utilise data mining techniques (e.g., stepwise linear regression).

Conclusions

This study demonstrated sex-related absolute and proportionality differences in girths, breadths, lengths, and heights of New Zealand military personnel. Waist girth, hip girth, bicep girth, and biacromial breadth classified sex with 95% accuracy. Knowing the key anthropometric differences between males and females provides the military with information to make decisions on gender-based clothing sizes and other ergonomic applications. This study also highlights a potential opportunity for other countries to follow in military anthropometric surveillance, analysis, and interpretation.

Chapter 7 Prediction of Military Combat Clothing Size Using Decision Trees and 3D Body Scan Data

Stephven Kolose, Tom Stewart, Patria Hume, Grant Tomkinson

Preface

The previous chapter identified sexual dimorphism in the NZDF using the NZDFAS dataset. The four key measurements identified could potentially be used to assist with single-sex military garments or equipment design. However, many uniforms in the military, in particular the combat uniform, are currently unisex. A correct fit is still of utmost importance for the wearer. Traditionally, garments for military personnel are sized by trained tailors who use traditional measurement techniques (e.g., tape measures) which can be time consuming, and, depending on their experience, subjective. The purpose of Chapter 7 is to explore the application of 3D anthropometric data for predicting tailor-assigned clothing sizes using decision tree modelling. This chapter also examines which combination of automatic, post-processed, and traditional anthropometric measurements collected in the NZDFAS led to the most accurate model.

Abstract

Aim: To determine how well decision tree models can predict tailor-assigned uniform sizes using anthropometry data from the New Zealand Defence Force Anthropometry Survey (NZDFAS). This information may inform automatic sizing systems for military personnel.

Methods: Anthropometric data from two separate samples of the New Zealand Defence Force military were used. Data on Army personnel from the NZDFAS ($n = 583$) were used to develop a series of shirt- and trouser-size prediction models based on decision trees. Different combinations of physical, automatic, and post-processed measurements (the latter two derived from a 3D body scan) were trialled, and the models with the highest cross-validation accuracy were retained. The accuracy of these models were then tested on an independent sample of Army recruits ($n = 154$).

Results: The automated measurement method (measurements derived automatically by the body scanner software) were the best predictors of shirt size (58.1% accuracy) and trouser size (61.7%), with body weight and waist girth being the strongest predictors. Clothing sizes that were incorrectly predicted by the model were generally one size above or below the tailor-predicted size.

Conclusions: Anthropometry measurements, when used with decision tree models, show promise for classifying clothing size. Methodological changes such as fitting gender-specific models, using additional anthropometry variables, and testing other data mining techniques are avenues for future work. More research is required before fully automated body scanning is a viable option for obtaining fast and accurate clothing sizes for military clothing and logistics departments.

Introduction

Correct fitting military uniforms and equipment are important for the survival and effectiveness of military personnel [219, 220]. These uniforms must be suitable for specific occupational tasks; for example, loose fitting uniforms can get caught in machinery and cause accidents [214], while tight fitting uniforms can severely restrict soldiers movement such as preparing to run from a prone position. The use of anthropometry in the design of apparel and equipment should contribute towards improved fit, better integration and compatibility among apparel items and equipment, and maximise mobility. Developing a clothing size range for a specific population can be challenging due to differences in body size and body proportions across different age, sex, and ethnic groups. Recent increases in the body size of military personnel (e.g., in Australia [221], Canada [7], and the U.S. [222] appear to have coincided with changes in body proportions [145, 165], which collectively create additional challenges for maintaining a current and effective uniform sizing scheme [223]. An increasing number of women in Army combat roles also has implications for integrating the female body shape into clothing and equipment that was originally designed for male operators [7, 224, 225]. Accurate and up-to-date anthropometric measurements are required to maintain optimal sizing systems.

Traditional anthropometric measurement techniques involve sizing the body using physical methods such as callipers, rulers, or measuring tapes [226, 227]. This approach has limitations including individual sizing being time-consuming (depending on the number of measures) and error-prone (e.g., measurement fatigue) [227] and heavily dependent on the measurer's judgement [228]. Furthermore, the precise location of body landmarks and how these are measured can be subjective [3]. These limitations can all result in inaccurate anthropometric dimensions that will subsequently lead to unfit garments [229].

More recently, the introduction of three-dimensional (3D) body scanner measurement systems have revolutionised the way anthropometric data are collected, assessed, and updated. This technology can provide highly detailed, accurate and reproducible anthropometric data (Istook and Hwang 2001; Lerch, MacGillivray, and Domino 2007; Wang, Wu, Lin, Yang, and Lu 2007; D'Apuzzo 2009) that can be stored and re-used in the future. The number of anthropometric variables that can be derived from a single body scan is almost limitless, and allows for the extraction of 1D (e.g., girths, lengths,

breadths), 2D (e.g., cross-sectional areas) and 3D (e.g., surface areas and body volumes) measures [86]. There have been several large-scale military anthropometric surveys conducted worldwide [7, 11, 14, 63, 166, 230] that have amassed large amounts of 3D anthropometric data. With these high dimensional datasets, it can be difficult to determine the best combination of variables required for developing a sizing system or determining the optimal clothing size category for an individual. These difficulties can be associated with the volume of variables (e.g., too many variables would require greater processing power) or the variables themselves are not related or specific to clothing design (e.g., dactylion length).

To overcome this problem, various data mining techniques have been used to understand anthropometry variables for the purposes of classifying clothing size and developing sizing systems. Esfandarani and Shahrabi [45] developed a suit sizing system based on principal component analysis (PCA) which identified height and chest circumference as the main components. Laing, Holland [46] used the k-means clustering to establish size charts for protective clothing used by New Zealand firefighters. Some studies used a combination of data mining techniques; for example, Hsu and Wang [231] used a two-step process combining both PCA and decision trees to establish a sizing system for Taiwanese soldiers' trousers. The PCA identified two factors (waist girth and outside leg length) that were utilised by a decision tree to classify clothing size. The resulting sizing system achieved 95% population coverage. Bagherzadeh, Latifi [48] used a three-method approach (PCA, two-step cluster analysis, and decision trees) to determine a sizing system for the lower body of Iranian males. These methods show that it is possible to develop and predict clothing sizes from high dimensional anthropometric data as opposed to using more traditional (physical measurement) methods [232].

Several studies have compared the accuracy of traditional versus 3D anthropometry measurements [111, 139, 233], but few studies have compared the efficiency and accuracy of tailor versus automated body scan-based clothing sizing in military combat uniforms. In 2019, the New Zealand Army (NZ Army) were interested in how 3D body scanning technology could optimise their recruit sizing process [234]. Sizing large numbers of recruits (up to 90 recruits a day) is time consuming, especially when conducted in parallel with other activities such as medical and dental checks. The use of automated measurements derived by 3D body scanning technology, has the potential to improve the efficiency of the NZ Army recruit sizing process. It has been successfully used in the Dutch military [235] but has never been tested in the NZDF.

This study specifically examined the NZ Army in-service combat uniform worn at the time and known as the Multi-Camouflage Uniform (MCU) (Figure 7—1). The MCU was available in 12 shirt and 12 trouser sizes (each ranging from 2XS to 7XL). All references to size in this paper refer to this (2XS to 7XL) size range.



Figure 7—1. NZ Army MCU shirt and trouser (courtesy of New Zealand Defence Force).

The NZ Army recruit garment sizing process is conducted by trained tailors employed by an external equipment supplier. When sizing the MCU, the tailor estimates the initial shirt size by observing the recruit's chest circumference and estimates initial trouser size by observing waist circumference and height. From this assessment, different garment sizes are trialled until the right fit is obtained. No measurement tape is used in the sizing process. The average processing time per individual ranges from 10 to 15 minutes [234].

Between 2016 and 2018 the New Zealand Defence Technology Agency (DTA) conducted the NZDF tri-service anthropometric survey (NZDFAS) of 1,003 uniformed personnel. During the survey, 84 different anthropometric measurements were assessed using one of three methods: physical measurements (using traditional anthropometry); 3D body scanner automatic measurements (generated automatically by the body scanner software, Anthroscan™); or post-processed measurements (processed after the data collection using third-party software called CySize™). Post-processed measurements could not be measured 'practically' by physical means (e.g., crotch height) or automatically (not

recognized as an automated measure in Anthroscan™). These require user input to identify landmarks and utilise digital tools (e.g., tapes, rulers, coordinates).

The purpose of this study was to investigate how accurate decision trees are at predicting well-fitting MCUs and to improve the selection of MCU shirt and trouser sizes. More specifically, the aims of this study were to: (1) determine how well decision tree models predict tailor-assigned uniform sizes using anthropometry data from the NZDFAS; and (2) examine which combination of automatic, post-processed, and physical measurements are the most accurate predictors. It is hoped that this information can inform automatic sizing systems for military personnel.

Method

Design

Anthropometric data from two separate samples of the NZDF military were used in this study. The first sample were those who participated in the New Zealand Defence Force Anthropometry Survey (NZDFAS). The second (smaller) sample consisted of New Zealand Army recruits. The NZDFAS dataset was used to develop a series of uniform size prediction models, while the recruit dataset was used to test the accuracy of each model. Both data collection activities had ethical approval from the Auckland University of Technology Ethics Committee (AUTECH #14/126 NZDF anthropometry Survey: Variations in kinanthropometry and implications for the New Zealand Defence Force).

Participants

NZDFAS

The NZDFAS dataset was collected between February 2016 and June 2018 and consisted of 1,003 uniformed participants from the Royal New Zealand Navy ($n = 131$), Royal New Zealand Air Force ($n = 289$) and the NZ Army ($n = 583$). The participants were recruited across the five major military establishments throughout New Zealand using a mixture of stratified and purposeful sampling. The participants were from various service backgrounds with the majority from engineering and technical (25%), combat (19%), and logistics and administration (11%). The ethnic composition of participants was mainly European (41%), New Zealand European (37%), and Māori/Pacific (20%). This study focussed on the NZ Army participants only ($n = 583$; 97 female and 485 male).

Recruits

The second sample consisted of 154 NZ Army recruits (19 females and 134 male) from the Waiouru Military Camp recruitment course (June 2019 intake). Testing occurred during their assigned medical examination and clothing sizing assessment week. These recruits were not involved in the 2016–2018 NZDFAS dataset. NZ Army recruits were chosen as the test population as the purpose of the study was to optimise the sizing process during recruitment intake.

In both samples (NZDFAS and recruits) the senior commanding officer for each regiment requested personnel to attend an initial brief with the research team where they were given information about the survey (e.g., purpose, scan procedure, rights to withdraw, informed consent). After the brief, the recruits were free to withdraw at any time without any consequences to their employment or recruitment course. This was supported by the senior leadership team.

Procedures

NZDFAS

In the NZDFAS sample, participants provided demographic information (gender, age, service) and self-reported ratings of their current uniform fit in terms of comfort (“Very good”, “Good”, “Acceptable”, “Poor” and “Very poor”, for both shirt and trousers). The tailor-assigned sizes for each participant’s current uniform were obtained from the military’s clothing store records.

Participants were then scanned inside a Vitus Smart XXL® body scanner (Human Solutions, Kaiserlauten, Germany) wearing tight-fitting underwear (e.g., briefs for males, and sports bra and underwear for females) and a swim cap (to standardise head-related measures such as standing height); whilst they were positioned in the ‘standard’ posture as shown in Figure 7—2.

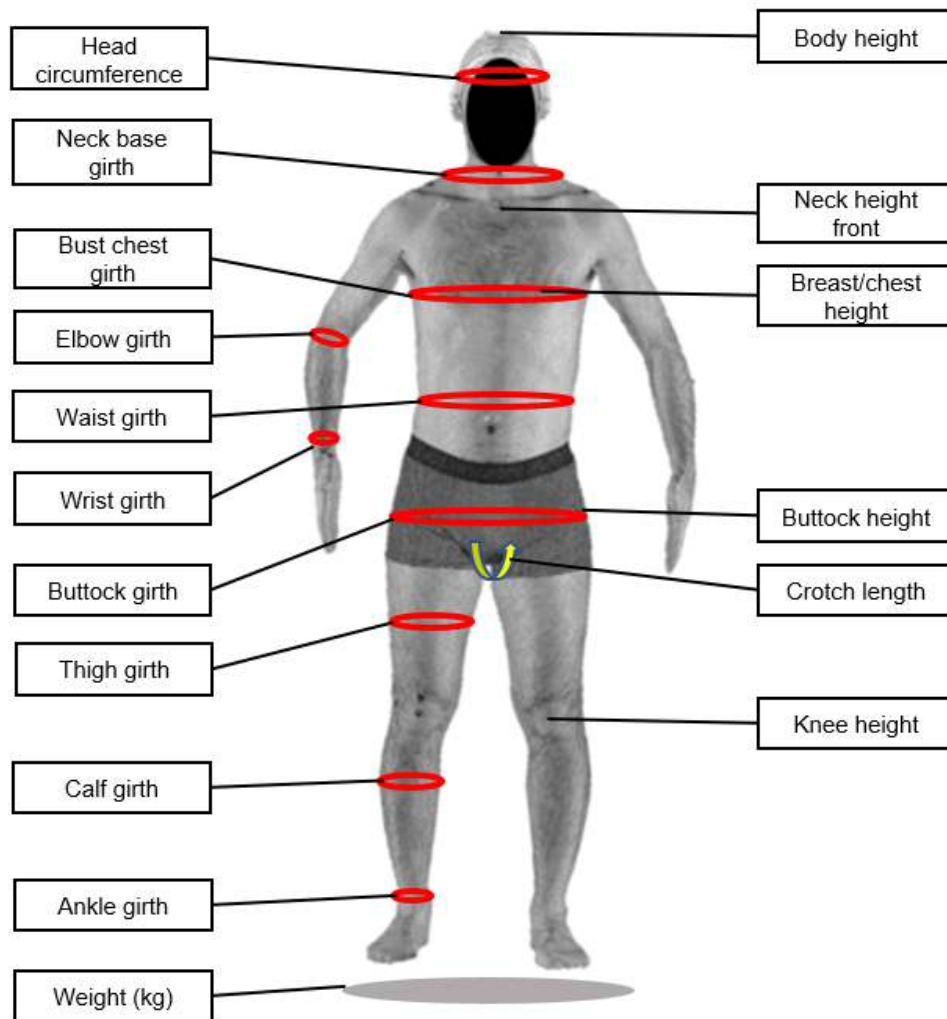


Figure 7—2. Body scan posture (standard posture) used in the NZDFAS. The labels identify the 17 automatic measurements that were captured.

The body scan data were processed in the Anthroscan™ Version 6.0 software (Human Solutions, Kaiserlauten, Germany) to automatically detect 17 anthropometric measurements that were previously validated against physical measurements [207]. The Anthroscan™ automated measurements are derived from ISO 7250 and ISO 8559 [192]. These measurements (Figure 7—2) were extracted and checked for scan errors; for example, incorrect scan posture, the presence of lighting artefacts in the scan, and checking that the hair bun did not interfere with head circumference measurements. The NZDFAS dataset also consisted of 25 physical measurements that were taken on each participant using traditional methods, and 42 post-processed measurements that were derived from the 3D scan data using the third-party software CySize™ (v3.4, Headus, Perth, Australia). The measurements were split across these three measurement methods (automatic, physical and post-processed) for the purpose of optimizing participant

throughput while limiting individual processing times at each data collection activity [207]. The three methods are summarised in Table 7-1.

Table 7-1. NZDFAS measurement methods description.

Method (n)	Description	Equipment	Processing time per individual (min)
Automatic (17)	Measurements are captured using an automatic landmark algorithm. Requires minimum operator effort except for final checking of measurement placement. The software extracts the measurements.	Vitus XXL 3-D body scanner and Anthroscan software. Human Solutions Ltd.	<1 (fastest)
Physical (25)	Traditional anthropometric measurements conducted by accredited anthropometrists. High operator input (physical palpation of skin surface etc) is required. High accuracy dependant on the skill of the anthropometrist.	Traditional anthropometry equipment (callipers, scales, stadiometer).	30–50 (slowest)
Post-processed (42)	The operator extracts the measurements from each body scan using a suite of digital tools (e.g., tapes, rulers). Requires high operator input with specialist skills in digital manipulation.	CySize™ by Headus Ltd.	20

The number in parentheses refer to the number of measurements in each method.

Recruits

The body scanning procedure for the NZ Army recruits was identical to the NZDFAS. No physical or post-processed measurements were derived in the recruit's dataset as this sample was collected for the purpose of validating prediction models that were fit using automatic measurements only (see analysis section). As the recruit sample had not yet been issued with their MCU uniform, they did not complete questions related to clothing fit. However, they were each measured by the clothing tailor and assigned an MCU trouser and shirt size. Like the NZDFAS sample, these sizes were obtained from the military's clothing store records and were treated as the optimal clothing size for each individual.

Analyses

In the first instance, key demographic and body size characteristics were compared between the NZDFAS and recruit samples using Fisher's exact test or the Mann-Whitney U test. The primary analysis focused on developing decision tree models for classifying tailor-assigned clothing sizes (MCU shirt and trouser) from the NZDFAS anthropometry variables. Several models were fit to test five different combinations of measurements (automatic, physical, post-processed, automatic + post-processed, and automatic + physical + post-processed). Prior to model fitting, shirt and trouser sizes with a low frequency (e.g., 3XL and 4XL) were combined into the next largest category (e.g., 2XL). Any individuals who rated the fit of the current uniform as 'Poor', 'Very poor', or provided no rating ($n = 135$) were removed as the intention was to predict an optimal-fitting uniform size. This meant the final analysis sample contained 437 individuals. Variables that were not conceptually related to shirt (e.g., ankle, calf, or crotch girth) or trouser (e.g., head circumference, radiale-styilion length) pattern sizing were removed to minimise model complexity. The final input variables for shirt were body height, breast height, bust chest girth horizontal, elbow girth, head circumference, neck at base girth, neck height front (supersternale), waist girth, weight, and wrist girth. The input variables for trousers were ankle girth, body height, bust chest girth horizontal, buttock girth, buttock height, calf girth right, crotch length, knee height, thigh girth right horizontal, waist girth, and weight. All decision trees were fit using the CART (classification and regression trees) algorithm in IBM SPSS Statistics[®] (v24, IBM Corp., Armonk, NY, USA) and validated using 10-fold cross-validation. CART was chosen because the output (a decision tree) is straightforward to interpret, the first nodes (or levels) of the tree are the most important variables, and there is no need for implicit assumptions (e.g., any preconceived knowledge of how different body measurements are related). The CART algorithm determined the optimal cut-off point for each explanatory variable. Several candidate hyperparameter values were trialled, and those that maximised model accuracy were selected as the optimal hyperparameters for the final model. These were set to: maximum tree depth = 4, minimum samples in the parent node = 20, minimum samples in the child node = 7, and maximum surrogates = 5.

Variables from the measurement combination with the greatest accuracy were used to develop the final shirt and trouser size models. These models were then applied to the recruit's dataset to test the models' generalisability in an independent sample. The statistical classification metrics [236] computed from the correct and incorrect predictions

were: (1) overall accuracy (the proportion of all cases correctly identified); and (2) Cohen’s Kappa score which measures the degree of agreement between the true values and the predicted values (clothing size), which is an indicator of each model’s performance (interpreted as ≤ 0 = no agreement, 0.01–0.20 = slight, 0.21–0.40 = fair, 0.41–0.60 = moderate, 0.61–0.80 = substantial, and 0.81–1.00 = almost perfect agreement); and for each size category [237] (3) sensitivity (the proportion of positive or true cases correctly identified, e.g., proportion of XS sizes predicted as XS); (4) specificity (the proportion of negative or false cases correctly identified, e.g., proportion of non-XS sizes predicted as non-XS); and (5) balanced accuracy (the mean of sensitivity and specificity). These metrics are presented in addition to overall accuracy to account for the unequal number of individuals across size categories [237, 238]. To inspect where the model was correct and incorrect, a comparison of the model-predicted sizes and the tailor-assigned sizes were presented as a confusion matrix table. A summary of the methods and analyses are provided in Figure 7—3.

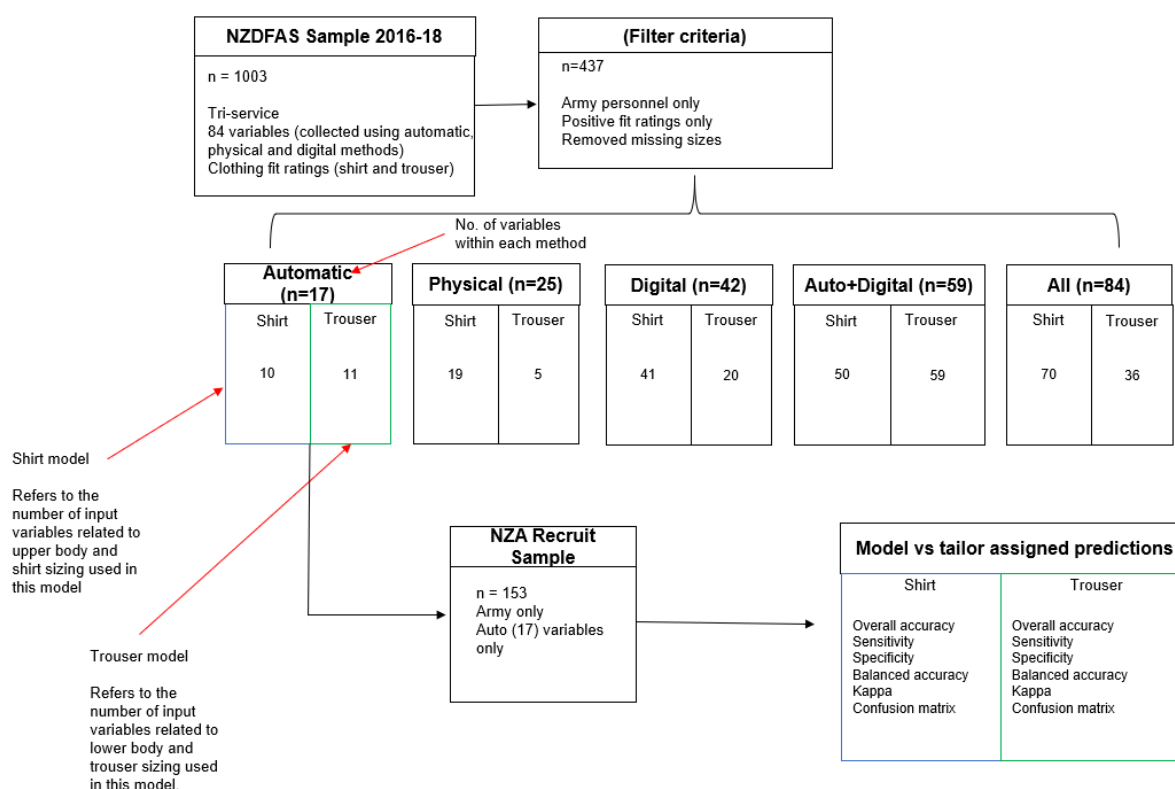


Figure 7—3. Overview of methods and analyses. Decision trees models were developed from the NZDFAS 2016-18 dataset and tested on the NZ Recruit datasets.

Results

Descriptive statistics

The demographic characteristics of both samples (NZDFAS and NZ Army recruits) are presented in Table 7-2. The mean and standard deviation for age within these samples was 32 ± 10.4 and 20 ± 2.1 years, respectively. The most common tailor-assigned shirt and trouser sizes were medium (39% and 44%) and small (37% and 40%) for each sample, respectively. Two NZDFAS participants possessed shirt sizes greater than 2XL, and three had trouser sizes greater than 2XL. No recruits had shirt and trouser sizes greater than 2XL. Key clothing-related anthropometry measures are also presented in Table 7-2. Although body height was similar for the samples, there were significant differences between the two samples for chest girth, buttock girth, crotch length, neck girth, waist girth, and body weight. The results of the fit satisfaction survey showed that a higher proportion of those experiencing a ‘Poor’ or ‘Very poor’ fit were female (31% vs. 7% of males).

Classification/Decision trees

Table 7-2. Descriptive characteristics of the NZDFAS and NZ Army recruit samples.

Variable	Level	NZDF	Recruits	Mean	P-value ^a
Gender	Male (n = 381)	297 (87%)	135 (88%)		0.96
	Female (n = 56)	39 (13%)	18 (12%)		
Shirt Size (n = 408)	XS	42 (10.3%)	33 (21.6%)		<0.001
	S	50 (14.9%)	56 (36.6%)		
	M	132 (39.3%)	49 (32%)		
	L	85 (25.3%)	10 (6.5%)		
	XL	31 (7.6%)	1 (0.7%)		
	2XL	20 (4.9%)	0		
Trouser Size (n = 337)	XS	17 (5.1%)	21 (13.7%)		<0.001
	S	64 (19%)	61 (39.9%)		
	M	146 (43.5%)	51 (33.3%)		
	L	85 (25.2%)	18 (11.8%)		
	XL	24 (7.1%)	2 (1.3%)		
Measures	Body height (mm)	1772 $\pm$ 74	1758 $\pm$ 72	13.4	0.08
	Chest girth (mm)	1041 $\pm$ 80	993 $\pm$ 67	47.9	<0.001
	Waist girth (mm)	880 $\pm$ 99	822 $\pm$ 64	58.0	<0.001
	Body weight (kg)	84 $\pm$ 12.5	76 $\pm$ 9.6	8.6	<0.001

Data are presented as mean $\pm$ SD or n (%) where appropriate; a P value of difference between NZDFAS and recruits (Fisher’s exact test or Mann-Whitney U test where appropriate). Bold items represent statistically significant results ($p < 0.05$).

Table 7-3 shows the results of the CART analysis for the five different measurement combinations in the NZDFAS sample. For shirt size, classification was most accurate for

automatic measurements followed by all categories (automatic + physical + post-processed), (58.1% and 55.1% cross-validation accuracy, respectively). For trousers, the automatic measurements were the most accurate (61.7%) followed by automatic + post-processing (57.3%). In general, models that used measurements obtained using the body scanner (e.g., automatic, and post-processed) demonstrated higher accuracy than models using only the physical measurements (Table 7-3).

Table 7-3. Classification results for shirt and trouser size for measurements obtained from cross-validation.

	Automatic	Physical	Post-	Automatic +	Automatic + Physical +
Shirt	58.1	43.4	54.9	57.4	55.1
Trouser	61.7	45.7	51.6	57.3	56.1

Data presented as overall accuracy (%) from 10-fold cross validation.

The shirt and trouser models that used the set of automatic measurements were deemed the final models, given their overall accuracy and simplicity. Figure 7—4 shows the final decision tree model for predicting shirt size, while Figure 7—5 shows the final decision tree model for predicting trouser size. The variable at each node and the split criteria are presented. The number and percent within each node represent the frequency of participants within each size category that pass through the node.

For shirt size classification, the root node (Node 0) was split according to body weight. The subsequent variables deemed important by the model were waist girth, neck height front, and body height. The final size classification in these nodes is based on the size with the highest frequency of cases. For trouser size, the root node was also split according to body weight. The subsequent variables deemed important by the model were waist girth, buttock girth, buttock height, thigh girth, and crotch length.

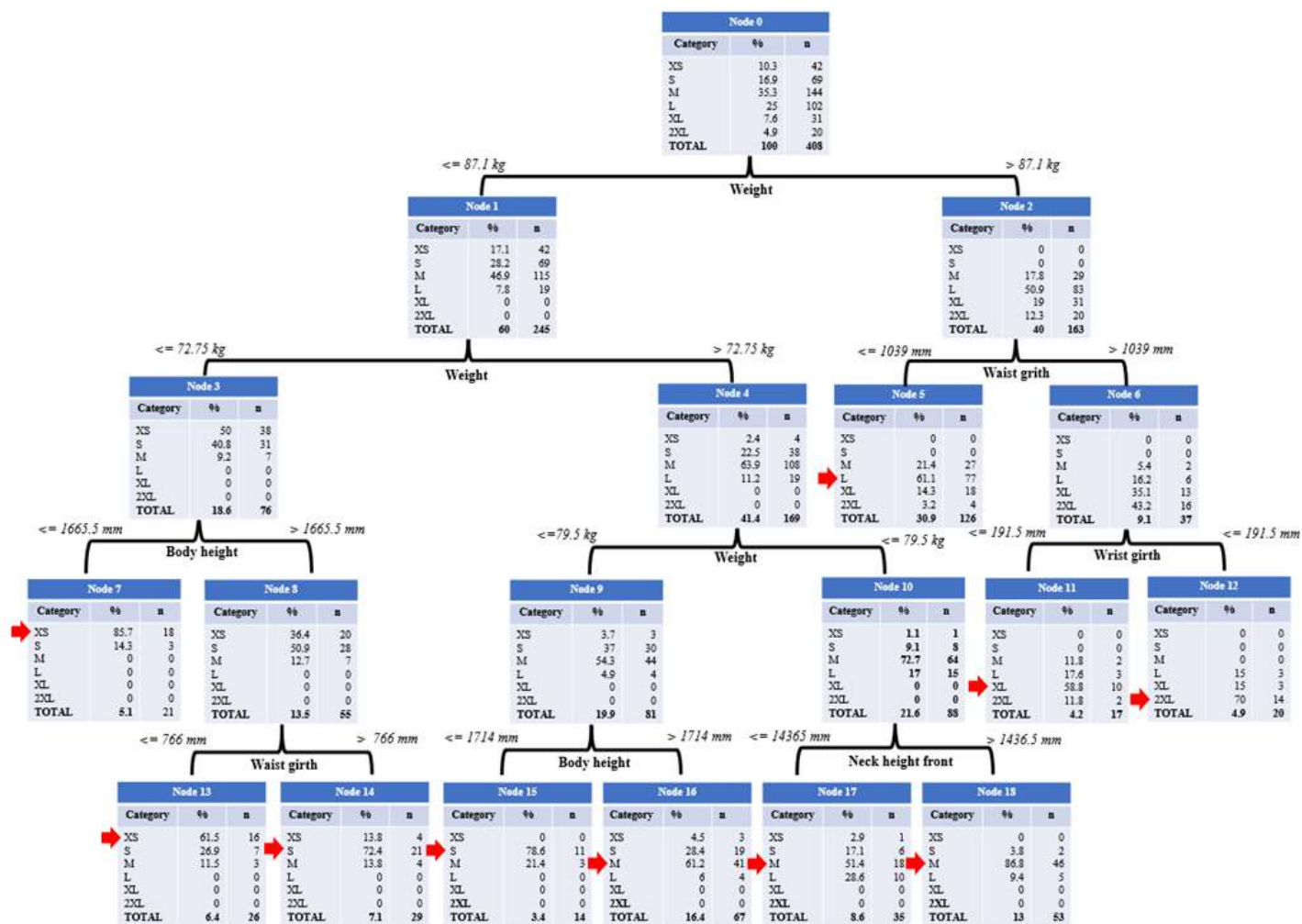


Figure 7—4. Shirt size classification for the NZ Army.

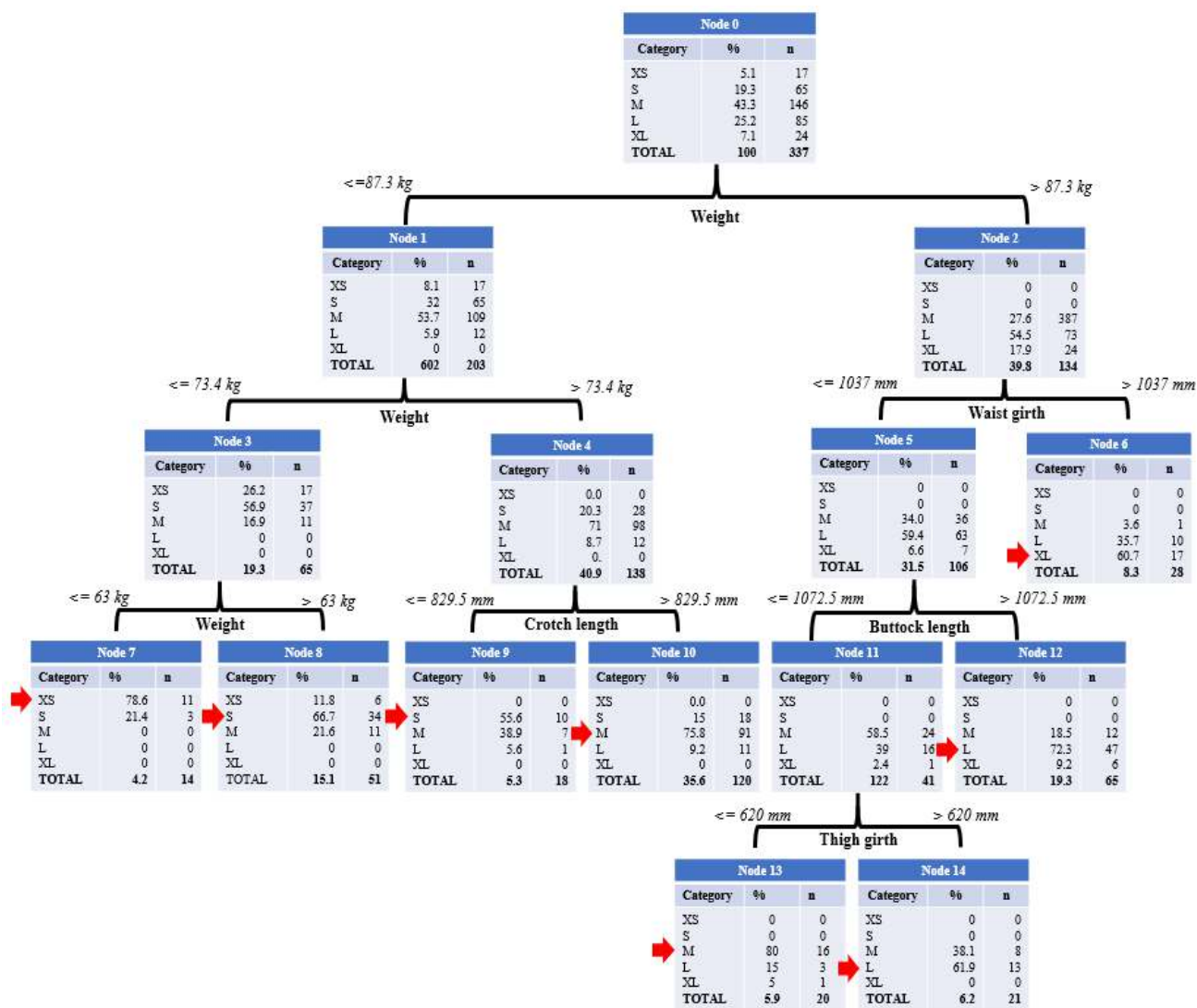


Figure 7—5. Trouser size classification for the NZ Army.

The models presented in Figure 7—4 and Figure 7—5 were tested in the recruit dataset. A greater overall accuracy and Kappa coefficient were observed for trouser size classification (OA = 62.8%; 95% CI [55, 70], κ = 0.45) compared to shirt size classification (OA = 54.9%; 95% CI [47, 63], κ = 0.38). The shirt model can be interpreted as having ‘slight’ agreement, while the trouser model achieved ‘moderate’ agreement. shows the shirt and trouser model performance for each clothing size. The shirt model was most accurate at classifying sizes L (balanced accuracy = 86.2%), XS (80.5%) and M (69.2%). For trouser sizes, the model performed best for XS (80.2%), and XL (75%) (Table 7-4)

Table 7-4. Classification results for shirt and trouser in the recruit dataset.

	Shirt						Trouser				
Metric	2XS	XS	S	M	L	XL	XS	S	M	L	XL
Sensitivity	0.0	72.7	35.7	65.3	80.0	0.0	61.9	65.6	66.7	44.4	50.0
Specificity	100	88.3	84.5	73.1	92.3	99.3	98.5	75.0	73.5	96.3	100
Balanced	50.0	80.5	60.1	69.2	86.2	49.7	80.2	70.3	70.1	70.4	75.0

Data are presented as percent (%).

Table 7-5 shows the confusion matrix comparing the model predictions to the tailor-assigned sizes. The individuals that were predicted by the model were generally predicted as one size above (e.g., medium instead of small for shirt) or one size below the correct size.

Table 7-5. Confusion matrix for shirt and trouser predictions in the recruit dataset.

		Tailor assigned size										
		Shirt						Trouser				
		2XS	XS	S	M	L	XL	XS	S	M	L	XL
Model predicted size	2XS	0	0	0	0	0	0	-	-	-	-	-
	XS	4	24	10	0	0	0	13	2	0	0	0
	S	0	8	20	7	0	0	8	40	13	2	0
	M	0	1	26	32	1	0	0	19	34	8	0
	L	0	0	0	10	8	1	0	0	4	8	1
	XL	0	0	0	0	1	0	0	0	0	0	1

Bold numbers along the diagonals indicate where tailor-assigned sizes (x-axis) and model prediction (y-axis) and were the same. For example, size XS, 24 (bold value) out of a possible 33 participants (sum of all values within the tailor assigned XS column) were predicted as size XS. However, eight of those participants were predicted as size S (and one size M).

Discussion

The aim of this study was to determine how well decision tree models predict tailor-assigned uniform sizes using anthropometry data from a military anthropometry survey, and to examine which combination of automatic, post-processed, and physical anthropometry measurements lead to the most accurate model. The classification of shirt

and trouser size was more accurate when based on the NZDFAS automatic measurements (body scanner derived) as opposed to the set of physical (traditional) measurements, or a combination of measurement types. When the decision tree models were tested on the recruit dataset, the classification accuracy was highest for trousers (particularly for the large size) compared to shirts. Body weight was the most important variable in both the shirt and trouser decision trees.

Common variables with previous research

Our findings identified body weight and waist girth as the most important measurements for both shirt and trouser size classification. Body weight has traditionally been an important measurement for developing size charts [239] and it is also highly correlated with many anthropometric measurements [240]. Research using linear regression to estimate sizing suggest that garment dimensions in the height direction can be calculated purely based on body height [228]. Previous studies also identified bust girth and waist girth as important variables for shirt sizing, and hip girth, height, and leg length as key measurements for trouser sizing [47, 48, 241].

Automatic versus physical

Using the set of automated measurements collected as part of NZDFAS led to a more accurate prediction model than using the physical measurements or post-processed measurements. This could have been attributed to the type of variables used in the analysis and their relevance to clothing size. For example, the automatic measurement variables were more closely related to traditional clothing pattern dimensions (e.g., bust chest girth, waist girth, and height) compared to the physical measurement variables (e.g., arm span, knee height, tibiale laterale height). Physical and post-processed variables had minimal effect on increasing the accuracy of clothing size classification. For example, the shirt model fit using Automatic + Physical + Post-processed measurements had less accuracy than the model fit using only Automatic measurements (55.1% vs 58.1%). This trend was similar for trouser size prediction (56.1% vs 61.7%) which showed a 5.6% difference.

Classification accuracy

Although the overall classification accuracy for shirt and trousers was modest (between 58–62%), the confusion matrix demonstrated that the incorrect model predictions were generally one size above or below the correct size. This suggests that participants who are difficult to classify may fall on the border between two different size categories. Thus,

prediction errors seem to be systematic (the correct size being one size up or down). This is in line with previous literature which has suggested that perfect accuracy when predicting a person's garment size from his or her body size is rarely achieved [242]. The incorrect sizes that are one size above or below the assigned size, may present safety implications (e.g., one size up may result in 'loose' fit or 'snags' during an emergency egress from a Pinzgauer vehicle; one size down may restrict mobility that is required for running quickly from a stationary prone firing position). Similarly in the US, male soldiers reported that wearing body armour that was one size too big was associated with increased exposure at the neck and underarm regions when compared to the soldiers wearing body armour that was one size too small or the correct fit [224, 243]. A small change in clothing size can have a detrimental effect on soldier safety.

The modest classification score may be attributed to several factors. First, it is possible that tailor-assigned sizes may have not been the optimal size for the participant's anthropometry. This may have arisen because the clothing tailors prioritise functional fit (e.g., slightly 'loose' fit to increase all round mobility) as opposed to a tailored fit [234]. There is also a small possibility that the clothing sizes obtained from the clothing store may have been out of date due to changes in anthropometry as a result of military training (i.e., participant sizes may have been assigned months prior to the NZDFAS data collection). Although excluding participants who rated their fit as 'Poor' or 'Very poor' may have alleviated some of these problems, these fit ratings were still subjective. Some participants may have preferred tight- or loose-fitting clothing, regardless of the functional fit. These issues may have caused a mismatch between a participant's anthropometry and the size they were allocated. This can be evidenced in Figure 7—4, where several participants with a tailor-assigned medium-sized shirt had a waist girth >1039 mm, yet other participants who were also assigned a medium-sized shirt had a waist girth <766 mm. The anthropometric measurements used in this study may not have been the most optimal variables for predicting clothing size. The NZDFAS dataset utilised 17 automatic measurements that were extracted using the Anthroscan™ software. It is possible that other automatic measurements may have increased the accuracy of the predictions, but the validity of these automatic measurements has not been tested.

Limitations and future implications

Future research in this area could focus on gender differences, particularly since female participants expressed greater dissatisfaction with uniform fit compared to male participants. This may be indicative of poor uniform design or sizing categories that do not align with the female form (given the MCU is unisex). As international military forces are looking to increase the number of females in the military, it may be more appropriate to have a gender-specific uniform and sizing system. A previous study [31] identified key anthropometric measurements that differentiate male and female personnel in the military (e.g., hip and shoulder breadth). This information may be useful for designing gender-specific uniforms. Cluster analysis has been applied to anthropometric datasets to develop distinct groups of military personnel based on their anthropometric characteristics [232, 244, 245] which in turn, have been used to develop clothing sizing systems. If combined with universal military clothing standards (e.g., NATO sizing standard), it may be possible to develop gender-specific size categories and garment dimensions specific to a military population.

Although this study comprised participants across multiple trades, well-fitting uniforms will likely be more beneficial (from a safety perspective) to those on the ‘front line’ compared to sedentary (office work) roles. Various data mining techniques have been used to understand anthropometry variables for the purposes of classifying clothing size and developing sizing systems. Significant differences between each model could not be assessed as it is currently not possible to compare two or more decision tree models using the SPSS software. Furthermore, it is possible that surface area or volume measures would have improved model accuracy, but the NZDFAS dataset only contained data on lengths, breadths, depths, and circumferences.

Conclusions

Anthropometric measurements, when used with decision tree methods, show promise for supplying a correct fitting clothing size, with body weight and waist girth being the strongest predictors. Methodological changes such as fitting gender-specific models, using additional anthropometry variables, and testing other data mining techniques are avenues for future work. More research is required before fully automated body scanning is a viable option for obtaining fast and accurate clothing sizes for military clothing and logistics departments.

Stephven Kolose, Tom Stewart, Patria Hume, Grant Tomkinson

Preface

The previous chapter examined how well decision tree models can predict tailor-assigned uniformed sizes using the NZDFAS dataset. The findings demonstrated that automated body scan measurements may be a viable method for obtaining fast and accurate clothing sizes. However, the prediction accuracy (comparing tailor-assigned and model-predicted sizes) was modest.

Several reasons for this were discussed, including participant preferences, and the incompatibility between the clothing size range and participants' anthropometry (particularly females). Rather than comparing tailor-assigned and model-predicted sizes, it may be that the sizing system itself was sub-optimal in relation to participants' anthropometry. The purpose of Chapter 8 is to examine how body measurements cluster in the NZDFAS dataset, with the intention of identifying distinct groups of individuals who share similar anthropometric measurements. This information, in conjunction with the sexual dimorphic measurements obtained earlier, could be used by clothing manufacturers to develop sizing systems that are specific to the NZDF population.

Abstract

Aim: To determine how anthropometric characteristics cluster in the New Zealand Defence Force, and to describe the characteristics of each cluster. This information can inform the development of new uniform sizing systems for the New Zealand Defence Force.

Methods: Anthropometric data (n=84 variables) from 1,003 participants in New Zealand Defence Force Anthropometry Survey (NZDFAS) were used. The dataset was stratified by gender and variables isolated based on their relevance to shirt and trouser sizing. Principal Component Analysis was used to identify the most important variables for clustering. A combination of two-step and k-means clustering was used to derive cluster characteristics.

Results: The PCA identified optimal clothing (shirt = body height and waist girth; and trouser = inseam length and hip girth for females; inseam length and waist girth for males) variables. Two-step and k-means clustering identified optimal cluster numbers of 6 and 10 for female and male clothing, respectively. The female clothing clusters were more variable (intra-cluster) and further apart (inter-cluster) compared to males. Male clusters were more defined while the proximity of the clusters suggest that ‘trial and error’ sizing for individuals at the border of multiple clusters may be required.

Conclusions: Anthropometric measurements in combination with clustering techniques show promise for partitioning individuals into distinct groups. The anthropometry dimensions associated with each cluster can be used by the garment industry to develop specific sizing systems for the New Zealand Defence Force population.

Introduction

A correctly sized uniform is extremely important for military personnel worldwide. Correct fitting clothing is important for performing various occupational and operational tasks (e.g., pack march, piloting an aircraft), for safety (e.g., body armour protects important organs, chemical suits must fit properly to seal against dangerous liquids or gases) [246] and the ability to provide sufficient mobility and adopting various postures (e.g., using a weapon in prone position). Accurate fitting garments depends on a robust sizing system, the availability of an accurate set of body measurements, and an understanding of anthropometry [15, 247]. A clothing sizing system consists of the number of sizes, intervals between sizes, and a size labelling system. It should ensure that the range of sizes fit as much as 95% of the target population [71, 248-250].

Unfortunately, obtaining the correct fit is challenging due to the vast differences in body types and the variation in body types within a given size interval [245]. Furthermore, the size intervals may not correspond with real size/shape combinations found in the population. Secular trends show that populations are growing taller (approximately 1 cm each decade) and becoming heavier for the general population [251]. These changes in body size and shape also vary by ethnicity, age, and gender [3, 252] and may not necessarily be reflected in current garment sizing systems. Recent increases in the body size of military personnel (e.g., in Australia, Canada and the U.S.) appear to have coincided with changes in body proportions which collectively create additional challenges for maintaining a current and effective uniform sizing scheme [145, 221-223, 246]. In addition to human growth, there has been an increase in the number of females in the military worldwide. Women are increasingly being integrated into military ‘front line’ combat roles in addition to being in long standing roles such as air force pilots, search and rescue technicians, and clearance divers. For example, the number of enlisted women in the US military increased by 17% (between 2000 and 2019) to 220,000 [253]. In the New Zealand Defence Force (NZDF), individual service gender targets were set to increase female participation in the Air Force and Navy to 25% and 30%, respectively, by 2025. While the NZ Army is targeting a 25% and 35% increase in females in combat support and combat service support respectively, by 2025 [254]. As a result of the increase in women participation, the female body shape must be considered for clothing and equipment that was originally designed for use by male personnel [223]. The implications of the changes in human growth and demographics in the military will influence clothing design, sizing, and fit.

In military apparel, key measurements or sizing systems are identified from the analysis of anthropometric data of military populations [250]. The use of 3D body scanners in military surveys have gained in popularity over the last 20 years. Military anthropometry surveys have a long history in the United States, United Kingdom, Australia, and Canada [207] and a growing presence in countries such as Brazil, Indonesia, India, and Iran [14, 15, 255, 256]. The introduction of 3D body scanners has improved the measurement process immensely. They enable the capture of surface anthropometric data in a time-efficient and non-invasive manner; a larger number of measurements can be taken at once while providing a digital record of the participant [15]. Numerous studies have investigated the reliability and/or validity of scan-derived measurements compared to more traditional (e.g., ISAK) systems. Body scanners have been shown to measure body volumes, circumferences, and lengths more rapidly and accurately than traditional techniques (Wang et al., 2006). Jaeschke et al. (2015) discovered strong correlations between automatic and traditional measurements for body height; however, the automatic measurements generally ‘overestimated’ most other measurements. Glock et al. (2017) found that body height, waist, upper arm, calf, and hip circumference showed high validity for both traditional and body scanner methods. Choi and Ashdown (2011) found that automatic measurements provided significantly larger values for waist circumference compared to traditional measurements. Alternatively, Wells et al. (2007) found that traditional measurements were more accurate at predicting buttock girth and hip girth.

Clothing measurements extracted from 3D body scans (e.g., sleeve in-seam and waist girth) can be used to develop sizing systems. Shape categorisation may use statistical techniques such as principal component analysis (PCA) or cluster analysis (CA) to identify "clusters" of body shapes, develop new size templates, and thus increase the likelihood of a good fit and adequate coverage of the target population [257, 258]. Previous research has utilised various types of cluster analysis (e.g., k-means, hierarchical, two-step) to establish sizing charts for the civilian sector such as the New Zealand fire service [46] and UK offshore workers [259]. These methods have also been used to size uniforms for the Sudanese and Indian militaries [15, 260], as well as ballistic protection for the Taiwanese and Indonesian militaries [256, 261].

Until recently, 3D body scanning technology had never been used to assist garment sizing and selection in the New Zealand Defence Force. In 2019, the New Zealand Army expressed interest in how this technology could optimise their recruit combat uniform sizing process [234]. Using the 2016–18 New Zealand Defence Force Anthropometric

Survey (NZDFAS) dataset, a previous study was conducted using decision tree models to predict clothing size, using the tailor-assigned clothing size as the gold standard. The study also captured subjective ratings of perceived clothing fit. Findings showed a modest level of size classification accuracy (up to 62%) and a high proportion of perceived poor fitting garments, particularly for females [234]. This may suggest inconsistencies between body anthropometry, sex-specific differences in body shape and fit, and the sizing system of the uniform at the time. Now that current 3D anthropometric data (NZDFAS) exists for this population, it may be possible to develop a more adequate sizing system. Therefore, the aims of this study were: (1) to determine how anthropometric characteristics cluster in the NZDFAS data, and (2) describe the characteristics of each cluster. This information may inform the development of a new sizing system for the NZDF.

Method

Anthropometric data from the 2016–18 NZDFAS was used in this study [207]. The study had ethical approval from the Auckland University of Technology Ethics Committee (AUTEC #14/126 NZDF anthropometry Survey: Variations in kinanthropometry and implications for the New Zealand Defence Force).

Participants

The NZDFAS dataset was collected between February 2016 and June 2018 and consisted of 1,003 uniformed participants from the Royal New Zealand Navy (n= 131), Royal New Zealand Air Force (n=289) and the New Zealand Army (n=583). The participants were recruited from nine NZDF centres across New Zealand using a mixture of stratified (e.g., based on selected demographics such as gender, service, trade, and ethnicity) and purposive (e.g., where a point of contact at each site helped identify participants based on their availability and suitability for the study) sampling.

Procedures

The data collection consisted of four stages run by a minimum of six staff (receptionist, four trained anthropometrists and a dedicated body scan technician).

- (i) Brief, where participants had the study aims explained to them and they completed written informed consent and an electronic demographic questionnaire. This questionnaire captured information such as their service

type, years of service, sex, ethnicity, trade, and questions on how they rated the fit of their current uniforms and other military equipment.

- (ii) Physical landmarking, where participants had 20 landmarks physically palpated and marked by anthropometrists trained at Levels 1 and 2 by the International Society for the Advancement of Kinanthropometry (ISAK). The landmarks were used to help identify and extract physical and post-processed measurements according to a measurement schedule [207].
- (iii) Physical measurements, where participants had 25 measurements [207] taken twice by the anthropometrist using equipment recommended by ISAK (e.g., anthropometer, large sliding calliper, small bone calliper, tape). If the first and second measurements were outside specified limits (i.e., 1% for breadths, length, and girths, 5% for reach measurements) then a third measurement was taken.
- (iv) Body scan, where participants were scanned inside the *Vitus Smart XXL*[®] body scanner (Human Solutions, Kaiserlauten, Germany) wearing tight-fitting underwear (e.g., briefs for males, and sports bra and underwear for females) and a swim cap (to standardise head-related measures such as standing height). Participants were scanned in three different postures (two standing and one sitting posture) whilst wearing stickered landmarks required for post-processed measurements.

The 84 measurements were derived using three measurement methods (automatic, physical, and post-processed) to optimize participant throughput while limiting individual processing times at each data collection activity [207]. The measurements were derived from a combination of various international standards: ISO 7250, ANSUR II, ISAK, NHANES and survey protocols from Australia, UK, Canada, and New Zealand (Centers for Disease Control Prevention, 2007; Gordon et al., 2014; International Organization for Standardization, 2008; Keefe et al., 2015; Kolose et al., 2020; Pringle et al., 2011; Tomkinson et al., 2012). The three methods are summarised Table 8-1.

Table 8-1 NZDFAS measurement methods description.

Method (n)	Description	Hardware	Software	Processing time per individual (min)
Automatic (17)	Measurements are captured using an automatic landmark algorithm. Requires minimum operator effort except for final checking of measurement placement. The software extracts the measurements.	Vitus XXL 3-D body scanner. Human Solutions Ltd.	Anthroscan™ software. Human Solutions Ltd.	<1
Physical (25)	Traditional anthropometric measurements conducted by accredited anthropometrists. High operator input (e.g., physical palpation of skin surface) is required. High accuracy dependant on the skill of the anthropometrist.	Traditional anthropometry equipment (callipers, scales, stadiometer).	Excel spreadsheet	30–50
Post-processed (42)	Raw body scans are analysed using a separate software called CySize™. The operator extracts the measurements from each body scan using a suite of digital tools (e.g., tapes, rulers). Requires high operator input with specialist skills in 3D anthropometric and digital manipulation.	Vitus XXL 3-D body scanner. Human Solutions Ltd.	CySize™ Headus Ltd	20–30

The number in parentheses in Column 1 refers to the number of measurements in each method. Processing time refers to approximate duration of the activity per participant.

Analysis

The analysis was stratified by clothing type (i.e. shirt and trouser) and sex (male and female). Two subsets of data were created by identifying measurements that were related to shirt (i.e. upper body and traditional shirt sizing dimensions) and trouser measurements (i.e. lower body and traditional trouser sizing dimensions). Variables common to both shirt and trouser sizing (i.e. body height and weight) were added to each dataset. Inseam

length (calculated as crotch height – 50.8 mm) is regularly used in conjunction with waist girth for sizing military clothing [71, 214-216] and was thus added to the trouser dataset. See Supplementary file 1 for a summary of all variables (and their respective reference protocols) used in these two datasets and Kolose, Hume [207] for a comprehensive breakdown of each measurement definition and protocol.

These datasets were analysed using principal component analysis and cluster (two-step and k-means) analysis using a similar process to previous work [48, 262]. All analyses were performed using IBM SPSS Statistics v24.0.

PCA

The filtered measurements were analysed using PCA to reduce the dimensionality of the dataset and to determine the variables best suited for the cluster analysis. The Kaiser-Meyer-Olkin measure of sampling adequacy, Bartlett's test of sphericity, and the assessment of the anti-image correlation and communalities matrices were administered to ensure the data were suitable for PCA. The Kaiser-Meyer-Olkin scores were all greater than 0.6, and the Bartlett's test of sphericity were all significant (i.e. female shirt [χ^2 (20672.5) = 2415, $p < .01$], female trouser [χ^2 (9521.4) = 666, $p < .01$], male shirt [χ^2 (82815) = 2415, $p < .01$], male trouser [χ^2 (41136.4) = 666, $p < .01$]).

Cluster analyses

Two-Step Cluster

The variables in the PCA step with the highest loadings that were also deemed practical measurements for clothing sizing were then utilised in the two-step cluster analysis (TSC). Two variables were used for each cluster based on previous cluster studies [48, 263]. TSC was selected because it allows the detection of natural groups within a dataset (in the form of clusters) based on different body types [264], and is frequently used to help simplify high dimensional anthropometric data for the purpose of determining garment size [259, 265, 266]. The TSC was used to identify the optimal number of clusters for female-shirt, female-trouser, male-shirt and male-trouser datasets by minimising the Akaike Information Criterion (AIC) score.

K-means

Next, a k-means analysis was performed using the optimal cluster number and the two main measurement variables used in the TSC. K-means was used to determine cluster

membership for each participant in the sample along with the cluster centroids. The body scan image of the individuals with the smallest distance to each cluster centroid were identified as a visual representative of each cluster. Finally, descriptive statistics including the Coefficient of Variation (CV%) percentage (calculated as $(\text{stdev}/\text{mean}) \times 100$) were calculated for the variables used in the analysis, for each cluster. An overview of the analysis process is presented in Table 8-2

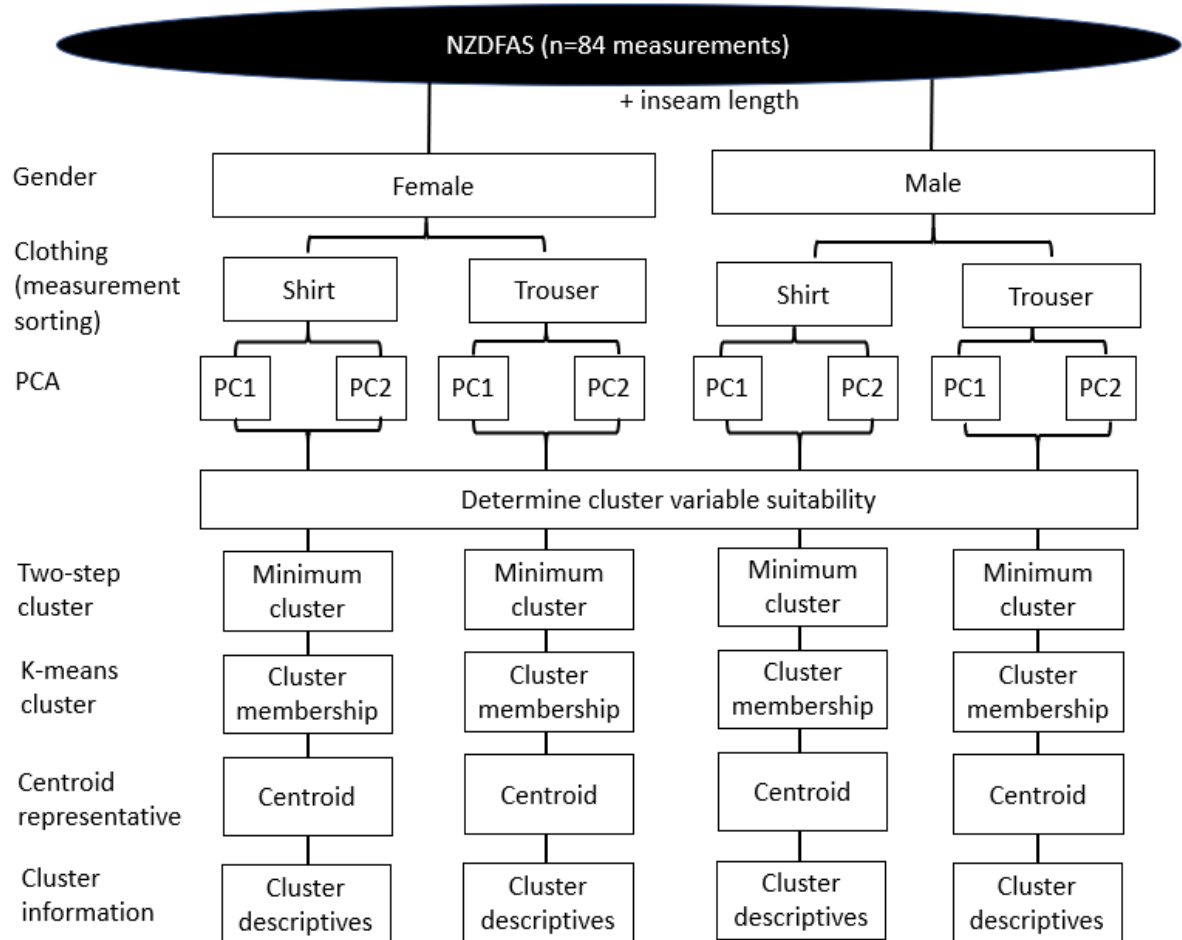


Figure 8—1. NZDFAS cluster analysis process for female-shirt, female-trouser, male-shirt and male-trouser datasets.

Results

Descriptive statistics

Over half of the participants (58%) were from the Army, and most participants had less than five years of full-time service. European and Other (mainly consisting of those who identify themselves as ‘New Zealanders’) were the most prominent ethnicities. One quarter of the sample comprised participants from the Engineering and Technical trades. Significant differences between males and females were observed for the proportion of personnel in each of the three services, as well as each trade (Table 8-2).

Table 8-2. Descriptive characteristics of the NZDFAS sample.

Variable (P-value ^a)	Level	Male (n = 791)	Female (n = 212)	Total (n= 1003)	P-value
Age		31.6±10.7	30.5± 0.4	31.3±10.4	(0.17)
Ethnicity	Asian	22 (2.8)	1 (0.5)	23 (2.3)	(0.14)
	European	327 (41.3)	81 (38.2)	408 (40.7)	
	Maori/Pacific	152 (19.2)	48 (22.6)	200 (19.9)	
	Other	290 (36.7)	82 (38.7)	372 (37.1)	
Service	Army	486 (61.4)	97 (45.8)	583 (58.1)	<0.001)
	Air Force	217 (27.4)	72 (34.0)	289 (28.8)	
	Navy	88 (11.1)	43 (20.3)	131 (13.1)	
Years of service	<5	331 (46.9)	90 (47.6)	421 (47.0)	(0.67)
	6–10	152 (21.5)	41 (21.7)	193 (21.6)	
	11–15	61 (8.6)	22 (11.6)	83 (9.3)	
	16–20	49 (6.9)	12 (6.3)	61 (6.8)	
	21–25	36 (5.1)	10 (5.3)	46 (5.1)	
	26–30	39 (5.5)	10 (5.3)	49 (5.5)	
	30+	38 (5.4)	4 (2.1)	42 (4.7)	<0.001)
Trade	Apprenticeship	45 (5.7)	2 (0.9)	47 (4.7)	
	Aviation	32 (4.0)	14 (6.6)	46 (4.6)	
	Combat	170 (21.5)	21 (9.9)	191 (19.0)	
	Engineering/Technical	225 (28.4)	25 (11.8)	250 (24.9)	
	Hospitality	20 (2.5)	14 (6.6)	34 (3.4)	
	Intelligence IT/COMS	69 (8.7)	25 (11.8)	94 (9.4)	
	Logistics/Administratio	56 (7.1)	56 (26.4)	112 (11.2)	
	Medical/Health	31 (3.9)	29 (13.7)	60 (6.0)	
	Other	54 (6.8)	19 (9.0)	73 (7.3)	
	Specialist	89 (11.3)	7 (3.3)	96 (9.6)	

Data are presented as mean±SD or n (%) where appropriate; the difference between males and females were assessed using Fisher’s exact test (for nominal data i.e. ethnicity, service, years of service and trade) or Mann-Whitney U test (for non-normal, continuous data i.e. age).

PCA

The first two principal components and their associated factor loadings are presented in Table 8-3. For female shirt, a height (e.g., eye height, acromiale height, body height) and mixed-dimension component (e.g., waist girth, ab-extension depth sitting, waist breadth), were identified. For female trouser, components related to girth (e.g., buttock girth, waist breadth, waist girth, buttock depth and hip girth) and height (e.g., inseam, knee height, buttock height) were identified. Male shirt consisted of a height (acromiale height, body height, eye height) and a mixed-variable (e.g., waist circumference preferred, waist girth, waist breadth, ab-extension depth sitting) component. For male trousers, a girth (e.g., waist circumference preferred, hip girth maximum) and height (e.g., inseam, knee height and buttock height) component were identified.

Some of the high loading variables identified in the PCA were not suitable to represent their respective component from a logical and practical clothing perspective. For female shirt sizing, eye height and acromial height obtained higher loadings than body height (Table 8-3). However, both variables would be difficult to measure digitally (acromial height requires physical skin surface palpation, a high degree of skill, and is time consuming) compared to body height (a validated and automatic measurement). We chose waist girth to represent the mixed-variable component for male and female shirt, as it was clearly the highest loading variable except for waist circumference preferred (male). Waist circumference preferred requires user input (e.g., where they would normally wear their belt) and thus deemed too subjective for a reliable clothing measure.

For female trousers, despite obtaining the 5th highest loading within PC1, we chose hip girth to represent the female girth component as it is commonly used in female garment manufacturing and previous cluster sizing research (Hsu and Wang, 2007). Buttock girth and waist breadth were the highest loading variables followed by buttock depth in PC1 (Table 8-3). However, they are not traditional trouser sizing variables as identified in the literature. Waist girth is the only other alternative that is well documented in the clothing literature [71, 215, 216]. For male trousers, waist girth was chosen to represent the girth component (PC1) based on the shortcomings of other high loading variables such as waist circumference preferred (subjective), waist breadth (non-traditional sizing variable), hip girth maximum (more popular for female as opposed to male trouser sizing), and weight (non-traditional clothing sizing dimension; increases in weight do not necessarily amount to increased size). For both female and male trousers, inseam length (calculated as crotch

height – 50.8 mm) was chosen to represent the length or height component. It was the highest loading variable for female trouser PC2 and ranked second for male PC2. Buttock height had a higher loading score for male but buttock height is also subjective (derived based on the height of the most posterior protruding point of the buttock). Finally, inseam length is regularly used in conjunction with waist girth for sizing clothing and military garments [71, 182, 214-216].

As such, body height and waist girth (automated measures based on International Organization for Standardization [267] were selected to represent shirt in the cluster analysis for both male and female. For female trouser, hip girth [190] and inseam length [216] were selected for use in the cluster analysis. Waist girth and inseam length were selected to represent male trousers in the cluster analysis.

Table 8-3. PCA results by gender and clothing type. An asterisk “*” depicts the greatest loading factor within the associated component. Square boxes depict variables selected for clustering.

	Female				Male			
	Shirt		Trouser		Shirt		Trouser	
	PC1	PC2	PC1	PC2	PC1	PC2	PC1	PC2
Eye height	0.92*							
Acromiale height	0.92				0.93*			
Body height	0.91			0.89	0.93			0.91
Neck height front	0.91				0.92			
T2 height	0.90							
Waist girth		0.94*	0.91			0.93	0.91	
Ab extension depth sitting		0.91				0.91		
Waist breadth		0.91	0.92			0.92	0.93	
Waist depth standing		0.89						
Weight		0.88				0.90	0.92	
Eye height					0.93			
Axilla height					0.92			
Waist circumference preferred						0.94*	0.94*	
Hip girth maximum			0.89				0.93	
Buttock height				0.90				0.93*
Inseam				0.92*				0.93
Knee height				0.90				0.93
Iliocristale height				0.89				0.91
Buttock girth			0.92*					
Buttock depth			0.91					
Chest girth		0.88				0.88		
Variance explained (%)	38.8	17.9	42.5	21.1	42.5	21.1	45.3	22.7
Total proportion (%)	38.8	56.7	42.5	63.7	41.2	60.0	45.3	68.1

Cluster analysis

A TSC analysis was performed using the variables identified from the PCA. Based on the TSC results, the optimal number of clusters for female clothing (shirt and trouser) was 6 (AIC scores of 141.2 and 140.1, respectively) and the optimal number of clusters for male clothing (shirt and trouser) was 10 (AIC scores of 324.3 and 317.8, respectively). The clusters and representative body shapes (based on cluster centroid) for each sex and

clothing type are presented in Figure 8—2 and Figure 8—3. The anthropometric variables from each cluster are summarised in Table 8-4 and Table 8-5.

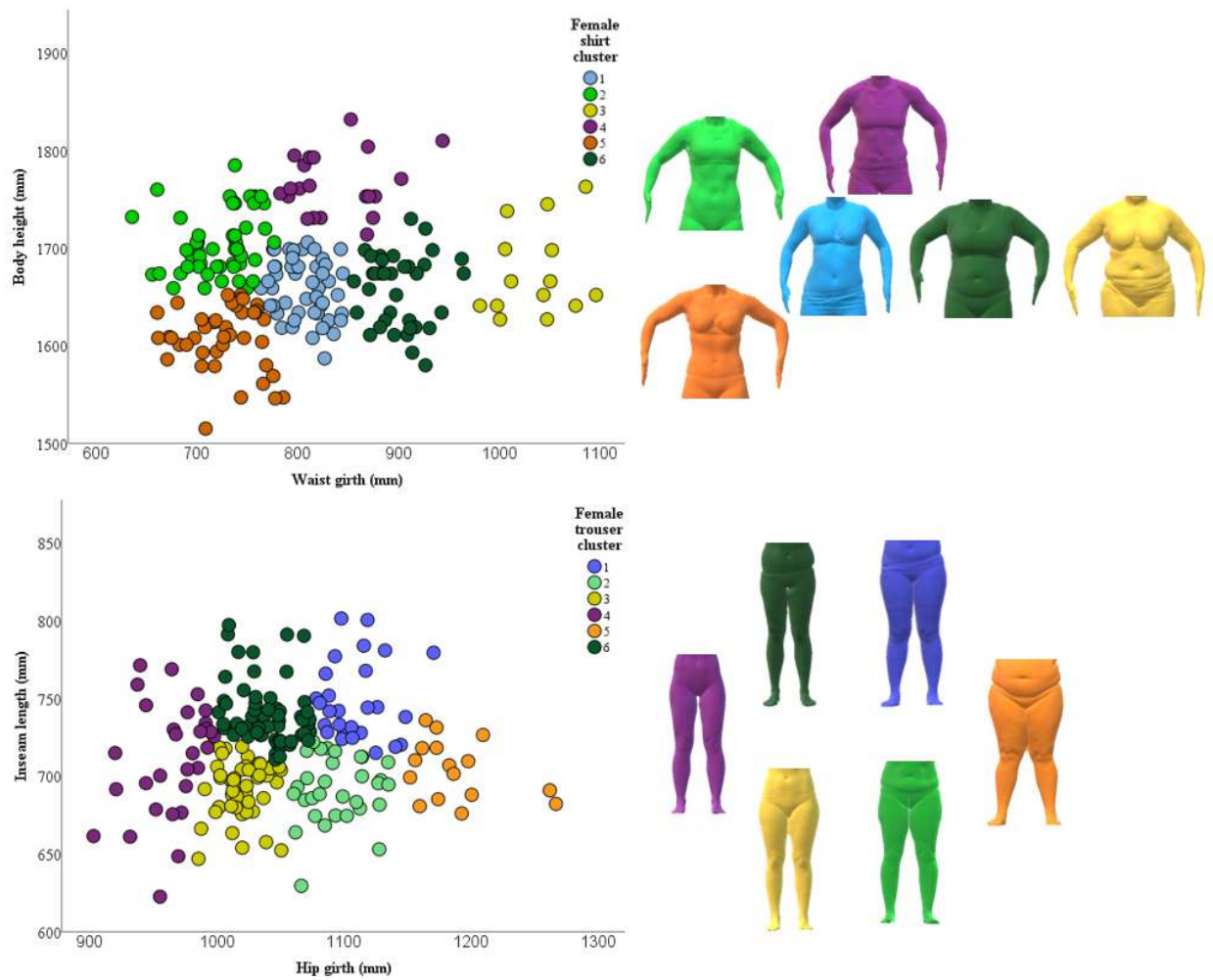


Figure 8—2. [Top] Scatter plot showing the different clusters for females shirt (body height vs waist girth) and body shape images representative of each cluster centroid [Bottom]. Scatter plot showing the different clusters for female trousers (Inseam length vs hip girth)

Table 8-4. Female shirt cluster number, measurement variable (mm) and descriptives by clothing type.

Clothing/cluster	Variable	N	Mean	S. D	Range	Min	Max	CV%
Shirt Cluster 1	Body height	50	1660	30.1	119	1587	1706	1.81
	Waist girth	50	806	22.8	81	764	845	2.83
Shirt Cluster 2	Body height	49	1704	31.5	126	1659	1785	1.85
	Waist girth	49	722	32.4	141	636	777	4.49
Shirt Cluster 3	Body height	14	1675	45.6	136	1627	1763	2.72
	Waist girth	14	1036	35.6	115	981	1096	3.44
Shirt Cluster 4	Body height	21	1765	30.8	118	1714	1832	1.75
	Waist girth	21	838	43.1	161	783	944	5.14
Shirt Cluster 5	Body height	42	1608	32.8	137	1515	1652	2.04
	Waist girth	42	727	33.9	125	661	786	4.66
Shirt Cluster 6	Body height	36	1658	37.1	150	1580	1730	2.24
	Waist girth	36	901	27.0	109	856	965	3.00
Trouser cluster 1	Hip girth	28	1110	22.9	92	1078	1171	2.06
	Inseam length	28	747	25.1	86	715	801	3.36
Trouser cluster 2	Hip girth	31	1095	23.7	75	1061	1135	2.16
	Inseam length	31	691	20.9	93	630	722	3.02
Trouser cluster 3	Hip girth	48	1020	16.3	65	986	1051	1.60
	Inseam length	48	691	17.7	72	647	719	2.56
Trouser cluster 4	Hip girth	30	965	25.2	95	903	998	2.61
	Inseam length	30	712	36.1	149	623	771	5.07
Trouser cluster 5	Hip girth	16	1188	34.1	115	1152	1267	2.87
	Inseam length	16	704	18.9	60	676	736	2.68
Trouser cluster 6	Hip girth	59	1040	20.8	72	1002	1073	2.00
	Inseam length	59	740	20.3	87	711	797	2.74

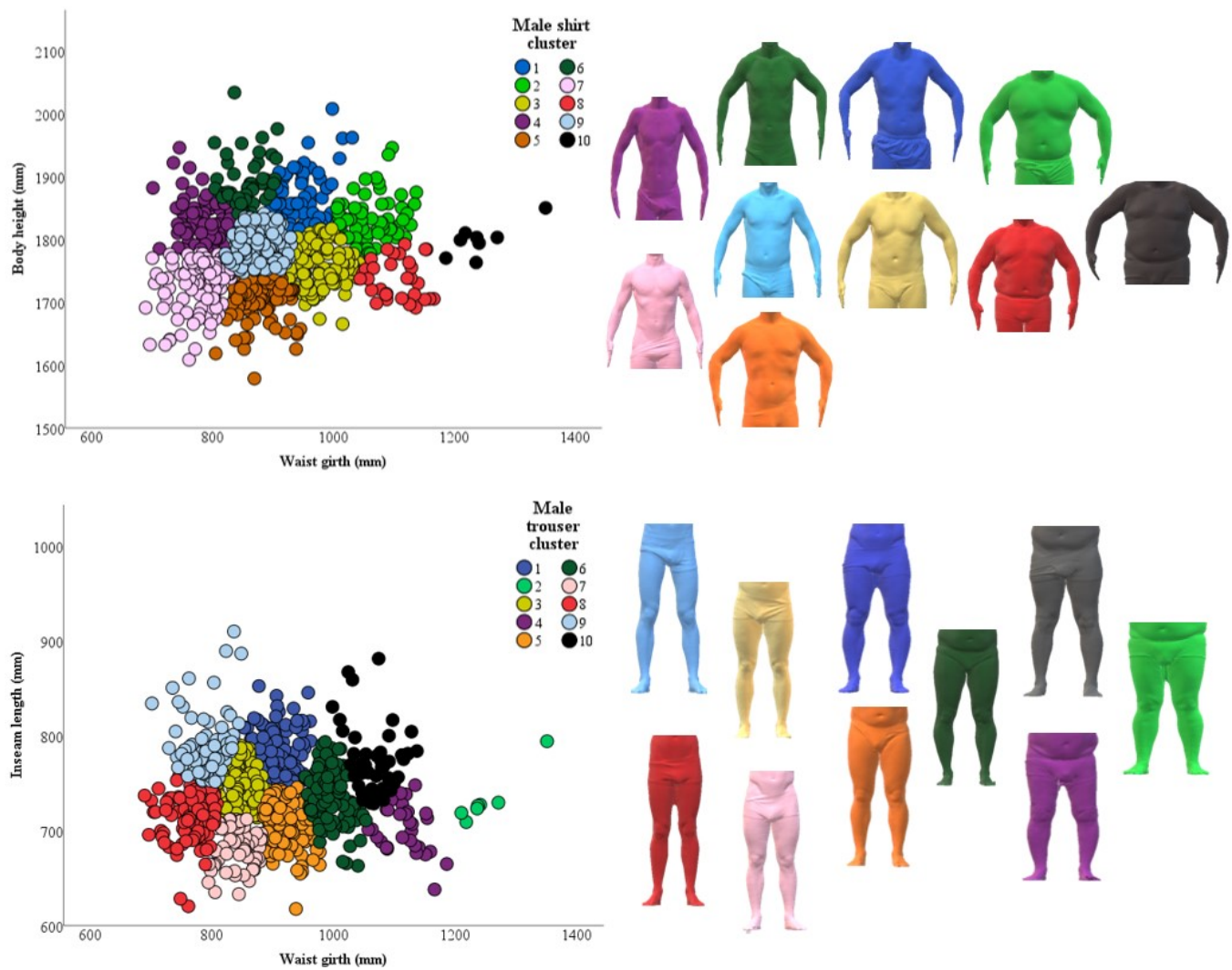


Figure 8—3. [Top] Scatter plot showing the different clusters for male shirt (body height vs waist girth) and body shape images representative of each cluster centroid [Bottom]. Scatter plot showing the different clusters for male trousers (Inseam length vs waist girth) and body shape images representative of each cluster centroid

Table 8-5. Male cluster number, measurement variable (mm) and descriptives by clothing type.

Clothing/cluster	Variable	N	Mean	S. D	Range	Min	Max	CV%
Shirt Cluster 1	Body height	66	1870	40.9	193	1816	2009	2.19
	Waist girth	66	947	32.0	135	896	1031	3.38
Shirt Cluster 2	Body height	64	1834	34.4	169	1778	1947	1.88
	Waist girth	64	1063	36.4	131	1006	1137	3.42
Shirt Cluster 3	Body height	107	1761	33.1	152	1666	1818	1.88
	Waist girth	107	979	30.4	116	926	1042	3.11
Shirt Cluster 4	Body height	91	1830	31.5	162	1785	1947	1.72
	Waist girth	91	785	29.8	134	701	835	3.80
Shirt Cluster 5	Body height	94	1704	33.0	167	1579	1746	1.94
	Waist girth	94	879	33.1	140	805	945	3.77
Shirt Cluster 6	Body height	51	1890	39.6	193	1842	2035	2.10
	Waist girth	51	854	28.8	104	803	907	3.37
Shirt Cluster 7	Body height	118	1729	38.2	169	1609	1778	2.21
	Waist girth	118	779	33.1	141	689	830	4.25
Shirt Cluster 8	Body height	31	1738	31.1	101	1692	1793	1.79
	Waist girth	31	1105	36.1	122	1044	1166	3.27
Shirt Cluster 9	Body height	161	1792	24.7	94	1748	1842	1.38
	Waist girth	161	876	26.8	109	821	930	3.06
Shirt Cluster 10	Body height	8	1800	26.5	87	1764	1851	1.47
	Waist girth	8	1244	50.0	165	1186	1351	4.02
Trouser Cluster 1	Waist girth	100	911	24.9	109	853	962	2.73
	Inseam length	100	782	25.8	108	745	853	3.30
Trouser Cluster 2	Waist girth	7	1252	47.8	141	1210	1351	3.82
	Inseam length	7	733	28.1	85	710	795	3.83
Trouser Cluster 3	Waist girth	143	851	20.8	88	806	894	2.44
	Inseam length	143	745	17.5	76	714	790	2.35
Trouser Cluster 4	Waist girth	32	1117	31.0	129	1057	1186	2.78
	Inseam length	32	703	25.1	110	638	748	3.57
Trouser Cluster 5	Waist girth	110	922	24.7	92	885	977	2.68
	Inseam length	110	706	24.3	128	618	746	3.44
Trouser Cluster 6	Waist girth	104	998	24.9	100	953	1053	2.49
	Inseam length	104	737	28.2	131	663	794	3.83
Trouser Cluster 7	Waist girth	60	841	24.7	88	794	882	2.94
	Inseam length	60	684	21.4	79	633	713	3.13
Trouser Cluster 8	Waist girth	101	767	28.7	119	689	808	3.74
	Inseam length	101	714	23.3	138	621	758	3.26
Trouser Cluster 9	Waist girth	84	792	30.2	147	701	848	3.81
	Inseam length	84	790	31.6	159	752	911	4.00
Trouser Cluster 10	Waist girth	50	1067	30.9	139	998	1137	2.90
	Inseam length	50	772	35.1	153	729	882	4.55

Cluster descriptives

Female clothing

For female shirt, cluster 5 represents small individuals based on medium-short stature (<1652 mm) and low waist girth (<786 mm) (Table 8-4 and Figure 8—2) based on visual fit. Clusters 1 and 6 represent medium-size individuals consisting of medium-tall body height (1587 mm to 1730 mm) and waist girth (1002 mm to 965 mm). Clusters 3 and 4 represent large individuals based on high waist girth (>984 mm) and tall body height (>1714 mm), respectively. For female trousers, cluster 4 covers the widest inseam length range (15 cm) with a low (<1000 mm) hip girth. Clusters 6 and 1 represent medium-large to large individuals based on their high inseam lengths (>711 mm) and medium hip girth values (>1002 mm). Cluster 5 represents large individuals with medium inseam lengths (676 mm to 736 mm) and high hip girth values (>1152 mm) (Table 8-4 and Figure 8—2). For shirt, the average CV% for body height and waist girth were 3.93 and 2.07, respectively. For trouser, the average CV% for hip girth and inseam length was 2.22 and 3.24, respectively.

Male clothing

For male shirt, cluster 7 represents small individuals with low waist girth (<830 mm) and the lowest stature range (1609 mm to 1778 mm) (Table 8-5 and Figure 8—3). Cluster 10 represent large individuals based on high waist girth values (>1186 mm) with medium stature (compared to other clusters). Clusters 3 and 9 appear to be at the centre and thus represent medium size individuals with respect to both body height and waist girth. For male trousers, cluster 8 represents small individuals based on a combination of low inseam length (<758 mm) and waist girth (<808 mm). Cluster 2 represent larger individuals based on high waist girth (>1210 mm) however they have medium to low inseam length (between 710 mm and 795 mm). Clusters 5 and 9 represent medium size individuals based on a combination of both inseam length and waist girth values relative to other clusters (Table 8-4). For shirt, the average CV% for body height and waist girth were 3.54 and 1.85, respectively. For trouser, the average CV% for waist girth and inseam length was 3.03 and 3.53, respectively.

Discussion

The aim of this study was to determine how anthropometric characteristics cluster in the NZDFAS dataset and to describe the characteristics of each cluster. PCA was used to determine key body dimensions for shirt (waist girth and body height) and trouser (waist girth, hip girth and inseam length) clustering. Two-step and k-means cluster analyses were performed on these variables, resulting in 6 and 10 clusters for female and males, respectively.

PCA findings

In contrast to previous studies [47, 48, 268] the highest loading variables for the second principal component for shirt (female and male) were not dominated by any one dimension (e.g., it was neither all girth nor all length variables). Hence, PC2 for shirt was named a ‘mixed-dimension’. However, the high loading variables for PC2 (waist girth, abdominal extension depth sitting, waist breadth and waist depth) were all related to the lower torso or waist region. This suggests that these variables could be important for garment sizing. The use of waist girth and inseam length for trouser sizing has worked successfully in the past [214, 260]. We selectively chose alternative measurements for the cluster analyses despite the presence of variables with slightly higher loadings in the PCA. The alternative measurements had minimal impact as loadings for the variables we selected were only marginally lower than the variable with the highest loading (between 0.005 and 0.03 units lower). A surprising finding is that chest girth, a traditional shirt sizing variable, was ranked 6th in the PC2 (female and male) variable loadings. Therefore, waist girth (highest loading variable traditionally used for clothing sizing) was used in the shirt cluster analysis.

Cluster findings

There were more male shirt and trouser clusters (10) than female (6). When considering gender differences in within-cluster variability for shirt, the male clusters were less variable for waist girth (CV = 3.54 vs. 3.91%) and height (1.85 vs. 2.07%) compared to females. For trousers, males had a higher within-cluster variation for waist girth (3.03% vs. female hip girth of 2.22%) and inseam length (3.53 vs. 3.24%) compared to females. Based on this evidence, a potential female shirt sizing system could have a smaller number of distinct sizes (e.g., S, M, L, XL), while a male shirt and trouser sizing system could have more distinct sizes. However, the higher number of clusters for males

compared to females could reflect their respective cohort sizes (791 male verses 212 females). In saying that, we would expect most of these body measurements to be normally distributed in the NZDF population, and there is sufficient evidence that most measurements in the NZDFAS sample are normally distributed for both males and females (see Kolose et al 2021).

The findings suggest that our cluster data could be used to develop gender-specific sizing systems (as opposed to unisex). The trouser variables (e.g., waist girth for male and hip girth for female) also support this separation. However, according to Table 8-5, some individuals (particularly male) may sit at the border of two or more clusters. For example, a male (1810 mm stature and 980 mm waist girth) may be placed within the common border of three shirt clusters (1, 3 and 9). Varying the cluster input parameters (e.g., using different fixed cluster numbers between 10 and 15) provided no meaningful separation of these clusters. Garment dimensions that are based on the observed clusters could pose problems for these individuals, as they could fall into the upper or lower extremes of a given size category.

Our results are comparable to previous work. Other studies using cluster analysis on anthropometric data for garment sizing have identified a minimum of 3 clusters for female lower body garment sizing [269] and used chest and waist girth variables to identify 8 clusters for the Sudanese military uniforms [270]. In terms of the optimal number of clusters for males, this study had fewer clusters than Purnomo and Kurnia [256] who identified 19 clusters. These comparisons demonstrate that cluster analysis is a popular method; however, comparisons are difficult to make due to the differences in population-specific anthropometry (e.g., NZ vs Sudanese body size).

Practical significance

In practical terms, if our six female and 10 male shirt and trouser clusters represented real-world clothing sizes for the NZDF, then it would provide fewer sizes for each sex compared to the NZDF unisex combat uniforms (currently consisting of up to 12 shirt sizes and 12 trouser sizes for Air force, Navy and Army). A reduction in sizes can be beneficial, as more sizes leads to increased costs (e.g., production) and complexity involved in both the manufacturing and the distribution process [271]. Clothing manufacturers could design a male and a female variant of the Multi Camouflage Uniform (MCU which is the NZ Army combat uniform that has recently been superseded), with the clothing dimensions for each size based on the cluster descriptives presented here.

However, given the creation of separate uniforms for males and females, these decisions are dependent on several external factors, particularly resources (e.g., cost and time of producing new MCU variants).

Strengths and limitations

Consistent with previous work [15, 216], this study examined both upper and lower body measurements separately, with others examining either the whole body [260] or either the upper or lower body [261]. Studying the upper and lower body separately may reduce complexity when interpreting factor loadings during PCA. For example, head circumference may provide a high loading variable for the lower body, despite having no logical relationship with trouser size. The cluster interpretations or labels (e.g., referring to clusters representing small, medium, or large individuals) were subjective. These labels were used in absence of any applied sizing system classification which was beyond the scope of this study.

Future Implications

Future improvements to this study include stratifying the analysis by service (Army, Navy or Air Force), as particular body types may be associated with each service. Given an adequate sample size, the study could focus on specific trades within the defence force (e.g., pilots, navy divers, special forces, or drivers) as these roles may be body-shape specific and require specialised sizing systems. Finally, future work could focus on more specific items of clothing such as body armour. The NZDF and associated industry partners (military garment manufacturers and suppliers) could utilise these results as a foundation for developing a sizing system specific to the New Zealand Defence Force population.

Conclusions

Anthropometric measurements in combination with dimensionality reduction and clustering techniques show promise for partitioning individuals into distinct groups; information that is useful for developing sizing systems for military uniform garments. The results suggested that participants could be organised into 6 and 10 clusters for females and males, respectively. The anthropometric dimensions associated with each cluster can be used by the garment industry to develop specific sizing system for the New Zealand Defence Force population.

Chapter 9 Discussion

The aim of this thesis was to conduct an anthropometric survey in the New Zealand Defence Force and explore potential implications and applications of 3D anthropometric data in a military context. To meet this aim we developed and completed a 3D anthropometric survey of New Zealand Defence Force personnel. The military applications of the resulting dataset were explored in a clothing context. Our objectives were to examine how the dataset could be used to identify sexually dimorphic characteristics, predict tailor-assigned clothing sizes (to improve sizing efficiency), and identify how the dataset clusters to inform future sizing systems for the New Zealand Defence Force.

Research Summary

Chapters 2 to 5 were equivalent to Chapters I to IV of the eBook, respectively. More specifically, Chapter 2 introduced kinanthropometry with a focus on traditional measurements. The chapter summarised popular anthropometric protocols while discussing advantages and disadvantages of different data collection methods. Chapter 3 provided an overview of 3D body scanning technology. It summarised the different types of 3D scanning systems, as well as the validity of these data. Chapter 4 summarised the history of anthropometric surveys in the military over the last 20 years. Finally, Chapter 5 presented the methods (including measurement selection, measurement validity, sampling scheme, survey protocol, and data treatment processes) used in the NZDF Anthropometric Survey (NZDFAS).

The dataset described in Chapter 5 was then applied in Chapters 6–8. Firstly, Chapter 6 explored sexual dimorphism in the human body dimensions of New Zealand Defence Force personnel. This was achieved by comparing the absolute and proportional anthropometric profiles of male and females using the Phantom stratagem. The most dimorphic measurements were then identified using stepwise binary logistic regression. The findings showed that males had significantly greater absolute and proportional measurements than females for most, but not all, measurements (hip and thigh girth being key exceptions). Additionally, waist, hip, and bicep girths, and biacromial breadth were the most sexually dimorphic measurements, which together classified sex with 95% accuracy. The results were comparable to previous research and provide basic information that could potentially assist with sizing gender-specific military clothing.

Chapter 7 used the NZDFAS dataset to determine how well decision tree models could predict tailor-assigned uniform sizes for the NZ Army. The study used 10-fold cross-validation to examine which combination of traditional and 3D scanning measurements lead to the most accurate model for both shirt- and trouser-size. The generalisability of the best model was then tested on an independent sample of Army recruits ($n = 154$). The model that utilised only 3D automated measurements was the best model for predicting shirt (58.1% accuracy) and trouser (61.7% accuracy) size. Additionally, body weight and waist girth were the strongest predictors. Clothing sizes that were incorrectly predicted by the model were generally one size above or below the tailor-predicted size. Acknowledging several limitations, the study concluded that automated body scanning is likely a viable option for obtaining fast and accurate clothing sizes — the application of which can significantly reduce recruit sizing time.

Chapter 8 used the NZDFAS dataset to examine how anthropometric characteristics cluster in the NZDF population, as well as describing the characteristics of each cluster in relation to combat clothing. Three statistical models (PCA, two-step and k-means clustering) were used to determine (1) the most optimal variables for clustering, (2) the optimal number of clusters, and (3) individual cluster characteristics (e.g., variability and measurement intervals). The results showed that body height and waist girth were considered the most important shirt-related measurements for both males and female. For trousers, inseam length and hip girth were important for females, while inseam length and waist girth were important for males. The optimal number of clusters was six and ten for female and males, respectively. These findings could be used by the garment industry to help develop gender-specific sizing systems for the NZDF population.

Significance of findings

Four significant themes were identified in this thesis, namely the creation of the NZDFAS database, sexual dimorphism in the NZDF, automated clothing sizing, and anthropometric considerations for developing future clothing systems. Each of these will be discussed in more detail below.

NZDFAS dataset and digital measurements

The work presented in this thesis consisted of the first 3D anthropometric survey to be conducted in New Zealand, and the first tri-service survey for the New Zealand Defence Force. The survey database is applicable to many domains and will provide support for

ergonomics, engineering, design, health, performance, and clothing research. The database will also be important outside the military. In the absence of an official New Zealand anthropometric dataset, the information could inform other research applications such as the New Zealand COVID-19 response (e.g., the anthropometric measurements could assist with design specifications for personal face masks, HAZMAT suits and other equipment for health professionals). Finally, the dataset can be applied to future clothing research, as uniforms are worn by all regular force personnel.

Our anthropometric measurement protocol was one of the few to utilise automated measurements, as well as traditional and post-processed measurements. This was especially evident in Chapter 4 where recent international (military) protocols (except the UK) were dominated by traditional measurements. As discussed previously (Chapter 3), a significant benefit of automated scanning methods is the ability to derive measurements quickly, which increases the efficiency of data collection while also increasing participant throughput [100]. The NZDFAS protocol was designed to minimise measurement time by replacing manual measurements with automated measurements. A reduced form of the NZDF protocol (concentrating on automated measurements only) would be extremely useful for conducting fast, and more focussed surveys (e.g., surveying height and weight of aircrew, sailors, or divers only) in the military. A reduced protocol would be cheaper (no physical measurers required), shorter (duration) and require less resources (reduction in support staff such as receptionists and measurement checkers) compared to the full protocol.

In our study, we used post-processing for its flexibility and time savings (e.g., measurements are only made after the survey). In hindsight, this was a risk as deriving measures weeks (or months) after the data collection may mask latent errors. These errors can manifest as poor scan quality, inaccurate measurements due to poor scan posture or incorrect or substandard landmarking (pre-scan). These factors affect the accuracy of measurements or lead to the removal of measurements altogether. This may explain why post-processed measurements contained the most missing values relative to the other methods (Chapter 7) as automated measures are based specifically on Posture 2 (and the images are presented immediately after scanning) and physical measures are frequently checked by two qualified anthropometrists. To address this imbalance, we recommend that all post-processed measurements are validated against both automated and physical measurements. In the past, studies have compared automated versus physical [272, 273] or post-processed versus physical [274] but limited research exists for comparisons of all

three (automated versus physical versus post-processed) – the results of which could help address any issues of imbalance.

Sexual dimorphism in the NZDFAS dataset

Our study showed evidence of sexual dimorphism in the NZDFAS dataset. The most sexually dimorphic measurements were waist girth, hip girth, bicep girth, and biacromial breadth. This information is extremely relevant and poignant for the NZDF and international military forces. With the increasing number of females joining the military worldwide [26, 27], and the NZDF looking to increase females numbers by 2025 (30% in the RNZAF, 25% in the RNZN and 25–40% in the NZ Army) [206] changes to the design or procurement of military equipment to fit both the male and female form warrants attention. In combat roles, inevitable changes are required to the design of body armour systems to reduce discomfort in the hip, shoulder (biacromial) and abdomen area of females wearers [224]. Waist and hip girth measurements may be used for a more inclusive seat design (e.g., design of aircraft passenger ‘bucket’ seats). Biacromial breadth (also known as shoulder breadth) data is useful in the design of Army vehicle seats restraints but also important for designing ship manholes (e.g., they must be wide enough to accommodate males with broad shoulders but also females with wider hip regions). It is likely that many of these examples would not have been designed (originally) based on female dimensions [28, 275-277].

Clothing size prediction

Our study was able to use 3D anthropometric data to predict military clothing size and identified key anthropometric characteristics that can be used to develop future clothing sizing systems. Our findings showed that the optimal shirt and trouser sizing model was based on automated measurements. This has significant implications for military garment sizing protocols. If a software system can be developed that integrates these models with the automated measurement output from the scanner, participants can be scanned and have their clothing sizes predicted in real time. We recently piloted this application with promising results (Appendix III; [234]). The use of automated sizing is highly relevant for military recruit sizing activities, where a large volume of recruits can be measured and sized consecutively. Furthermore, the body scanning process requires less staff (one scan operator) while requiring minimal space for setting up the scanner.

While the prediction model for automatic measurements had the highest accuracy, the accuracy level (58–62%) is rather modest. Potential reasons for the modest prediction

accuracy were covered in Chapter 7. A mismatch between the sizing system (e.g., the number of sizes and intervals between each size) and participants anthropometry may have been the contributing factor. This is particularly relevant given the uniform was unisex and we identified important proportional differences between males and females in Chapter 6. The ratings of perceived fit results also illustrated that a higher proportion of females expressed dissatisfaction with their uniform fit. Our final study (Chapter 8) attempted to address some of these issues by exploring how the NZDFAF dataset can be used to create a new gender-specific sizing system that is specific to NZDF anthropometry. Using cluster analysis, we identified a greater number of male shirt and trouser clusters ($n = 10$) than female ($n = 6$). In previous studies [278, 279] clothing size systems have been derived from a similar, or equivalent number of cluster sizes. A gender-specific sizing range does increase the number of clothing items, but if our gender-specific clusters are used as the basis for a sizing range, each are less than the current number of sizes available for shirt and trousers ($n = 12$). The decision whether to adopt unisex or gender-specific uniforms will likely depend on economics considerations (e.g., costs associated with manufacturing unisex or sex-specific variants).

Limitations

In addition to the limitations discussed within each research chapter, there are some overall limitations that should be outlined. Firstly, when analysing the raw survey results, there were several missing values for some measurements (e.g., hip breadth 43%, trochanterion height 49%, and axilla height 46%). Most of the missing values were associated with the post-processing methodology (e.g., the absence of landmarks, incorrect landmarks, measurements obstructed by clothing or limbs, or poor image quality due to incomplete body auto-filling). As post-processing is not conducted in real-time, but in the lab months after the data collection, it is too late to rectify some of these issues. All missing values were estimated using a method of multiple imputation (random forests) with a small error rate (RMSE = 0.03). This method of imputation has been shown to produce less error than traditional methods of imputation, such as Multiple Imputation using Chained Equations [209]. In the future, many of these issues can be resolved through more accurate posturing, developing an intermediary tool that can produce CySize™ images in real-time post-scan (while the participant is still present), and improving quality checking procedures.

Secondly, some of the automatic measurements did not achieve acceptable validation accuracy. Of the 23 measurements validated (to determine whether they should be derived automatically for the survey), 12 passed the validity criteria (where the mean difference between physical and automatic measurements was below 5%). However, 11 measurements were still accepted due to participant measurement time constraints and privacy. For example, head circumference and chest girth were not within the <5% threshold (7.7% and 5.4% mean difference, respectively) but were still added to the automatic protocol to reduce participant burden. Ankle girth was a late addition to the protocol and did not undergo validation. Crotch length was not validated but was included in the automatic measurements as it was deemed too intrusive for physical measurement.

In Chapter 5, we deliberately chose alternative measurements for the cluster analyses despite the presence of 'higher loading' variables from the PCA. Our decision to promote waist girth, body height, and hip girth measurements over other variables with higher loadings (within each component) was unconventional but not uncommon. Previous studies have done the same either because the alternate variable was more practical, or the variable was considered more appropriate for clothing. For example, Zakaria [280] opted to use bust girth to represent the girth factor. Higher loading variables (e.g., upper arm girth) were not considered as they did not vary enough to constitute a stable sizing system [280] that is, small changes in upper arm girth resulted in large changes in size. Hsu and Wang [47] chose waist girth at the expense of hip girth stating that waist girth was important for establishing sizing systems for trousers. In our study, waist girth was used for both male and female shirt clusters, and male trouser clusters. Waist girth not only had a high loading in the PCA, it was also the most important measurement both shirt and trouser size classification (Chapter 7) and proven as key variable in trouser sizing [71, 214-216].

Finally, this research was mainly based on anthropometric data and clothing sizes in the military. The research does not specifically address the significant amount of research conducted in the commercial apparel and apparel research sector over the last 30 years. This includes comparing and evaluating different measurement methods, the development of highly accurate predictive garment fit systems, and the development of body shape-based sizing systems for better fit. Some of this research could have informed aspects of this thesis (e.g., provided an alternative or comparative clothing prediction model against our decision tree study, identified candidate clothing dimensions for modelling).

Future directions

The newly established NZDFAS measurement protocol can be used as the official methodology for future NZDF surveys and other militaries. The protocol can be shortened or adapted as necessary (e.g., capture automatic measurements only). Although this thesis collected 3D anthropometry data, the measurements derived for the NZDFAS (and thus the later chapters in this thesis) were based on lengths, breadths, and girths. One of the major advantages of 3D data is the derivation of shape, area, and volume metrics. Given the raw scan data are saved and available for later use, future work (or surveys) should explore the utility of these shape-specific measurements and their application to the military. Three-dimensional body shape data has been used to design helmets, as traditional head dimensions do not always lead to the best helmet design. Previous studies have shown that participants with the same head circumferences had different head shapes [281].

The aim of this thesis was to explore applications of 3D anthropometry in the military. While clothing was a main theme, there are other areas where 3D technology and data can be useful (as discussed in Chapter 3). These include health and medical research; for example, the data can be used for creating prosthetics [8], detecting scoliosis in peoples back shape (linked to work-related injuries), scanning human feet to detect anomalies [10-12] (which has repercussions for detecting running injuries). The dataset can also be used for future ergonomics applications. As discussed in Chapter 3, the scan images can be imported, via human modelling programs, into virtual environments. The virtual bodies can be manipulated to perform real-world tasks and analysed to assess uncomfortable or awkward postures [282]. While the scope of this thesis did not include the development of a sizing system, we recommend that the NZDF Clothing and Logistics Directorate utilise the cluster information to inform their manufacturing and procurement decisions with regards to military clothing.

Conclusion

The aim of this thesis was to conduct an anthropometric survey in the New Zealand Defence Force (NZDF) and explore potential applications of 3D anthropometric data in a military context. The thesis represents an important milestone for the NZDF. We introduced the first anthropometric survey in the NZDF based on international standards and best practice. The survey was conducted by trained personnel using a measurement protocol that is novel and approved by international experts. With the help of modern statistical techniques, we used the dataset to develop methods that can identify the key differences in male and female anthropometry, predict military clothing sizes, and identify key anthropometric characteristics to inform the development of clothing garments for New Zealand's servicemen and women. The NZDFAS measurement protocol can be used for future military surveys. In addition to clothing applications demonstrated in this thesis, the 3D data can be used for future ergonomics, design, engineering, and health related research that will serve the NZDF well into the future.

References

1. Markiewicz, Ł., et al., *3d Anthropometric Algorithms for the Estimation of Measurements Required for Specialized Garment Design*. Expert Systems with Applications., 2017. **85**: p. 366-385.
2. Tsoli, A., M. Loper, and M.J. Black. *Model-Based Anthropometry: Predicting Measurements from 3D Human Scans in Multiple Poses*. in *IEEE Winter Conference on Applications of Computer Vision*. 2014.
3. Apeagyei, P., *Application of 3D Body Scanning Technology to Human Measurement for Clothing Fit*. International Journal of Digital Content Technology., 2010. **4**(7): p. 58-68.
4. Daniell, N., *Three-Dimensional Scanning in Anthropometry- Bringing New Techniques and Applications to An Old Science.*, in *Health and Use of Time Group, Sansom Institute for Health Research*. 2011, University of South Australia: Adelaide.
5. Heuberger, R., T. Domina, and M. MacGillivray, *Body Scanning as a New Anthropometric Measurement Tool for Health-Risk Assessment*. International Journal of Consumer Studies, 2007. **32**: p. 34-40.
6. Wells, J.C., P. Treleaven, and T.J. Cole, *BMI Compared With 3-Dimensional Body Shape: The Uk National Sizing Survey*. American Journal of Clinical Nutrition, 2007. **85**(2): p. 419-25.
7. Keefe, A., H. Angel, and B. Mangan, *2012 Canadian Forces Anthropometric Survey (CFAS). Scientific Report*. 2012, Defense Research and Development Canada: Toronto, Canada. p. 1-439.
8. DOD-HDBK-743A, *Military Handbook Anthropometry of U.S. Military Personnel*. 1991, U.S. Army Natick: Natick, Massachusetts, U.S.
9. Friedl, K.E., *Body Composition and Military Performance - Many Things to Many People*. Journal of Strength and Conditioning Research, 2012. **26**(SUPPL. 2): p. 87-100.
10. Gordon, C.C., et al., *2012 Anthropometric Survey of U.S. Army Pilot Personnel: Methods and Summary Statistics*. 2016, Army Natick Soldier Research Development and Engineering Center. p. 449.
11. Pringle, R.H., et al., *Anthropometry Survey of UK Military Personnel 2006-7 (Issue 3)*. 2011, QinetiQ Ltd: Swindon, UK.
12. Coleman, J.L. and P. Blanchonette. *Preliminary Comparison of Anthropometric Datasets for the Australian Defence Force*. in *Ergonomics Australia—HFESA 2011 Conference Edition*. 2011.
13. Pourtaghi, G., et al., *Anthropometric Characteristics of Iranian Military Personnel and Their Changes Over Recent Years*. International Journal of Occupational Environmental Medicine., 2014. **5**(3): p. 115 - 124.

14. Da Silva, G.V., M. Halpern, and C.C. Gordon, *Anthropometry of Brazilian Air Force pilots*. Ergonomics., 2017. **60**(10): p. 1445-1457.
15. Varte, L.R., et al., *Personal Protective Ensemble Reference Size Development for Indian Male Defence Personnel Based on 3D Whole Body Anthropometric Scan*. The Journal of the Textile Institute, 2020: p. 1-8.
16. Wibneh, A., A. Singh, and S. Karmakar, *Anthropometric Measurement and Comparative Analysis of Ethiopian Army Personnel Across Age, Ethnicity, and Nationality*. Defence Science Journal, 2020. **70**: p. 383-396.
17. NZDF Statement of Intent, *2018-19-2021/22 Statement of Intent*. 2018, New Zealand Defence Force: Wellington, New Zealand.
18. NZDF Personal Summary Online. *Personnel summary* (<http://www.nzdf.mil.nz/personnel-records/personnel-branch/default.htm>). 2019; Available from: <http://www.nzdf.mil.nz/personnel-records/personnel-branch/default.htm>.
19. Toulson, P.K., *Report on the Anthropometric Survey of RNZAF Aircrew*, Royal New Zealand Air Force. 1973, Royal New Zealand Air Force.: Auckland.
20. Baxter, M.L. and D.G. Baxter, *Anthropometric Characteristics of Feet of Soldiers in the New Zealand Army*. Military Medicine, 2011. **176**: p. 438 - 445.
21. Iremonger, G. and B. Dobson, *Cockpit Accommodation in the C-130 LEP*. 2011, Aviation Medicine Unit, Royal New Zealand Air Force: Auckland, New Zealand.
22. Slappendel, C. and B.D. Wilson, *Anthropometric Estimates for New Zealand Adults*. Ergonomics NZ, 1992. **7**(3): p. 5-7.
23. Pheasant, S., *Bodyspace: Anthropometry, Ergonomics and Design*. 1986, London, UK: Taylor & Francis.
24. Legg, S., *New Zealand Army Anthropometry Project Pre-scoping Report. A pre-scoping report for the Human Systems Group of the New Zealand Defence Technology Agency*. 2008, Massey University: Palmerston North, New Zealand.
25. NATO HFM-266, *3D Scanning for Clothing Fit and Logistics. Findings of Task Group HFM-266*. 2017, North Atlantic Treat Organization.
26. Berkowitz, S.M., et al., *Occupational Back Disability in U.S. Army Personnel*. Military Medicine., 1999. **164**(6): p. 412-418.
27. Smit, N., *Ease Allowance and Fit of Selected Female Military Upper Garments*, in *Visual Arts and Design*. 2007, Vaal University of Technology: South Africa.
28. Todd, W.L., *Chapter 10: Sizing for the Military*, in *Sizing in Clothing. Developing Effective Sizing Systems for Ready-to-Wear Clothing*, S.P. Ashdown, Editor. 2007, Woodhead Publishing Limited: Cambridge.
29. Alexander, M., L. Jo Connell, and A. Beth Presley, *Clothing Fit Preferences of Young Female Adult Consumers*. International Journal of Clothing Science and Technology, 2005. **17**(1): p. 52-64.

30. Bougourd, J.P., et al., *A Comparison of Women's Sizing by 3D Electronic Scanning and Traditional Anthropometry*. The Journal of The Textile Institute, 2000. **91**(2): p. 163-173.
31. Fullenkamp, A.M., K.M. Robinette, and H.A.M. Daanen, *Gender Differences in NATO Anthropometry and the Implication for Protective Equipment*. 2008, Air Force Research Laboratory Human Effectiveness Directorate Biosciences and Protection Division.: Dayton, Ohio, U.S.
32. Ahmed, A.A. and N. Omer, *Estimation of Sex From the Anthropometric Ear Measurements of a Sudanese Population*. Legal Medicine, 2015. **17**(5): p. 313-319.
33. Aliyu, J., et al., *Sexual Dimorphism and Estimation of Height From Body Length Anthropometric Parameters Among the Hausa Ethnic Group of Nigeria*. Arab Journal of Forensic Sciences & Forensic Medicine (AJFSFM). 2017. **1**(6): p. 612-624.
34. Anuthama, K., et al., *Determining Dental Sex Dimorphism in South Indians Using Discriminant Function Analysis*. Canadian Journal of Dietetic Practice and Research, 2011. **212**(1-3): p. 86-9.
35. Brzobohatá, H., et al., *Sexual Dimorphism of the Human Tibia Through Time: Insights Into Shape Variation Using A Surface-Based Approach*. PloS one, 2016. **11**(11): p. 1-21.
36. Hall, R.L., *Sexual Dimorphism in Homo Sapiens: A Question Of Size*. 1982, New York, U.S.: Praeger Publishers.
37. Hemy, N., et al., *Sex Estimation Using Anthropometry of Feet And Footprints in a Western Australian Population*. Forensic Science International, 2013. **231**(1): p. 1-3.
38. Keogh, J.W.L., et al., *To What Extent Does Sexual Dimorphism Exist in Competitive Powerlifters?* Journal of Sports Sciences,, 2008. **26**(5): p. 1841-50.
39. Varley-Campbell, J., et al., *Sex-Specific Changes in Physical Performance Following Military Training: A Systematic Review*. Sports Medicine (Auckland, N.Z.), 2018. **48**(11): p. 2623-2640.
40. Wang, S., et al., *Gender Differences in Hip Anatomy: Possible Implications for Injury Tolerance in Frontal Collisions*. Annual Proceedings. Association for the Advancement of Automotive Medicine, 2004. **48**: p. 287-301.
41. Wells, J.C.K., *Sexual dimorphism of body composition*. Best Practice & Research Clinical Endocrinology & Metabolism,, 2007. **21**(3): p. 415-430.
42. Zheng, W.X., et al., *Sex assessment using measurements of the first lumbar vertebra*. Forensic Science International, 2012. **219**(1-3): p. 285.e1-285.e5.
43. Gordon, C.C., et al., *2012 Anthropometric Survey of U.S. Army Personnel: Methods and Summary Statistics*. 2014, Natick Soldier Research, Development of Engineering Center: Yellow Springs, Ohio, US.

44. Blackwell, S., et al. *Civilian American and European Surface Anthropometry Resource (CAESAR). Final Report, Volume II: Descriptions*. 2002. Dayton, US.
45. Esfandarani, M.S. and J. Shahrabi, *Developing a New Suit Sizing System Using Data Optimization Techniques*. International Journal of Clothing Science and Technology., 2012.
46. Laing, R.M., et al., *Development of Sizing Systems for Protective Clothing for the Adult Male*. Ergonomics, 1999. **42**(10): p. 1249-1257.
47. Hsu, C.H. and M.J.J. Wang, *Using Decision Tree-Based Data Mining to Establish A Sizing System for the Manufacture of Garments*. The International Journal of Advanced Manufacturing Technology, 2005. **26**(5): p. 669-674.
48. Bagherzadeh, R., M. Latifi, and A. Faramarzi, *Employing a Three-Stage Data Mining Procedure to Develop Sizing System*. World Applied Sciences Journal., 2010. **8**(8): p. 923-929.
49. Stewart, A.D. and P.A. Hume *Bideloid Breadth Measurement*. J.E. Lindsay Carter Kinanthropometry Archive 3D Scanning Protocols, 2014. 2.
50. Gupta, G., *New Directions in the Field 1 of Anthropometry, Sizing and Clothing Fit.*, in *Anthropometry, Apparel Sizing and Design.*, N. Zakaria and G. Gupta, Editors. 2020, Elsevier: India.
51. Roebuck, J.A., *Anthropometric Methods: Designing to Fit the Human Body*. 1995: Human Factors and Ergonomics Society. null.
52. Stewart, A., *Kinanthropometry and Body Composition: A Natural Home for Three-Dimensional Photonic Scanning*. Journal of Sports Sciences, 2010. **28**: p. 455-7.
53. Pheasant, S. and C. Haslegrave, *Bodyspace: Anthropometry, Ergonomics and the Design of Work. Third Edition*. 2006, London, UK: Taylor & Francis null.
54. Norton, K., *Standards for Anthropometry Assessment.*, in *Kinanthropometry and Exercise Physiology: Volume One Anthropometry*. 2018. p. 68-137.
55. Hume, P.A., D.A. Kerr, and T.R. Ackland, *Best Practice Protocols For Physique Assessment In Sport*. 2018, Auckland: Springer.
56. Veitch, D., V. Blewett, and D. Caple. *Sizing Up Australia: What Use Have Designers Made of Anthropometric Data?* in *17th World Congress on Ergonomics: International Ergonomics Association*. 2009.
57. Mellow, P., et al., *Digital Photogrammetry Versus ISAK Anthropometry in Determining Body Segment Lengths of Powerlifters*. Medicine & Science in Sports & Exercise., 2003. **6**(4): p. 25-27.
58. Shu, C., P. Xi, and A. Keefe, *Data Processing and Analysis for the 2012 Canadian Forces 3D Anthropometric Survey*. Procedia Manufacturing, 2015. **3**: p. 3745-3752.

59. International Society for the Advancement of Kinanthropometry, *International Standards For Anthropometric Assessment*. 2001, South Australia, Australia: International Society for the Advancement of Kinanthropometry.
60. Robinette, K.M. and H.A.M. Daanen, *Lessons Learnt from CAESER: A 3-D anthropometric Survey*. 2003, Air Force Research Laboratory: Wright-Patterson Air Force Base, Ohio, U.S.
61. Centers for Disease Control Prevention, *National Health and Nutrition Examination Survey (NHANES): Anthropometry Procedures Manual*, in *Centers for Disease Control and Prevention*. 2007.
62. ISO, *Basic Human Body Measurements for Technological Design: Part 2: Statistical summaries of body measurements from national populations*. 2010.
63. Gordon, C.C., et al., *2010 Anthropometric Survey of U.S. Marine Corps Personnel: Methods and Summary Statistics*. 2013, Army Natick Soldier Research Development and Engineering Center: Yellow Springs, Ohio, U.S.
64. Viviani, C., et al., *Accuracy, Precision and Reliability in Anthropometric Surveys for Ergonomics Purposes in Adult Working Populations: A Literature Review*. *International Journal of Industrial Ergonomics*, 2018. **65**: p. 1-16.
65. Kupke, T. and T. Olds, *Chapter 15: Towards a Generalised Anthropometric Language.*, in *Kinanthropometry X: Proceedings of the 10th International Society for the Advancement of Kinanthropometry Conference, Held in Conjunction With The 13th Commonwealth International Sport Conference*, M. Marfell-Jones and T. Olds, Editors. 2007, Routledge: US and Canada.
66. Stewart, A. and T. Ackland, *Anthropometry in Physical Performance and Health. Body Composition: Health and Performance in Exercise and Sport.*, 2017: p. 89-108.
67. Marfell-Jones, M., A.D. Stewart, and T. Olds, *International Standards for Anthropometric Assessment.*, in *International Standards for Anthropometric Assessment*. 2001, International Society for the Advancement of Kinanthropometry.
68. Robinette, K.M., et al., *Anthropometry Resource (CAESAR) Final Report, Volume I: Summary*. 2002: Dayton, OH, US.
69. Harrison, C.R. and D.B. Burnside, *A Method of Comparing 3-D Image Consistency and Quality Between Commercially Available 3-D Scanners*, in *SAE Technical Paper 2003-01-2177*. 2003, SAE International: Wright-Patterson Air Force Base, . p. 9.
70. Veitch, D. and K.M. Robinette. *World Engineering Anthropometry Resource WEAR: A Review*. in *Human Factors and Ergonomics Society of Australia Inc. Annual Conference*. 2006.
71. Zakaria, N. and W. Ruznan, *4 - Developing apparel sizing system using anthropometric data: Body size and shape analysis, key dimensions, and data segmentation*, in *Anthropometry, Apparel Sizing and Design (Second Edition)*, N. Zakaria and D. Gupta, Editors. 2020, Woodhead Publishing. p. 91-121.

72. Bravo, G., et al., *A Literature Review of Anthropometric Studies of School Students For Ergonomics Purposes: Are Accuracy, Precision and Reliability Being Considered?* Work, 2018. **60**(1): p. 3-17.
73. Bullas, A.M., *The Importance of Complex Anthropometrics in the Assessment of Cyclists*. 2017, Sheffield Hallam University: Sheffield, UK.
74. Simmons, K.P., *Body Measurement Techniques: A Comparison of Three-Dimensional Body Scanning and Physical Anthropometric Methods.*, in *TTM Graduate Faculty, College of Textiles*. 2001, North Carolina State University: Raleigh, North Carolina.
75. Sicotte, M., et al., *Reliability of Anthropometric Measures in A Longitudinal Cohort of Patients Initiating Art in West Africa*. BMC Medical Research Methodology., 2010. **10**(1): p. 102.
76. Atkinson, G., et al., *Distribution of Power Output During Cycling*. Sports Medicine, 2007. **37**(8): p. 647-667.
77. Fairclough, J.A., et al., *Abdominal Girth: An Unreliable Measure of Intra-Abdominal Bleeding*. Injury, 1984. **16**(2): p. 85-87.
78. Maylia, E., et al., *Can Thigh Girth be Measured Accurately? A Preliminary Investigation*. Journal of Sport Rehabilitation, 1999. **8**: p. 43-49.
79. Katch, F.I. and V.L. Katch, *Measurement and Prediction Errors in Body Composition Assessment And The Search for the Perfect Prediction Equation*. Research Quarterly for Exercise and Sport, 1980. **51**(1): p. 249-260.
80. Lohman, T., A. Roche, and R. Martorell, *Anthropometric Standardization Reference Manual*. 1988, Champaign: Human Kinetics Books.
81. Simenko, J. and I. Cuk, *Reliability and Validity of NX-16 3D Body Scanner*. International journal of Morphology, 2016. **34**(4).
82. Olds, T., *The Rise and Fall of Anthropometry*. Journal of Sport Sciences, 2004. **22**(4): p. 319-20.
83. DuBois, D.F., *A Formula to Estimate the Approximate Surface Area if Height and Body Mass Be Known*. Arch intern med, 1916. **17**: p. 863-871.
84. Ashdown, S.P., *Full body 3-D Scanners*, in *Anthropometry, Apparel Sizing and Design*. 2020, Elsevier. p. 145-168.
85. Olds, T., P. Blanchonette, and D. Stratton, *Fitting the man to the machine: the ADAPT project*. Australian Defence Force Journal, 2007(172): p. 95.
86. Daanen, H.A. and G.J. Van de Water, *Whole Body Scanners*. Displays, 1998. **19**(1998): p. 111-120.
87. Ng, R., S. Ashdown, and A. Chan. *Intelligent size table generation*. in *Proceedings of the Asian Textile Conference (ATC), 9th Asian Textile Conference, Taiwan*. 2007.

88. Seidl, A., et al. *SizeNorthAmerica—The New North American Anthropometric Survey: Conceptual Design, Implementation and Results*. 2016. Cham: Springer International Publishing.
89. Charoensiriwath, S. and C. Tanprasert. *An Overview of 3D Body Scanning Applications in Thailand*. in *Proceedings of the International Conference on 3D Body Scanning Technologies*. 2010.
90. Kulkarni, D., et al., *Size India - Anthropometric Size Measurement of Indian Driving Population*. 2011, SAE Technical Paper.
91. Alemany, S., et al. *Anthropometric Survey of the Spanish Female Population Aimed at the Apparel Industry*. in *Proceedings of the 2010 International Conference on 3D Body Scanning Technologies*. Lugano, Switzerland. 2010.
92. Cools, J., A. De Raeve, and H. Bossaer, *The Use of 3D Anthropometric Data for Morphotype Analysis to Improve Fit and Grading Techniques*. 5th IntConf on 3D Body Scanning Technologies, Hometrica Consulting, Lugano, Switzerland, 2014.
93. Istook, C.L. and S.J. Hwang, *3d Body Scanning Systems With Application to the Apparel Industry*. *Journal of Fashion Marketing and Management: An International Journal*, 2001. **5**(2): p. 120-132.
94. Olaru, S., C. Niculescu, and M. Teodorescu, *Shape Categories for the Romanian Female Population and Specific Clothing Recommendations*. De Redacție, 2011: p. 154.
95. Bastos, S.F., et al. *SizeBR - The Brazilian Study on Anthropometric*. 2013.
96. Stampfli, P., et al., *SizeITALY-The Actual Italian Measurement Survey*. 3D Body Scanning Technologies, Lugano, Switzerland, 2012: p. 261-268.
97. Ramôa, A.F., et al., *The Anthropometric Study of the Portuguese Population Using 3D Body Scanning Technology—Its Contribution to the Improvement of Size Tables*.
98. Zhao, C., et al. *Anthropometric Survey of Chinese Adult Population*. in *Congress of the International Ergonomics Association*. 2018. Springer.
99. Scataglini, S. and G. Paul, *DHM and Posturography*. 2019: Academic Press.
100. Njoku, C.O., et al., *Non-imaging Method: 3D Scanning*, in *Best Practice Protocols for Physique Assessment in Sport*, P.A. Hume, D.A. Kerr, and T.R. Ackland, Editors. 2018, Springer Singapore. p. 71-85.
101. Marfell-Jones, M., A. Stewart, and T. Olds, *Kinanthropometry IX: Proceedings of the 9th International Conference of the International Society for the Advancement of Kinanthropometry*. 2006: Taylor & Francis.
102. Kumar, L., et al., *Rapid Manufacturing: Classification and Recent Development*. *International Journal of Advanced Engineering Research and Science*., 2017. **4**(3): p. 29-40.

103. Straub, J. and S. Kerlin, *Development of a Large, Low-Cost, Instant 3D Scanner*. Technologies, 2014. **2**(2): p. 76-95.
104. Ares, M., et al. *3D Scanning System for In-Vivo Imaging of Human Body*. in *Fringe 2013 - 7th International Workshop on Advanced Optical Imaging and Metrology*. 2014.
105. Schievano, S., et al., *Reconstruction of Fetal and Infant Anatomy Using Rapid Prototyping of Post-Mortem Mr Images*. Insights Into Imaging, 2010. **1**(4): p. 281-286.
106. Haleem, A. and M. Javaid, *3D Scanning Applications in the Medical Field: A Literature-Based Review*. Clinical Epidemiology and Global Health, 2019. **7**(2): p. 199-210.
107. Daniell, N., T. Olds, and G.R. Tomkinson, *Technical Note: Criterion Validity of Whole Body Surface Area Equations: A Comparison Using 3D Laser Scanning*. American Journal of Physical Anthropology, 2012. **148**(1): p. 148-55.
108. Kuehnappel, A., et al., *Body Surface Assessment With 3D Laser-Based Anthropometry: Reliability, Validation, and Improvement of Empirical Surface Formulae*. European Journal of Applied Physiology, 2017. **117**(2): p. 371-380.
109. Felici, A., J. Verweij, and A. Sparreboom, *Dosing Strategies for Anticancer Drugs: The Good, The Bad and Body-Surface Area*. European Journal of Cancer, 2002. **38**(13): p. 1677-1684.
110. Jones, M.L.H., et al., *Development of a Three-Dimensional Body Shape Model of Young Children for Child Restraint Design*. Computer Methods in Biomechanics and Biomedical Engineering., 2018. **21**(15): p. 784-794.
111. Glock, F., et al., *Validity and Intraobserver Reliability of Three-Dimensional Scanning Compared with Conventional Anthropometry for Children and Adolescents from a Population-Based Cohort Study*. Pediatric Research, 2017. **81**(5): p. 736-744.
112. Ma, L., et al., *Integrating Digital Human Modeling Into Virtual Environment for Ergonomic Oriented Design*, in *ASME 2010 World Conference on Innovative Virtual Reality, WINVR 2010*. 2010. p. 203-210.
113. Hemaraju, S., K. Yermal, and A. Ms, *Ergonomic Evaluation through Digital Human Modelling: A Review*. 2019.
114. Schranz, N., et al., *Three-Dimensional Anthropometric Analysis: Differences Between Elite Australian Rowers and the General Population*. Journal of Sports Sciences, 2010. **28**(5): p. 459-469.
115. <Schutz Cardello and Winterhalter 2005 Perceptions of fiber ad fabric uses and the factors contributing to military clothing comfort and satisfaction.pdf>.
116. Schueler, A., I. Fichtner, and O. Ueberschär, *Using the 3D Body Scanner in Elite Sports*. 2018. 216-221.

117. Gorea, A. and F. Baytar, *Using 3D Body Scanning to Measure Compression Variations in a Seamless Knitted Sports Bra*. International Journal of Fashion Design, Technology and Education, 2020. **13**(2): p. 111-119.
118. Petrak, S., M.M. Naglić, and J. Geršak, *Sizing and Fit for Swimsuits and Diving Suits*, in *Anthropometry, Apparel Sizing and Design.*, N. Zakaria and D. Gupta, Editors. 2020, Elsevier: India. p. 255-287.
119. Wannop, J.W., et al., *Development of a Footwear Sizing System in the National Football League*. Sports Health, 2019. **11**(1): p. 40-46.
120. Friel, K., et al., *The Use of 3D Scanning for Sporting Applications*. International Society for Optics and Photonics,, 2015. **9495**: p. 949517-949517-8.
121. Garimella, R., et al., *Estimating Cycling Aerodynamic Performance Using Anthropometric Measures*. Applied Sciences, 2020. **10**(23): p. 8635.
122. Medina-Inojosa, J., et al., *Reliability of a 3D Body Scanner for Anthropometric Measurements of Central Obesity*. Obesity, 2016. **2**(3).
123. Derouchey, J.D., *Reliability of the Styku 3d Whole Body Scanner for the Assessment Of Body Size in College Athletes*. 2018, University of North Dakota: North Dakota, US.
124. Derouchey, J.D., et al., *Reliability of the Styku 3D Whole-Body Scanner for the Assessment of Body Size in Athletes*. Measurement in Physical Education and Exercise Science, 2020. **24**(3): p. 228-234.
125. Treleaven, P. and J. Wells, *3D Body Scanning and Healthcare Applications*. Computer, 2007. **40**: p. 28-34.
126. Robinette, K.M. and H.A.M. Daanen, *Precision of the Caesar Scan-Extracted Measurements*. Applied Ergonomics,, 2006. **37**(3): p. 259-265.
127. Braganca, S., P. Arezes, and M. Carvalho, *An Overview of the Current Three-Dimensional Body Scanners for Anthropometric Data Collection.*, in *Occupational Safety and Hygiene III*. 2015, CRC Press.
128. Daanen, H. and T. Haar, *3D Whole Body Scanners Revisited*. Displays, 2013. **34**(4): p. 270-275.
129. D'Apuzzo, N., *Recent Advances in 3D Full Body Scanning with Applications to Fashion and Apparel*, in *Optical 3-D Measurement Techniques IX*, A. Gruen and H. Kahmen, Editors. 2009: Vienna, Austria.
130. van der Mark, W., et al. *3-D Scene Reconstruction with a Handheld Stereo Camera*. in *Proceedings Cognitive Systems with Interactive Sensors*. 2007. Stanford, US.
131. Silver, B. and P.B. Wilson, *Reliability and Minimal Detectable Change of the Styku 3D Body Scanner*. Measurement in Physical Education and Exercise Science, 2020. **24**(3): p. 165-171.

132. Paquette, S., *3D scanning in apparel design and human engineering*. IEEE Computer Graphics and Applications, 1996. **16**(5): p. 11-15.
133. Buxton, B.F., et al., *Reconstruction and Interpretation of 3D Whole Body Surface Images*. 2000, Department of Computer Science University College London.
134. Wang, J., et al., *Validation of a 3-Dimensional Photonic Scanner for the Measurement of Body Volumes, Dimensions, and Percentage Body Fat*. American Journal of Clinical Nutrition, 2006. **83**(4): p. 809-816.
135. Jaeschke, L., A. Steinbrecher, and T. Pischon, *Measurement of Waist and Hip Circumference with a Body Surface Scanner: Feasibility, Validity, Reliability, and Correlations with Markers of the Metabolic Syndrome*. PLoS One, 2015. **10**(3): p. e0119430.
136. Choi, K. and S.P. Ashdown, *3D Body Scan Analysis of Dimensional Change in Lower Body Measurements for Active Body Positions*. Textile Research Journal, 2011. **81**(1): p. 81-93.
137. Zhang, K., et al., *Rapid-Accurate Anthropometric Body Shape Assessment With Low-Cost Novel 3d Imaging System*. The FASEB Journal, 2014. **28**(Supplement).
138. Wells, J., et al., *Acceptability, Precision and Accuracy of 3D Photonic Scanning for Measurement of Body Shape in a Multi-Ethnic Sample of Children Aged 5-11 Years: the SLIC study*. PloS one, 2015. **10**(4): p. 1-15.
139. Kuehnappel, A., et al., *Reliability of 3D Laser-Based Anthropometry and Comparison with Classical Anthropometry*. Scientific Reports., 2016. **6**(1): p. 1-11.
140. Lu, J.M., M.J. Wang, and R. Mollard, *The Effect of Arm Posture on the Scan-Derived Measurements*. Applied Ergonomics, 2010. **41**(2): p. 236-241.
141. Lu, J. and M.J.J. Wang, *The Evaluation of Scan-Derived Anthropometric Measurements*. IEEE Transactions on Instrumentation and Measurement, 2010. **59**(8): p. 2048-2054.
142. Beazley, A. and T. Bond, *Computer-aided Pattern Design and Product Development*. 2009: Wiley.com.
143. Suikerbuik, R., et al., *Automatic Feature Detection in 3D Human Body Scans*. 2004, SAE International.
144. Ulijaszek and C.G.N. Mascie-Taylor, *Anthropometry the individual and the population*. 1994: Cambridge University Press.
145. Tomkinson, G.R., et al., *Time Changes in the Body Dimensions of Male Australian Army Personnel Between 1977 and 2012*. Applied Ergonomics, 2017. **58**: p. 18-24.
146. Ulijaszek, S.J. and C.G.N. Mascie-Taylor, *Anthropometry: The Individual and the Population*. 2005, Cambridge, UK: Cambridge University Press.

147. Friedl, K.E., *Body Composition and Military Performance: Origins of Army Standards*, in *Body Composition and Military Performance*. 1992, National Academy of Sciences.: Washington.
148. Gould, B.A., *Investigations in the Military and Anthropological Statistics of American Soldiers: By Benjamin Apthorp Gould*. 1869: Hurd and Houghton.
149. Baxter, J.H., *Statistics, Medical and Anthropological, of the Provost-marshal-general's Bureau, Derived from Records of the Examination for Military Service in the Armies of the United States During the Late War of the Rebellion*. Vol. 1. 1875: US Government Printing Office.
150. Davenport, C.B. and A.G. Love, *Army Anthropology: Based on Observations Made on Draft Recruits, 1917-1918, and on Veterans at Demobilization, 1919*. Vol. 15. 1921: US Government Printing Office.
151. Newman, R.W., *The Assessment of Military Personnel by 1912 Height-Weight Standards*. 1952: Quartermaster Climactic Research Laboratory, Department of the Army, Office.
152. Randall, F.E. and E.H. Munro, *Reference Anthropometry of Army Women*. 1949, Department of the Army, Office of the Quartermaster General, Military.: Lawrence, Massachusetts, US.
153. Hertzberg, H., *Anthropometric Survey of Turkey, Greece and Italy*. 1963: Macmillan.
154. Gifford, E.C., J.R. Provost, and J. Lazo, *Anthropometry of Naval Aviators 1964*. 1965, Naval Air Engineering Center Lakehurst Nj Aerospace Crew Equipment Lab: Naval Air Engineering Center.
155. White, R.M. and E. Churchill, *The Body Size of Soldiers: US Army Anthropometry-1966*. 1971, Army Natick Labs Ma Clothing And Personal Life Support Equipment Lab.
156. Grunhofer, H.J. and G. Kroh, *A Review of Anthropometric Data of German Air Force and United States Air Force Flying Personnel 1967-1968*. 1975, North Atlantic Treaty Organization Advisory Group For Aerospace Research And Development. p. 1-180.
157. Clauser, C.E., *Anthropometry of Air Force Women*. Vol. 70. 1972: Aerospace Medical Research Laboratory, Aerospace Medical Division.
158. Churchill, E., et al., *Anthropometry of US Army Aviators-1970*. 1971, Anthropology Research Project Incorporated.: Yellow Springs Ohio, US.
159. Churchill, E., et al., *Anthropometry of Women of the US Army--1977. Report Number 2. The Basic Univariate Statistics*. 1977, Webb Associates Yellow Springs US.
160. Gordon, C., et al., *Anthropometric Survey of U.S. Army Personnel: Summary Statistics, Interim Report for 1988*. 1989.

161. Furnell, A. and J. Coleman. *Trends in Military Anthropometry*. in *Proceedings 19th Triennial Congress of the IEA*. 2015. Melbourne, Australia: Land Division, Defence Science and Technology Organisation.
162. Cole, T.J., *The Secular Trend In Human Physical Growth: A Biological View*. Economics & Human Biology, 2003. **1**(2): p. 161-168.
163. Baten, J. and M. Blum, *Growing Tall But Unequal: New Findings and New Background Evidence on Anthropometric Welfare in 156 Countries, 1810–1989*. Economic History of Developing Regions, 2012. **27**(sup1): p. S66-S85.
164. Iqbal, M., et al., *Body Segment Dimensions of Indonesian Male Army*. IOP Conference Series: Materials Science and Engineering, 2020. **931**: p. 012013.
165. Tomkinson, G.R., A.J. Clark, and P. Blanchonette, *Secular Changes in Body Dimensions of Royal Australian Air Force Aircrew (1971-2005)*. *Ergonomics*, 2010. **53**(8): p. 994-1005.
166. Tomkinson, G.R., et al., *Australian Warfighter Anthropometry Survey (AWAS). Methods, Temporal Changes and Summary Statistics.*, S.I.f.H.R. Health and Use of Time Group, Editor. 2012, University of South Australia: Adelaide, Australia.
167. Blanchonette, P. and A. Smith, *Comparison of the Size of the ADF Aircrew and US Army Personnel*. 2013, Defence Science And Technology Organisation: Fishermans Bend (Australia) p. 12.
168. Blachonette, P., *Australian Defence Force Anthropometry; A Summary of Historic Surveys* 2017, Defence Science and Technology Group.: Melbourne, Australia.
169. Olds, T., et al., *ADAPT Procedures Manual*. 2004, University of South Australia: Adelaide.
170. Allen, R., *Review of Scanning Technologies*. 2003, Unreferenced Shape Analysis Customer
171. ISO, *Garment Construction and Anthropometric Surveys*. 1989, International Organization for Standardization
172. McDowell, M.A., et al., *Anthropometric Reference Data for Children and Adults: United States, 2003–2006*. National Health Statistics Reports, 2008(10): p. 1-48.
173. Kennedy, S.J., R.M. White, and W. Hendrix, *Anthropometric Survey of the Imperial Iranian Armed Forces. Phase III. Technical Summary*. 1971, Ft. Belvoir: Army Natick Labs, M. A.. Defense Technical Information Center.
174. Furnell, A., et al., *Sizing Up the ADF: The Australian Warfighter Anthropometry Survey*. 2014.
175. Hendy, K.C., *Australian Tri-Service Anthropometric Survey, 1977. Part 1. Survey Planning, Conduct, Data Handling and Methods of Analysis*. 1979, Aeronautical Research Labs Melbourne, Australia.

176. Tomkinson, G.R., et al., *Validation Trial Report*. 2013, Health and Use of Time Group, School of Health Sciences, University of South Australia: Adelaide, Australia.
177. Hotzman, J.L., et al. *Measurer's Handbook: US Army and Marine Corps Anthropometric Surveys, 2010-2011*. 2011.
178. Furnell, A., et al. *Scoping Analyses for the Anthropometric Survey of the Royal Australian Navy (ASRAN)*. in *Proceedings 19th Triennial Congress of the IEA*. 2015.
179. Ponton, K., et al., *Revised Anthropometry Guidance for the Royal Australian Navy*, M. Division., Editor. 2019, Maritime Division. Defence Science and Technology Group.
180. Ponton, K., et al., *Sizing up Royal Australian Navy Sailors*. 2016, Maritime Division, Defence Science Technology Group, Australia Defence Force: Melbourne, Australia.
181. ISO, *ISO 15535:2006: General Requirements for Establishing Anthropometric Databases*. 2006.
182. International Standards Organisation, *Size Designation of Clothes — Men's and Boys' Outerwear Garments*. 1977, International Organization for Standardization: Geneva, Switzerland.
183. Statistics New Zealand, *2013 Census Quickstats About Culture and Identity*. 2014, Statistics New Zealand: Wellington, New Zealand.
184. International Standardization Organization, *General Requirements for Establishing Anthropometric Databases*. 2012, International Standards Organization (ISO): Geneva, Switzerland.
185. DEF STAN 00-250, *Human Factors for Designers of Systems*. 2008, UK Defence Standardization.
186. International Organization for Standardization, *ISO 7250-1-2008. Basic Human Body Measurements for Technological Design*. 2008, International Organization for Standardization: Geneva.
187. International Organization for Standardization, *Basic Human Body Measurements for Technological Design: Body Measurement Definitions and Landmarks*. 2008: International Organization for Standardization.
188. Human Solutions Group, *Anthroscan: Definition of Body Measurements*. 2013, Human Solutions Group.: Kaiserslautern, Germany.
189. JIS-Z 8500, *Ergonomics - Basic Human Body Measurements for Technological Design*. 2002, Japanese Standards Association: Tokyo, Japan.
190. Tomkinson, G.R., et al., *Australian Warfighter Anthropometry Survey (AWAS): Landmarking and Measurement Manual*. 2012, Health and Use of Time Group, Sansom Institute for Health Research, University of South Australia: Adelaide, Australia.

191. Stewart, A.D., et al., *International standards for anthropometric assessment*. 2011, Lower Hutt, New Zealand: ISAK. 125.
192. Human Solutions Group, *Anthroscan User Guide Version 3*. 2015, Human Solutions GmbH: Kaiserslautern, Germany. p. 1-329.
193. Tomkinson, G.R., et al., *Australian Warfighters Anthropometry Survey (AWAS). Procedures Manual*. 2012, Health and Use of Time Group, Sansom Institute for Health Research, University of South Australia.: Adelaide, Australia.
194. Hanson, L., et al., *Swedish Anthropometrics For Product and Workplace Design*. Applied Ergonomics, 2009. **40**(4): p. 797-806.
195. Carter, J.E.L. and T.R. Ackland, *Kinanthropometry in Aquatic Sport: A Study Of World Class Athletes*. HK Sport Science Monograph Series Volume 5. 1994, Leeds, United Kingdom.: Human Kinetics.
196. Fessler, D.M.T., K.J. Haley, and R.D. Lal, *Sexual dimorphism in foot length proportionate to stature*. Annals of Human Biology, 2005. **32**(1): p. 44-59.
197. Coetzee, B., *Proportionality and Sexual Dimorphism in Elite South African Crawl Stroke Swimmers*, in *Kinanthropometry X*, M.J. Marfell-Jones and T. Olds, Editors. 2007, Routledge: London. p. 243-262.
198. Schranz, N., et al., *Is Three-Dimensional Anthropometric Analysis as Good As Traditional Anthropometric Analysis In Predicting Junior Rowing Performance?* Journal of Sports Sciences, 2012. **30**(12): p. 1241-8.
199. Barkla, D., *The Estimation of Body Measurements of British Population in Relation to Seat Design*. Ergonomics, 1961. **4**(2): p. 123-132.
200. Ross, W.D. and N.C. Wilson, *A Stratagem for Proportional Growth Assessment*. Acta Paediatrica Belgica., 1974. **28**: p. 169–182.
201. Ross, W.D. and R. Ward, *Human Proportionality and Sexual Dimorphism.*, in *Sexual Dimorphism in Homo Sapiens: A Question Of Size.*, R.L. Hall, Editor. 1982, Praeger: New York.
202. Ross, W.D., et al., *Proportionality and Body Composition in Male and Female Olympic Athletes: A Kinanthropometric Overview*, in *The Female Athlete*. 1981, Karger Publishers. p. 74-85.
203. Ross, W.D., et al., *On Human and Animal Geometry*, in *Proceedings of the VII Commonwealth and International Conference On Sport, Physical Education, Recreation and Dance*, M.L. Howell and B.O. Wilson, Editors. 1982, University of Queensland: Brisbane. p. 77 - 97.
204. Schafer, E. and B.T. Bates, *Anthropometric Comparisons Between Body Measurements of Men and Women*. 1988, Bio-Dynamics Research and Development Corp Eugene, OR ,US.
205. Chan, A.C.K., *7. Anthropometry and the Design and Production of Apparel: An Overview.*, in *Anthropometry, Apparel Sizing and Design.*, D. Gupta and N. Zakaria, Editors. 2014, Woodhead Publishing Limited: Cambridge, UK.

206. NZDF, *Women in the NZDF*. 2019, New Zealand Defence Force: Wellington.
207. Kolose, S., et al., *Three-Dimensional Physique Assessment in the Military: New Zealand Defence Force Anthropometry Survey Protocols and Summary Statistics*. 2021, SPRINZ, Auckland University of Technology: Auckland, New Zealand.
208. Furnell, A., J. Coleman, and S. Davis, *Preliminary Results From the Land 500 Australian Warfighter Anthropometry Survey*. 2012, Human Protection and Performance Division, Defence Science and Technology Organisation: Melbourne, Australia.
209. Stekhoven, D.J. and P. Bühlmann, *Missforest—Non-Parametric Missing Value Imputation for Mixed-Type Data*. *Bioinformatics*, 2011. **28**(1): p. 112-118.
210. Keogh, J.W.L., et al., *Anthropometric Dimensions of Male Powerlifters of Varying Body Mass*. *Journal of Sports Sciences*, 2007. **25**(12): p. 1365-1376.
211. Singh, S.P. and P. Mehta, *Human Body Measurements: Concepts and Applications*. 2010, New Delhi, India.: PHI Learning Private Limited.
212. Cohen, J., *Statistical Power Analysis for the Behavioral Sciences*. 2nd ed. 1988: Academic Press.
213. Cheng, H., D. Bruening, and D. Lochtefeld, *Gender and Ethnicity Classification From Small Subsets of Human Body Measurements*. 2014, Air Force Research Laboratory Dayton, OH, US.
214. Traumann, A., et al., *Analysis of 3-D Body Measurements to Determine Trousers Sizes of Military Combat Clothing*. *Textile Leather Review*, 2019. **2**(1): p. 6-14.
215. Dāboliņa, I., A. Viļumsone, and E. Lapkovska. *Anthropometric Parametrization of Uniforms for Armed Forces*. in *Proceedings of the 11th International Scientific and Practical Conference. Volume III*. 2017.
216. Brantley, D., *New Standard Army Anthropometric Sizing System for Clothing and Equipment*, U.S.A.C.C.D. Command, Editor. 2020, Department of the Army, U.S. Department of Defence: Natick, Massachusetts, U.S.
217. Strydom, M., *An Evaluation of South African Clothing Related Population Measures and Sizing Systems*, in *Department of Consumer Science*. 2006, University of Pretoria: Pretoria, South Africa.
218. World Health Organization, *Waist Circumference and Waist-Hip Ratio. Report of a Who Expert Consultation*. 2008, World Health Organization: Geneva.
219. Sparks, E., *Advances in Military Textiles and Personal Equipment*, ed. E. Sparks. 2012: Woodhead Publishing. xxiii-xxiv.
220. Choi, T.M., *Information Systems for the Fashion and Apparel Industry*, T.-M. Choi, Editor. 2016, Woodhead Publishing. p. xix-xx.
221. Tomkinson, G., A. Clark, and P. Blanchonette, *Body Size Changes of Royal Australian Air Force Aircrew: 1971 - 2005*, D.S.a.T.O.A.O. Division., Editor. 2009: Melbourne, Australia. p. 28.

222. Knapik, J.J., et al., *Secular Trends in the Physical Fitness of United States Army Infantry Units and Infantry Soldiers, 1976–2015*. Military Medicine, 2018. **183**(11-12): p. e414-e426.
223. Keefe, A., J. Kuang, and H. Daanen. *NATO Research Task Group: 3D Scanning for Clothing Fit and Logistics*. 2017. Montreal, Canada,: *Proceedings of 3DBODY.TECH 2017. 8th International Conference and Exhibition on 3D Body Scanning and Processing Technologies*.
224. Coltman, C.E., et al., *Are Female Soldiers Satisfied With the Fit and Function of Body Armour?* Applied Ergonomics., 2020. **89**: p. 103197.
225. Toma, D., et al. *Improved Fit and Performance of Female Bulletproof Vests*. in *International Conference on Advanced Materials and Systems (ICAMS)*. 2016. The National Research & Development Institute for Textiles and Leather-INCOTEX.
226. Simmons, K.P. and C.L. Istook, *Body Measurement Techniques*. Journal of Fashion Marketing and Management: An International Journal, 2003. **7**(3): p. 306-332.
227. Vinué, G., *Anthropometry: An R Package for Analysis of Anthropometric Data*. Journal of Statistical Software, 2017. **77**(6): p. 39.
228. Liu, K., et al., *Construction of a Prediction Model for Body Dimensions Used in Garment Pattern Making Based on Anthropometric Data Learning*. The Journal of The Textile Institute., 2017. **108**(12): p. 2107-2114.
229. Liu, Z., et al., *Predicting Detailed Body Sizes By Feature Parameters*. International Journal of Clothing Science and Technology, 2014. **26**.
230. Hart, G.L., G.E. Rowland, and R. Malina, *Anthropometric Survey of the Armed Forces of the Republic of Korea*. 1967: Natick, Massachusetts, US.
231. Hsu, C.H. and M.J.J. Wang, *Using decision tree-based data mining to establish a sizing system for the manufacture of garments*. 2005. p. 669-674.
232. Hsu, C.H., *Data Mining to Improve Industrial Standards and Enhance Production and Marketing: An Empirical Study in the Apparel Industry*. Expert Systems with Applications., 2009. **36**(3, Part 1): p. 4185-4191.
233. Koepke, N., et al., *Comparison of 3D Laser-Based Photonic Scans and Manual Anthropometric Measurements of Body Size and Shape in a Validation Study of 123 Young Swiss Men*. PeerJ, 2017.
234. Kolose, S., T. Stewart, and P.A. Hume, *NZDF Uniform Size Prediction Model and Application Development: Technical Report to NZDF*. 2019, Auckland University of Technology.: Auckland, New Zealand.
235. Daanen, H.A., et al., *Optimization of Military Garment Fit*. Ambience 2014. **14**(10): p. 7-9.
236. Lavrač, N., *Selected Techniques for Data Mining In Medicine*. Artificial Intelligence in Medicine, 1999. **16**(1): p. 3-23.

237. McHugh, M.L., *Interrater Reliability: The Kappa Statistic*. Biochemia Medica, 2012. **22**(3): p. 276-282.
238. Narayanan, A., et al., *Application of Raw Accelerometer Data and Machine-Learning Techniques to Characterize Human Movement Behavior: A Systematic Scoping Review*. 2020. **17**(3): p. 360.
239. Emanuel, I., et al., *A Height-Weight Sizing System for Flight Clothing*. WADCTR 56-365. 1959, Ohio, USA: Wright Air Development Center, Air Research and Development Command.
240. Behnke, A.R., *Anthropometric Fractionation of Body Weight*. Journal of Applied Physiology., 1961. **16**(6): p. 949-954.
241. Gupta, D. and B.R. Gangadhar, *A Statistical Model for Developing Body Size Charts for Garments*. International Journal of Clothing Science and Technology., 2004. **16**(5): p. 458-469.
242. Bradtmiller, B., *Predicting Product Accommodation: The Role of the Anthropometric Fit Test*. Procedia Manufacturing., 2015. **3**: p. 4464-4471.
243. Choi, H.J., T.N. Garlie, and K.B. Mitchell. *Effects of Body Armor Fit on Encumbered Anthropometry Relative to Bulk and Coverage*. in *International Conference on Applied Human Factors and Ergonomics*. 2018. Springer.
244. Chung, M.J., H.F. Lin, and M.J. Wang, *The Development of Sizing Systems for Taiwanese Elementary and High-School Students*. International Journal of Industrial Ergonomics., 2007. **37**(8): p. 707-716.
245. Loker, S., S.P. Ashdown, and K. Schoenfelder, *Size-Specific Analysis of Body Scan Data to Improve Apparel Fit*. Journal of Textile and Apparel, Technology and Management., 2005. **4**(3): p. 1-15.
246. Keefe, A., H. Angel, and B. Mangan, *2012 Canadian Forces Anthropometric Survey (CFAS) - Final Report*. 2015, Defense Research and Development Canada.
247. Vuruskan, A., B. Seider, and U. Detering-Koll. *Data Compatibility Analysis of 3D Body Scanning*. in *2nd International Conference on 3D Body Scanning Technologies*. 2011.
248. McCulloch, C.E., B. Paal, and S.P. Ashdown, *An Optimisation Approach to Apparel Sizing*. Journal of the Operational Research Society., 1998. **49**(5): p. 492-499.
249. Keefe, A., J. Kuang, and H. Daanen. *3D Scanning for Clothing Fit and Logistics*. in *Proceedings of 3DBODY.TECH 2017. 8th International Conference and Exhibition on 3D Body Scanning and Processing Technologies*. 2017. Montreal, Canada,.
250. Carr, D.J., C.A. Wilson, and R.M. Laing, *3 - Anthropometric Methods for the Successful Design of Military Clothing and Equipment*, in *Advances in Military Textiles and Personal Equipment*, E. Sparks, Editor. 2012, Woodhead Publishing. p. 49-63.

251. Marfell-Jones, M. and T. Olds, *Kinanthropometry X: Proceedings of The 10th International Society for the Advancement of Kinanthropometry Conference, Held in Conjunction with the 13th Commonwealth International Sport Conference*. 2007: Routledge.
252. Kroemer, K.H.E., H.J. Kroemer, and K.E. Kroemer-Elbert, *Engineering Physiology: Bases of Human Factors/Ergonomics*. 1997: John Wiley & Sons.
253. Eagan, S.M., *Menstrual Suppression For Military Women: Barriers to Care in the United States*. *Obstetrics & Gynecology*., 2019. **134**(1): p. 72-76.
254. New Zealand Defence Force, *Women in the NZDF*, D.D. Inclusion, Editor. 2019, New Zealand Defence Force: Wellington, New Zealand.
255. Pourtaghi, G., et al., *Anthropometric Characteristics of Iranian Military Personnel and their Changes over Recent Years*. *International Journal of Occupational Environmental Medicine*., 2014. **5**(3): p. 115 - 124.
256. Purnomo, H. and F. Kurnia, *An Analysis of Body Armor Sizing and the Development of an Existing Sizing System for the Indonesian National Army*. *Engineering Letters*, 2020. **28**(3): p. 1-7.
257. Kaufmann, K., *Invasion of the Body Scanners*. *IEEE Circuits and Devices Magazine*, 1997. **13**(3): p. 12-17.
258. Olds, T. and F. Honey. *The Use of 3D Whole-Body Scanners in Anthropometry*. in *Proceedings of the 9th International Conference of the International Society for the Advancement of Kinanthropometry*. 2006. Taylor & Francis.
259. Stewart, A., R.L. Ledingham, and H. Williams, *Variability in Body Size and Shape Of UK Offshore Workers: A Cluster Analysis Approach*. *Applied Ergonomics*, 2017. **58**: p. 265-272.
260. Elfaki, E. and A. Ali, *A Comparison Between the New Established Sizing Systems Sud and Sur Military Clothing Factory Sizing Chart for Poshirt (U4)-Part 1*. *International Journal of Advanced Research in Engineering and Applied Sciences*., 2016. **5**(1): p. 32-41.
261. Wen, C.H. and Y.C. Shih, *Designing New Sizing Bulletproof Vests for Taiwanese Soldiers*. *International Journal of Clothing Science and Technology*., 2020.
262. Tiwari, M. and N. Anand, *An Anthropometric Study of Young Indian Men for Bottom Wear Sizing*. *International Journal of Forensic Engineering and Management*, 2020. **1**(1): p. 24-41.
263. Kausher, H. and S. Srivastava, *Developing Structured Sizing Systems for Manufacturing Ready-Made Garments of Indian Females Using Decision Tree-Based Data Mining*. *International Journal of Materials and Textile Engineering*., 2019. **13**(12): p. 517-575.
264. Majumder, J. and L.K. Sharma, *Identifying Body Size Group Clusters from Anthropometric Body Composition Indicators*. *Journal of Ecophysiology and Occupational Health*, 2015. **15**(3/4): p. 81.

265. Bari, S.B., N.M. Salleh, and S. Osman, *Development of Female Adolescents Clothing Sizing Based on Cluster Analysis Classification*, in *Proceeding: International Business Management Conference (IBMC 2017)*. 2017: Adya Hotel Langkawi, Kedah, Malaysia.
266. Hu, T.C., et al., *Development of a Military Uniform Size System Using Hybrid Support Vector Clustering With a Genetic Algorithm*. *Symmetry*, 2019. **11**(5): p. 1-19.
267. International Organization for Standardization, *ISO 8559: Garment construction and anthropometric surveys—Body dimensions*. 1989.
268. Hsu, C.H., H.F. Lin, and M.J.J. Wang, *Developing Female Size Charts for Facilitating Garment Production by Using Data Mining*. *Journal of the Chinese Institute of Industrial Engineers.*, 2007. **24**(3): p. 245-251.
269. Moon, J.Y. and Y.J. Nam. *A Study the Elderly Women's Lower Figure Type Classification and Lower Garment Sizing Systems*. in *Proceedings of International Ergonomics Association Conference, Seoul, Korea*. 2003.
270. Elnour, E.F.E., et al., *International Journal of Engineering Sciences & Research-Technology Application of Data Mining Methods In Establishing Sizing System for Clothing Industry*. 2015.
271. Viktor, H.L., E. Paquet, and H. Guo. *Measuring to Fit: Virtual Tailoring Through Cluster Analysis and Classification*. in *European Conference on Principles of Data Mining and Knowledge Discovery*. 2006. Springer.
272. Azouz, Z.B., C. Shu, and A. Mantel. *Automatic Locating of Anthropometric Landmarks On 3D Human Models*. in *Third International Symposium on 3D Data Processing, Visualization, and Transmission (3DPVT'06)*. 2006. IEEE.
273. Leong, L., J. Fang, and M. Tsai, *Automatic Body Feature Extraction From a Marker-Less Scanned Human Body*. *Computer-Aided Design*, 2007. **39**(7): p. 568-582.
274. Olds, T. and D. Stratton, *Validation Trial Report*, in *Australian Defence Anthropometric Personnel Testing (ADAPT)*. 2005, University of South Australia: Adelaide.
275. Toma, D., et al., *Improved Fit and Performance of Female Bulletproof Vests*, in *International Conference on Advanced Materials and Systems (ICAMS)*. 2016, The National Research & Development Institute for Textiles and Leather. p. 417-422.
276. Epstein, Y., et al., *Physiological Employment Standards IV: Integration of Women in Combat Units Physiological and Medical Considerations*. *European Journal of Applied Physiology*, 2013. **113**(11): p. 2673-2690.
277. Weber, R.N., *Manufacturing Gender in Commercial and Military Cockpit Design*. *Science, Technology, & Human Values*, 1997. **22**(2): p. 235-253.

- 278. Peña, I., H.L. Viktor, and E. Paquet. *Finding Clothing That Fit Through Cluster Analysis and Objective Interestingness Measures*. in *International Conference on Data Warehousing and Knowledge Discovery*. 2009. Springer.
- 279. Zakaria, N., *Sizing System for Functional Clothing—Uniforms for School Children*. 2011.
- 280. Zakaria, N., et al. *Using Data Mining Technique to Explore Anthropometric Data Towards the Development of Sizing System*. in *2008 International Symposium on Information Technology*. 2008.
- 281. Morlock, S., et al. *Using 3D Scanning for Improved Helmet Design*. in *Proceedings of the 7th international conference on 3D body scanning technologies*. 2016. Lugano.
- 282. Godil, A.A. and S.P. Ressler, *Shape and Size Analysis and Standards*, in *Handbook of Digital Human Modeling for Applied Ergonomics and Human Factors Engineering*, V.G. Duffy, Editor. 2008, Taylor & Francis eBooks.

APPENDIX I Ethics confirmation letters

NZDFAS Study



9 June 2014

Patria Hume
Faculty of Health and Environmental Sciences

Dear Patria

Re Ethics Application: **14/126 NZDF anthropometry Survey: Variations in kinanthropometry and implications for the New Zealand Defence Force.**

Thank you for providing evidence as requested, which satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTC).

Your ethics application has been approved for three years until 9 June 2017.

As part of the ethics approval process, you are required to submit the following to AUTC:

- A brief annual progress report using form EA2, which is available online through <http://www.aut.ac.nz/researchethics>. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 9 June 2017;
- A brief report on the status of the project using form EA3, which is available online through <http://www.aut.ac.nz/researchethics>. This report is to be submitted either when the approval expires on 9 June 2017 or on completion of the project.

It is a condition of approval that AUTC is notified of any adverse events or if the research does not commence. AUTC approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

AUTC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to obtain this. If your research is undertaken within a jurisdiction outside New Zealand, you will need to make the arrangements necessary to meet the legal and ethical requirements that apply there.

To enable us to provide you with efficient service, please use the application number and study title in all correspondence with us. If you have any enquiries about this application, or anything else, please do contact us at ethics@aut.ac.nz.

All the very best with your research,

A handwritten signature in black ink, appearing to read 'K O'Connor', is written over a horizontal line.

Kate O'Connor
Executive Secretary
Auckland University of Technology Ethics Committee

Cc: Stephen Kolose setefano@gmail.com

NZ Army Study



AUTECH Secretariat

Auckland University of Technology
D-88, WU406 Level 4 WU Building City Campus
T: +64 9 921 9999 ext. 8316
E: ethics@aut.ac.nz
www.aut.ac.nz/researchethics

28 May 2018

Patria Hume
Faculty of Health and Environmental Sciences

Dear Patria

Re Ethics Application: **14/126 NZDF anthropometry Survey: Variations in kinanthropometry and implications for the New Zealand Defence Force.**

Thank you for providing evidence as requested, which satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTECH).

Your ethics application has been approved for three years until 30 June 2018.

Standard Conditions of Approval

1. A progress report is due annually on the anniversary of the approval date, using form EA2, which is available online through <http://www.aut.ac.nz/researchethics>.
2. A final report is due at the expiration of the approval period, or, upon completion of project, using form EA3, which is available online through <http://www.aut.ac.nz/researchethics>.
3. Any amendments to the project must be approved by AUTECH prior to being implemented. Amendments can be requested using the EA2 form: <http://www.aut.ac.nz/researchethics>.
4. Any serious or unexpected adverse events must be reported to AUTECH Secretariat as a matter of priority.
5. Any unforeseen events that might affect continued ethical acceptability of the project should also be reported to the AUTECH Secretariat as a matter of priority.

Please quote the application number and title on all future correspondence related to this project.

AUTECH grants ethical approval only. If you require management approval for access for your research from another institution or organisation then you are responsible for obtaining it. You are reminded that it is your responsibility to ensure that the spelling and grammar of documents being provided to participants or external organisations is of a high standard.

For any enquiries, please contact ethics@aut.ac.nz

Yours sincerely,

Kate O'Connor
Executive Manager
Auckland University of Technology Ethics Committee

Cc: setefano@gmail.com

Ethics completion 2019



Auckland University of Technology Ethics Committee (AUTEC)

Auckland University of Technology
D-88, Private Bag 92006, Auckland 1142, NZ
T: +64 9 921 9999 ext. 8316
E: ethics@aut.ac.nz
www.aut.ac.nz/researchethics

25 September 2019

Patria Hume
Faculty of Health and Environmental Sciences

Dear Patria

Ethics Application: **14/126 NZDF anthropometry Survey: Variations in kinanthropometry and implications for the New Zealand Defence Force.**

At their meeting of 23 September 2019, the Auckland University of Technology Ethics Committee (AUTEC) received the report on your ethics application. AUTEC noted your report and asked me to thank you.

On behalf of AUTEC, I congratulate the researchers on the successful completion of the project.

When communicating with us about this application, we ask that you use the application number and study title to enable us to provide you with prompt service. Should you have any further enquiries regarding this matter, you are welcome to contact me by email at ethics@aut.ac.nz or by telephone on 921 9999 at extension 6038.

Yours sincerely

A handwritten signature in black ink, appearing to read 'K O'Connor', is written over a light grey horizontal line.

Kate O'Connor
Executive Manager
Auckland University of Technology Ethics Committee

Cc: setefano@gmail.com

NZDFAS data collection participant information sheet



Defence Technology Agency
New Zealand Defence Force
Naval Base
Private Bag 32901
Auckland 0744, New Zealand

T +64 (0)9 445 5914
F +64 (0)9 445 5914
E s.kolose@dfa.mil.nz
www.nzdf.mil.nz

1 March 2016

NZDF ANTHROPOMETRIC SURVEY: PARTICIPANT INFORMATION SHEET

Aim:

The main goal of this study is to create an anthropometric database for the New Zealand Defence Force (NZDF). This will be achieved by taking a series of physical measures of a representative population of the NZDF. These measures will be taken manually (using measuring tapes and callipers), and by a 3-D anthropometric body scanner. The benefits of creating an anthropometric database are substantial for the whole NZDF. It will help in future assessments existing of uniform and equipment for NZDF, as well as determining if new products will suit the NZDF, before purchasing. In turn this will enable the NZDF to use, operate and/or wear equipment that is better suited to the sizes present in the NZDF.

The database research project aims to provide a repository of de-identified data and information collected from defence force personnel. One of the on-going difficulties is the location and preservation of anthropometric data. The anthropometric database for NZDF will serve as a central repository of data from assessments undertaken and will form the basis for on-going research. This database incorporating a wide range of participants will provide comparative and normative data, not only for New Zealand, but as a basis for world defence force research.

NZDF database benefits:

The potential benefits to this database are the ability to access a broad database of normative data for human performance and human engineering research. Other NZDF health departments (e.g. Medical, PTI etc.) can use this database for their own independent research. Information gained from research associated with this database has potential to assist engineering, health and fitness, clothing, human factors, recruit selection and so forth.

Your role in the anthropometric survey/study:

You will be part of the very first NZDF-wide anthropometric survey. By volunteering the information gathered from your body composition will be used to develop an anthropometric database. This database will enable researchers and key decision makers in the NZDF to acquire equipment, tools or platforms which suit the current anthropometric fit of our soldiers and support agencies within defence. With this information there should be no excuse for purchasing items based on incorrect anthropometric data. The benefits for the participants are endless as the data generated from the study will help improve clothing fit, fit of weapons, fit in platforms (aircraft, vehicles or ships).

Participation in the study is entirely voluntary. There is no obligation to take part in the study, and if you choose not to participate there will be no detriment to your career of

future health care. You may withdraw at any time with no detriment to your career or to your future health care. You will be given the opportunity to ask questions at any time, and all of your concerns will be addressed.

We are asking for up to 65 minutes of your time to take a number of measurements of your body size and shape. The following basic demographic information may also be recorded: sex, month and year of birth, country of birth, education level, service, and your current trade. Your name will not be recorded in the database. We require this demographic information to ensure the survey sample accurately reflects the current New Zealand Defence Force regular forces population. The measurements and techniques may vary in different investigations, but as a general rule will fall into the following categories:

- Height and weight
- Breadths, such as wrist breadth and shoulder breadth
- Circumferences, such as arm, hip, waist and chest

The 3D body scanning system uses an eye-safe class 1 visible red laser light to capture a highly accurate 3D digital statue (point cloud) of the surface of your body. This digital statue is identifiable as you. The laser passes over your body from head to toe in about 10 seconds. A technician (potentially of the opposite sex) will use special software to closely examine the digital statue to identify key points on the body and extract body dimensions.

Measurements will be made carefully in a quiet room without due haste and the presence of unnecessary people. The measurer may be of either sex. If you prefer the measurer to be of a particular sex, effort will be made to accommodate your wish. If this is not possible, you may withdraw consent to participate without detriment to their career or future health care. You may also nominate to have a friend/colleague (of either sex) present during measurements if you desire.

You will usually be barefooted or in thin socks. Undressing down to underclothes may be necessary so that the positioning of the body can be seen and the anatomical landmarks may be palpated, identified and marked. Marking the measurement sites and applying the measurement instruments will usually require manual contact by the person marking of measuring you. All measurements will be taken either sitting or standing. All individuals taking these measurements have experience in the acquisition of anthropometric data. All measurements will be made according to accepted and widely published international techniques.

What are the risks in participating in this research?

It is important to point out to you that there will be a number of potential risks associated with participation in this study. However, as you would expect, a range of safeguards have been put in place to make that these risks will be minimised. There will be relatively low risk to you.

- Physical harm such as fatigue or dehydration will be minimised by encouraging you to drink water throughout the study, and enabling you to sit down and take breaks when necessary. This is not a substantial risk, but you may be standing for up to 40 -50 minutes through the dressing, landmarking and scanning phases of the protocol.
- You may also get cold when in the under garments. The research team will keep the rooms temperate to avoid this. However, if this does occur, you will be provided with a temporary s to warm up. You can wear a top when leg-related landmarks are being identified and measured. Likewise, you may wear shorts when hip, buttock or upper leg landmarks and measures are not being performed.
- There may be a time when you will be waiting to be scanned. During this time you will be given a temporary robe to keep warm. Just before you enter the scanning room the anthropometrist will attach the balsa wood markers on the associated landmarks. This late placement of landmarks, ensures that the markers do not fall off when a) wearing the robe and b) natural skin perspiration.
- The Vitus XXL scanner uses Class 1 visible red laser light (wavelength = 600 nm, power output = 40 mW). After reflection losses at the mirror and attenuation through the plastic cover, <1mW (Class 1) is projected into the scanning area. It is manufactured and developed in compliance with U.S. Food and Drug Administration regulations pertaining to laser safety (21CFR1040.10, 21CFR1040.11). Class 1 lasers are considered safe according to this regulation.
- There will be both male and female researchers present to conduct the measurements. You will also be seen in under garments by as few people as possible, and not by members of the public.

How will my privacy be protected?

To protect your privacy, your name will be coded on all materials used for data collection, analysis, reports and publications. During the project, only the applicant and named investigators will have access to the data collected. The results of the study may be used for further analysis and submission to peer-reviewed journals or submitted at conferences. However, your name will remain coded and anonymous. Your privacy and anonymity will be of primary concern when handling the data. All data will be stored on password protected computers or in locked files. Following completion of data analysis your data will be stored in a secured location within DTA for ten years. Following the ten-year storage period all hard copies of data will be destroyed (shredded) and electronic data will be wiped.

What are the costs of participating in this research?

There will be no extra costs on your part.

What opportunity do I have to consider this invitation?

We would appreciate it if you could let us know within two weeks whether you would be available to take part in the study or not. After consideration you may withdraw your participation at any time.

How do I agree to participate in this research?

If you agree to participate please fill in the attached consent form and return to Mr Stephven Kolose. The contact details for Stephven are 021 139 7941 and stephven.kolose@nzdf.mil.nz.

Will I receive feedback on the results of this research?

Yes, upon completion to the study a written report will be sent to you detailing the results in graphical form as well as specific recommendations for yourself based on your test results. It is your choice whether you share this information with other people.

Your role in the NZDF database:

We are also seeking your consent to use the data we collect from you for any future research beyond the current, specific survey study for the purposes described in the opening paragraph. Such further use would ensure no stored data allowed association of an individual with the specific stored data items.

Your role is primarily that of sharing data through carrying out the specified protocols. Your data will be able to be compared to the normative data within this database and will be able to inform you where are in terms of a range of measures of defence personnel.

Who has access to the NZDF database?

Only approved NZDF personnel has access to the raw data (namely Mr Stephven Kolose – project lead; Mr. Andy Richardson – Director Human Systems, DTA). All original data collection forms are kept for 10 years and then permanently deleted (physical hard drives terminated). The electronic de-identified data is kept indefinitely on the NZDF database. Researchers from other Universities and organisations may collaborate with NZDF for the purposes of data analysis and publication. These researchers will go through an approval process. Please note that the information from the database will be also be used for PhD research for Mr. Stephven Kolose who is the project lead for the NZDFAS. This research is with AUT University.

How are data collected for the database:

You will be fully informed of the protocols and procedures and your rights prior to clinics data collection. Consent forms are signed prior to any collection of data. Data are collected at NZDF locations following approved protocols. You are given time and are encouraged to consult with the researchers, colleagues, friends and family prior to agreeing for your de-identified data collected in the assessment session to be submitted into the NZDF database.

How you can provide your permission for your data to be included in the database:

You are invited to provide your permission for your data collected during your assessment to be included in the NZDF database via signing the "NZDF anthropometry survey and database: Informed consent for use of data for research" form that contains the statements:

- *I agree that my data may be stored indefinitely in the NZDF database. I agree that my de-identified data can be used for future research projects, and shared with other approved researchers without me providing any additional consent beyond this consent. The kind of projects my de-identified data might be used for include approved student research for degree completions and international collaborative research. The de-identified database is accessible to an approved international team of researchers and may also be shared with other researchers overseas for approved projects. My data are linked to my name only on the subject identifier section of the database which is separate from the de-identified data on the NZDF database. I may request withdrawal of my data from the database at any time.*
- *I agree to my contact details being stored indefinitely in the subject identifier section of NZDF database in case I need to be contacted for possible follow-up research (e.g. long term follow-up studies).*

Name: _____

Sign: _____

Date: _____



Stephven Kolose
Human Factors Scientist
Defence Technology Agency

Participant informed consent NZDFAS form



Defence Technology Agency
New Zealand Defence Force
Naval Base
Private Bag 32901
Auckland 0744, New Zealand

T +64 (0)9 445 5914
F +64 (0)9 445 5890
E s.kolose@dfa.mil.nz

File Number

21 March 2016

NZDF ANTHROPOMETRY SURVEY AND DATABASE: INFORMED CONSENT FOR USE OF DATA FOR RESEARCH

Name:	_____
Address:	_____ _____
Phone:	_____ E-mail: _____
Emergency contact:	
Name:	_____ Relationship: _____
Phone #1:	_____ Phone #2: _____

1. The details of the NZDF anthropometry survey/test and on-going anthropometry database have been explained to me. I am clear about what will be involved (test protocol and measures) and I am aware of the purpose of the test(s), the potential benefits and the potential risks. Any questions I have about the test session have been answered.	Yes ☐ No ☐
2. I have disclosed any injury or illness that will affect my ability to complete the test(s).	Yes ☐ No ☐
3. My permission to perform this test(s) is voluntary; I am free to stop the test(s) at any time if I so desire.	Yes ☐ No ☐
4. I acknowledge that there are risks and dangers inherent in any testing and declare that I know of no reason why I should not complete the test(s) described.	Yes ☐ No ☐
5. I agree that my data may be stored indefinitely in the NZDF anthropometry database. I agree that my de-identified can be used for future research projects, and shared with other NZDF approved researchers without me providing any additional consent beyond this consent. The kind of projects my de-identified data might be used for include AUT University approved student research for degree completions and international collaborative research. The de-identified database is accessible to an approved list of researchers and may also be shared with other researchers overseas for approved projects. My data are linked to my name only on the subject identifier section of the database which is separate from the de-identified data on the NZDF anthropometry database. I may request withdrawal of my data from the database at any time.	Yes ☐ No ☐
6. I agree to my contact details being stored indefinitely in the subject identifier section of NZDF anthropometry database in case I need to be contacted for possible follow-up research (e.g. long term follow-up studies).	Yes ☐ No ☐
7. My individual test results are confidential and will only be communicated to others if I agree in advance. I agree to the following people or organizations receiving a copy of my results that have my name attached to them: Name: _____ Email: _____	Yes ☐ No ☐

Participant name: _____ **Signed:** _____

Date: _____

Signature of parent/guardian if under 18: _____

Tester name: _____ **Signed:** _____ **Date:** _____



Stephen Kolose
Human Factors Scientist
Defence Technology Agency



ETHICS APPROVAL: 14/126 NZDF anthropometry survey: Variations in kinanthropometry and implications for the New Zealand Defence Force.

Any concerns regarding the nature of the DTA anthropometry testing or database should be notified in the first instance to the Professor Patria Hume, SPRINZ, AUT University, Private Bag 92008, Auckland 1020, patria.hume@aut.ac.nz, 921 9999 ext. 7306. Concerns regarding the conduct of the testing or database should be notified to the Executive Secretary, AUTEK, Kate O'Connor <koconnor@aut.ac.nz>, 921 9999.

Participant information sheet for NZ Army clothing study



Defence Technology Agency
New Zealand Defence Force
Naval Base
Private Bag 32901
Auckland 0744, New Zealand

T +64 (0)9 445 5902
F +64 (0)9 445 5890
E reception@dfa.mil.nz
www.nzdf.mil.nz

File Number

22 May 2019

NZDF CLOTHING SIZING PREDICTION VALIDATION TRIAL: INFORMATION SHEET

Aim: The main goal of this study is to validate a clothing sizing prediction model that will enable the prediction of accurate uniform sizes for the New Zealand Defence Force (NZDF).

This will be achieved by 3-D body scanning NZ Army recruits in Waikouru. The clothing sizing prediction model will then estimate their combat uniform shirt and trouser size. The participants will be sized by trained tailors from the Work Wear group (WWG). The clothing sizing prediction model and tailor measurement results will be compared to determine the overall accuracy of the model.

The data from the validation trial also forms part of Stephen Kolosos PhD degree at the Auckland University of Technology (AUT). The PhD is entitled 'NZDF anthropometry Survey: Variations in Kinanthropometry and implications for the New Zealand Defence Force'.

NZDF benefits: It is envisaged that upon successful validation, the procedures and models used in this study can be applied to other clothing and equipment systems such as body armour, vests, coveralls, and Personal Protective Equipment (PPE). Future work may also consist of comparing the sizing results of the validated model with the output from more expensive 3-D garment fitting software. Alternatively, the model may provide direction as to what software is most suitable for the NZDF.

Your role in the anthropometric survey/study: You will be part of validating NZDFs first in-house 3-D body scanning clothing size prediction model. By volunteering, the information gathered from your body measurements will be used to strengthen the accuracy of the clothing sizing prediction model. This database will enable researchers and key decision makers in the NZDF to acquire uniforms that suit the current anthropometric fit of our regular force personnel. With this information there will be improved purchasing of items based on correct anthropometric sizing.

Participation in the study is entirely voluntary. There is no obligation to take part in the study, and if you choose not to participate there will be no detriment to your career or future health care. You may withdraw at any time with no detriment to your career or to your future health care. You will be given the opportunity to ask questions at any time, and all of your concerns will be addressed.

We are asking for up to 6 minutes of your time to take a body scan to determine your body size and shape. The following basic demographic information may also be recorded: sex, month and year of birth, country of birth, education level, service, and your current trade. Your name will not be recorded in the results or any subsequent publication from this research. We require this demographic information to ensure the survey sample accurately reflects the current New Zealand Defence Force regular forces population.

The 3D body scanning system uses an eye-safe class 1 visible red laser light to capture a highly accurate 3D digital statue (point cloud) of the surface of your body. This digital statue is identifiable as you. The

laser passes over your body from head to toe in about 10 seconds. A technician (potentially of the opposite sex) will use special software to closely examine the digital statue to identify key points on the body and extract body dimensions. The automatic body measurements are made using the body scanner software 'Anthroscan'.

You will usually be barefooted or in thin socks. Undressing down to underclothes will be necessary so that the positioning of the body can be seen. The body scanner technician will provide further instructions on the day (e.g. how to stand and where to look while you are being scanned).

We ask that male participants wear briefs or close-fitting boxer shorts. Female participants are required to wear a sports bra and underwear. Loose shorts are not recommended. Bike shorts are acceptable. The WWG will provide underclothing if required.

What are the risks in participating in this research?

It is important to point out to you that there will be a number of potential risks associated with participation in this study. However, as you would expect, a range of safeguards have been put in place to make that these risks will be minimised. There will be relatively low risk to you.

- For the scanning process, you will be required to stand in your underclothing for up to 4 minutes. You may get changed inside the body scanner (it is covered with curtains).
- You may also get cold when in the undergarments. The research team will keep the rooms temperate to avoid this.
- The Vitus XXL scanner uses Class 1 visible red laser light (wavelength = 600 nm, power output = 40 mW). After reflection losses at the mirror and attenuation through the plastic cover, <1mW (Class 1) is projected into the scanning area. It is manufactured and developed in compliance with U.S. Food and Drug Administration regulations pertaining to laser safety (21CFR1040.10, 21CFR1040.11). Class 1 lasers are considered safe according to this regulation.
- There will be both male and female researchers present to conduct the measurements. You will also be seen in undergarments by as few people as possible, and not by members of the public.

How will my privacy be protected?

To protect your privacy, your name will be coded on all materials used for data collection, analysis, reports and publications. During the project, only the applicant and named investigators will have access to the data collected. The results of the study may be used for further analysis and submission to peer-reviewed journals or submitted at conferences. However, your name will remain coded and anonymous. Your privacy and anonymity will be of primary concern when handling the data. All data will be stored on password protected computers or in locked files. Following the completion of data analysis, your data will be stored in a secured location within AUT University for ten years. Following the ten-year storage period, all hard copies of data will be destroyed (shredded) and electronic data will be wiped.

What are the costs of participating in this research?

There will be no extra costs on your part.

What opportunity do I have to consider this invitation?

We would appreciate it if you could let us know within two weeks whether you would be available to take part in the study or not. After consideration, you may withdraw your participation at any time.

How do I agree to participate in this research?

If you agree to participate please fill in the attached consent form and return to Mr Stephven Kolose. The contact details for Stephven are 021 139 7941 and s.kolose@dta.mil.nz.

Will I receive feedback on the results of this research?

Participants body measurement results are available by request. They are only available to the participant who was scanned.

Your role in the NZDF database: We are also seeking your consent to use the data we collect from you for any future research beyond the current, specific survey study for the purposes described in the opening paragraph. Such further use would ensure no stored data allowed association of an individual with the specific stored data items. Your role is primarily that of sharing data through carrying out the specified protocols.

Who has access to the data: Only approved NZDF and AUT personnel have access to the raw data. All original data collection forms are kept for 10 years and are then shredded. The electronic de-identified data is kept indefinitely on the NZDF database. Researchers from other Universities and organisations may collaborate with NZDF and AUT researchers for the purposes of data analysis and publication. These researchers go through an approval process.

Thank you for your time.

Regards



Stephven Kolose
Human Factors Scientist
Defence Technology Agency



**AUT SPORTS PERFORMANCE
RESEARCH INSTITUTE NEW ZEALAND**

ETHICS APPROVED: 27 May 2019 14/126 NZDF anthropometry survey: Variations in Kinanthropometry and implications for the New Zealand Defence Force.

Any concerns regarding the nature of the DTA anthropometry testing or database should be notified in the first instance to the Professor Patria Hume, SPRINZ, AUT University, Private Bag 92006, Auckland 1020, patria.hume@aut.ac.nz, 921 9999 ext. 7306. Concerns regarding the conduct of the testing or database should be notified to the Executive Secretary, AUTECH, Kate O'Connor <kocconnor@aut.ac.nz>, 921 9999.

Participant informed consent NZ Clothing study form.



Defence Technology Agency
New Zealand Defence Force
Naval Base
Private Bag 32901
Auckland 0744, New Zealand

T +64 (0)9 445 5914
F +64 (0)9 445 5890
E s.kolose@dfa.mil.nz

File Number

21 May 2019

NZDF CLOTHING SIZING PREDICTION VALIDATION PILOT STUDY: INFORMED CONSENT FOR USE OF DATA FOR RESEARCH

Name:	_____
Address:	_____
Phone:	_____ E-mail: _____
Emergency contact:	
Name:	_____ Relationship: _____
Phone #1:	_____ Phone #2: _____

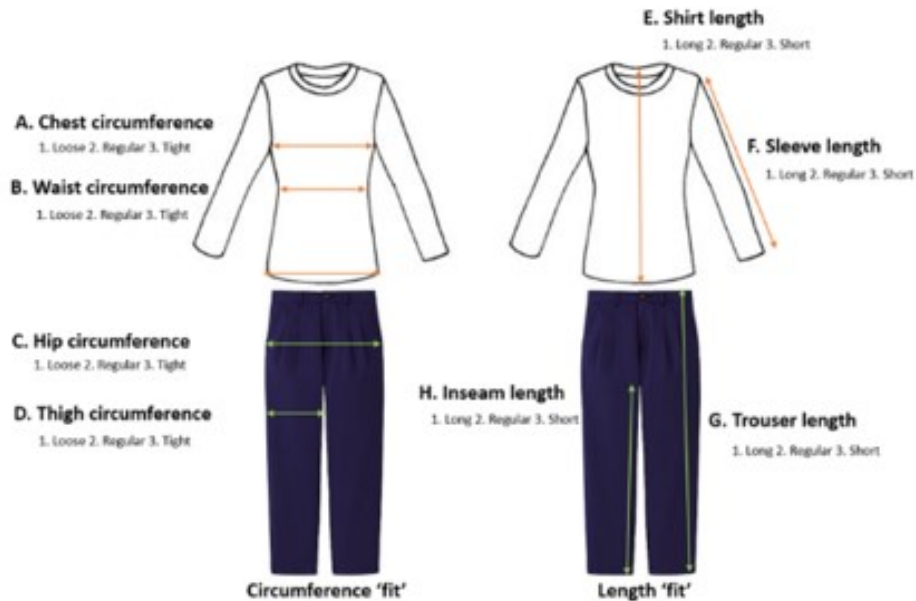
1. The details of the NZDF clothing sizing prediction trial have been explained to me. I am clear about what will be involved (scan protocol) and I am aware of the purpose of the test(s), the potential benefits and the potential risks. Any questions I have about the test session have been answered.	Yes ☐ No ☐
2. I have disclosed any injury or illness that will affect my ability to complete the test(s).	Yes ☐ No ☐
3. My permission to perform this test(s) is voluntary; I am free to stop the test(s) at any time, if I so desire.	Yes ☐ No ☐
4. I acknowledge that there are risks and dangers inherent in any testing and declare that I know of no reason why I should not complete the test(s) described.	Yes ☐ No ☐
5. I agree that my data may be stored indefinitely in the NZDF anthropometry database. I agree that my de-identified data can be used for future research projects and shared with other NZDF approved researchers without me providing any additional consent beyond this consent. The kind of projects my de-identified data might be used for include AUT University approved student research for degree completions and international collaborative research. The de-identified database is accessible to an approved list of researchers and may also be shared with other researchers overseas for approved projects. My data are linked to my name only on the subject identifier section of the database which is separate from the de-identified data on the NZDF anthropometry database. I may request withdrawal of my data from the database at any time.	Yes ☐ No ☐
6. I agree to my contact details being stored indefinitely in the subject identifier section of NZDF anthropometry database in case I need to be contacted for possible follow-up research (e.g. long term follow-up studies).	Yes ☐ No ☐
7. I agree that my data will contribute towards a PhD research degree at AUT University.	Yes ☐ No ☐
8. My individual test results are confidential and will only be communicated to others if I agree in advance. I agree to the following people or organizations receiving a copy of my results that have my name attached to them: Name: _____ Email: _____	Yes ☐ No ☐

Participant name: _____ Signed: _____

Date: _____

Tester name: _____ Signed: _____ Date: _____

Please rate how you prefer garments to 'fit' your body. Circle the appropriate rating below each key measurement.



Stephen Kolose
Human Factors Scientist
Defence Technology Agency



SPORTS PERFORMANCE
RESEARCH INSTITUTE, NEW ZEALAND
AN INSTITUTE OF AUT UNIVERSITY



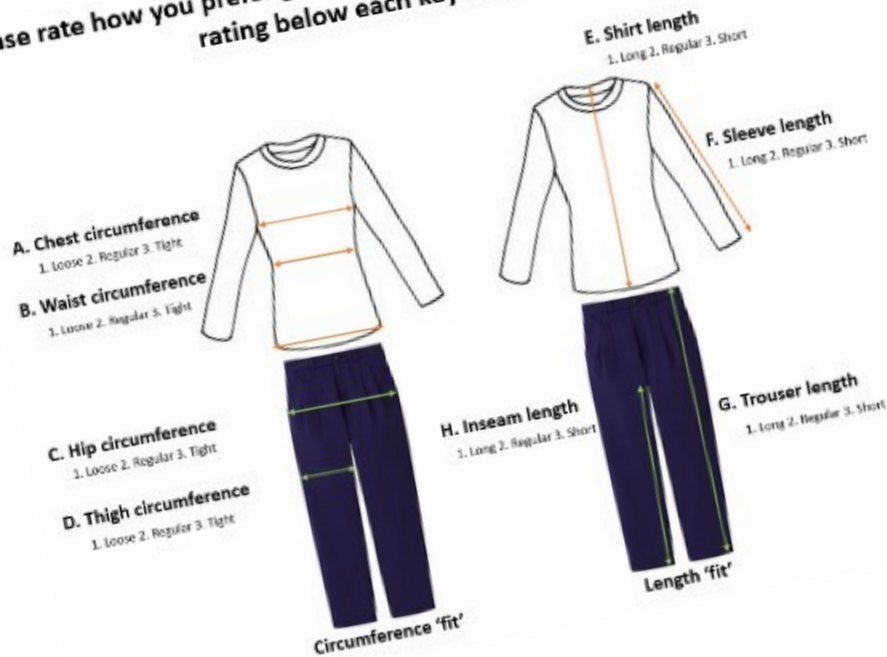
ETHICS APPROVED 27 May 2019: 14/126 NZDF anthropometry survey: Variations in kinanthropometry and implications for the New Zealand Defence Force.

Any concerns regarding the nature of the DTA anthropometry testing or database should be notified in the first instance to the Professor Patria Hume, SPRINZ, AUT University, Private Bag 92006, Auckland 1020. patria.hume@aut.ac.nz, 921 9999 ext. 7306. Concerns regarding the conduct of the testing or database should be notified to the Executive Secretary, AUTEC, Kate O'Connor <kcoconnor@aut.ac.nz>, 921 9999.

**APPENDIX III NZDF Uniform Size Prediction Model and Application
Development: Technical Report to New Zealand Defence Force (NZDF)**

**NZDF UNIFORM SIZE PREDICTION MODEL AND APPLICATION
DEVELOPMENT: TECHNICAL REPORT TO THE NEW ZEALAND DEFENCE
FORCE (NZDF)**

Please rate how you prefer garments to 'fit' your body. Circle the appropriate rating below each key measurement.



By research team members

Stephven Kolose^{1,2}, Tom Stewart¹, Patria A. Hume¹

¹ Sports Performance Research Institute New Zealand, Auckland University of Technology;

²Defence Technology Agency, NZDF.

This technical report represents part of the research work in the collaboration between the Defence Technology Agency (DTA), New Zealand Defence Force (NZDF) and AUT Sports Performance Research Institute New Zealand (SPRINZ).



**AUT SPORTS PERFORMANCE
RESEARCH INSTITUTE NEW ZEALAND**



Acknowledgements

The authors declare that there are no competing interests associated with the research contained within this report. The research was funded by the New Zealand Defence Force (NZDF), via the Defence Technology Agency (DTA), under contract signed 6th May 2019 and Deed signed 17th July 2019. We thank SSGT Bryce Wright – The Army Depot (TAD) for help with recruiting the participants for the study. We thank Miss Wilhelmina Pou and Ms Patricia Goddard for providing insight into the tailoring process at Waiouru. We thank Dr Samantha Rodrigues and Mr Hugh Terry from DTA, and Mr Ewan Henderson from NZDF Clothing, for help with data collection, and providing comments on the process and outcomes.

Contributor's statement

According to the definition given by the International Committee of Medical Journal Editors (ICMJE), the authors listed qualify for authorship based on making one or more of the substantial contributions to the intellectual content of this report. Study conception and design [Hume, Stewart, Kolose], ethics application [Hume, Kolose, Stewart], funding contract [Hume, Kolose, Stewart], acquisition of data [Hume, Stewart, Kolose], extraction of data [Stewart], interpretation of data [Hume, Stewart, Kolose], drafting of report [Hume, Stewart, Kolose], critical revision of report [Hume, Stewart, Kolose].

Research team

Professor Patria Hume – AUT SPRINZ, Professor Human Performance, ISAK level 4 Kinanthropometrist

Dr Tom Stewart – AUT SPRINZ HPC, Research Fellow, Data Scientist and BodyClothApp developer

Mr Stephven Kolose – DTA and AUT SPRINZ PhD student

Dr Samantha Rodrigues – DTA Research Scientist

Mr Hugh Terry – DTA Research Scientist

Mr Ewan Henderson – Technical Advisor, NZDF Clothing

SSGT Bryce Wright – TAD

Overview

Background: This project focused on the development of a computer application “BodyClothApp” that automatically converts a Human Solutions Ltd VITUS XXL 3D body scanner output into a NZ Army Multi Camouflaged Uniform (MCU) size prescription. The uniform size prediction model that is embedded within the application required validation testing.

Purpose: To conduct a validation trial as part of the Army recruit sizing activity (TAD 395) in Waiouru on 30–31 July 2019. The trial tested whether the 3D body scan data and uniform size prediction model produced the same NZ Army MCU shirt and trouser size as that determined by the Workwear Group (WWG) tailors.

Methods: New NZ Army recruits in the July 2019 intake undergoing basic training at the Waiouru military camp were invited to participate during their routine medical/dental assessment day. Each recruit stood in their underwear in the VITUS XXL 3D body scanner and underwent a 12-s body scan. The Anthroscan™ automatic body measurements calculated from the body scan were used by the BodyClothApp to predict MCU shirt and trouser sizes. Each recruit was also sized by a WWG tailor at the Waiouru military camp clothing store.

Recruits also rated how they preferred clothing to fit their body by circling ratings of loose, regular, or tight for circumference-related clothing dimensions (chest, waist, hip, and thigh) and by circling ratings of long, regular, or short for length-related dimensions (shirt, sleeve, inseam, and trouser). Statistical techniques were used to compare WWG sizes to the BodyClothApp predicted sizes for each recruit.

Results: In total, 153 army recruits (135 males, 18 females) completed a body scan and were also sized by the tailors. The scan procedure averaged 2 minutes and 15 s per recruit. Of the 153 recruits, 87 (56.9%) were assigned the same MCU shirt size by the BodyClothApp prediction model and the tailors. Higher agreement between the BodyClothApp prediction model and the tailors was observed for medium and large sizes (both 80% agreement). For MCU trousers, 97 of 153 recruits (63.4%) were assigned the same size by the BodyClothApp and the tailors. Higher agreement was observed for the medium trouser size (86% agreement). The recruits’ preference of clothing fit was not related to the agreement between the BodyClothApp and the tailors.

Discussion: This trial demonstrated that the use of body scanning technology has the potential to improve the efficiency of the recruit uniform sizing activity. Small changes to the scanning protocol and better computer hardware could further minimise scanning time. The analysis assumed that the size allocated by the tailors was the optimal size for each recruit – this may not be the case given the mixture of body dimensions observed within each MCU size category. Therefore, obtaining accurate uniform size information should be a priority for future enhancement of the prediction model.

Conclusions: This trial demonstrated that 3D body scanning technology in conjunction with statistical learning models has the potential to predict correct fitting NZ Army MCU. There are several areas of future research which could be used to make further refinements to the prediction model.

Recommendations: Obtain optimal uniform size information that is accurate. An example of this could be a tailor sizing a recruit by measuring their key body dimensions with a tape measure, and then using these dimensions to assign a clothing size. A correct optimal size is crucial for future enhancement of the prediction model.

Conduct a follow-up survey of user fit ratings after the recruits have worn their MCU for an acceptable period. Recruits who do not feel they have a good fitting MCU should have the opportunity to try an alternate size. This updated information could be used to re-evaluate and/or retrain the prediction model.

Explore further research avenues such as applying cluster analysis or unsupervised machine learning to the NZDF anthropometry database to create distinct groups of NZ Army personnel based on their body size. Creating groups that are as distinct as possible may aid in developing appropriate (and minimal) size categories and garment dimensions for future MCU clothing.

Follow-up study scanning clothed personnel, as opposed to wearing underwear. If the accuracy of the prediction model is maintained under these conditions, it could minimise the time and privacy issues associated with undressing.

Add the 3D body scan data collected during this trial to the main NZDFAS database of 1003 personnel.

Background

Project scope

As per the contract for work, this project involved the refinement of a previously created uniform size prediction model and the development of a functional computer application. The application (BodyClothApp) automatically converts the Human Solutions Ltd VITUS XXL 3D body scanner output into a NZ Army Multi Camouflaged Uniform (MCU) size prescription (both shirt and trousers) in real-time. The purpose of the BodyClothApp was to simplify and increase the accuracy of the Army uniform sizing process. This project included the development of the BodyClothApp and trialling its usability at a NZ Army sizing activity in July 2019.

Purpose

To conduct a validation trial as part of the Army recruit sizing activity (TAD 395) in Waiouru on 30–31 July 2019. The trial tested whether the 3D body scan data and clothing size prediction model (embedded within the BodyClothApp) produced the same NZ Army MCU shirt and trouser size as that determined by the tailors (Workwear Group staff).

Methods

Design

A cross sectional cohort study.

Participants

New NZ Army recruits part of the July intake undergoing basic training at the Waiouru military camp were invited to participate during their routine medical/dental assessment day. Four platoons, consisting of approximately 40 individuals each, were included in the study.

The trial had ethics approval from the Auckland University of Technology Ethics Committee (AUTEC #14/126 NZDF anthropometry Survey: Variations in kinanthropometry and implications for the New Zealand Defence Force). The aims of the study, what to wear during the scan, and how to stand during the scanning process were explained to each participant. Written informed consent was provided by each participant,

confirming they understood the study requirements before they participated. Participants could withdraw from the study at any time.

Procedure and Measures

BodyClothApp: The 3D body scan clothing prediction application

The BodyClothApp is written in the R programming language. It is presented as a user-friendly dashboard interface that runs alongside the Anthroscan™ (body scanner) software. The BodyClothApp can make individual predictions of MCU shirt and trouser size and display these immediately after an individual is scanned. The BodyClothApp also provides visual inspection of individual body measurements, group-level results, and generates a PDF report with a summary of key results for each participant.

The prediction model embedded within the BodyClothApp is a machine learning classifier that uses a random forest architecture. The BodyClothApp model was created using data collected as part of the NZDF Anthropometry Survey 2016–2018. These data were a combination of manual body measurements (by tape measure), automatic measurements (from the AnthroScan™ software), and post-scan digital measurements (using the CySize™ software). The details of the BodyClothApp model development are explained in DTA Report 438 ‘The relationship between NZDF combat uniform and anthropometry measurements’. For the purpose of this project, the BodyClothApp model was adapted to only use automatic body measurements provided by the Anthroscan™ software.

NZ Army recruit sizing activity: 3D scanning and prediction of uniform size

Participants presented themselves at the body scanner centre, removed their clothing except their underwear, and put on a swim cap (to compress their hair for height and head circumference measurement). To optimise the accuracy of the 3D scan, male participants wore tight fitting briefs only. Female participants wore a sports bra and underwear only. All glasses, watches, socks and shoes were removed before the scan.

The scan operator asked the participants to stand in the scanner and assume a standard scanning pose of feet shoulder width apart, arms flexed at the elbows and aligned at the sides, fingers together with thumbs facing forwards, head up and eyes facing forward (Figure 1).

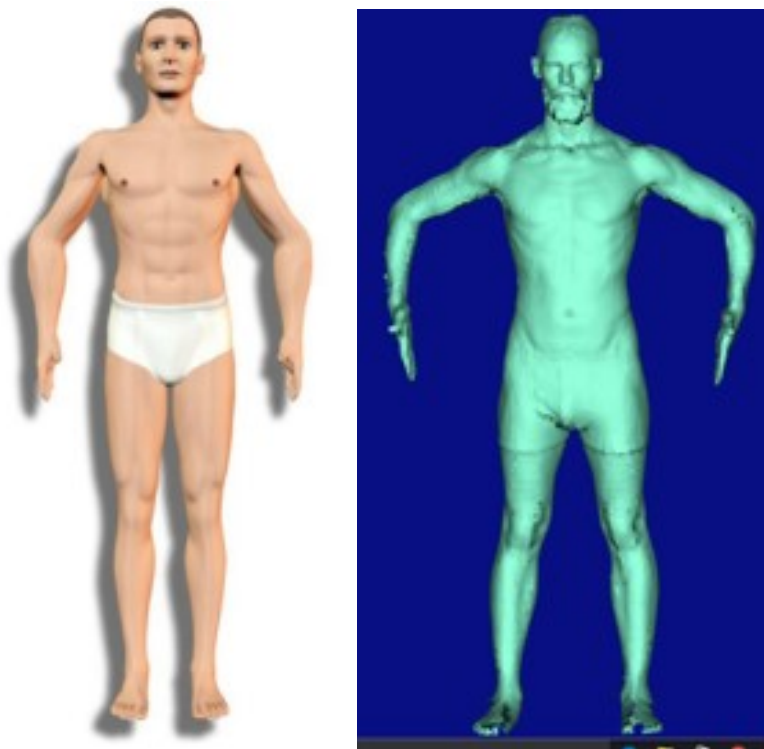


Figure 1. Left – Example 3D body scanning standard pose for participants (image courtesy of Tomkinson et al., 2012); Right – Example scan viewed in the Anthroscan™ software.

At the completion of the 12-second scan, the scan operator checked the scan quality, generated automatic body measurements using the Anthroscan™ software, and then used the BodyClothApp to estimate clothing size. The BodyClothApp (Figure 2) provided visual inspection of individual body measurements and size predictions. The BodyClothApp also generated a PDF report with a summary of results for each participant, which the scan operator printed. The participant re-dressed and then left the scanner room with their individual feedback report (Figure 3). The process is summarized in Figure 5.

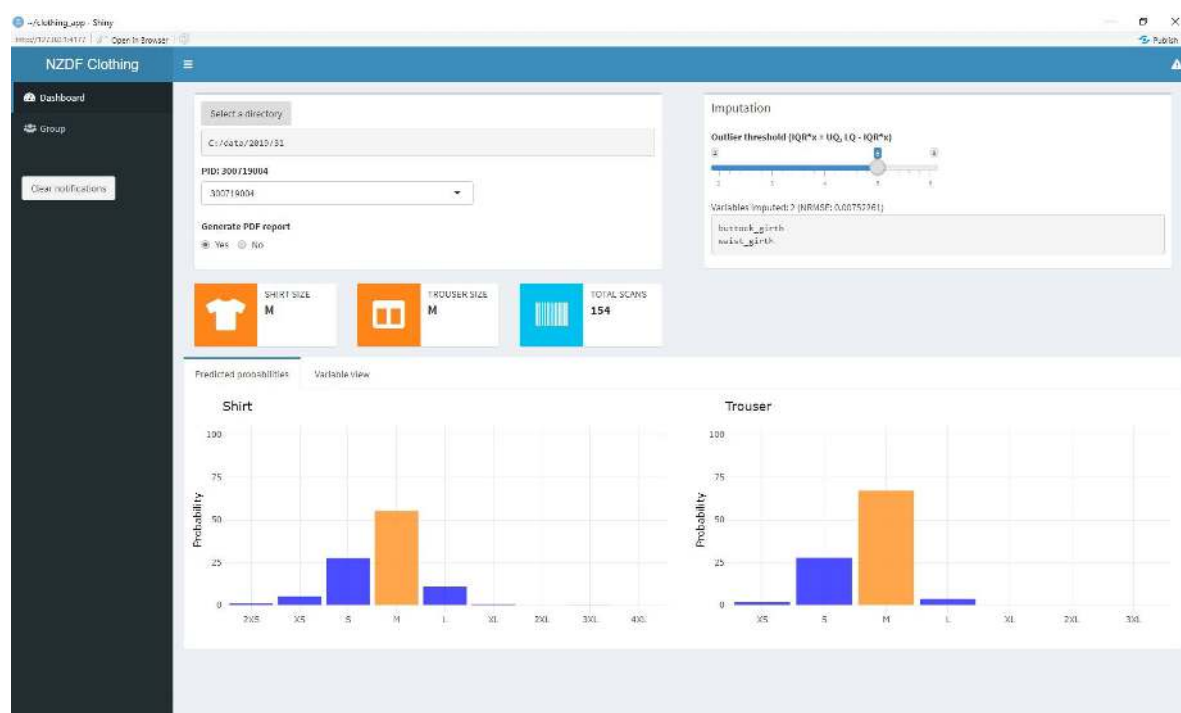


Figure 2. Top – Example BodyClothApp screen for visual inspection of individual body

measurements and clothing size predictions; Bottom – Example BodyClothApp screen showing group results (frequency of sizes predicted).

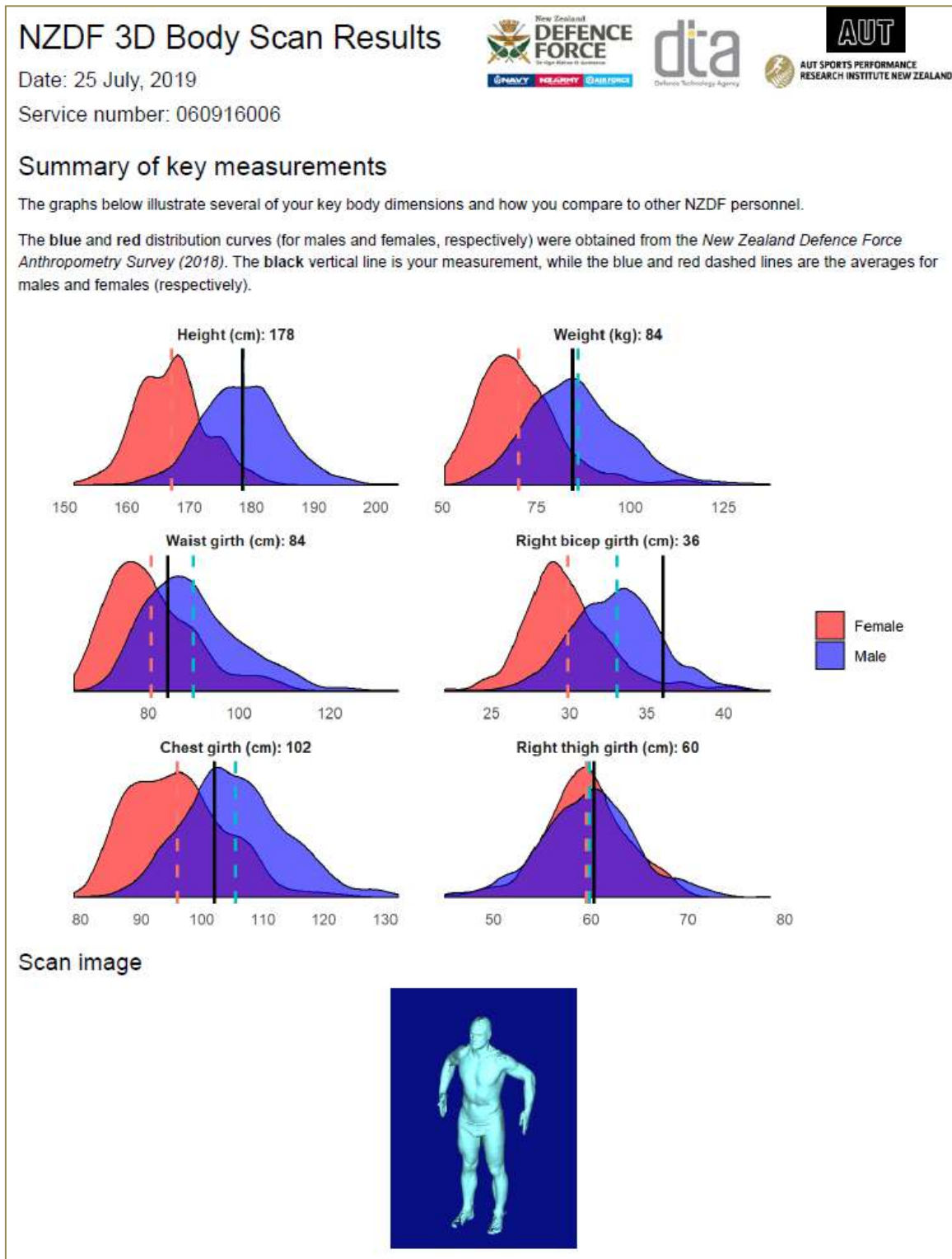


Figure 3. Example BodyClothApp individual feedback report for a participant.

Clothing fit survey

Each recruit was asked to rate how they preferred clothing to fit their body by circling ratings of loose, regular, or tight for circumference-related clothing dimensions (chest, waist, hip, and thigh), and by circling ratings of long, regular, or short for length-related (shirt, sleeve, inseam, and trouser) dimensions (Figure 4). These questions were designed to provide an additional layer of analysis when comparing the uniform sizes predicted by the BodyClothApp to those assigned by the tailors. As the MCU had not been issued to recruits at the time of assessment, these questions were not specific to the MCU.

Please rate how you prefer garments to 'fit' your body. Circle the appropriate rating below each key measurement.

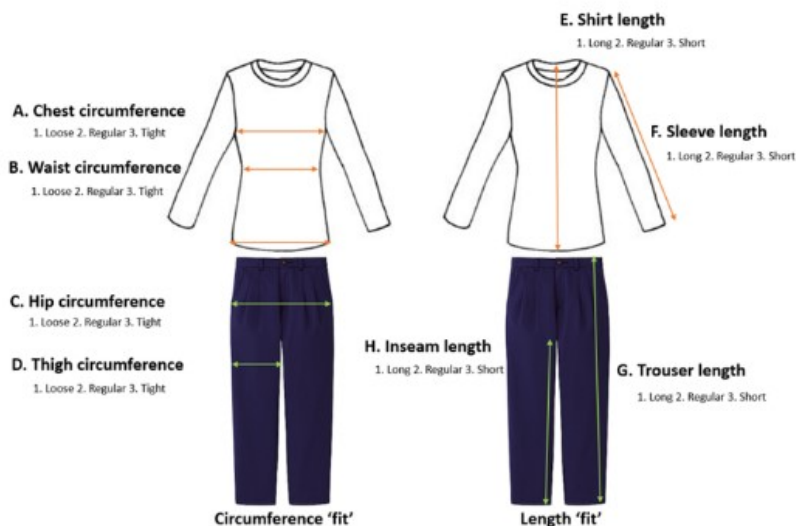


Figure 4.: Fit of clothing rating question posed to participants in the study.

Tailor sizing activity

Each participant was sized by trained tailors from the clothing store at the Waiouru military camp. The tailors size recruits based on 'sight' or personal judgement acquired through experience. According to the tailors, the key determinants of size are chest circumference (for shirts) and height and waist circumference (for trousers). No tape measures are used during their sizing method (Miss Wilhelmina Pou and Mrs Patricia Goddard, Workwear Group). The MCU shirt and MCU trouser size assigned by the tailors was collected so it could be compared to the size predicted by the BodyClothApp.

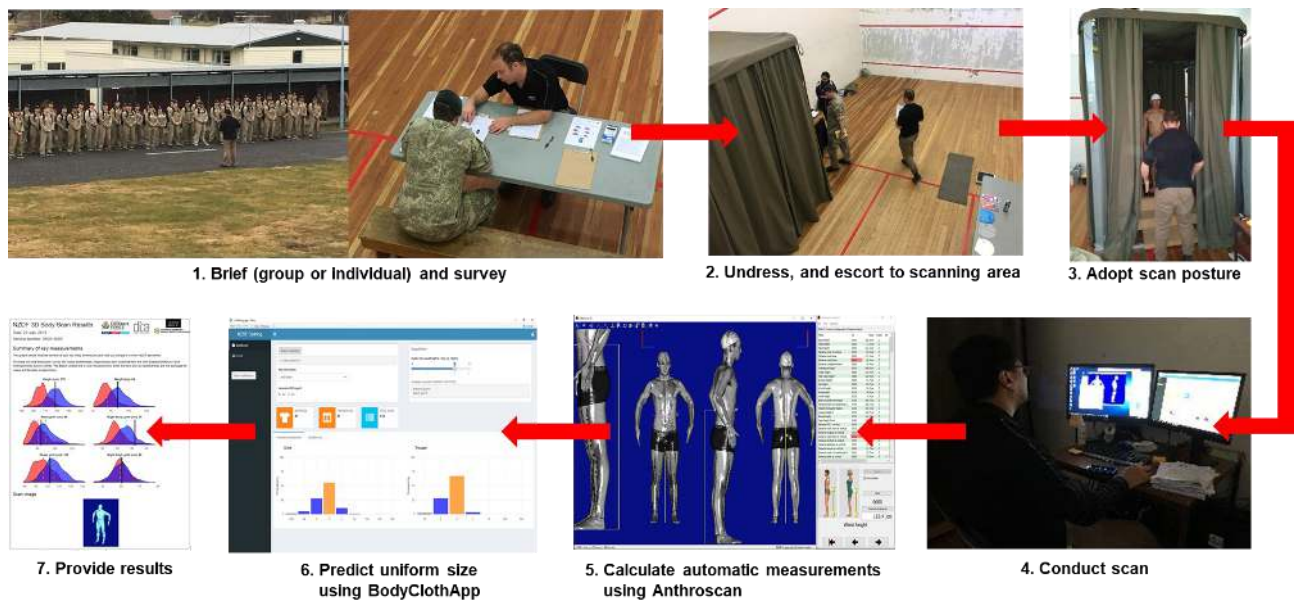


Figure 5. Summary of validation trial procedure.

Statistical analyses

The predictive performance of the model embedded within the BodyClothApp was evaluated via cross validation. The sizes predicted by the BodyClothApp model were compared against the uniform sizes assigned by the tailors. Therefore, the participants used to develop the BodyClothApp model (i.e., from the NZDF Anthropometry Survey 2016–2018) and those used to evaluate the BodyClothApp model were independent. The overriding assumption of this analysis was that the size allocated to each recruit by the tailors was the optimal size for that person (which may not be the case – an issue alluded to in DTA Report 438 titled ‘The relationship between NZDF combat uniform and anthropometry measurements’).

Confusion matrices were generated to visualise the classification error for each size. A confusion matrix shows the correct (true positive, true negative) and incorrect (false positive, false negative) predictions. Table 1 provides an explanation of the interpretation of a confusion matrix using size medium as an example.

Table 1. Interpretation of a confusion matrix.

		Predicted size	
		Medium	Not medium
Tailor size	Medium	True positive	False negative
	Not medium	False positive	True negative

The statistical classification metrics computed from the correct and incorrect predictions were (1) accuracy, (2) sensitivity, (3) specificity, (4) precision, (5) fl score, and (6) balanced accuracy. These metrics are presented in addition to simple accuracy to account for the small number of individuals in some size categories, and to enable comparison with other literature. To aid interpretation, the formula and a brief description of each metric is presented in Table 2.

Table 2. Description of evaluation metrics.

Metric	Formula	Description
Accuracy	$\frac{TP + TN}{TP + TN + FP + FN}$	The proportion of all cases correctly identified.
Sensitivity	$\frac{TP}{TP + FN}$	The proportion of positive (true) cases correctly identified.
Specificity	$\frac{TN}{TN + FP}$	The proportion of negative (false) cases correctly identified.
Precision	$\frac{TP}{TP + FP}$	The proportion of positive cases identified as positive.
F1 score	$2 * \frac{\text{precision} * \text{sensitivity}}{\text{precision} + \text{sensitivity}}$	The harmonic mean of precision and sensitivity.
Balanced accuracy	$\frac{\text{sensitivity} + \text{specificity}}{2}$	The mean of sensitivity and specificity.

TP = true positive, TN = true negative, FP = false positive, FN = false negative.

Any gender or group differences were examined using independent samples t-tests or chi-square tests (where appropriate), with an a-priori alpha set at 0.05. All analyses were performed in R version 3.6.0.

Results

Participants

In total, 154 army recruits were scanned – 77 on each day of data collection. One recruit was not sized by the tailors and was therefore excluded from further analysis. Table 3 presents body size summary statistics for the final sample of 153 recruits (135 males, 18 females).

Table 3. Participant body size descriptives.

	135 Males	18 Females	153 Total
Height (cm)	177.1 $\pm$ 6.4	163.8 $\pm$ 6.0*	175.8 $\pm$ 7.2
Weight (kg)	76.3 $\pm$ 9.7	70.0 $\pm$ 7.5*	75.6 $\pm$ 9.6
BMI (kg/m ²)	24.3 $\pm$ 2.9	25.3 $\pm$ 2.6	24.5 $\pm$ 2.8

Values presented as mean $\pm$ SD; *Significantly different from males at $p < 0.01$.

3D body scanning duration

On the second day of data collection 35 consecutive scans (including 5 females) were timed using a stopwatch. The mean $\pm$ SD time from when a recruit entered the scan room to when they left the scan room was 2 min 15 s $\pm$ 24 s. There was no difference between males (2 min 14 s $\pm$ 26 s) and females (2 min 17 s $\pm$ 20 s) in scan room duration ($p = 0.843$). The actual laser scan inside the scanner took 12 seconds. The calculation of automatic body size measurements in the Anthroscan™ software took approximately 30 s. The size prediction and PDF report generation by the BodyClothApp took approximately 5 s of computer processing time. The remaining time was used to position the recruit in the standard pose. The positioning time varied depending on each recruit's natural body posture and shape (e.g., it was faster to posture individuals with longer arms) and the posturing competency of the scan operator. As recruits were already undressed when they entered the scan room, these time estimates do not include undressing or waiting time.

Clothing sizing allocation by Tailors and BodyClothApp

Figure 6 shows the number of individuals allocated each size by the tailors (left) and by the BodyClothApp prediction model (right). Small and medium sizes were the most

frequent for both shirt and trousers. The tailors allocated four 2XS shirts, one XL shirt, and two XL trousers, whereas the BodyClothApp did not predict any of these extreme sizes.

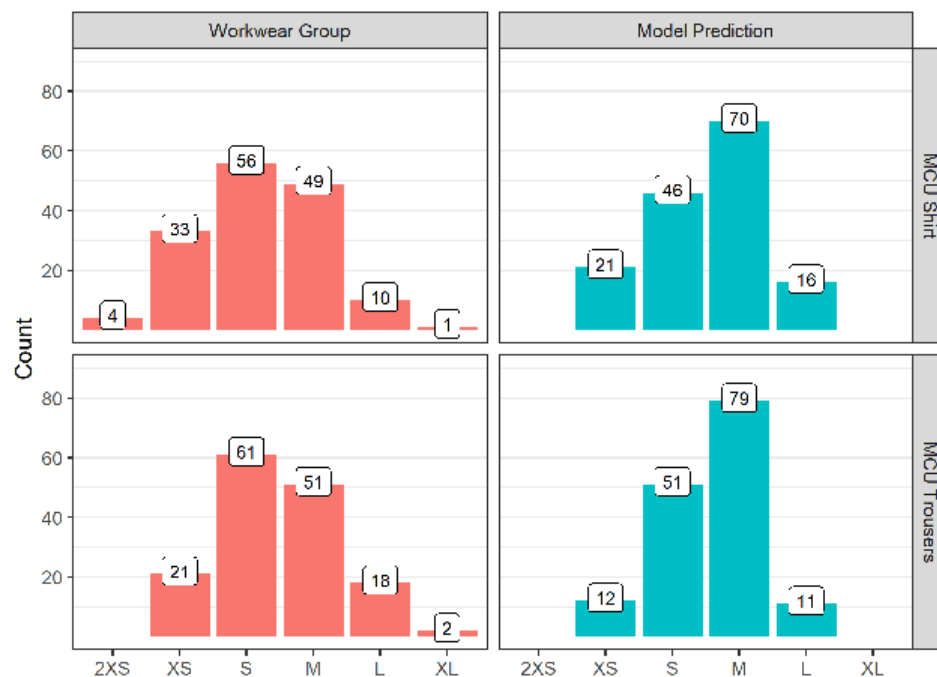


Figure 6. MCU shirt and trousers sizing summary for 153 participants from the tailors and BodyClothApp model prediction.

Clothing fit preference survey

Figure 7 shows the fit preference of circumference-related clothing dimensions at the chest, waist, hip, and thigh. A regular fit was most often preferred for all clothing dimensions, followed by a tight fit and then a loose fit. The chest clothing dimension had a larger proportion who preferred a tight fit compared to other clothing dimensions. The only difference between males and females was for hip circumference, where a lower proportion of females preferred a regular fit (56% vs. 84%), but a higher proportion preferred a loose (11% vs. 3%) or a tight (33% vs. 13%) fit, $\chi^2(2, N = 153) = 8.3, p < 0.05$.

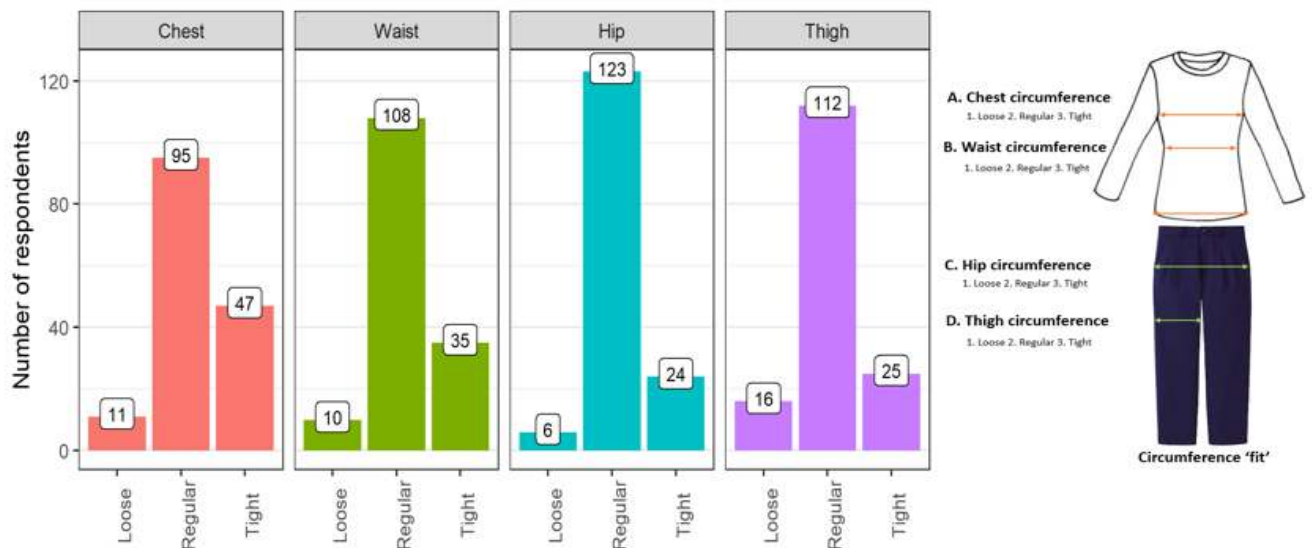


Figure 7. Fit preference of circumference-related clothing dimensions for 153 participants who responded to the fit of clothing rating question.

Figure 8 shows the fit preference of length-related clothing dimensions of the shirt, sleeve, inseam, and trouser. A regular fit was preferred for all clothing dimensions, followed by a long fit and then a short fit. The only difference between males and females was observed for trouser length, where a lower proportion of females preferred a regular length (44% vs. 80%), but a higher proportion preferred a long (39% vs. 14%) or a short (17% vs. 6%) length, $\chi^2 (2, N = 153) = 10.9, p < 0.01$.

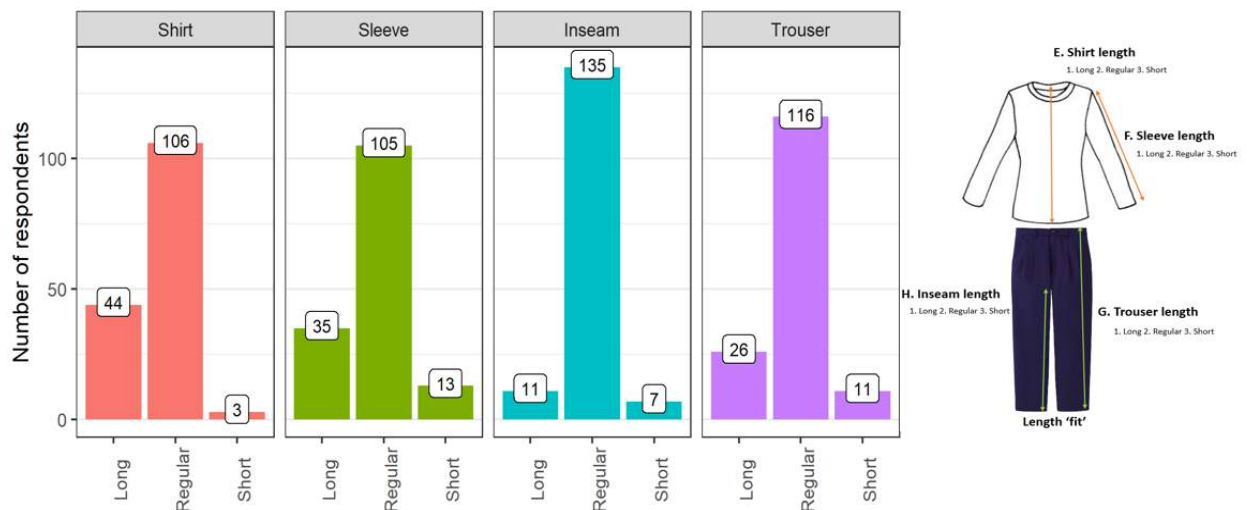


Figure 8. Fit preference of length-related clothing dimensions for 153 participants who responded to the fit of clothing rating question.

MCU shirt size predictions by the BodyClothApp

Figure 9 shows the confusion matrix of MCU shirt size predictions. The overall accuracy was 56.9%; the BodyClothApp model-predicted size was the same as that assigned by the tailors for 87 of 153 recruits (i.e., sum of diagonal squares). The significant areas of disagreement were between S and M sizes, and between XS and S sizes. In both cases the BodyClothApp favoured the larger size, while the tailors assigned the smaller size.

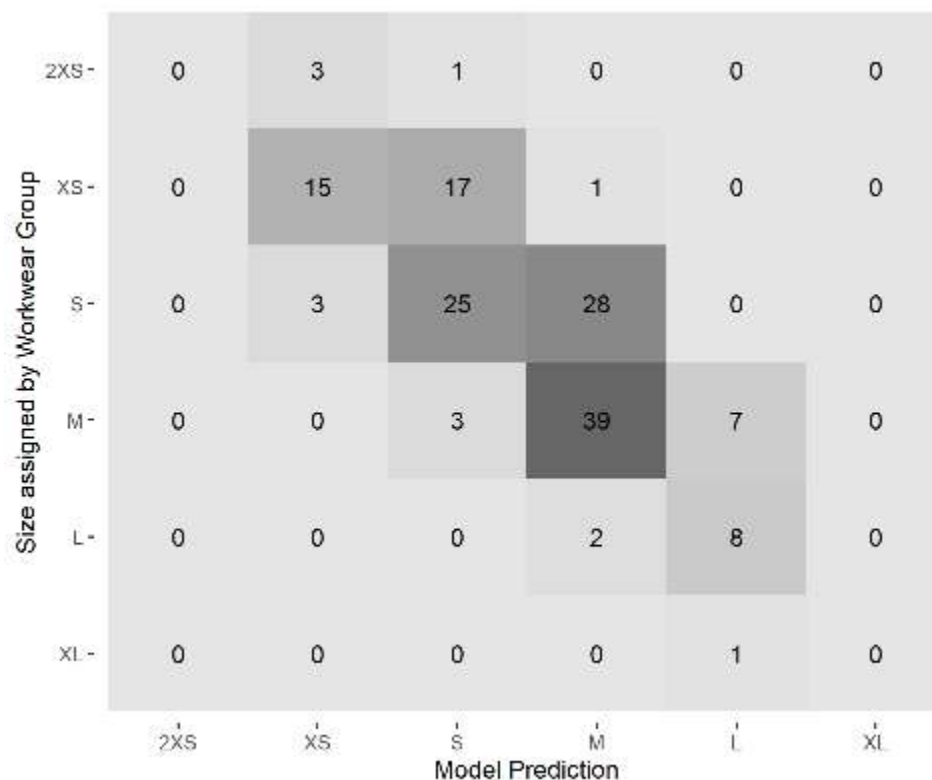


Figure 9. Confusion matrix of MCU shirt size predictions comparing tailors versus BodyClothApp model prediction.

Table 4 displays several classification metrics for the shirt size predictions. The BodyClothApp model's size predictions were more closely aligned with the Workwear-assigned sizes for M and L sizes (80% sensitivity – meaning 80% of Workwear-assigned medium and large sizes were also assigned by the BodyClothApp model). The majority of the Workwear-assigned XS and S sizes were predicted as one size higher (46% and 45% sensitivity, respectively). Very few individuals fell into the extreme size categories (2XS: $n = 3$, XL: $n = 1$) meaning the results for these sizes should be interpreted with caution.

Table 4. Classification results of the MCU shirt for tailors versus BodyClothApp model prediction.

	MCU shirt size					
	2XS ^b	XS	S	M	L	XL ^b
Sensitivity	0.00	0.46	0.45	0.80	0.80	0.00
Specificity ^a	1.00	0.95	0.78	0.70	0.94	1.00
Precision		0.71	0.54	0.56	0.50	
F1-score		0.56	0.49	0.66	0.62	
Balanced accuracy	0.50	0.70	0.62	0.75	0.87	0.50

^aSpecificity calculated using a ‘one-vs-all’ approach; ^bBlank cells indicate insufficient number of cases for calculation.

MCU trouser size predictions by the BodyClothApp

Figure 10 shows the confusion matrix of MCU trouser size predictions. The overall accuracy was 63.4%; the BodyClothApp model-predicted size was the same as the size assigned by the tailors for 97 of 153 recruits (i.e., sum of diagonal squares). The three evident areas of disagreement were between S and M sizes, XS and S sizes, and M and L sizes. The BodyClothApp model tended to estimate a larger size for the Workwear-assigned XS and S, but estimate a smaller size for the Workwear-assigned L.

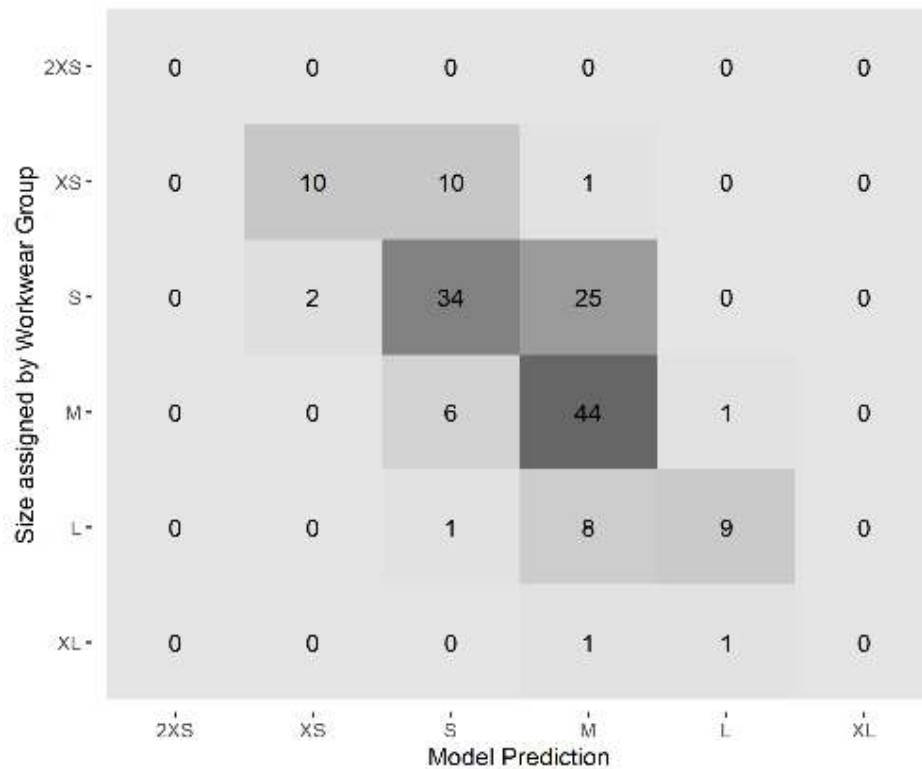


Figure 10. Confusion matrix of MCU trouser size predictions comparing tailors versus BodyClothApp model prediction.

Table 5 displays several classification metrics for the trouser size predictions. The predictions for the M size were the most closely aligned with the Workwear-assigned size (86% sensitivity). Approximately half of the Workwear-assigned XS and L sizes were predicted by the BodyClothApp model (48% and 50% sensitivity, respectively). No individuals were assigned (or predicted) 2XS, and only two individuals were assigned XL by the tailors. As such, the XL results should be interpreted with caution.

Table 5. Classification results of the MCU trousers for tailors versus BodyClothApp model prediction.

	MCU trouser size					
	2XS ^b	XS	S	M	L	XL ^b
Sensitivity		0.48	0.56	0.86	0.50	0.00
Specificity ^a		0.99	0.82	0.66	0.99	1.00
Precision		0.83	0.67	0.56	0.82	
F1-score		0.61	0.61	0.68	0.62	
Balanced accuracy		0.73	0.69	0.76	0.74	0.50

^aSpecificity calculated using a ‘one-vs-all’ approach; ^bBlank cells indicate insufficient number of cases for calculation.

3D body scanning dimensions and MCU shirt sizes by tailors and BodyClothApp

The following graphs illustrate the span of several key body measurements within each of the allocated MCU shirt sizes. Each panel represents a different size allocated by the Tailors (from 2XS to XL). The colour of the marker indicates the BodyClothApp model-predicted size, and the shape represents the agreement between the Workwear-assigned size and the BodyClothApp model-predicted size. Jitter (lateral movement) has been applied to the points to minimise overlap. Figures 11 to 13 show body height, body weight, and arm length within each MCU shirt size, respectively. The confusion between XS and S sizes, and the S and M sizes that was observed in the confusion matrix (Figure 10) is evident in the figures: the BodyClothApp model generally classified taller and heavier recruits, and those with longer arms as one size above the Workwear-assigned size.

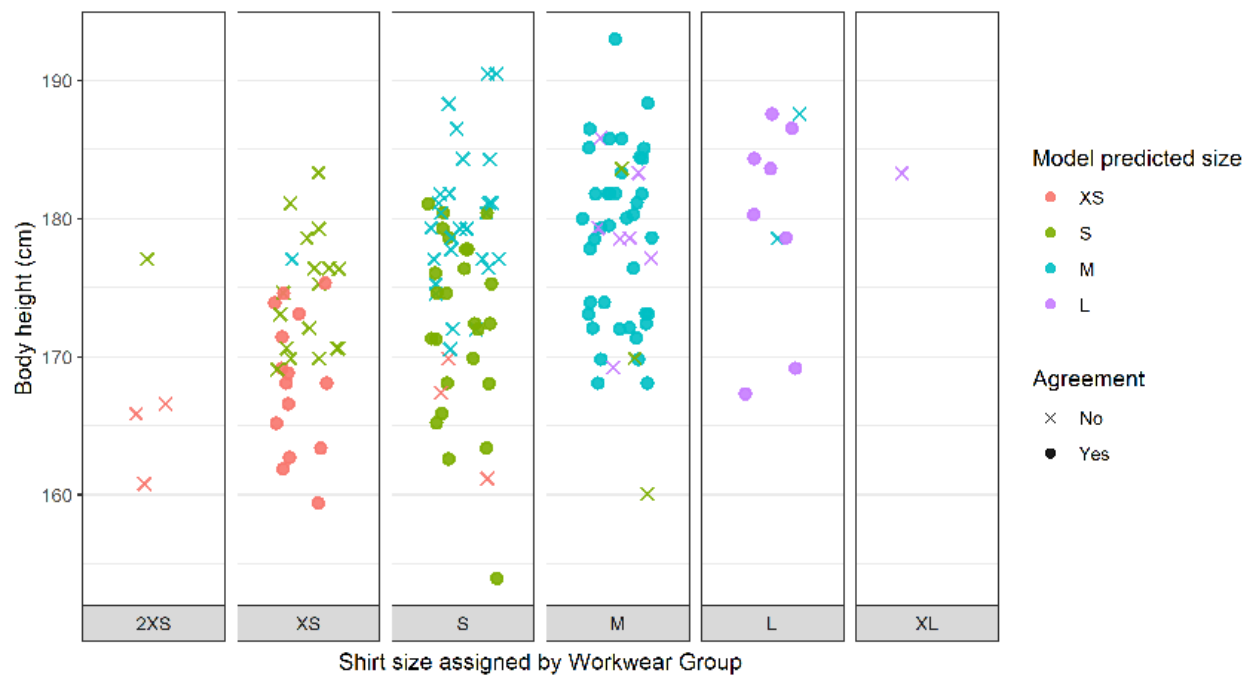


Figure 11. MCU shirt size assigned by Tailors and BodyClothApp versus body height.

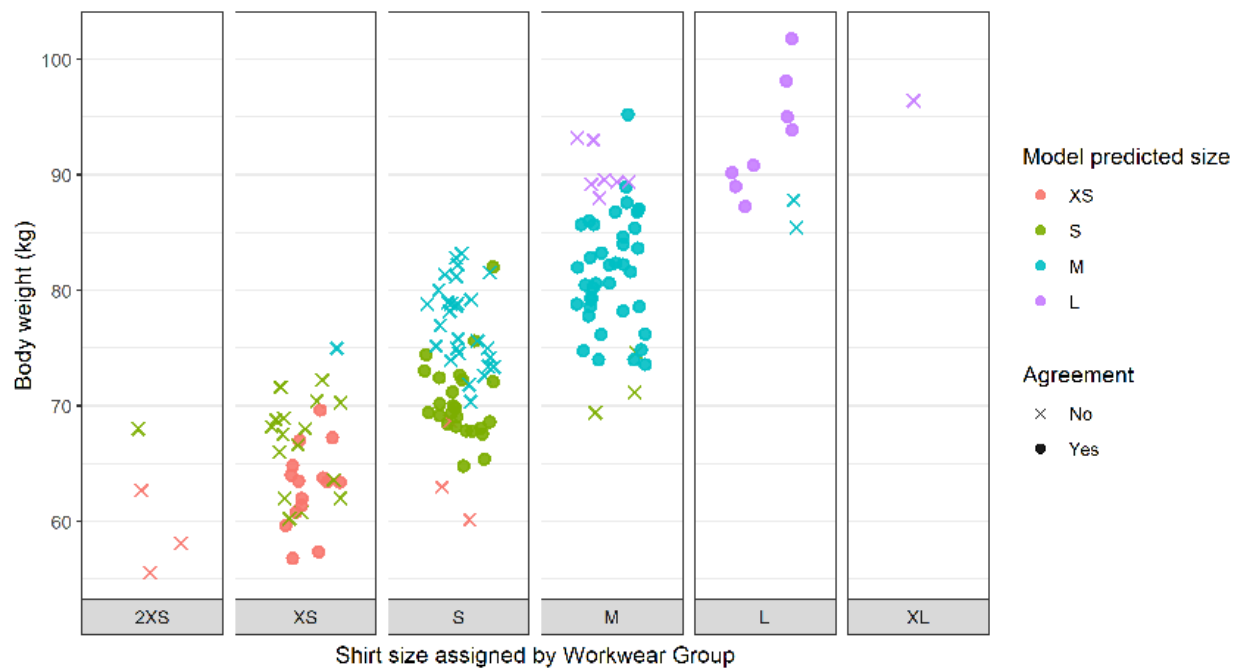


Figure 12. MCU shirt size assigned by Tailors and BodyClothApp versus body weight.

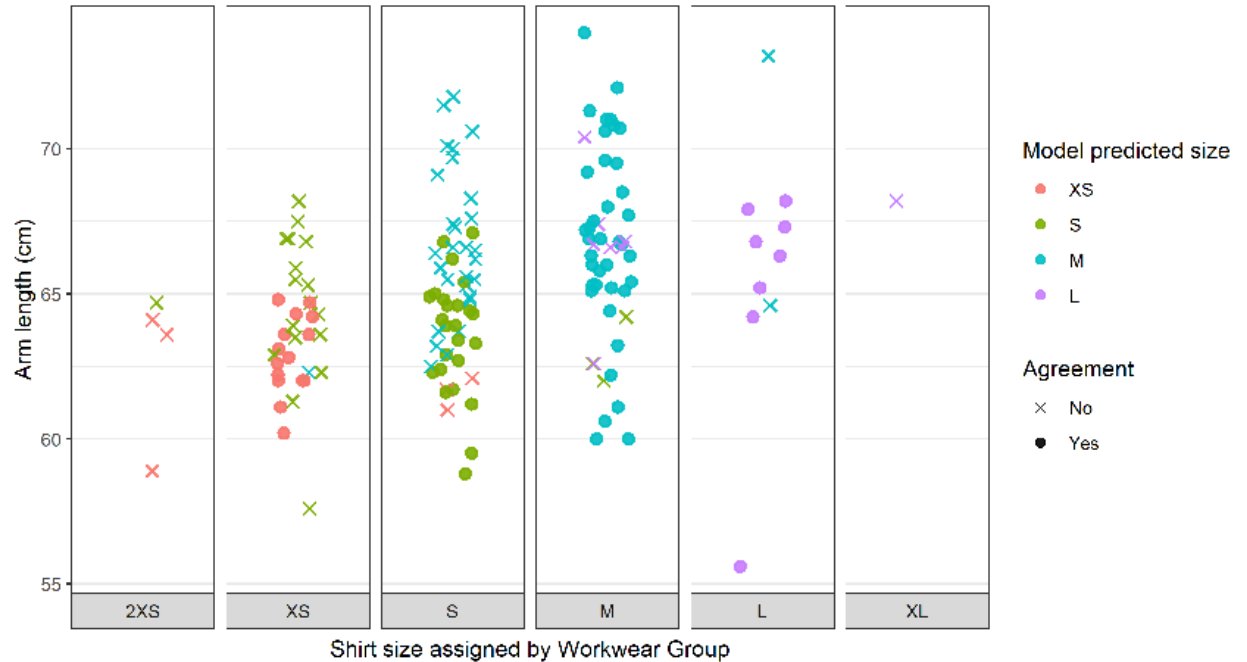


Figure 13. MCU shirt size assigned by Tailors and BodyClothApp versus arm length.

Clothing fit preference and MCU shirt size prediction

There was no association between a correct shirt size prediction and a recruit's fit preference for:

Chest circumference, $\chi^2 (2, N = 153) = 1.8, p = 0.408$

Waist circumference, $\chi^2 (2, N = 153) = 2.6, p = 0.271$

Sleeve length, $\chi^2 (2, N = 153) = 0.14, p = 0.934$

Shirt length, $\chi^2 (2, N = 153) = 0.12, p = 0.941$

3D body scanning dimensions and MCU trouser sizes by Tailors and BodyClothApp

The following graphs illustrate the span of several key body measurements within each of the allocated MCU trouser sizes. Each panel represents a different size allocated by the Tailors (from XS to XL). The colour of the marker indicates the BodyClothApp model-predicted size, and the shape represents the agreement between the Workwear-assigned size and the BodyClothApp model-predicted size. Jitter was applied to the points to minimise overlap. Figures 14 to 16 show body height, waist girth, and sideseam length within each MCU trouser size, respectively. The trouser confusion matrix (Figure 10) revealed three main areas of uncertainty: between S and M sizes, XS and S sizes, and M and L sizes. Figures 14 to 16 help to illustrate possible reasons for this uncertainty – taller recruits and those with a longer sideseam were predicted as one size above the Workwear-assigned size. Recruits with a smaller waist girth were predicted as M as opposed to L.



Figure 14. MCU trouser size assigned by Tailors and BodyClothApp versus body height.

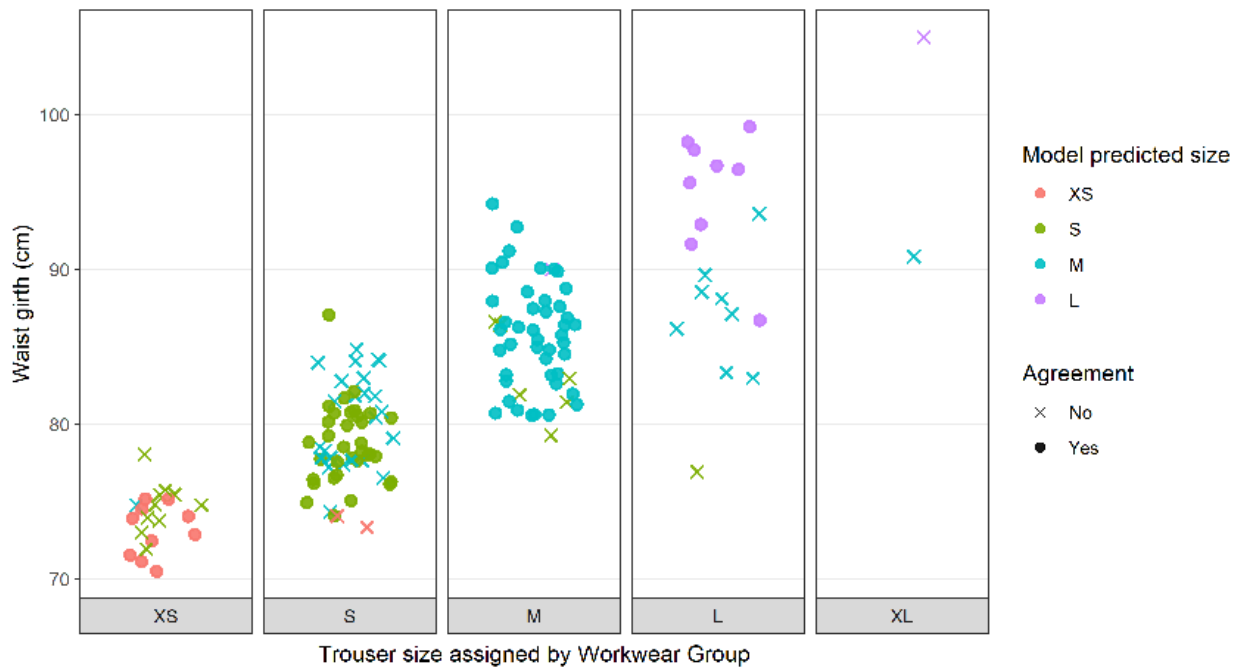


Figure 15. MCU trouser size assigned by Tailors and BodyClothApp versus waist girth.

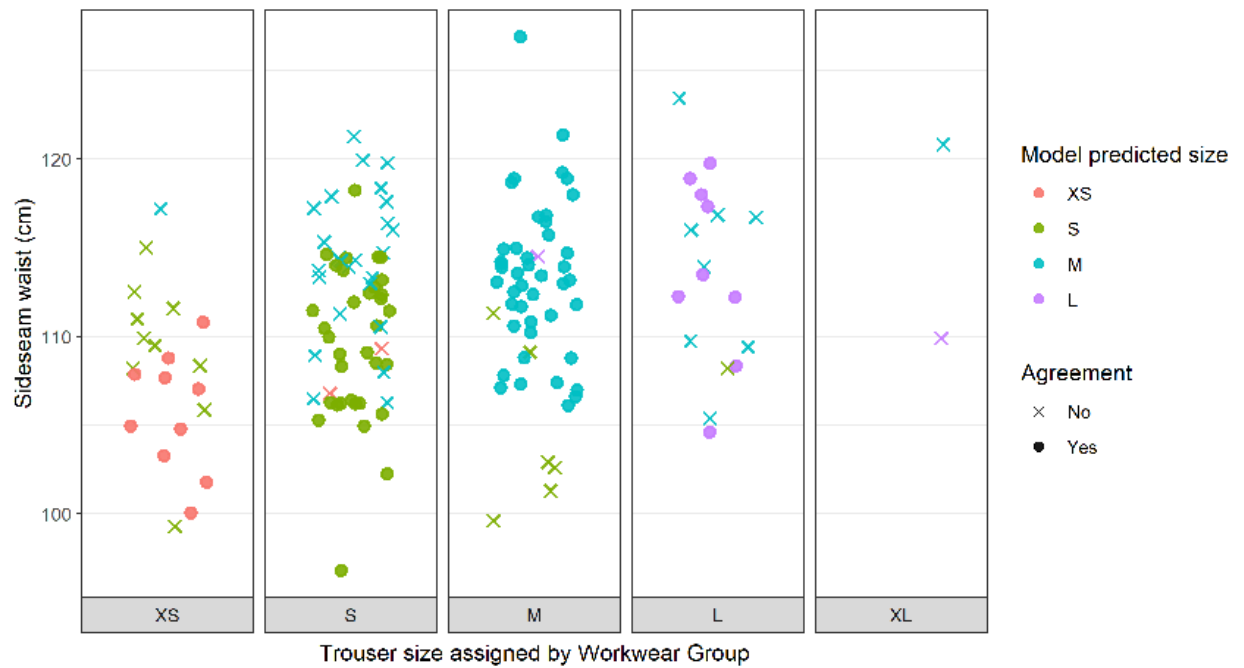


Figure 16. MCU trouser size assigned by Tailors and BodyClothApp versus side seam waist.

Clothing fit preference and MCU trouser size prediction

There was no association between a correct trouser size prediction and a recruit's fit preference for:

Waist circumference, $\chi^2 (2, N = 153) = 3.3, p = 0.191$

Hip circumference, $\chi^2 (2, N = 153) = 3.8, p = 0.151$

Thigh circumference, $\chi^2 (2, N = 153) = 2.4, p = 0.306$

Inseam length, $\chi^2 (2, N = 153) = 0.6, p = 0.758$

Trouser length, $\chi^2 (2, N = 153) = 2.7, p = 0.266$

3D body scanning recruit database

All individual and group-level results were exported to Excel. The `waiouru_scan_data.csv` (Figure 17) contains all 148 body measurements for each participant. This database was checked for outliers (defined as 5 interquartile ranges above or below the median value) and all outliers were removed and imputed (i.e., replaced with a predicted value, given the rest of their body measurements) using non-parametric methods (Stekhoven & Bühlmann, 2011)

pid	across_back_width_arpit_level	across_back_width	across_front_width	ankle_girth_right	ankle_height	arm_length_left	...
300719001	401	406	432	273	74	536	
300719002	385	392	396	234	72	474	
300719003	342	351	388	267	74	530	
300719004	363	375	377	270	76	617	
300719005	401	408	406	274	78	606	
300719006	380	388	452	294	81	631	
300719007	396	411	420	261	77	595	
300719008	394	404	429	282	79	605	

Figure 17. Example lines for the `waiouru_scan_data.csv` containing all 148 body measurements.

The `waiouru_clothing_preds.csv` contains the clothing size predictions for each participant for each clothing item (Figure 18). The probabilities for each size along with the predicted size (i.e., size with highest probability; 3rd column) are presented.

pid	Item	Size	2XS	XS	S	M	L	XL	...
300719001	Shirt	S	0.15	23.14	45.82	26.35	4.53	0.00	
300719001	Trouser	S		6.92	64.95	27.17	0.96	0.00	
300719002	Shirt	S	3.34	41.32	42.46	10.75	2.10	0.03	
300719002	Trouser	S		14.71	51.57	31.90	1.72	0.10	
300719003	Shirt	XS	2.25	59.59	29.52	8.12	0.53	0.00	
300719003	Trouser	S		35.34	44.14	19.64	0.88	0.00	
300719004	Shirt	M	1.04	4.99	27.52	55.27	10.68	0.44	
300719004	Trouser	M		1.60	27.80	67.14	3.45	0.00	
300719005	Shirt	M	0.40	4.41	23.32	63.91	7.47	0.42	

Figure 18. Example lines for the `waiouru_clothing_preds.csv` containing the clothing size predictions for each participant.

Discussion

Efficiency of the 3D body scanning process

The normal sizing process by the tailors is estimated to take 10–15 minutes per recruit (information provided by Miss Wilhelmina Pou, Workwear Group). This trial demonstrated that the use of body scanning technology has the potential to improve the efficiency of the recruit uniform sizing activity. The scanning process took 2 min and 15 s on average. This time could be further minimised with small changes to the scanning protocol and computer hardware. Using computer hardware of a higher specification could reduce the processing time the Anthroscan™ software takes to derive automatic body measurements. Most of the scanning time was used to position the recruit in the correct standard scanning pose. Displaying an animation of the scan during the waiting period may reduce this time, as the recruit can simply assume the standard scanning pose upon entering the scanner, and the scan operator can adjust their position if necessary. The integration between the Anthroscan™ software and the BodyClothApp could also be enhanced by minimising required user input. Currently, the scan operator must interact with the BodyClothApp after each scan; however, this could be completely automated. To further streamline the uniform sizing process, the body scanner could be setup in the clothing store, as opposed to the squash court where this validation trial took place. No recruits or NZDF staff expressed concerns with the scanning procedure.

Agreement between Tailors sizing and BodyClothApp predictions

The overall agreement between the tailors size allocation and the BodyClothApp prediction was 56.9% for MCU shirt and 63.4% for MCU trousers. The agreement was generally above 80% for medium and large sized items. During the analysis it was assumed that the size allocated by the tailors was the optimal size for each recruit. The results of this trial illustrated that with the current range of MCU sizes, deciding the optimal uniform size for a given person is not straightforward. There was considerable overlap of key body dimensions between size categories assigned by the tailors. For example, a 175 cm tall individual could have been assigned a 2XS shirt size, while another individual of the same height could have been assigned a L size (Figure 14). It is currently unclear if an individual would ‘fit’ multiple sizes, or if they would find multiple sizes comfortable, or if they would perceive a clear difference in fit among different sizes.

Similarly, we observed a wide span of body dimensions within a single uniform size category; for example, the arm length of recruits assigned a size S shirt by the tailors had a range of 15 cm (58–73 cm), as observed in Figure 16. The MCU shirt garment specifications state that there are 1 cm increments in sleeve length from a 2XS shirt through to a 5XL shirt. A 15 cm arm length range within a single size suggests that some recruits may have been assigned a shirt size that was not optimal, or that there was error within the Anthroscan™ automatic arm length measurements. Incorrect positioning of the arms during pre-scan posturing may explain variations in the automatic arm length measurements. The experience and competency of the scan operator is important in this regard. Through personal communication with Workwear Group staff (Miss Wilhelmina Pou, Workwear Group), a tailor may size a recruit's shirt by 'eyeballing' their chest circumference and size their trousers by 'eyeballing' their waist circumference and body height. DTA Report 438 (The relationship between NZDF combat uniform and anthropometry measurements) showed that 21.4% and 19% of participants in the NZDF Anthropometry Survey 2016–2018 rated the fit of their shirt and trouser as less than 'Good'. Despite demonstrating the agreement between tailors sizing and BodyClothApp predictions, these circumstances make it hard to definitively quantify the accuracy of the BodyClothApp for predicting the true optimal uniform size.

Limitations of the trial

The primary limitation of this trial is the subjective nature of the optimal (i.e., 'gold standard') clothing size in both the NZDF Anthropometry Survey 2016–2018 data (used to train the prediction model used in the BodyClothApp) and in the current trial (used to evaluate the BodyClothApp model). A suboptimal clothing size could have been allocated in two ways: the tailors could have issued a size that was not optimal, or an individual could have requested a specific size due to their preference of fit (e.g., tight or loose). To minimise this source of error, only individuals that rated their uniform fit as 'Good' or 'Very good' in the NZDF Anthropometry Survey 2016–2018 were used during the model training process; however, this does not guarantee that these individuals were wearing the optimal size MCU.

A second limitation is the assumption that automatic body measurements calculated by the Anthroscan™ software are valid and reliable. DTA Report 439 (NZDF anthropometry survey: body measurement selection and methods validation study) suggested that some automatic measurements were valid while others required post processing before they aligned with manual measurements. For example, there was a 1% difference between

manual (i.e., using a tape measure) and automatic measurements for body height, but a 5.4% difference for chest girth. Automatic measurement inaccuracies would have introduced error into the model prediction.

As the participants in this trial were new recruits, the clothing fit preference survey was general, and not related specifically to the MCU. Ideally, recruits would wear their MCU for an appropriate length of time and then evaluate its functional fit.

Future research

Given the results and the limitations of this project, the following lines of effort are recommended:

Follow-up survey of user fit ratings:

Survey the 153 recruits having worn their MCU for an acceptable period. Recruits who do not feel they have a good fitting MCU should have the opportunity to try an alternate size. This updated information would be used to re-evaluate and/or retrain the prediction model.

Follow-up study where clothes are given to individuals based on the BodyClothApp predicted size, and comfort ratings of fit and adjustments needed for sleeve and leg length are assessed.

Cluster analysis or unsupervised machine learning applied to the NZDF anthropometry database to create distinct groups of NZ Army personnel based on their body size. Creating groups that are as distinct as possible may aid in developing appropriate (and minimal) size categories and garment dimensions for future MCU clothing.

Follow-up study scanning clothed personnel, as opposed to wearing underwear. If the accuracy of the prediction model is maintained under these conditions, it could minimise the time and privacy issues associated with undressing.

Enhancement of prediction model:

The current prediction model can be modified to account for trouser length (short, regular, tall), and assess tailoring requirements (if any). Similarly, it could be adapted to account for the special MCU shirt with a 'slit' used for individuals with a larger waist girth.

Manufacturer clothing dimensions could be embedded into the set of predictor variables used by the model. For example, a new variable might be the difference between the automatic arm length measurement and the sleeve length for a medium size MCU shirt.

Conclusions

This trial demonstrated that 3D body scanning technology in conjunction with statistical learning models has the potential to predict correct fitting NZ Army MCU. There are several areas of future research which could be used to make further refinements to the prediction model and to the sizing process.

Recommendations

Obtain optimal uniform size information that is accurate. An example of this could be a tailor sizing a recruit by measuring their key body dimensions with a tape measure, and then using these dimensions to assign a clothing size. A correct optimal size is crucial for future enhancement of the prediction model.

Conduct a follow-up survey of user fit ratings after the recruits have worn their MCU for an acceptable period. Recruits who do not feel they have a good fitting MCU should have the opportunity to try an alternate size. This updated information could be used to re-evaluate and/or retrain the prediction model.

Explore further research avenues such as applying cluster analysis or unsupervised machine learning to the NZDF anthropometry database to create distinct groups of NZ Army personnel based on their body size. Creating groups that are as distinct as possible may aid in developing appropriate (and minimal) size categories and garment dimensions for future MCU clothing.

Follow-up study scanning clothed personnel, as opposed to wearing underwear. If the accuracy of the prediction model is maintained under these conditions, it could minimise the time and privacy issues associated with undressing.

Add the 3D body scan data collected during this trial to the main NZDFAS database of 1003 personnel.

References

Stekhoven, D. J., & Bühlmann, P. (2011). MissForest—non-parametric missing value imputation for mixed-type data. *Bioinformatics*, 28(1), 112-118.

Tomkinson, G., Daniell, N., Dale, M., & Bowler, T. (2012). Australian Warfighter Anthropometry Survey (AWAS): Methods, temporal changes and summary statistics. Adelaide: University of South Australia.

Appendix – Photos of Waiouru data collection and equipment set-up









The photos show the process of the 3D body scanner set-up and the explanation of the study to a participant in the study.

APPENDIX IV International military survey variable comparison

Measurement comparisons of military surveys (D=digital; P=physical; Ded=derived; L/R=left and right).

MEASUREMENTS/SURVEY	CAESE	UK	ANSUR	AWAS	CAF	ASRA
	R 2002	2007	2012	2012	2012	N
	(Civilian) [44]	(Tri service) [11]	(Army) [10]	(Army) [193]	(Tri service) [7]	2015 (Navy) [161]
Abdomen/buttock depth		D				
Abdominal extension depth, sitting		D	P	P		P
Abdominal link			Ded			
Acromial height		D	P		P	
Acromial height left or right						
Acromial height standing left or right	D L/R					
Acromial height, sitting	P					
Acromial height, sitting left or right	D L/R		Ded	P	P	P
Acromial to elbow length		Ded				
Acromial to wrist length left or right		D L/R				
Acromion height				P		P
Acromion-axilla length			Ded			
Acromion-radiale length			P	D		D
Acromion-radiale length left or right	D L/R					
Acromion-wall depth					P	
Across back breadth (across base of scyes)		D				
Across back width						
Across front width						
Ankle bone height (inside) or left (uk)		D				
Ankle bone height (outside) or right (uk)		D				
Ankle breadth						
Ankle circumference	P	D	P	D		D

Ankle circumference		D					
Ankle circumference at ankle bones		D					
Ankle circumference height		D					
Ankle circumference left			P				
Ankle depth							
Ankle height				D			D
Arm inseam left or right	D L/R						
Arm inseam right	D						
Arm length			Ded		P		
Arm length (shoulder elbow)	P						
Arm length (shoulder wrist)	P						
Arm length (spine wrist)	P						
Arm span							
Armscye circumference (scye circumference over acromion)	P						
Axilla height			P				
Axilla height		D					
Axilla height left	D						
Axilla height right	D						
Axilla height right							
Axillary arm circumference					P		
Axilla-waist length (omphalion)			Ded				
Back length				D			D
Back waist length (cervicale to waist following contour over shoulder blade)		D					
Back width				D			D
Ball of foot circumference			P				
Ball of foot length			P	D			D
Biacromial breadth digital	D	D		D			D
Biacromial breadth physical			P	P	P		
Biceps breadth, flexed							
Biceps circumference flexed			P	P			P
Biceps depth							
Bicristal breadth	D		P	P			P
Bideltoid breadth		D	P	P	P		P

Bigonial breadth	D					
Bi-lateral femoral epicondyle breadth sitting	D					
Bi-lateral humeral epicondyle breadth sitting	D					
Bimalleolar breadth		P				
Bispinous (iliac spine) breadth	D					
Bitragion						
Bitragion breadth	D					
Bitragion chin arc		P				
Bitragion coronal arc				P		
Bitragion frontal arc						
Bitragion submandibular arc		P	D			D
Bitragion subnasale arc						
Bi-trochanteric breadth sitting	D					
Bi-trochanteric breadth standing	D					
Bizygomatic breadth	P	P	P	P		P
Body depth						
Body mass index				EST		
Breast/bust prominence	D					
Bust level			D			D
Bust/chest circumference	P					
Bust/chest circumference under bust	P					
Bust point breadth	D					
Bustpoint bustpoint breadth	D					
Buttock circumference	D	P	P	P		P
Buttock depth		P				
Buttock height*	D	P				
Buttock to trochanter length	D					
Buttock-knee length	P	D	P	P	P	P
Buttock-popliteal length		D	P	P	P	P
Calf breadth						
Calf circumference	D	P	D			D
Calf depth						
Calf height	D					
Calf link		Ded				

Cervicale height	D	D	P	P		P
Cervicale height, sitting			Ded			
Cervicale to breast point		D				
Cervicale to waist		D				
Cervicale wrist length					P	
Chest breadth			P	P	P	P
Chest bust height (at nipple) height		D				
Chest circumference			P	P	P	P
Chest circumference at axilla		D				
Chest circumference at scye						
Chest circumference below breast				P		P
Chest depth		D	P	P		P
Chest girth (chest P circumference at scye)						
Chest height	D	D	P			
Chest height, sitting			Ded			
Chest level				D		D
Chest/bust circumference at nipple						
Chest-waist drop (omphallion)			Ded			
Chin height		D				
Clavicle link			Ded			
Crotch height	P	D	P	P	P	P
Crotch length		D				
Crotch length anterior (omphallion)			Ded			
Crotch length omphallion			P	D		D
Crotch length posterior omphallion			P			
Dactyllion height			Ded			
Dactyllion reach from wall			Ded			
Deltoid point height						
Ear breadth			P			
Ear length			P			P
Ear length above tragon						
Ear protrusion			P			

Ecto-orbitale to top of head							
Elbow breadth							
Elbow circumference	D						
Elbow depth							
Elbow fully bent, circumference	P						
Elbow functional reach	P						
Elbow girth						P	
Elbow height sitting (comfortable) left or right	D L/R						
Elbow height sitting right	P						
Elbow height standing left or right	D L/R						
Elbow rest height				P			
Elbow rest height, sitting	P	P			P	P	
Elbow rest height, standing	Ded	Ded					
Elbow to elbow breadth							
Elbow-centre of grip length							
Elbow-wrist length		Ded					
Eye height		Ded					
Eye height, sitting	P	D	P	P	P	P	
Eye height, standing		Ded			P		
Face length	P						
Femoral epicondyle lateral left (or right) to malleolus lateral left (or right)	D L/R						
Foot breadth						P	
Foot breadth horizontal			P	P			P
Foot breadth left	D L/R						
Foot breadth right	D						
Foot length	P		P	D	P		D
Forarm-center of grip length			P				
Forearm circumference	D						
Forearm circumference flexed			P	P			P
Forearm circumference right							
Forearm depth							
Forearm fingertip length							
Forearm-forearm breadth			P	P			P

Forearm-hand length			P			
Functional grip reach			Ded			
Functional leg length			P			
Functional reach - seated		D				
Gluteal furrow height						
Hand breadth	P	P	P	D	P	D
Hand circumference	P	P	P	D	P	D
Hand depth						P
Hand length	P	P	P	D	P	
Hand thickness at metacarpale iii						
Head breadth	P	P	P	D	P	D
Head breadth sitting						
Head circumference (physical)	P	P	P	P		P
Head circumference (scanned)		D				
Head length	P	P	P	D	P	P
Heel ankle circumference			P			
Heel breadth			P			
Heel instep circumference						
Heel instep circumference		D				
Heel instep circumference right						
Height sitting						
Helmet rim to top of head						
High hip				D		D
Hip				D		D
Hip breadth			P		P	
Hip breadth standing		D				
Hip breadth, sitting	P	D	P	P	P	P
Hip circumference (maximum height)	P					
Hip circumference (maximum)	P					
Hip height						
Hip level female				D		D
Hip level male				D		D
Illiocristale height			P	P		P
Index finger breadth, distal						P
Index finger breadth, proximal						
Index finger length					P	

Index finger reach							Ded
Infraorbital height sitting left	D						
Infraorbital height sitting right	D						
Infraorbital height standing left	D						
Infraorbital height standing right	D						
Inter-elbow span		P					
Interpupillary breadth		P	P	P	P	P	
Interpupillary distance	D						
Interscye distance	D						
Interscye i			P				
Interscye ii			P				
Knee breadth							
Knee circumference				D			D
Knee circumference		D					
Knee circumference right							
Knee fully bent circumference		P					
Knee height		D					
Knee height midpatella			P				
Knee height right							
Knee height sitting	P	D	P	P	P	P	
Knee height standing left	D						
Knee height standing right	D						
Knee level				D			D
Lateral femoral epicondyle height			P				
Lateral malleolus height			P				
Leg length (outside)							
Lower leg length							
Lower thigh circumference			P				
Malleolus height lateral left	D						
Malleolus height lateral right	D						
Malleolus height medial left	D						
Malleolus height medial right	D						
Maximum hip circumference				D			D
Menton to top of head							
Menton-sellion height			P	D	P		
Menton-sellion length							D

Mid thigh breadth						
Mid thigh circumference						
Mid thigh circumference	D					
Mid thigh circumference right						
Mid thigh depth						
Mid thigh height	D					
Mid thigh height right						
Midshoulder height, sitting	D					
Mouth width						
Nape to bustpoint thelion length			D			D
Nape to waist centre back			D			D
Nape to waist over bust			D			D
Neck base circumference	P					
Neck base height, front	D					
Neck breadth						
Neck circumference	D	P	D			D
Neck circumference base		P	P			P
Neck depth						
Neck height	D					
Neck height, font						
Neck height, right						
Neck height, side	D					
Neck link			Ded			
Neck-buttock length			Ded			
Neck-gluteal furrow						
Neck-scye length			Ded			
Outside leg length			D	P		D
Outside leg length	D					
Outside leg length right						
Overhead fingertip reach						P
Overhead fingertip reach, sitting		P				
Palm length		P				
Pelvic link		Ded				
Popliteal height	D	P	P	P		P
Pupil to vertex	Ded					
Radiale-styllion length		P	D			D

Radiale-styllion length left	D						
Radiale-styllion length right	D						
Rise (omphallion)			Ded				
Sagittal arc						P	
Scye circumference						P	
Scye depth				D			D
Seat angle				D			D
Seat level				D			D
Sellion supramenton length	D						
Sellion-back of head							
Sellion-top of head							
Shoulder breadth (bideltoid)	P						
Shoulder circumference			P				
Shoulder drop		D					
Shoulder drop right							
Shoulder height (90cm from mid-line)			Ded				
Shoulder height sitting							
Shoulder height standing							
Shoulder length			P		P		P
Shoulder slope (degree)							
Shoulder waist length (natural indentation)							
Shoulder-elbow length			P				
Shoulder-waist length (omph)			Ded				
Side back waist to ground left		D					
Side back wait to ground right							
Side waist to hip		D					
Side waist to hip right							
Sitting height	P	D	P		P	P	P
Sleeve inseam			Ded				
Sleeve length spine-elbow							
Sleeve length spine-scye							
Sleeve length spine-wrist			P				
Sleeve outseam			P		D		D
Sleeve outseam left	D						
Sleeve outseam right	D						
Span			P			P	

Sphyrion height, left or right	D L/R					
Spine to elbow (bent)		P				
Spine to scye (half back)		P				
Spine to wrist		P				
Stature	P	P	P	P	P	P
Stomach depth (to individuals back) - abdominal extension depth - seated		D				
Stomach depth (to wall)		D				
Stool height		D				
Strap length						
Subscapular skinfold	P					
Substernale height				P		
Suprasternale height	D		P	P		P
Suprasternale height, sitting			Ded			
Suprasternale tenth rib length			Ded			
Suprasternale waist (omph) length			Ded			
T2 height				P		
Tenth rib height			P	P		
Thelion-thelion breadth						
Thigh breadth						
Thigh circumference			P	D		D
Thigh circumference (max gluteal fold level)		D				
Thigh circumference maximum	P					
Thigh clearance			P	P	P	P
Thigh clearance height		D				
Thigh depth, crotch						
Thigh height		D				
Thigh link			Ded			
Thorax depth at nipple						
Thorax link			Ded			
Thumb breadth						
Thumbtip reach	P		P	P	P	P
Thumbtip reach extended					P	
Tibial height			P			
Torso length						D

Total crotch length	P				
Tragion height				Ded	
Tragion height, sitting				Ded	
Tragion-top of head				P	
Triceps skinfold	P				
Trochanter height, left or right	D L/R				
Trochanter to femoral epicondyle lateral, left or right	D L/R				
Trochanter to seated surface, left or right	D L/R				
Trochanterion height			P	D	D
Underbust chest circumference height	D				
Underbust circumference	D				
Underbust circumference height	D				
Upper arm (biceps) circumference	D				
Upper arm circumference right					
Vertical functional reach sitting	P				
Vertical functional reach standing	Ded				
Vertical grip reach				Ded	
Vertical grip reach down				Ded	
Vertical grip reach, sitting				Ded	
Vertical index fingertip reach				Ded	
Vertical index fingertip reach sitting				Ded	
Vertical thumbtip reach, sitting				Ded	
Vertical thumb tip reachdown					
Vertical trunk circumference right	P	D	P		P
Vertical trunk circumference, wide				D	D
Vertical wrist height					
Vertex-eye height					
Vertex-mid shoulder height					

Waist (natural) circumference		D					
Waist back length (cervicale to waist)		D					
Waist back length omphallion			P				
Waist back vertical omphallion			Ded				
Waist breadth			P				
Waist circumference omphallion			P	P	P	P	
Waist circumference preferred	P			D			D
Waist depth			P				
Waist front length	P						
Waist front length, omphalion							
Waist front length, sitting			P				
Waist height (natural indentation)		D					
Waist height omphallion			P				
Waist height preferred	P						
Waist level centre back				D			D
Waist level centre front				D			D
Waist-buttock drop (omphallion)			Ded				
Waist-hip distance				D			D
Waist-waist omphallion over shoulder			Ded				
Weight	P	P	P	P	P	P	P
Wrist breadth							
Wrist centre grip distance							P
Wrist centre thumb tip distance							P
Wrist circumference		D	P	D			D
Wrist depth							
Wrist height			P				
Wrist wall length							
Wrist-centre of grip							
Wrist-index finger length							
Wrist-thumb tip length							
Total measures	99	95	135	84	47		86

MEASUREMENTS AND NORMATIVE DATA FOR THE NEW ZEALAND DEFENCE FORCE (NZDF) KINANTHROPOMETRY SURVEY

Stephen Kolose, Patria Hume, Grant Tomkinson, Arthur Stewart, Tom Stewart, Stephen Legg

Introduction

Data are for 1,003 (791 male and 212 female) New Zealand military personnel who had 84 physique measures obtained manually using surface anthropometry and digitally using a 3D body scanner.

How to read the proformas

The physique proformas have been created from data from the 1,003 (791 male and 212 female) New Zealand military personnel who had 85 physique measures obtained manually using surface anthropometry and digitally using a 3D body scanner. The purpose of these proformas is to provide a clear and concise record of the measurement protocol used for each physique variable, and the data summary statistics. The data is the newest and most comprehensive anthropometric dataset of New Zealanders. To assist with the application of the data for research purposes (e.g. for ergonomics, health research or design activities etc) each body measurement proforma (comprising of two pages) was developed to be used as a quick reference guide. The first page of each proforma presents general information regarding the origin of each measurement, instructions on how to capture the landmarks and measurements and an illustration of the measurement.

The key for interpreting the information on the first page (see Figure 1 for an example):

1. Measurement name.
2. Whether the measure is a physical (manual anthropometric), automatic (computer calculated), or digital measurement (using computer software), and the units.
3. Measurement equipment used (e.g. Physical, Anthroscan automatic or CySlice tool).
4. The source of the measurement definition.
5. The measurement definition.
6. Landmark(s) required. Note that automatic measures do not require landmarks.
7. Posture required refers to a) specific postures for the physical measurements and b) body scan postures 1 to 3.
8. The procedure describes the steps that the assessor, body scan operator or CySlice operator must perform to extract the measurements.
9. Full citation of the protocols named in the 'Source' section.
10. Notes refer to special instructions that the assessor must consider. These instructions are those which do not fit under the previous headings.

- 1 **Buttock depth** 2
Digital measurement (mm)
- 3 **Measuring instrument:**
CySlice
- 4 **Source:**
UK Anthropometry Survey, NZDFAS
- 5 **Definition:**
The maximum circumference of the body (excluding the appendages) at or about the height of the hip. This measure must be taken below the height of the iliac crest in Anthroscan.
- 6 **Landmark required:**
None as the caliper function is used.
- 7 **Posture required:**
Scan position posture 1. Stand with feet together, arms straight at the sides with the palms facing in towards the thigh. Fingers together and extended with the thumb facing forward. Stand with back erect and head in the Frankfort plane.
- 8 **Procedure:**
In CySlice use the caliper tool. When viewed from the side, highlight the area of the buttocks that is above the height of the crotch and below the level of the ilioacristale right landmark. Avoid any artefacts of webbing between the right hand and the thigh. Select the X function (to create a coronal plan) to record the depth. Measurements are reported in mm.
- 9 **Reference**
Pringle, R. H., Puxley, A. J., Puxley, K. P. M., Turner, G. M., & Tyrell, A. K. (2011). Anthropometry Survey of UK Military Personnel 2006-7 (Issue 3) (QINETIQ/07/01821/3.0): QinetiQ Ltd.

Kolose, S., Hume, P. A., Stewart, A., Tomkinson, G., Stewart, A. D., & Legg, S. J. (2020). Size and Shape of the New Zealand Defence Force 2012: A 3D scanning survey. Auckland: Auckland University of Technology.
- 10 **Notes:**
Use the Crosshair tool to align the participants posture. If the measurement is taken on a fold or crease in the briefs, consider remeasuring. If the anterior portion of the measure is taken on the male genitalia make minor adjustments to move the point away.

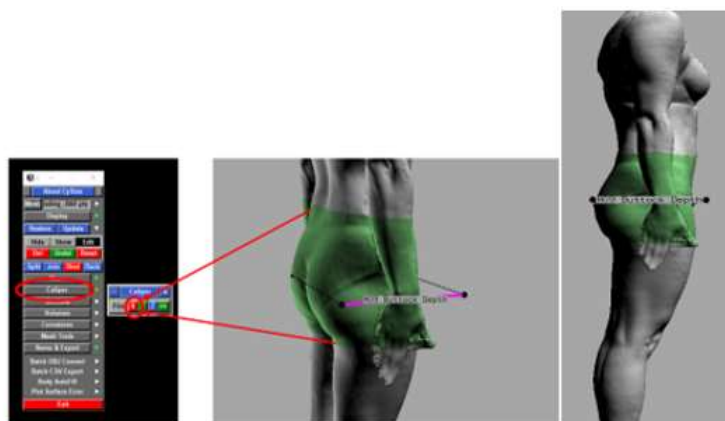


Figure 1. Example of the first page of proforma content.

Bust chest girth

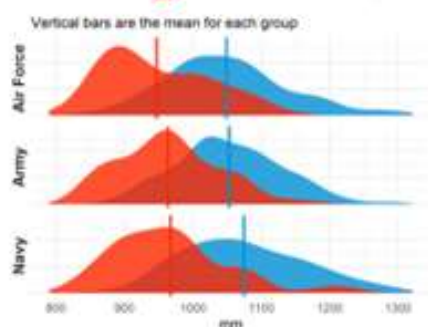
Automatic measurement (mm)

1

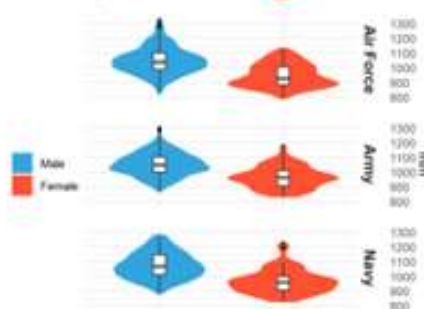
Male					Female				
All	Air Force	Army	Navy		Air Force	Army	Navy	All	
790	216	486	88	N	72	97	43	212	
1054	1049	1053	1075	Mean	947	964	967	959	
83	91	79	89	SD	79	73	86	78	
824	824	867	880	Min	790	829	827	790	
1321	1321	1300	1285	Max	1136	1174	1226	1226	
1281	1283	1248	1282	P99	1110	1147	1212	1171	
1244	1274	1217	1271	P98	1096	1121	1198	1132	
1219	1250	1203	1252	P97	1089	1092	1187	1099	
1196	1203	1180	1228	P95	1085	1071	1095	1085	
1165	1176	1157	1198	P90	1085	1087	1070	1067	
1145	1142	1138	1165	P85	1035	1049	1064	1045	
1123	1116	1120	1152	P80	1026	1025	1015	1025	
1105	1101	1104	1146	P75	1006	1011	1000	1008	
1094	1082	1094	1120	P70	993	991	991	992	
1080	1074	1081	1096	P65	983	981	986	982	
1070	1064	1069	1088	P60	982	974	972	973	
1061	1056	1061	1076	P55	940	970	969	963	
1048	1038	1048	1070	P50	928	963	958	954	
1037	1027	1037	1057	P45	920	954	955	941	
1026	1021	1027	1042	P40	908	947	935	930	
1019	1009	1020	1030	P35	898	937	924	922	
1009	996	1012	1017	P30	891	929	919	907	
998	988	1000	1012	P25	884	907	906	897	
987	980	989	994	P20	877	897	896	886	
986	959	966	977	P15	872	880	887	875	
949	942	954	963	P10	857	870	872	864	
925	920	928	948	P5	848	853	857	850	
914	894	917	942	P3	847	845	848	845	
902	883	910	936	P2	844	845	842	843	
883	865	887	925	P1	826	842	835	830	

2

Distribution plots for each service and gender



3



The second page of each proforma presents (see Figure 2):

- Summary statistics table (e.g., showing sample size, mean, standard deviation, minimum, maximum, and percentiles [1–99]).
- A density plot which shows the measurement distribution. The vertical bars represent the sample mean.
- A violin plot (with a built-in boxplot) is an alternative view of the measurement distribution.

Both the density and violin plots show data for gender (male, female) and service type (Army, Air Force or Navy).

Figure 2. Example of Page 2 of proforma content.

Abdominal extension depth sitting - Post-processed measurement (mm)

Measuring instrument:

CySlice. Measurements should be in mm.

Source:

ANSUR.

Definition:

The horizontal distance between the Abdominal Point Anterior and a point on the back at the same level.

Landmark required:

None.

Posture required:

Scan position posture 3. Ensure that the participant is sitting with their knee bent at a 90. This can be done by moving the body scanner seat up or down. This can also be facilitated by aligning the popliteal fossa (vertically) in line with Pternion (back of the foot).

Procedure:

In CySlice use the caliper tool. View from the front. Create a rectangle at the same level as the Omphalion. Select the X function (to create a coronal plan) to record the depth. Measurements are reported in mm.

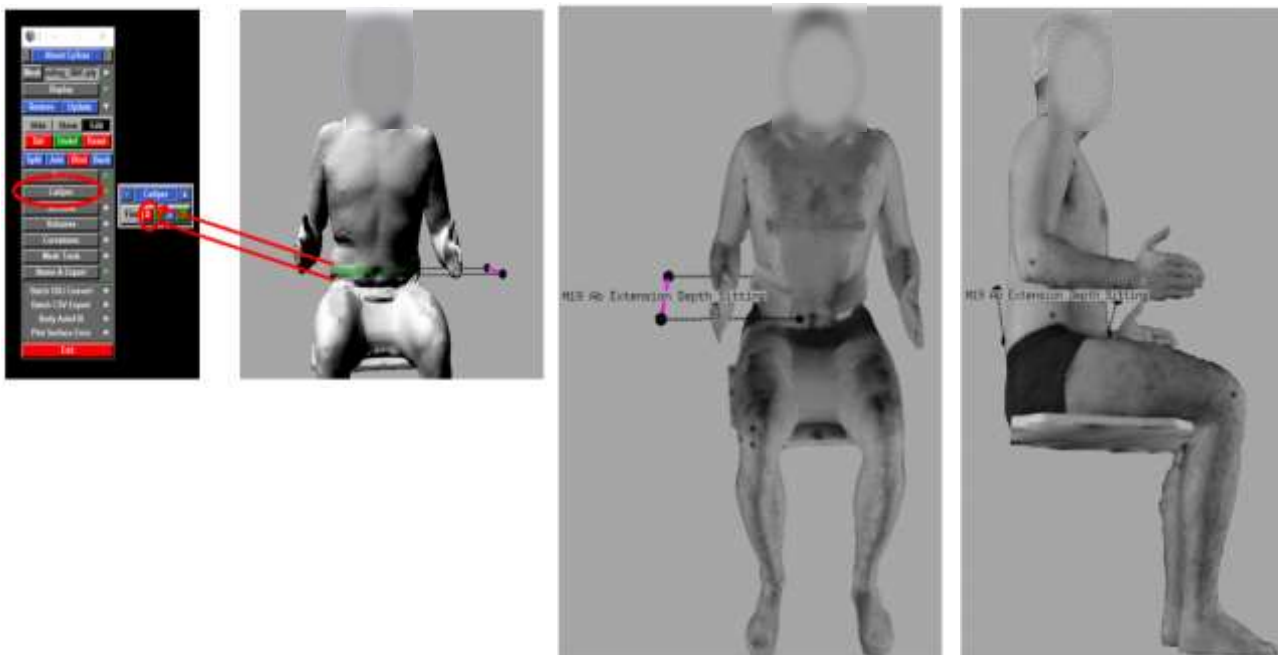
Reference:

Gordon, C.C., Blackwell, C.L., Bradtmiller, B., Parham, J.L., Barrientos, P., Paquette, S.P., Corner, B., Carson, J.M., Venezia, J.C., Rockwell, B.M., Mucher, M., Kristensen, S., 2014. 2012 Anthropometric survey of U.S. army personnel: Methods and summary statistics., Natick Soldier Research, Development of Engineering Center, Yellow Springs, Ohio, U.S. (p46).

Kolose, S., Hume, P.A., Tomkinson, G.R., Stewart, A., Stewart, T., Legg, S.J. (2021). Three-dimensional physique assessment in the military: New Zealand Defence Force Anthropometry Survey protocols and summary statistics., SPRINZ: Auckland, New Zealand.

Notes:

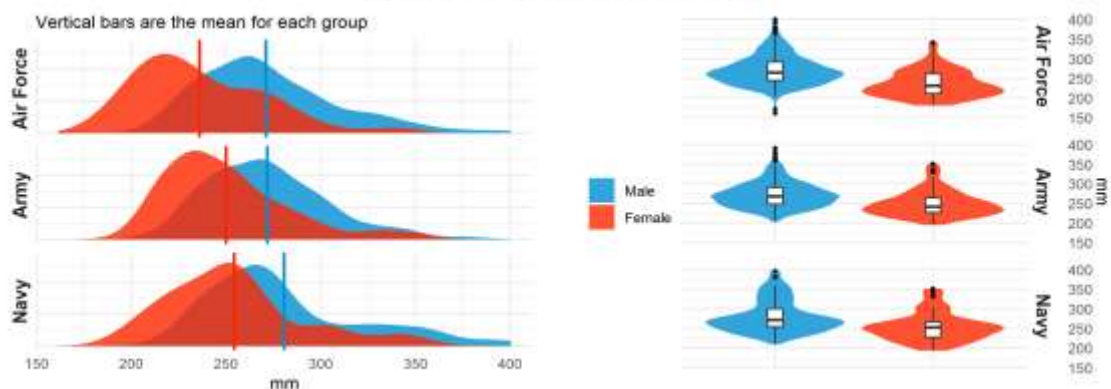
The Omphalion is often obscured due to shadowing caused by the hands. If the Omphalion is not visible, then skip this measure.



Abdominal extension depth sitting summary statistics - Post-processed measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
273	271	272	281	Mean	236	250	254	246
35	38	33	41	SD	34	33	37	35
161	161	203	210	Min	181	195	194	181
400	400	390	396	Max	342	351	352	352
379	379	366	396	P99	338	351	348	350
359	362	350	385	P98	324	338	343	341
350	353	344	368	P97	306	331	339	335
340	340	335	359	P95	293	320	329	312
322	326	313	347	P90	280	294	306	292
307	310	305	332	P85	271	280	293	279
299	298	297	317	P80	267	273	274	271
292	292	291	300	P75	261	265	266	264
285	286	285	285	P70	252	259	261	259
280	278	281	278	P65	241	255	259	254
275	273	276	276	P60	235	252	256	252
271	268	272	274	P55	234	248	253	246
267	265	268	271	P50	231	242	252	240
265	262	265	266	P45	224	238	249	235
261	259	262	264	P40	220	235	242	233
256	254	256	259	P35	218	233	239	230
251	251	251	258	P30	216	232	234	225
248	244	248	254	P25	211	227	228	220
243	239	244	245	P20	209	223	226	216
237	236	238	240	P15	202	218	219	213
232	229	233	237	P10	200	215	213	209
227	223	227	233	P5	193	210	208	201
222	218	223	231	P3	187	209	203	197
218	215	219	230	P2	186	208	200	194
210	207	213	227	P1	185	204	197	187

Distribution plots for each service and gender



Acromiale height sitting - Post-processed measurement (mm)

Measuring instrument:

CySlice. Measurements should be in mm.

Source:

AWAS, NZDFAS.

Definition:

The vertical distance between a sitting surface and the Thigh Point Top landmark.

Landmark required:

Acromiale Right and Seat Pan Height landmarks.

Posture required:

Scan position posture 2. Stand with feet shoulder width apart, trunk and head are erect with eyes looking forward. The upper arms are abducted away from the body with the forearms hanging vertically. All fingers are together and extended with the palm facing (medially) the thigh and the thumb pointing forward.

Procedure:

The acromiale points may be misplaced or difficult to see. With "Colour" mode off, follow the bony ridge of the top shoulder. These points should be located at the end of this ridge (i.e. the 'drop off' point) on the most lateral aspect of the acromion. This measure is represented by the Y coordinate (mm on the Y or vertical axis) of the Acromiale landmark (the superior aspect of the most lateral part of the acromion border) minus the Y coordinate (mm on the Y or vertical axis) of the Seat Pan Height (top edge or surface of the body scanner seat) landmark in Posture 3. This calculation is performed in Excel. Measurements are reported in mm.

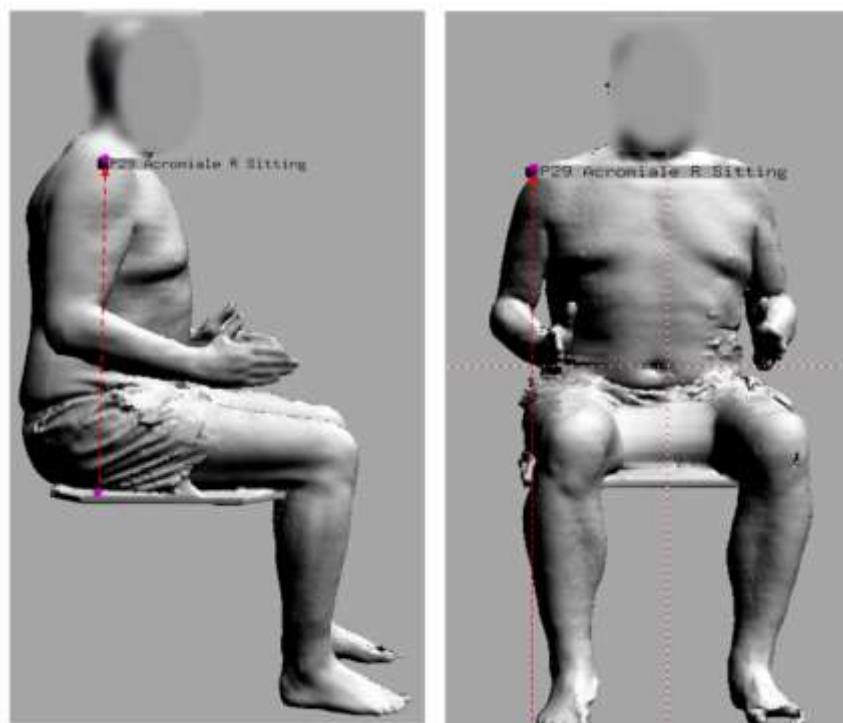
Reference:

Tomkinson, G. R., Daniell, N., Dale, M., & Bowler, T. (2012). Australian Warfighter Anthropometry Survey (AWAS): Landmarking and measurement manual. Adelaide, Australia: Health and Use of Time Group, Sansom Institute for Health Research, University of South Australia.

Kolose, S., Hume, P.A., Tomkinson, G.R., Stewart, A., Stewart, T., Legg, S.J. (2021). Three-dimensional physique assessment in the military: New Zealand Defence Force Anthropometry Survey protocols and summary statistics., SPRINZ: Auckland, New Zealand.

Notes:

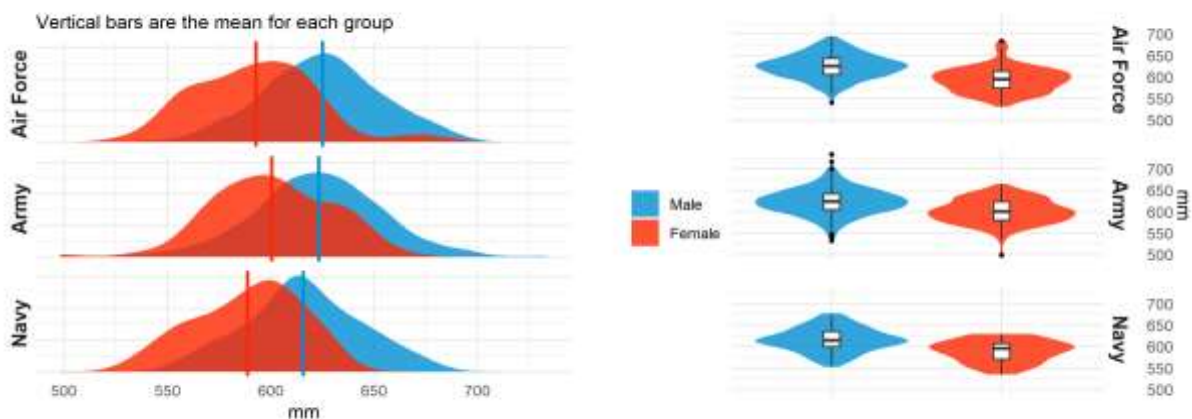
Ensure that the participant is sitting erect.



Acromiale height sitting summary statistics - Post-processed measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
623	625	623	616	Mean	593	600	589	595
30	28	30	28	SD	29	29	25	29
532	540	532	552	Min	531	498	535	498
734	695	734	678	Max	683	664	630	683
694	687	695	674	P99	673	655	629	665
683	680	688	670	P98	667	650	628	653
678	678	681	668	P97	661	648	627	648
673	676	674	662	P95	633	645	627	640
659	662	659	650	P90	622	636	621	633
654	656	654	646	P85	616	634	617	625
647	649	648	639	P80	615	629	608	619
642	643	642	635	P75	613	623	606	614
637	639	638	628	P70	611	615	604	611
634	634	634	625	P65	603	611	602	606
630	632	631	619	P60	599	606	599	603
626	629	626	617	P55	597	603	596	600
622	625	624	614	P50	594	600	595	596
619	622	620	613	P45	589	596	585	593
615	617	616	610	P40	585	593	585	588
612	615	612	608	P35	582	589	581	585
608	610	608	605	P30	576	585	577	580
604	605	604	599	P25	573	580	570	576
599	601	600	592	P20	564	576	563	571
593	597	593	588	P15	559	574	559	564
584	589	584	579	P10	558	565	553	558
574	576	572	568	P5	553	562	548	552
567	574	564	567	P3	552	551	542	548
561	571	558	564	P2	545	547	539	540
552	560	550	561	P1	537	533	537	535

Distribution plots for each service and gender



Acromiale height - Post-processed measurement (mm)

Measuring instrument:

CySlice. Measurements should be in mm.

Source:

AWAS.

Measuring instrument:

Anthropometry tape.

Definition:

The vertical distance from the standing surface to Acromiale R.

Landmark required:

T2 landmark.

Posture required:

Scan position posture 1. Stand with feet together, arms straight at the sides with the palms facing in towards the thigh. Fingers together and extended with the thumb facing forward. Stand with back erect and head in the Frankfort plane.

Procedure:

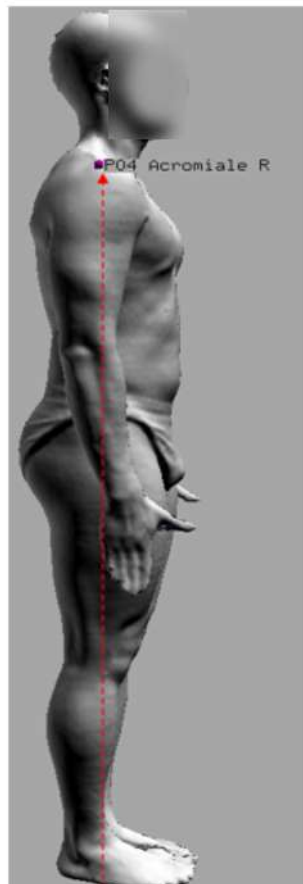
See). This measure is represented by the Y coordinate (mm on the Y or vertical axis) of the Acromiale landmark in Posture 1 (see Appendix A in Kolose, et. al., 2020; or Tomkinson et al., 2012). Measurements are reported in mm.

Reference:

Tomkinson, G. R., Daniell, N., Dale, M., & Bowler, T. (2012b). Australian Warfighters Anthropometry Survey (AWAS). Procedures Manual. Adelaide, Australia.: Health and Use of Time Group, Sansom Institute for Health Research, University of South Australia.

Notes

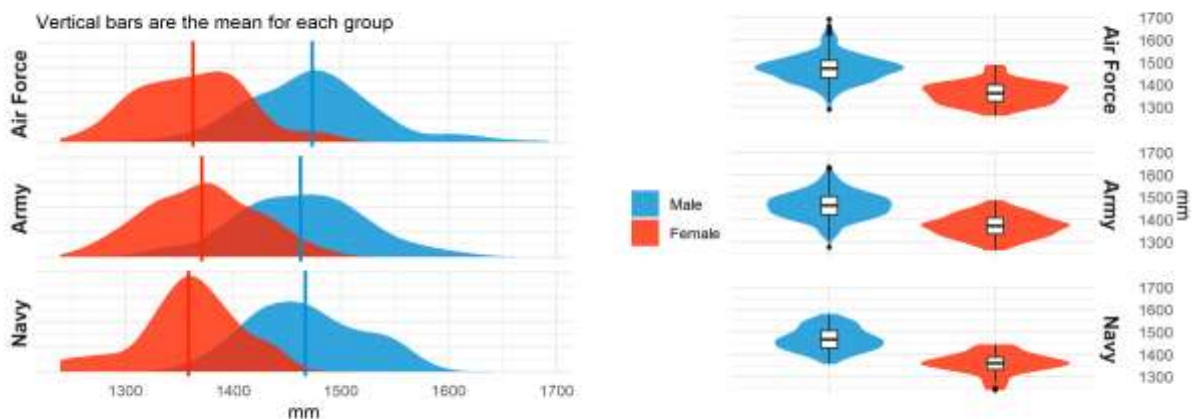
None.



Acromiale height summary statistics - Post-processed measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
1466	1473	1463	1467	Mean	1363	1371	1359	1366
60	62	60	52	SD	50	50	47	50
1276	1289	1276	1356	Min	1261	1262	1240	1240
1691	1691	1634	1580	Max	1489	1486	1444	1489
1618	1642	1603	1568	P99	1484	1478	1441	1482
1599	1620	1592	1561	P98	1477	1474	1438	1473
1588	1612	1579	1558	P97	1469	1458	1436	1460
1565	1590	1564	1553	P95	1447	1452	1431	1445
1540	1543	1537	1542	P90	1418	1435	1422	1431
1525	1529	1523	1531	P85	1405	1426	1400	1418
1514	1515	1511	1516	P80	1402	1417	1396	1405
1504	1508	1502	1505	P75	1399	1408	1388	1399
1496	1498	1495	1498	P70	1392	1396	1381	1391
1488	1493	1486	1483	P65	1387	1385	1375	1384
1481	1485	1478	1474	P60	1377	1382	1367	1379
1472	1479	1469	1467	P55	1371	1378	1363	1373
1467	1472	1464	1466	P50	1362	1372	1360	1366
1459	1467	1454	1458	P45	1355	1370	1358	1359
1450	1460	1446	1450	P40	1351	1358	1353	1355
1442	1453	1437	1441	P35	1341	1349	1352	1347
1433	1445	1431	1436	P30	1330	1342	1341	1337
1425	1430	1422	1428	P25	1326	1334	1334	1330
1416	1422	1412	1424	P20	1312	1327	1329	1326
1406	1414	1402	1415	P15	1307	1320	1321	1314
1393	1402	1388	1402	P10	1301	1306	1298	1301
1371	1381	1365	1388	P5	1292	1290	1274	1287
1352	1363	1344	1380	P3	1280	1285	1255	1274
1341	1359	1335	1374	P2	1269	1276	1248	1262
1327	1330	1326	1367	P1	1262	1265	1244	1261

Distribution plots for each service and gender



Acromiale-radiale length - Post-processed measurement (mm)

Measuring instrument:

CySlice.

Source:

ISAK, AWAS.

Definition:

The point-to-point distance between the digitally extracted Acromion Right and Radiale landmarks. Note that despite the appearance of a contour distance in the figure, CySlice extracts this measurement as a point-to-point distance.

Landmark required:

Acromiale Right and Radiale Right landmarks.

Posture required:

Scan position posture 1. Stand with feet together, arms straight at the sides with the palms facing in towards the thigh. Fingers together and extended with the thumb facing forward. Stand with back erect and head in the Frankfort plane.

Procedure:

Identify and select the digital Acromiale Right, centre wrist and Radiale (point at the proximal and lateral border of the head of the radius) landmarks. Look for the stickered Radiale landmark and skip this landmark if it is absent as it will be extremely difficult to identify by sight. See AWAS Section 7.2.20 of the Procedures Manual (Tomkinson et al., 2012). Measurements are reported in mm.

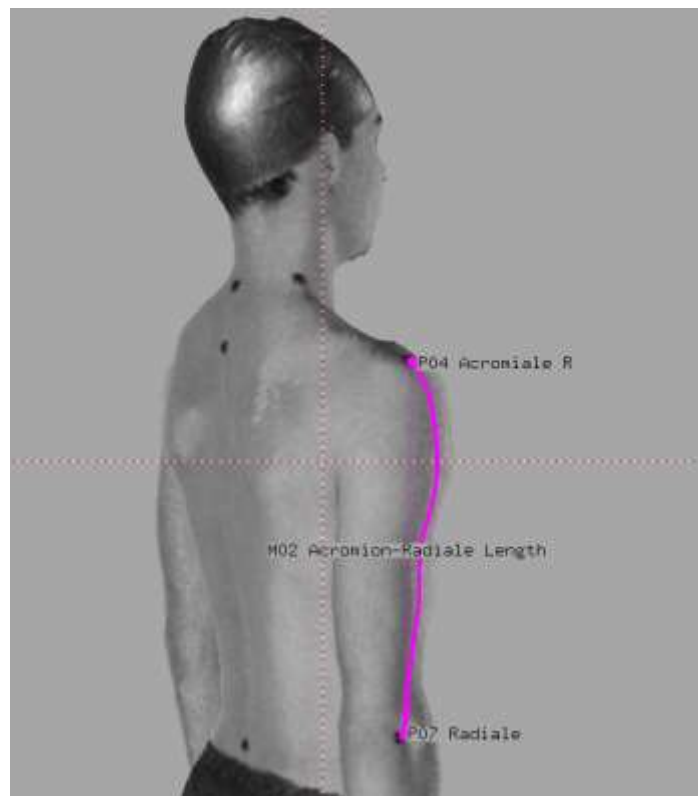
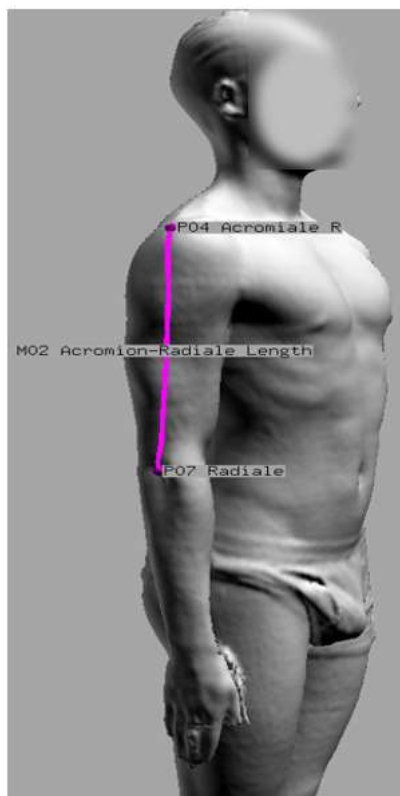
Reference:

Marfell-Jones, M.J., A.D. Stewart, and J.H. De Ridder, International Standards for Anthropometric Assessment. 2012.

Tomkinson, G. R., Daniell, N., Dale, M., & Bowler, T. (2012b). Australian Warfighters Anthropometry Survey (AWAS). Procedures Manual. Adelaide, Australia.: Health and Use of Time Group, Sansom Institute for Health Research, University of South Australia.

Notes:

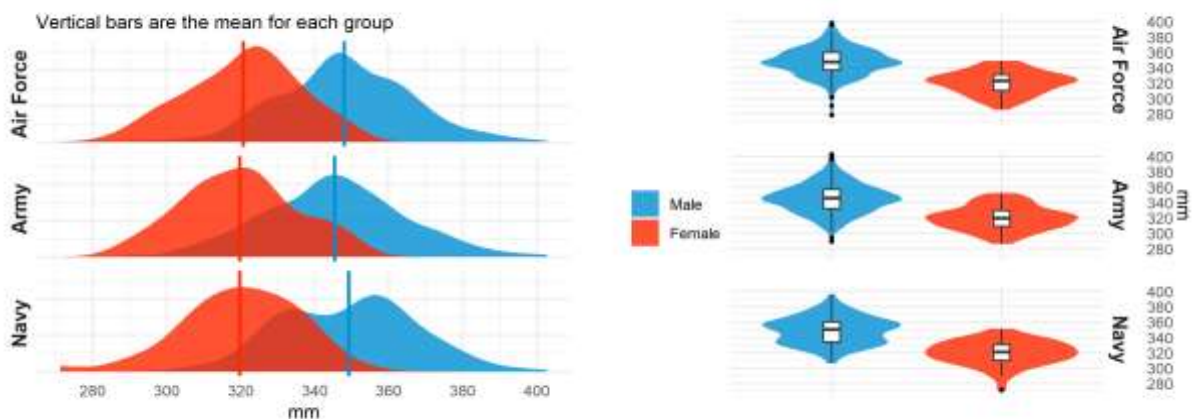
None.



Acromiale-radiale length summary statistics- Post-processed measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
346	348	345	349	Mean	321	320	320	320
19	18	19	18	SD	15	15	16	15
278	278	289	306	Min	285	286	271	271
403	398	403	396	Max	349	352	351	352
392	388	392	386	P99	349	351	348	350
386	386	385	383	P98	348	349	345	349
383	383	383	381	P97	347	348	343	348
377	376	377	377	P95	345	347	342	345
371	370	371	372	P90	338	342	338	341
365	365	365	367	P85	336	338	335	337
362	363	360	363	P80	333	332	335	333
359	360	357	360	P75	331	330	331	330
356	358	354	359	P70	329	326	329	328
353	354	352	357	P65	327	325	327	326
350	351	349	356	P60	324	324	324	324
348	349	347	353	P55	323	322	323	323
346	348	346	350	P50	323	319	321	321
345	346	343	349	P45	321	318	318	318
342	345	341	344	P40	319	316	317	317
340	343	339	340	P35	315	313	314	314
337	341	336	336	P30	313	311	313	312
333	337	332	334	P25	310	309	310	309
330	333	329	332	P20	308	307	308	308
328	329	326	331	P15	305	304	306	305
323	325	321	328	P10	299	300	301	299
317	321	313	322	P5	297	296	291	296
311	316	310	320	P3	292	291	290	291
307	311	306	318	P2	292	290	287	290
305	302	305	311	P1	290	289	279	287

Distribution plots for each service and gender



Ankle girth - Automatic measurement (mm)

Measuring instrument:

Anthroscan software.

Source:

Human Solutions

Definition:

Horizontal circumference measured at the height of the medial condyle of the tibia. The circumference is measured parallel to the standing surface.

Landmark required:

None.

Posture required:

Scan position posture 2. Stand with feet shoulder width apart, trunk and head are erect with eyes looking forward. The upper arms are abducted away from the body with the forearms hanging vertically. All fingers are together and extended with the palm facing (medially) the thigh and the thumb facing forward.

Procedure:

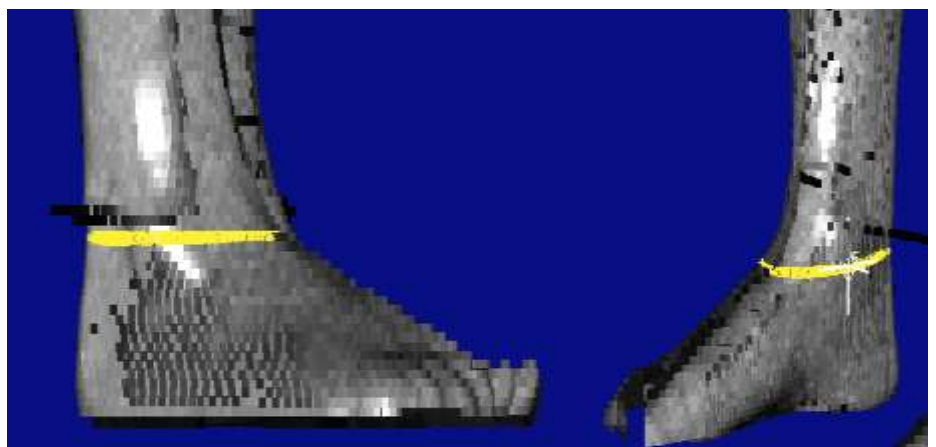
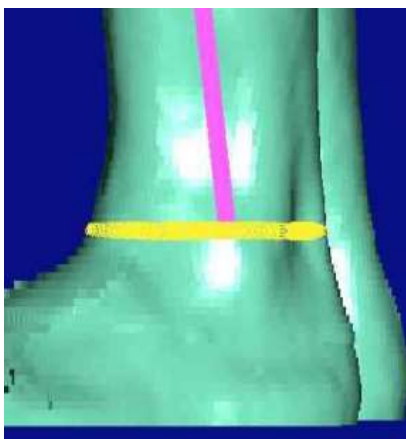
See Section 6 of Human Solutions (2015). Measurements are reported in mm.

Reference:

Human Solutions, 2015. Anthroscan user guide version 3. Human Solutions GmbH, Kaiserslautern, Germany.

Notes:

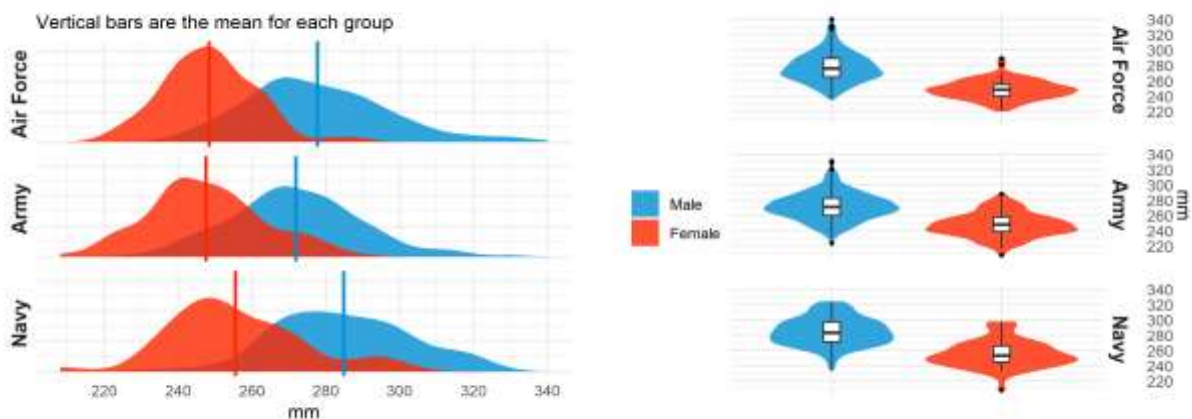
Check that the digital tape (yellow line below) is complete (no areas missing) and horizontal. Use software to correct the tape where appropriate.



Ankle girth summary statistics- Automatic measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
275	278	272	285	Mean	248	248	255	249
19	19	18	18	SD	13	16	18	16
224	235	224	234	Min	220	208	208	208
340	340	331	324	Max	289	288	298	298
325	331	317	321	P99	284	282	298	291
318	327	314	319	P98	277	279	297	289
315	319	309	318	P97	270	278	295	282
309	312	302	317	P95	266	275	291	276
299	302	294	311	P90	264	270	276	270
294	298	290	302	P85	262	263	272	265
290	292	286	300	P80	259	259	269	262
286	289	283	297	P75	255	258	266	258
283	287	280	294	P70	254	254	264	256
281	284	278	292	P65	252	251	260	254
278	281	276	289	P60	251	251	256	251
276	278	273	286	P55	249	249	254	250
273	276	271	283	P50	248	248	253	248
271	273	269	281	P45	247	243	250	247
269	271	267	279	P40	245	241	250	245
267	268	265	277	P35	243	240	247	242
265	266	263	275	P30	241	240	246	241
263	265	260	271	P25	240	239	244	240
260	263	258	269	P20	239	236	242	238
256	258	254	266	P15	236	233	239	235
251	255	249	265	P10	234	227	237	232
245	249	243	261	P5	228	223	233	226
242	246	241	254	P3	226	222	232	223
240	244	238	248	P2	226	221	228	221
235	242	234	245	P1	224	217	218	217

Distribution plots for each service and gender



Arm span - Physical measurement (mm)

Measuring instrument:

This measure can be done in any number of ways. A clear section of wall is required that is flat and at least 2.5 m wide. A wall chart or blank sheet of paper (approximately 0.5 m x 1 m) can be temporarily fixed to the wall. The paper must be positioned 1.5 m from the left edge of the wall (it is rare to have someone an arm span of 1 m). A large whiteboard is also ideal. In the absence of a wall chart, paper, or a whiteboard then a pencil and rubber (to remove markings) will suffice.

Source:

ANSUR.

Definition:

The perpendicular distance between the dactylia of the left and right arms with the arms outstretched horizontally, i.e. the distance from the tip of the middle finger (dactylion) of one hand to the other.

Landmark required:

None.

Posture required:

The participant stands erect against a wall with feet together, facing the clinician and with their arms raised to the horizontal (90 degree angle to the body). The heels, buttocks, and upper back, together with dorsal aspects of the arms should contact the wall. Participants stand with arms stretched out at. The left dactylion will be pressed against the edge of the wall. The right dactylion should be in front of the wall chart, paper or whiteboard. The participant inspires maximally and will stretch out their arms while maintaining contact with the wall edge.

Procedure:

The assessor stands in front of the participants right hand. The assessor will prompt the participant to stretch as far as possible while the scribe holds the participant's right wrist. The measure will be taken by scribing a dot on the wall at the tip of the right dactylion. The participant will step away. With the scribe's assistance, a builder's tape is used to measure the distance of the marking from the edge of the wall. Measure to the nearest 0.1 cm. The easiest way to conduct this measurement is to have a chart strip attached to the wall close to a corner where one finger is placed. A non-permanent marker pen is used to mark the distance to the other finger.

Reference:

Gordon, C.C., Blackwell, C.L., Bradtmiller, B., Parham, J.L., Barrientos, P., Paquette, S.P., Corner, B., Carson, J.M., Venezia, J.C., Rockwell, B.M., Mucher, M., Kristensen, S., 2014. 2012 Anthropometric survey of U.S. army personnel: Methods and summary statistics., Natick Soldier Research, Development of Engineering Center, Yellow Springs, Ohio, U.S.

Notes:

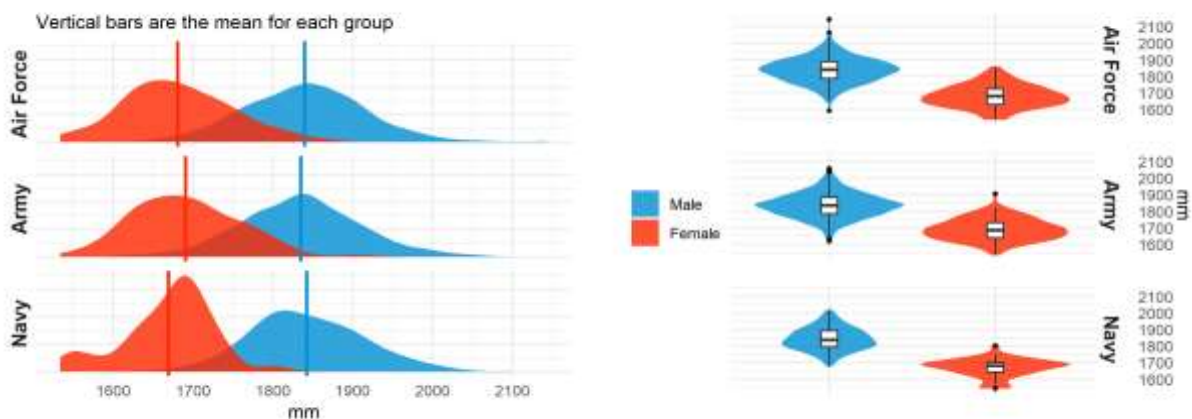
Before taking the reading, with the tape stretched out, ask the participant to check if the tape is horizontal. Some rooms may have obstructions on the wall (e.g. coat hanger, window, shelf etc) that may affect the ability to take accurate measures. Note that individuals with a marked kyphosis cannot be measured accurately.



Arm span summary statistics - Physical measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
1837	1840	1835	1843	Mean	1681	1690	1669	1683
75	78	75	69	SD	68	66	56	65
1593	1593	1620	1678	Min	1538	1534	1544	1534
2144	2144	2058	2020	Max	1860	1906	1802	1906
2021	2034	2019	1998	P99	1831	1824	1780	1821
1998	2001	1994	1984	P98	1816	1820	1758	1818
1986	1982	1986	1978	P97	1813	1817	1747	1813
1965	1965	1963	1955	P95	1802	1797	1739	1795
1931	1929	1928	1934	P90	1761	1776	1726	1771
1910	1910	1910	1908	P85	1752	1766	1717	1751
1898	1900	1892	1901	P80	1737	1750	1709	1735
1885	1888	1883	1893	P75	1724	1732	1702	1721
1875	1877	1870	1878	P70	1713	1718	1696	1712
1862	1866	1857	1864	P65	1710	1711	1694	1706
1852	1857	1852	1857	P60	1688	1706	1689	1695
1844	1847	1842	1847	P55	1683	1695	1685	1687
1837	1841	1836	1837	P50	1680	1685	1681	1682
1828	1832	1828	1827	P45	1670	1675	1677	1672
1820	1823	1818	1818	P40	1660	1671	1666	1666
1810	1813	1808	1809	P35	1648	1658	1663	1656
1799	1800	1795	1804	P30	1639	1650	1647	1647
1787	1788	1785	1797	P25	1630	1638	1642	1636
1776	1775	1775	1791	P20	1627	1631	1631	1630
1763	1759	1761	1775	P15	1619	1624	1618	1620
1742	1743	1738	1765	P10	1608	1616	1585	1610
1719	1720	1718	1741	P5	1576	1591	1548	1576
1702	1699	1700	1725	P3	1556	1577	1545	1558
1680	1683	1679	1716	P2	1547	1571	1545	1545
1663	1671	1660	1701	P1	1541	1566	1544	1543

Distribution plots for each service and gender



Axilla height - Post-processed measurement (mm)

Measuring instrument:

CySlice.

Source:

ANSUR.

Definition:

The vertical distance between a standing surface and the Anterior-Scye-on-the-Torso landmark.

Landmark required:

Axilla right landmark.

Posture required:

Scan position posture 1. Stand with feet together, arms straight at the sides with the palms facing in towards the thigh. Fingers together and extended with the thumb facing forward. Stand with back erect and head in the Frankfort plane.

Procedure:

This measure is represented by the Y coordinate (mm on the Y or vertical axis) of the Axilla landmark (cavity beneath the junction of the arm and shoulder in the anterior aspect) in posture 1. Look for the stickered landmark. This landmark is generally missing, difficult to see or misplaced. As an aid, visualize a caliper branch coming up from the bottom of the armpit. Place the landmark point on the area of the arm where this branch would make contact. See Appendix A in Kolose, et. al. (2020). Measurements are reported in mm.

Reference:

Gordon, C.C., Blackwell, C.L., Bradtmiller, B., Parham, J.L., Barrientos, P., Paquette, S.P., Corner, B., Carson, J.M., Venezia, J.C., Rockwell, B.M., Mucher, M., Kristensen, S., 2014. 2012 Anthropometric survey of U.S. army personnel: Methods and summary statistics., Natick Soldier Research, Development of Engineering Center, Yellow Springs, Ohio, U.S. (p46).

Kolose, S., Hume, P.A., Tomkinson, G.R., Stewart, A., Stewart, T., Legg, S.J. (2021). Three-dimensional physique assessment in the military: New Zealand Defence Force Anthropometry Survey protocols and summary statistics., SPRINZ: Auckland, New Zealand.

Notes:

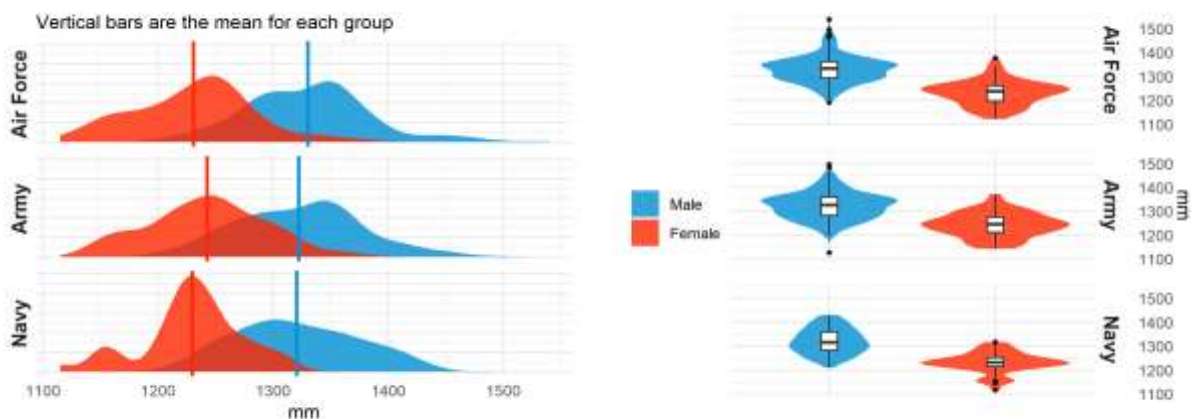
None.



Axilla height summary statistics - Post-processed measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
1324	1330	1322	1320	Mean	1231	1243	1230	1236
55	55	56	53	SD	52	51	44	50
1126	1190	1126	1209	Min	1122	1143	1115	1115
1538	1538	1495	1430	Max	1376	1372	1317	1376
1464	1474	1454	1427	P99	1354	1360	1312	1358
1448	1468	1444	1419	P98	1342	1350	1307	1344
1438	1451	1434	1414	P97	1337	1330	1305	1328
1416	1436	1415	1410	P95	1314	1316	1300	1312
1392	1390	1392	1393	P90	1291	1309	1285	1301
1377	1377	1376	1384	P85	1276	1295	1270	1287
1364	1367	1364	1366	P80	1263	1287	1263	1274
1360	1361	1359	1359	P75	1261	1275	1252	1265
1354	1356	1351	1354	P70	1257	1267	1249	1258
1346	1350	1345	1338	P65	1253	1257	1244	1253
1340	1343	1339	1335	P60	1247	1252	1239	1249
1334	1340	1333	1324	P55	1243	1251	1234	1244
1327	1333	1326	1315	P50	1237	1245	1231	1239
1316	1325	1315	1309	P45	1230	1241	1229	1233
1309	1314	1308	1302	P40	1222	1232	1224	1227
1301	1306	1299	1295	P35	1214	1223	1222	1220
1294	1300	1291	1288	P30	1210	1216	1216	1214
1284	1294	1282	1282	P25	1196	1211	1215	1209
1276	1285	1274	1274	P20	1183	1205	1205	1198
1266	1276	1261	1258	P15	1173	1184	1198	1175
1254	1267	1252	1252	P10	1157	1171	1163	1164
1237	1244	1234	1241	P5	1150	1158	1152	1152
1229	1233	1227	1237	P3	1144	1151	1147	1147
1218	1224	1218	1235	P2	1132	1150	1141	1144
1205	1215	1201	1231	P1	1124	1145	1128	1126

Distribution plots for each service and gender



Biacromial breadth - Post-processed measurement (mm)

Measuring instrument:

CySlice

Source:

ISAK, AWAS

Definition:

The point-to-point distance between the digitally extracted Acromion, Right and Acromion, Left landmarks. Note that despite the appearance of a contour distance in the figure, CySlice extracts this measurement as a point-to-point distance.

Landmark required:

Acromiale Right and Acromiale Left landmarks.

Posture required:

Scan position posture 1. Stand with feet together, arms straight at the sides with the palms facing in towards the thigh. Fingers together and extended with the thumb facing forward. Stand with back erect and head in the Frankfort plane.

Procedure:

Identify and select the digital Acromiale Right and Acromiale Left landmarks. AWAS Section 7.2.8 of the Procedures Manual (Tomkinson et al., 2012). Measurements are reported in mm.

Reference:

Marfell-Jones, M.J., A.D. Stewart, and J.H. De Ridder, International Standards for Anthropometric Assessment. 2012.

Tomkinson, G. R., Daniell, N., Dale, M., & Bowler, T. (2012b). Australian Warfighters Anthropometry Survey (AWAS). Procedures Manual. Adelaide, Australia.: Health and Use of Time Group, Sansom Institute for Health Research, University of South Australia.

Notes:

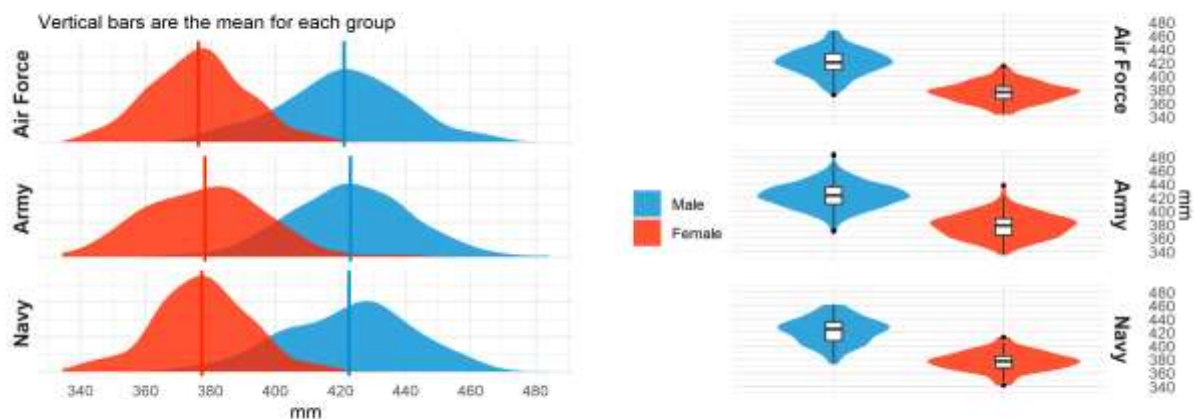
In the absence of a landmark, use knowledge of anatomical features to identify the correct location. For example, follow the ridge of the clavicle.



Biacromial breadth summary statistics - Post-processed measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
422	421	423	423	Mean	376	378	377	377
19	19	19	19	SD	15	18	15	16
370	372	370	373	Min	343	334	342	334
484	468	484	461	Max	415	438	413	438
466	464	467	460	P99	410	422	409	415
460	460	460	458	P98	407	415	406	412
458	458	458	457	P97	406	410	403	407
454	451	454	453	P95	398	405	398	404
446	444	448	446	P90	396	402	394	397
441	441	442	443	P85	392	397	393	394
438	437	438	439	P80	389	393	389	391
435	434	436	435	P75	384	389	385	388
432	431	433	432	P70	383	388	384	385
430	429	430	430	P65	381	386	382	384
428	426	428	430	P60	380	384	380	381
425	424	425	428	P55	379	381	379	379
422	421	423	425	P50	376	378	377	377
420	420	421	421	P45	374	376	376	376
419	418	419	419	P40	373	374	374	374
416	415	416	418	P35	371	370	373	371
413	412	414	412	P30	369	368	370	368
410	409	410	408	P25	367	364	368	366
406	406	407	405	P20	364	362	366	363
403	401	404	402	P15	361	359	364	360
398	396	399	397	P10	358	356	362	357
390	387	393	390	P5	353	349	353	351
385	384	389	386	P3	350	347	350	348
383	382	384	381	P2	347	347	348	345
378	378	379	380	P1	344	344	345	343

Distribution plots for each service and gender



Bicep girth flexed - Physical measurement (mm)

Measuring instrument:

Anthropometric tape.

Source:

ISAK.

Definition:

The circumference of the arm perpendicular to the long axis of the arm at the level of the peak of the contracted Biceps Brachii when the upper arm is raised anteriorly to the horizontal.

Landmark required:

None.

Posture required:

The participant stands with the right shoulder and elbow flexed at a 90 degree angle to the body. The assessor stands on the right side of the participant facing directly towards their outer bicep.

Procedure:

The measurement is taken at the widest point of the bicep when the muscle is at maximum tension. Ensure the tape applies light pressure or minimal skin indentation. Measurements are reported in mm.

Reference:

Marfell-Jones, M.J., A.D. Stewart, and J.H. De Ridder, International Standards for Anthropometric Assessment. 2012.

Notes:

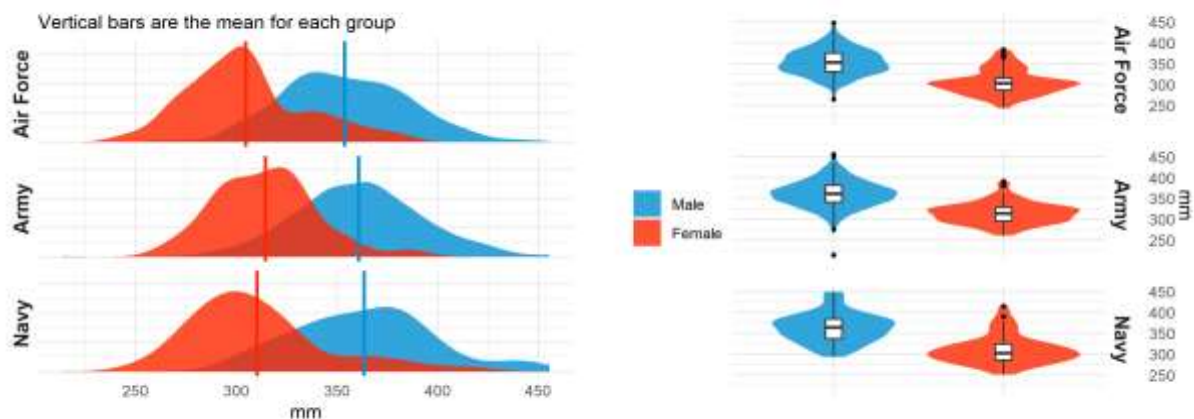
The measure can be taken either seated or standing depending on how tall the participant is relative to the assessor. Check the tape follows the curvature of the skin, with minimal 'gaps' between the tape and the skin.



Bicep girth flexed summary statistics - Physical measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
359	354	361	364	Mean	305	315	310	310
32	31	32	35	SD	30	25	34	29
214	264	214	294	Min	242	260	251	242
456	447	456	449	Max	384	391	415	415
438	427	435	446	P99	379	387	404	389
429	415	426	445	P98	374	380	394	383
422	414	422	442	P97	369	364	387	379
415	406	416	431	P95	360	356	379	363
401	394	402	403	P90	345	343	362	352
390	386	392	393	P85	339	334	337	337
385	381	386	386	P80	332	332	327	332
381	375	382	384	P75	316	328	324	326
376	371	376	381	P70	312	326	318	324
370	367	371	378	P65	309	324	315	317
367	362	368	375	P60	306	322	311	314
364	356	365	367	P55	304	315	307	310
359	352	361	364	P50	302	314	302	307
355	348	356	360	P45	300	311	301	304
350	342	352	354	P40	295	309	297	301
346	340	348	349	P35	292	302	296	296
342	336	345	345	P30	287	300	293	294
337	330	341	336	P25	286	296	286	291
332	328	336	334	P20	280	293	285	286
327	324	329	326	P15	275	289	280	282
320	316	322	317	P10	269	286	275	275
306	304	309	308	P5	266	277	270	268
303	302	304	305	P3	259	271	265	265
298	301	298	304	P2	254	270	261	261
290	292	290	301	P1	249	267	256	252

Distribution plots for each service and gender



Bideltoid breadth sitting - Post-processed measurement (mm)

Measuring instrument:

CySlice

Source:

ANSUR, NZDFAS

Definition:

The maximum horizontal distance between the lateral margins of the upper arms on the deltoid muscles.

Landmark required:

None. This is performed using the Caliper function of CySlice.

Posture required:

Scan position posture 3. Ensure that the participant is sitting with their knee bent at a 90° angle. This can be done by moving the body scanner seat up or down. This can also be facilitated by aligning the popliteal fossa (vertically) in line with Pternion (back of the foot). Ensure that the arms (triceps when viewed posteriorly) are hanging vertically (as much as possible).

Procedure:

In CySlice use the caliper tool. This can be viewed from the front or the back of the participant. Highlight a horizontal line that is lower than the Acromiale but higher than the Axilla landmarks. Select the Y function (to create a coronal plane) to calculate and record the breadth. Measurements are reported in mm.

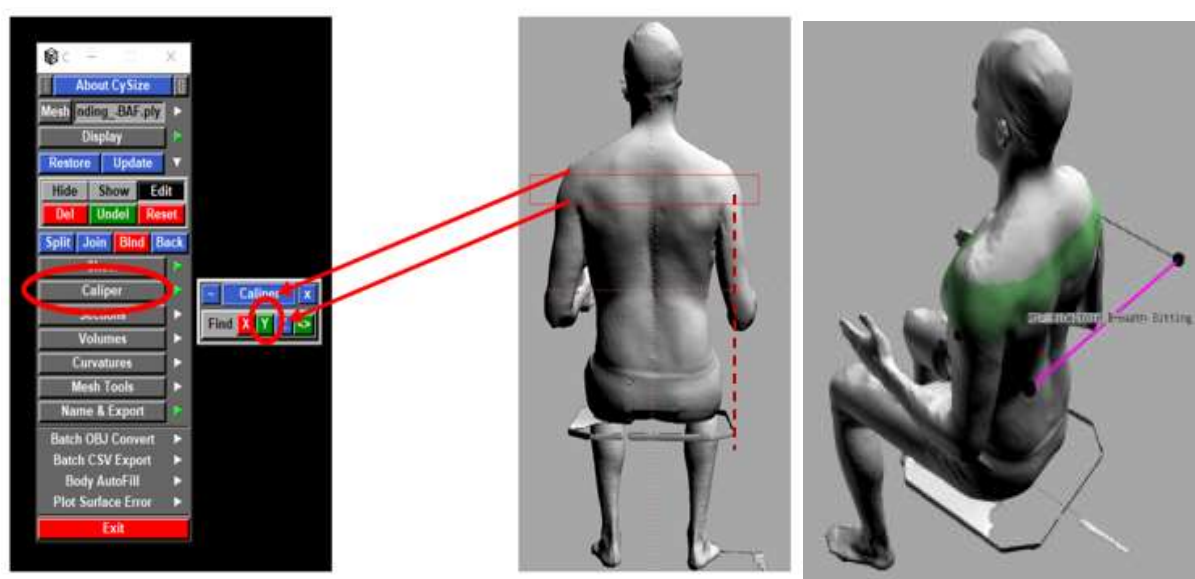
Reference:

Gordon, C.C., Blackwell, C.L., Bradtmiller, B., Parham, J.L., Barrientos, P., Paquette, S.P., Corner, B., Carson, J.M., Venezia, J.C., Rockwell, B.M., Mucher, M., Kristensen, S., 2014. 2012 Anthropometric survey of U.S. army personnel: Methods and summary statistics., Natick Soldier Research, Development of Engineering Center, Yellow Springs, Ohio, U.S.

Kolose, S., Hume, P.A., Tomkinson, G.R., Stewart, A., Stewart, T., Legg, S.J. (2021). Three-dimensional physique assessment in the military: New Zealand Defence Force Anthropometry Survey protocols and summary statistics., SPRINZ: Auckland, New Zealand.

Notes:

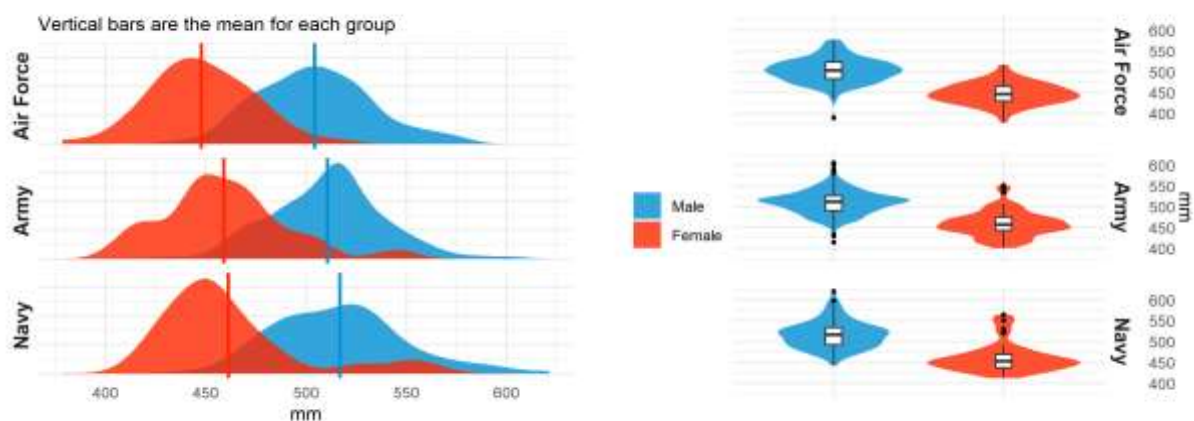
Use the Crosshair tool to align the participant. Another method is to view the participant from the side view, then highlight a square rectangle on the around the most lateral centre of the deltoid.



Bideltoid breadth sitting summary statistics - Post-processed measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
510	504	511	517	Mean	448	459	461	456
29	29	28	33	SD	26	31	36	31
390	390	414	442	Min	378	401	412	378
621	578	606	621	Max	518	552	564	564
588	575	587	600	P99	508	548	559	551
575	569	571	592	P98	500	544	554	547
567	562	565	590	P97	493	536	551	533
560	557	557	576	P95	488	507	549	507
547	543	546	560	P90	478	498	515	493
537	531	538	547	P85	474	489	485	482
531	527	532	538	P80	470	479	477	475
527	524	526	534	P75	465	475	470	471
523	518	523	530	P70	461	470	466	467
519	514	520	528	P65	458	467	461	464
516	511	517	527	P60	452	465	458	458
514	507	515	518	P55	449	460	455	455
511	504	512	516	P50	447	457	453	452
507	500	510	511	P45	443	453	450	449
503	496	505	509	P40	441	449	448	447
498	493	502	499	P35	436	446	446	444
495	490	497	496	P30	434	444	444	440
490	484	491	493	P25	430	443	437	436
485	479	488	490	P20	427	436	436	430
478	473	480	483	P15	424	427	432	427
472	469	473	477	P10	419	419	427	420
464	462	465	471	P5	410	414	425	412
460	457	461	466	P3	406	410	421	410
454	453	454	464	P2	399	408	419	406
442	436	450	460	P1	390	405	415	401

Distribution plots for each service and gender



Bitracion mandibular arc - Physical measurement (mm)

Measuring instrument:

Anthropometric tape. Before measuring, ensure that the metal tape surface is not damaged and the scale is clear, and the tape can be retracted freely. There are various models. Tapes used in the NZDFAS were Cesorf and Rosscraft. Measurements are in mm.

Source:

ANSUR.

Definition:

The surface distance between the right and left tracion landmarks across the submandibular landmark is measured with a tape. The head is in the Frankfort plane, and the teeth are lightly occluded.

Landmarks required:

Tracion left and right, Submandibular.

Posture required:

Sitting. The measure can also be taken while standing depending on the height of the assessor relative to the participant.

Procedure:

The participant sits erect, looking straight ahead with any headwear/eyewear removed. The assessor stands in front and slightly to the side of the participant. With the thumb and index finger place the 0 point of the tape against the Tracion right landmark (the 0 rests in the middle of the landmark sticker). The assessor uses their left thumb to hold the tape to the skin (at the 0 point) and extends the tape under the throat towards the Tracion right landmark. The opposite index finger is used to hold the tape to Tracion left. The measure is read from the scale pressed on Tracion Right. The centre of the tape must run through the Submandibular landmark. Measure to the nearest mm.

Reference:

Gordon, C.C., Blackwell, C.L., Bradtmiller, B., Parham, J.L., Barrientos, P., Paquette, S.P., Corner, B., Carson, J.M., Venezia, J.C., Rockwell, B.M., Mucher, M., Kristensen, S., 2014. 2012 Anthropometric survey of U.S. army personnel: Methods and summary statistics., Natick Soldier Research, Development of Engineering Center, Yellow Springs, Ohio, U.S.

Notes:

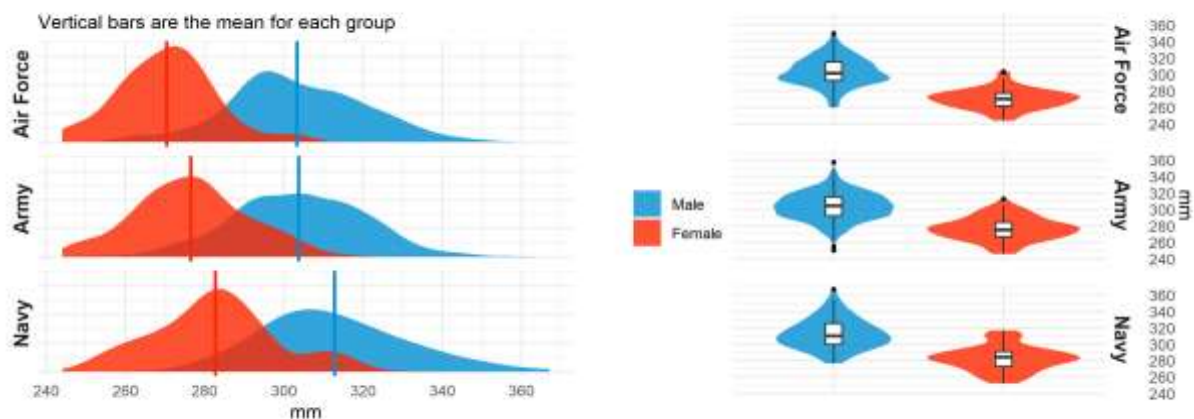
The position of the head has no influence on the measurement. Ensure that the jaw is still and the head is in the Frankfort plane. Take care when placing the tape against the skin.



Bitragion mandibular arc summary statistics - Physical measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
305	303	304	313	Mean	270	276	283	276
17	17	17	18	SD	12	14	15	14
250	260	250	277	Min	244	246	252	244
367	350	357	367	Max	304	313	317	317
346	343	343	357	P99	303	305	315	312
340	337	336	352	P98	299	304	313	310
336	335	334	350	P97	294	303	312	305
333	330	330	346	P95	290	300	311	301
325	325	325	337	P90	283	295	305	294
323	322	320	331	P85	281	292	295	290
320	317	318	327	P80	280	290	293	285
315	315	315	325	P75	277	284	291	284
315	312	314	320	P70	275	284	289	281
311	310	310	318	P65	275	280	285	280
309	306	308	315	P60	273	280	285	279
305	305	305	312	P55	272	278	285	277
304	301	304	310	P50	270	275	284	275
302	300	301	310	P45	270	275	280	274
300	297	300	307	P40	267	273	280	271
296	295	296	304	P35	265	270	279	270
295	295	295	301	P30	265	270	276	268
293	293	292	300	P25	262	266	273	266
290	290	290	300	P20	260	265	269	265
288	288	287	295	P15	259	263	268	260
284	284	284	292	P10	256	260	261	259
275	275	275	286	P5	251	252	259	252
274	271	273	283	P3	247	250	256	250
270	265	270	282	P2	246	248	255	248
265	263	265	280	P1	245	247	254	246

Distribution plots for each service and gender



Bizygomatic breadth - Physical measurement (mm)

Measuring instrument:

Small bone caliper. The Rosscraft small bone caliper is 18 cm with pressure plates that are 10 mm diameter. Before measuring, the distance between the plates when touching should be verified as 0 cm to ensure it has been assembled correctly.

Source:

ANSUR.

Definition:

The maximum horizontal breadth between the most lateral aspects of the Zygions left and right.

Landmark required:

Zygon left and right.

Posture required:

The participant sits erect, looking straight ahead with glasses removed.

Procedure:

The assessor stands in front and slightly to the side of the participant. This measurement can be taken sitting or standing depending on the height of the assessor relative to the participant. The caliper is placed at a 45° angle. Opening the caliper beyond the anticipated distance, rest the device on the back of the hands and using the thumbs and index fingers, use the long finger (middle finger) to palpate the skin and visually identifying the most lateral aspect of the Zygion Left and Zygion Right. When identified, slowly move the plates towards one another until they rest on this point. Record the measurement to 0.1 cm or 0.05 cm precision.

Reference:

Gordon, C.C., Blackwell, C.L., Bradtmiller, B., Parham, J.L., Barrientos, P., Paquette, S.P., Corner, B., Carson, J.M., Venezia, J.C., Rockwell, B.M., Mucher, M., Kristensen, S., 2014. 2012 Anthropometric survey of U.S. army personnel: Methods and summary statistics., Natick Soldier Research, Development of Engineering Center, Yellow Springs, Ohio, U.S.

Notes:

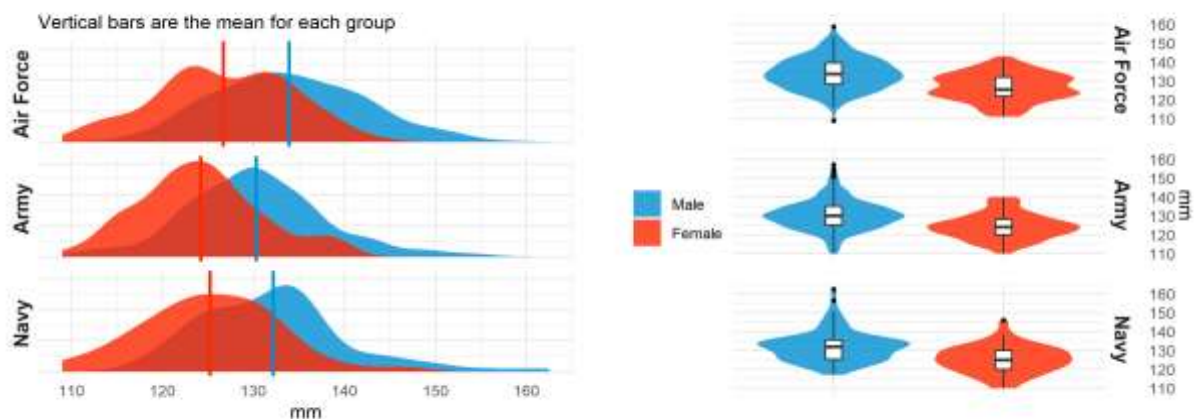
The caliper branches must be placed on the skin, but not indent the skin. The position of the head has no influence on the measurement. If the participant's Zygion distance is greater than the length of the small bone caliper considering using the large sliding caliper. For the NZDFAS, the small bone caliper was used instead of the large sliding caliper (more traditional tool for this measurement) as the assessor had a greater level of control and avoided potential injuries to the eye (sharp end of the large sliding caliper prongs).



Bizygomatic breadth summary statistics - Physical measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
131	134	130	132	Mean	127	124	125	125
8	8	8	8	SD	7	7	7	7
109	109	110	117	Min	111	110	110	110
162	158	157	162	Max	143	140	146	146
153	153	151	157	P99	141	140	143	140
150	152	149	152	P98	139	139	140	139
149	150	148	150	P97	139	138	138	139
145	148	144	147	P95	138	138	136	138
142	144	140	143	P90	136	132	133	134
140	143	137	137	P85	134	132	132	132
138	141	136	136	P80	133	129	130	132
136	140	135	136	P75	132	128	130	130
135	138	134	135	P70	131	127	130	130
134	137	132	134	P65	130	126	129	128
133	136	132	134	P60	130	126	127	126
132	135	131	132	P55	128	125	126	126
131	134	130	132	P50	125	124	125	125
130	132	129	132	P45	125	123	124	124
129	132	128	130	P40	125	122	124	123
128	130	128	129	P35	123	122	123	122
127	129	126	128	P30	123	120	122	122
126	128	125	125	P25	122	120	120	120
125	126	124	125	P20	122	119	119	120
124	125	123	125	P15	120	117	118	118
122	124	121	123	P10	117	115	116	115
120	122	118	121	P5	114	114	115	114
117	120	115	120	P3	113	114	111	113
115	118	114	120	P2	112	113	110	111
112	117	112	119	P1	112	110	110	110

Distribution plots for each service and gender



Body height - Automatic measurement (mm)

Measuring instrument:

Anthroscan software.

Source:

Anthroscan.

Definition:

Vertical height from standing surface to the visual top of the head. The vertical distance is measured between the standing surface and the top of the head.

Landmark required:

None.

Posture required:

Scan position posture 2. Stand with feet shoulder width apart, trunk and head are erect with eyes looking forward. The upper arms are abducted away from the body with the forearms hanging vertically. All fingers are together and extended with the palm facing (medially) the thigh and the thumb facing forward.

Procedure:

See Section 6 of Human Solutions (2015). Measurements are reported in mm.

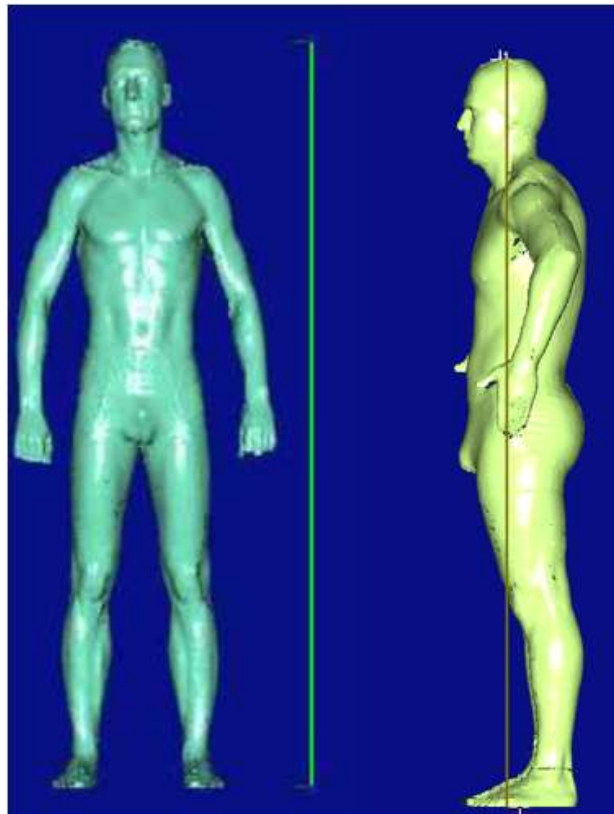
Reference:

Human Solutions, 2015. Anthroscan user guide version 3. Human Solutions GmbH, Kaiserslautern, Germany.

Notes:

Check that the head is in the Frankfort position. If not, the height is measured near the rear of the head, then remove this measure. Anthroscan takes body height with legs positioned shoulder-width apart. Traditional protocols have legs and feet together. The Anthroscan method was used to represent a more 'natural' standing position.

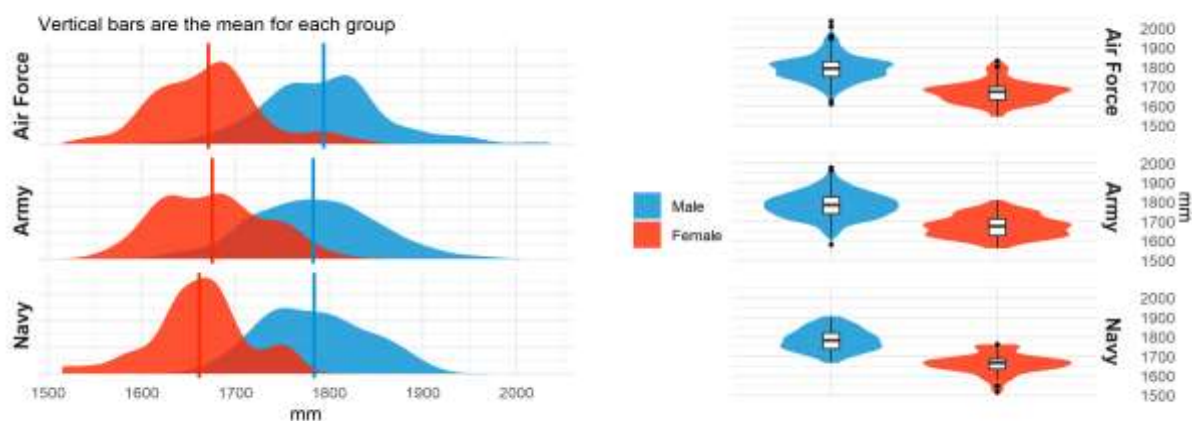
Eye height (Ectocantus) in CySlice is taken from the Posture 1 (feet together position).



Body height summary statistics - Automatic measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
1786	1794	1783	1784	Mean	1671	1675	1661	1671
65	67	66	56	SD	57	56	53	55
1579	1609	1579	1666	Min	1546	1561	1515	1515
2035	2035	1977	1905	Max	1832	1810	1761	1832
1954	1962	1941	1899	P99	1812	1796	1758	1803
1930	1953	1918	1887	P98	1799	1786	1754	1793
1915	1937	1908	1883	P97	1793	1773	1753	1785
1897	1918	1891	1876	P95	1789	1763	1753	1762
1868	1877	1868	1858	P90	1732	1753	1731	1753
1851	1851	1851	1851	P85	1715	1746	1704	1731
1836	1833	1842	1833	P80	1699	1730	1696	1712
1825	1828	1825	1820	P75	1698	1713	1684	1699
1818	1825	1818	1811	P70	1696	1699	1681	1698
1811	1818	1810	1804	P65	1690	1698	1676	1689
1803	1811	1801	1801	P60	1681	1687	1674	1681
1793	1803	1793	1786	P55	1681	1681	1673	1674
1785	1793	1785	1782	P50	1674	1674	1666	1674
1778	1785	1773	1771	P45	1666	1667	1658	1666
1764	1777	1764	1763	P40	1658	1655	1651	1652
1760	1764	1755	1753	P35	1647	1643	1646	1644
1752	1760	1746	1746	P30	1641	1634	1641	1638
1739	1753	1738	1739	P25	1632	1627	1634	1633
1731	1745	1723	1739	P20	1620	1626	1634	1626
1720	1731	1713	1731	P15	1616	1618	1616	1618
1706	1720	1705	1713	P10	1608	1609	1597	1608
1683	1691	1676	1706	P5	1597	1592	1580	1587
1667	1677	1656	1690	P3	1581	1585	1556	1579
1652	1668	1644	1684	P2	1560	1578	1542	1563
1639	1653	1633	1673	P1	1547	1569	1528	1547

Distribution plots for each service and gender



Breast height - Automatic measurement (mm)

Measuring instrument:

Anthroscan software.

Source:

Anthroscan.

Definition:

The vertical height of the front breast/chest circumference level (code 4510 or 4515) to the standing surface.

Landmark required:

None.

Posture required:

Scan position posture 2. Stand with feet shoulder width apart, trunk and head are erect with eyes looking forward. The upper arms are abducted away from the body with the forearms hanging vertically. All fingers are together and extended with the palm facing (medially) the thigh and the thumb facing forward.

Procedure:

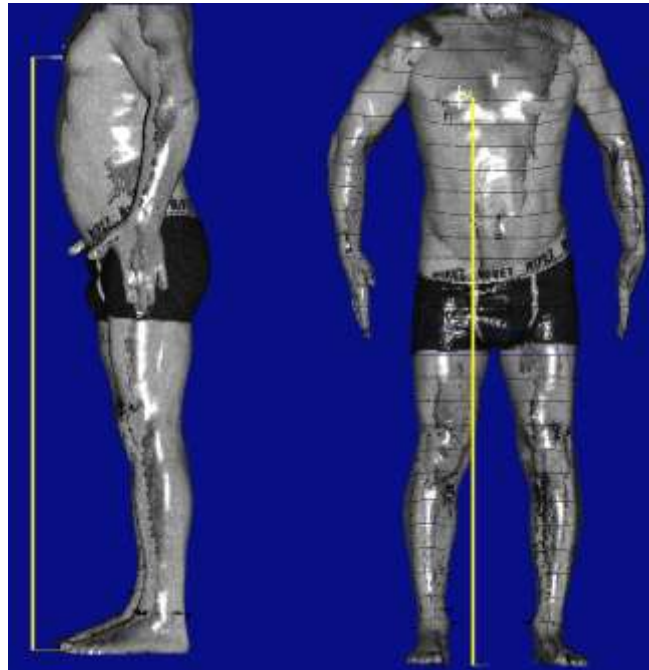
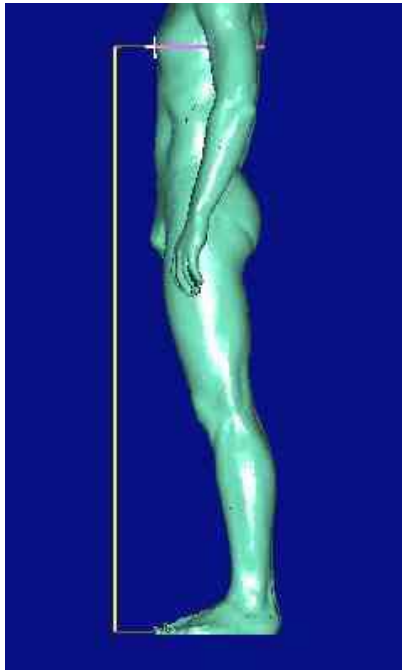
See Section 6 of Human Solutions (2015). Measurements are reported in mm.

Reference:

Human Solutions, 2015. Anthroscan user guide version 3. Human Solutions GmbH, Kaiserslautern, Germany.

Notes:

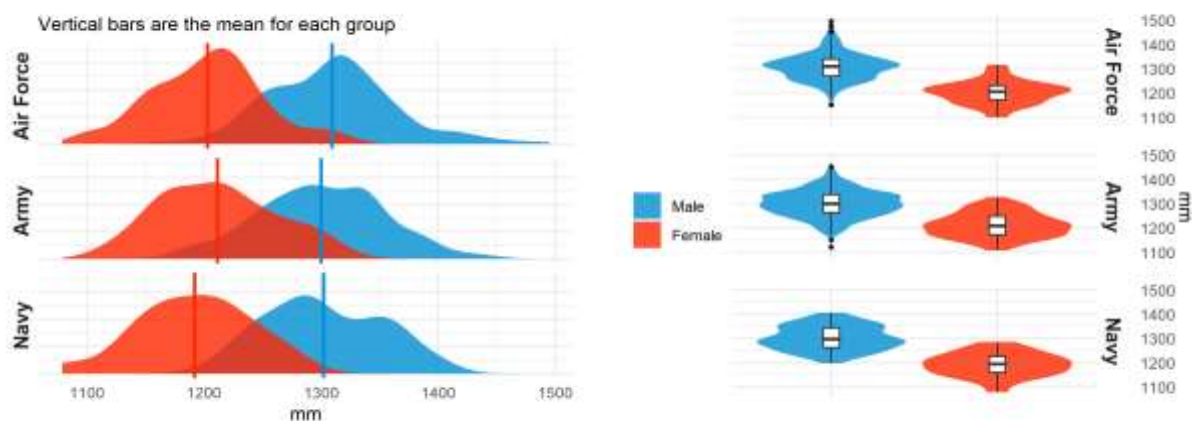
None.



Breast height summary statistics - Automatic measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
1303	1309	1300	1302	Mean	1203	1212	1192	1205
54	55	55	50	SD	48	50	48	49
1121	1151	1121	1198	Min	1100	1108	1079	1079
1495	1495	1451	1406	Max	1317	1327	1285	1327
1434	1454	1427	1400	P99	1315	1314	1280	1314
1421	1436	1410	1398	P98	1308	1304	1276	1303
1407	1427	1397	1397	P97	1300	1303	1272	1301
1393	1409	1390	1384	P95	1290	1299	1266	1294
1371	1373	1371	1366	P90	1256	1286	1257	1272
1357	1360	1353	1361	P85	1245	1270	1240	1256
1345	1346	1343	1358	P80	1234	1256	1233	1247
1339	1339	1338	1344	P75	1230	1249	1226	1234
1334	1333	1332	1336	P70	1227	1237	1218	1229
1325	1323	1325	1325	P65	1223	1226	1211	1223
1317	1321	1317	1307	P60	1216	1222	1207	1216
1310	1315	1307	1303	P55	1211	1214	1202	1211
1303	1310	1300	1298	P50	1205	1209	1195	1206
1296	1307	1293	1292	P45	1200	1206	1186	1198
1289	1299	1287	1285	P40	1195	1195	1179	1192
1281	1288	1279	1280	P35	1187	1186	1170	1182
1274	1280	1272	1274	P30	1179	1179	1168	1175
1264	1271	1263	1263	P25	1172	1172	1160	1169
1256	1262	1255	1257	P20	1158	1168	1151	1160
1247	1252	1244	1245	P15	1154	1158	1146	1154
1234	1245	1230	1242	P10	1144	1153	1134	1144
1213	1231	1206	1227	P5	1131	1137	1123	1130
1199	1211	1194	1223	P3	1107	1128	1095	1119
1193	1209	1189	1217	P2	1102	1122	1085	1104
1180	1184	1180	1208	P1	1101	1118	1082	1100

Distribution plots for each service and gender



Bust chest girth - Automatic measurement (mm)

Measuring instrument:

Anthroscan software.

Source:

Anthroscan.

Definition:

The circumference of the chest is measured across the Bust Point (females) or Thelion (males) landmarks. The circumference is measured parallel to the standing surface.

Landmark required:

None.

Posture required:

Scan position posture 2. Stand with feet shoulder width apart, trunk and head are erect with eyes looking forward. The upper arms are abducted away from the body with the forearms hanging vertically. All fingers are together and extended with the palm facing (medially) the thigh and the thumb facing forward.

Procedure:

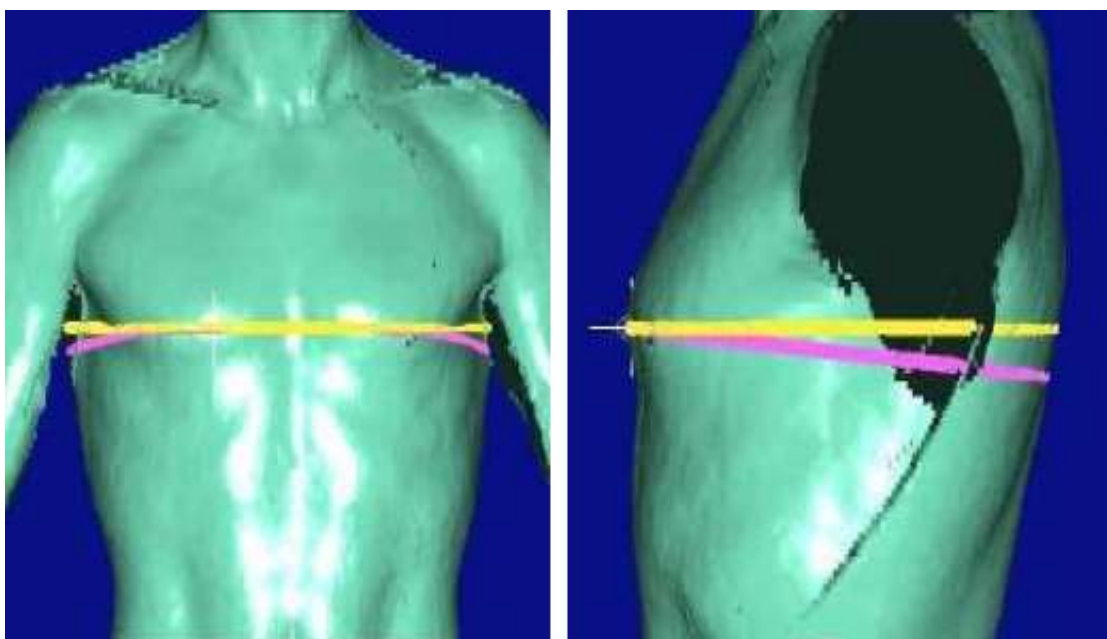
The Thelion (nipple) or bust point (most anterior point of bra/bust) is located visually. For males, it is the centre of right nipple. For females, eyeball most anterior point from the side. Then add 'X-loop' to identify the most protruding point within that area. This is difficult especially with females with thick pad bras. See Section 6 of Human Solutions (2015). Measurements are reported in mm.

Reference:

Human Solutions, 2015. Anthroscan user guide version 3. Human Solutions GmbH, Kaiserslautern, Germany.

Notes:

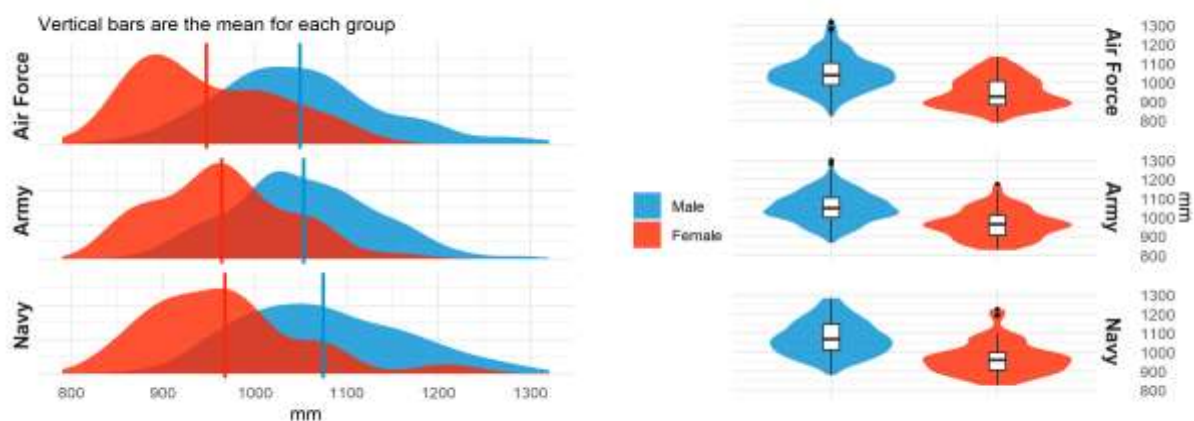
Check that the digital tape (yellow line below) is horizontal and that it does not pass around the left and right arms. If so, skip this measure. Ensure that the arms are abducted sufficiently away from the body. This must be explained clearly during the posturing phase.



Bust chest girth summary statistics - Automatic measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
1054	1049	1053	1075	Mean	947	964	967	959
83	91	79	89	SD	79	73	86	78
824	824	867	880	Min	790	829	827	790
1321	1321	1300	1285	Max	1136	1174	1226	1226
1281	1283	1248	1282	P99	1110	1147	1212	1171
1244	1274	1217	1271	P98	1096	1121	1198	1132
1219	1250	1203	1252	P97	1089	1092	1167	1099
1196	1203	1180	1228	P95	1085	1071	1095	1085
1165	1176	1157	1198	P90	1065	1067	1070	1067
1145	1142	1138	1165	P85	1035	1049	1064	1045
1123	1116	1120	1152	P80	1026	1025	1015	1025
1105	1101	1104	1146	P75	1006	1011	1000	1008
1094	1082	1094	1120	P70	993	991	991	992
1080	1074	1081	1096	P65	983	981	986	982
1070	1064	1069	1088	P60	962	974	972	973
1061	1056	1061	1076	P55	940	970	969	963
1048	1038	1048	1070	P50	928	963	958	954
1037	1027	1037	1057	P45	920	954	955	941
1026	1021	1027	1042	P40	908	947	935	930
1019	1009	1020	1030	P35	898	937	924	922
1009	996	1012	1017	P30	891	929	919	907
998	988	1000	1012	P25	884	907	906	897
987	980	989	994	P20	877	897	896	886
966	959	966	977	P15	872	880	887	875
949	942	954	963	P10	857	870	872	864
925	920	928	948	P5	848	853	857	850
914	894	917	942	P3	847	845	848	845
902	883	910	936	P2	844	845	842	843
883	865	887	925	P1	826	842	835	830

Distribution plots for each service and gender



Buttock depth - Post-processed measurement (mm)

Measuring instrument:

CySlice

Source:

UK Anthropometry Survey, NZDFAS

Definition:

The maximum circumference of the body (excluding the appendages) at approximately hip height. This measure must be taken below the height of the iliac crest in Anthroscan.

Landmark required:

None as the caliper function is used.

Posture required:

Scan position posture 1. Stand with feet together, arms straight at the sides with the palms facing in towards the thigh. Fingers together and extended with the thumb facing forward. Stand with back erect and head in the Frankfort plane.

Procedure:

In CySlice use the caliper tool. When viewed from the side, highlight the area of the buttocks that is above the height of the crotch and below the level of the Iliocristale right (most superior point on iliac crest) landmark. If the landmark is not present, this point can still be identified depending on bone structure and body type of the participant (e.g. lean). Avoid any artefacts of webbing between the right hand and the thigh. Select the X function (to create a coronal plan) to record the depth. Measurements are reported in mm.

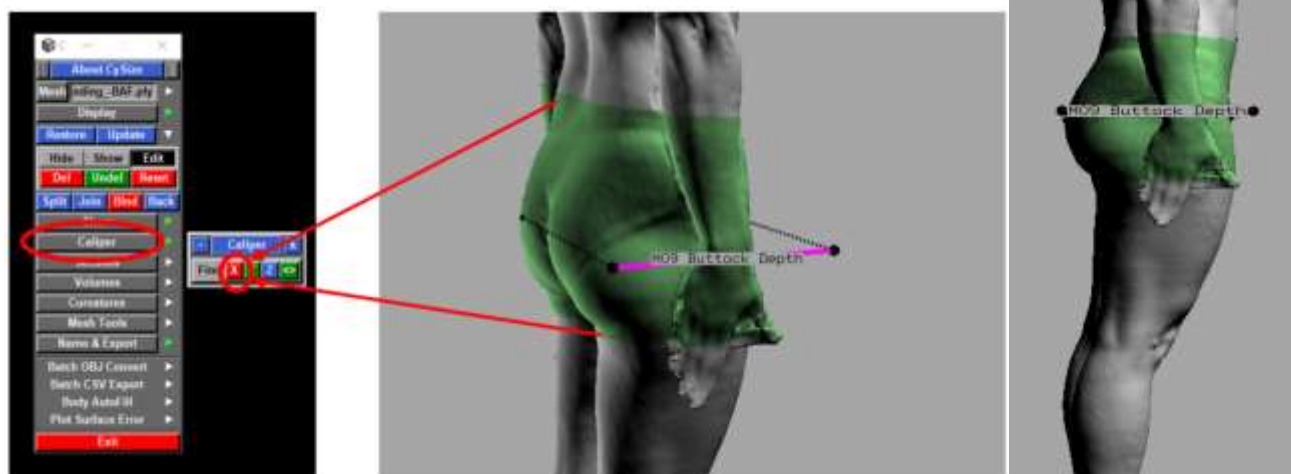
Reference:

Pringle, R. H., Puxley, A. J., Puxley, K. P. M., Turner, G. M., & Tyrell, A. K. (2011). Anthropometry Survey of UK Military Personnel 2006-7 (Issue 3) (QINETIQ/07/01821/3.0): QinetiQ Ltd.

Kolose, S., Hume, P.A., Tomkinson, G.R., Stewart, A., Stewart, T., Legg, S.J. (2021). Three-dimensional physique assessment in the military: New Zealand Defence Force Anthropometry Survey protocols and summary statistics., SPRINZ: Auckland, New Zealand.

Notes:

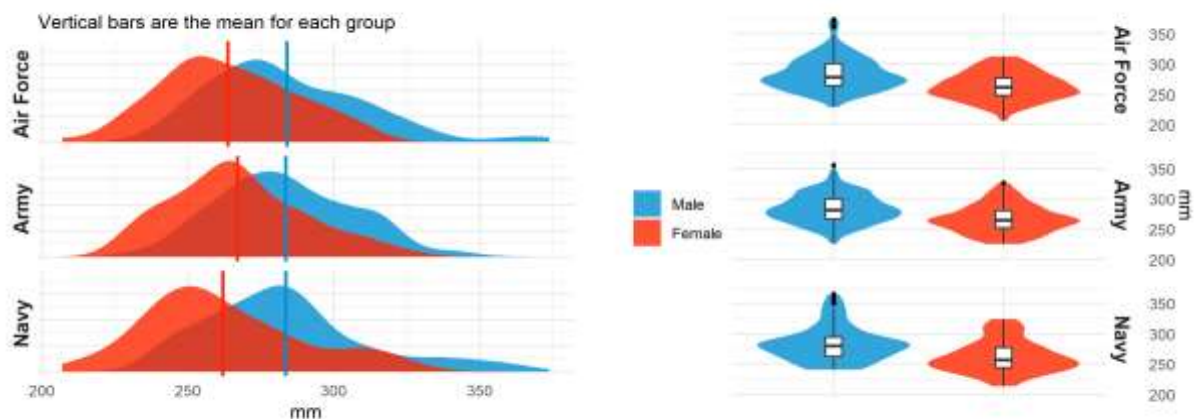
Use the Crosshair tool to align the participants posture. If the measurement is taken on a fold or crease in the briefs, consider remeasuring. If the anterior portion of the measure is taken on the male genitalia make minor adjustments to move the point away.



Buttock depth summary statistics - Post-processed measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
284	284	284	284	Mean	264	267	262	265
25	27	24	28	SD	23	23	27	24
227	229	227	241	Min	207	226	214	207
374	374	356	365	Max	313	327	325	327
356	370	341	359	P99	309	322	321	321
341	362	332	353	P98	307	315	317	314
335	343	327	351	P97	307	313	315	313
326	330	322	340	P95	305	309	313	309
317	320	315	324	P90	296	299	307	297
311	311	311	311	P85	290	291	289	291
305	307	305	300	P80	285	288	281	285
300	301	300	295	P75	277	281	277	279
295	296	296	291	P70	276	276	274	276
291	292	291	288	P65	273	271	265	271
287	286	288	286	P60	269	269	262	268
283	281	285	283	P55	264	267	259	265
281	279	282	280	P50	262	265	257	263
278	276	279	278	P45	257	263	255	260
275	274	276	276	P40	255	262	253	256
272	272	272	272	P35	254	257	248	255
269	268	270	267	P30	250	254	247	252
266	265	267	263	P25	248	252	244	248
262	260	264	261	P20	246	247	241	245
258	257	258	257	P15	241	242	239	241
253	253	253	249	P10	235	238	233	237
247	248	248	244	P5	230	233	230	231
244	244	244	243	P3	227	231	220	229
241	242	240	242	P2	226	231	216	226
236	239	235	241	P1	220	230	215	218

Distribution plots for each service and gender



Buttocks girth - Automatic measurement (mm)

Measuring instrument:

Anthroscan software.

Source:

Anthroscan

Definition:

The circumference is measured at the height of the most posteriorly protruding surface of the buttocks when gluteal muscles are relaxed. The circumference is measured parallel to the standing surface.

Landmark required:

None.

Posture required:

Scan position posture 2. Stand with feet shoulder width apart, trunk and head are erect with eyes looking forward. The upper arms are abducted away from the body with the forearms hanging vertically. All fingers are together and extended with the palm facing (medially) the thigh and the thumb facing forward. Measurements are reported in mm.

Procedure:

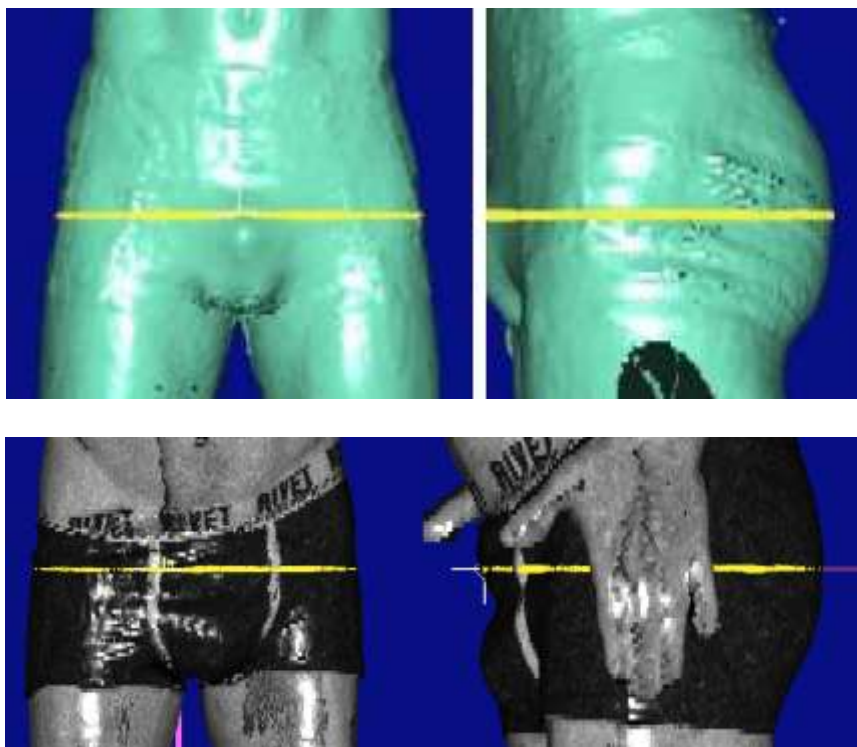
See Section 6 of Human Solutions (2015).

Reference

Human Solutions, 2015. Anthroscan user guide version 3. Human Solutions GmbH, Kaiserslautern, Germany.

Notes:

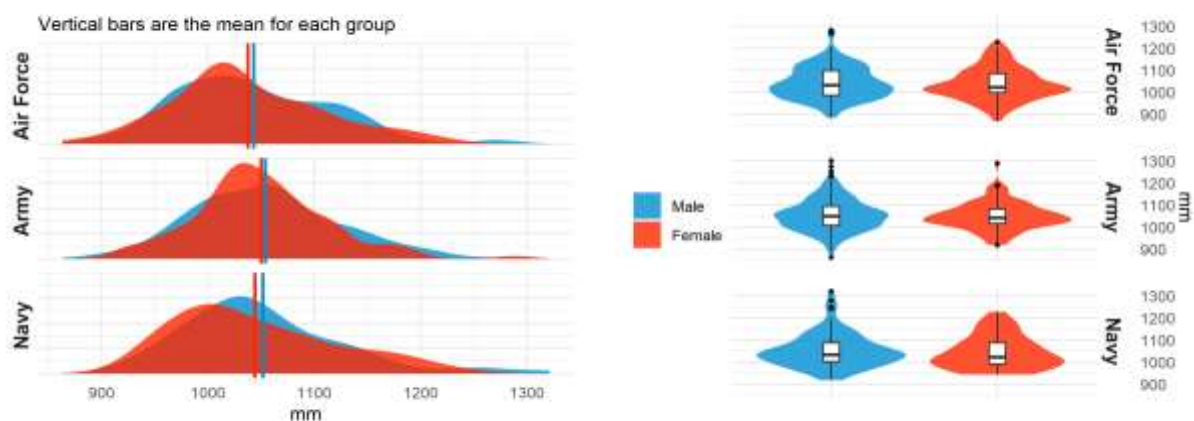
Check that the digital tape is horizontal and that it does not pass around the hands.



Buttocks girth summary statistics - Automatic measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
1051	1043	1054	1052	Mean	1037	1050	1044	1045
72	74	70	77	SD	73	62	75	69
863	884	863	917	Min	870	919	944	870
1321	1281	1301	1321	Max	1228	1289	1228	1289
1254	1268	1226	1284	P99	1209	1193	1211	1225
1214	1199	1211	1258	P98	1196	1188	1195	1189
1200	1183	1200	1245	P97	1187	1178	1189	1188
1175	1155	1178	1188	P95	1176	1162	1186	1174
1144	1138	1148	1143	P90	1138	1122	1159	1132
1128	1126	1129	1125	P85	1114	1112	1124	1117
1111	1109	1114	1108	P80	1088	1099	1110	1097
1096	1098	1096	1088	P75	1084	1082	1086	1085
1082	1080	1084	1072	P70	1075	1072	1074	1073
1071	1065	1074	1064	P65	1054	1067	1069	1064
1063	1053	1066	1057	P60	1036	1060	1051	1053
1053	1040	1058	1046	P55	1028	1051	1032	1040
1045	1031	1050	1033	P50	1023	1042	1022	1035
1035	1022	1044	1030	P45	1018	1039	1020	1025
1026	1018	1032	1029	P40	1014	1035	1011	1021
1018	1008	1021	1022	P35	1008	1024	1000	1017
1010	999	1012	1008	P30	1004	1021	994	1009
1001	987	1007	1001	P25	998	1017	990	1002
989	977	995	987	P20	986	1009	986	991
977	969	982	979	P15	962	992	965	982
966	962	971	972	P10	954	974	955	960
948	945	949	949	P5	928	960	954	948
933	925	935	944	P3	921	933	947	930
918	916	921	933	P2	911	930	945	925
903	897	903	918	P1	895	927	944	919

Distribution plots for each service and gender



Buttock-heel length - Physical measurement (mm)

Measuring instrument:

Standard builders' tape, two measurement plates (or Rosscraft headboard plates).

Source:

Canadian Land Forces Survey 1997.

Definition:

The distance between the most posterior aspect of the buttock (right leg and sitting) to the inferior-posterior aspect of the calcaneus.

Landmark required:

None.

Posture required:

The participant sits on the floor with their right leg outstretched with toes pointing towards the ceiling. The posterior aspect of the buttock is against the wall (as much as physically possible). For increased comfort, the left leg can be folded while waiting for the measurement to start. During the time of measurement, the participant is required to sit erect with their hands resting on their thighs.

Procedure:

The assessor kneels beside the participant and in front of the foot. The scribe will be in the same position but next to the hip region. Both participant and assessor are facing the same direction.

The scribe will place one plate perpendicular to the most posterior aspect of the buttock (not the wall). The assessor will place a second plate perpendicular to the heel of the outstretched foot. The flat 'zero' mark of the tape is pressed firmly against the plate near the buttock. The assessor will place the second plate against the heel with the edge resting (foot side) of the tape. The participant is prompted to *"please sit up straight, right leg flat to the floor and point your right foot to the ceiling"*. A reading is taken immediately after the prompt to avoid physical discomfort. Measure to the nearest 0.1 cm.

Reference:

Chamberland, A., Carrier, R., Forest, F. and Hachez, G. (1998). *1997 Anthropometric Survey of the Land Forces. Final Report*. 1998, Department of National Defence, Canada.: Ontario, Canada. p. DCIEM-98-CR-15.

Notes:

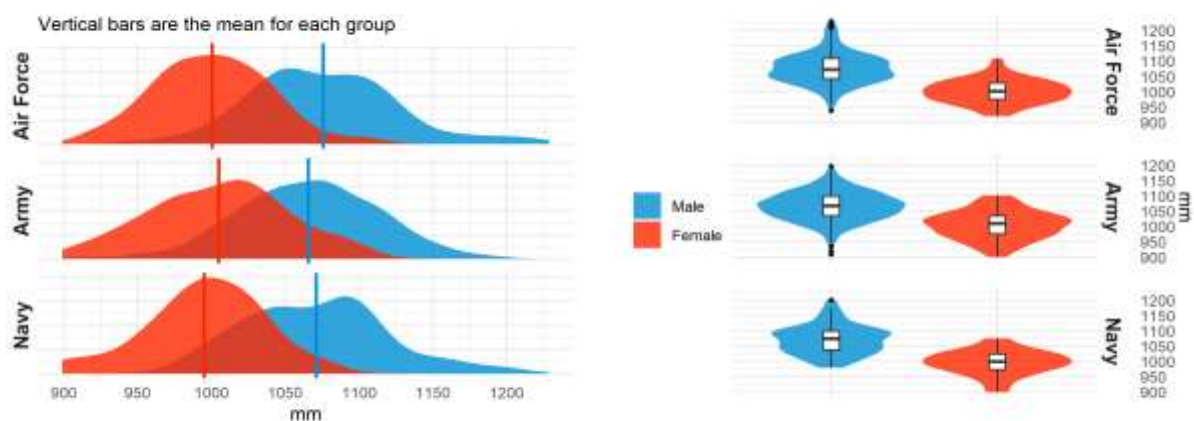
It is important that both measurement plates are held in a perpendicular (not angled) to avoid erroneous values. Another method is to use a small right-angled plate to ensure the plate is exactly vertical. This measure is highly reliant on the flexibility of the participant hence the measurements need to be swift and precise. Ensure that the tape is 'straight' and runs parallel to the participant's leg. For increased accuracy place the tape as close to the leg as possible.



Buttock-heel length summary statistics - Physical measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
1069	1076	1066	1071	Mean	1000	1005	995	1001
49	51	48	48	SD	39	46	40	43
909	938	909	980	Min	919	900	899	899
1229	1229	1196	1200	Max	1108	1102	1074	1108
1196	1214	1175	1199	P99	1098	1101	1073	1100
1175	1203	1160	1180	P98	1084	1091	1072	1090
1163	1190	1154	1167	P97	1070	1090	1067	1087
1149	1170	1142	1159	P95	1064	1084	1056	1074
1128	1135	1125	1128	P90	1043	1063	1038	1053
1116	1121	1115	1113	P85	1040	1050	1033	1042
1109	1113	1108	1104	P80	1034	1042	1026	1035
1102	1108	1099	1098	P75	1028	1035	1024	1032
1094	1102	1091	1095	P70	1019	1030	1018	1024
1088	1093	1084	1091	P65	1015	1024	1012	1018
1081	1088	1078	1087	P60	1009	1018	1007	1012
1076	1083	1073	1080	P55	1005	1011	1001	1009
1069	1071	1067	1073	P50	1001	1010	998	1002
1062	1064	1060	1062	P45	996	1001	993	998
1055	1060	1054	1054	P40	990	995	990	990
1049	1051	1047	1048	P35	981	983	985	983
1043	1048	1040	1045	P30	977	977	980	977
1037	1042	1035	1036	P25	975	975	973	974
1029	1037	1026	1027	P20	972	967	965	968
1021	1026	1019	1021	P15	960	952	958	957
1009	1016	1005	1010	P10	952	943	949	948
992	998	990	1001	P5	940	926	926	927
984	988	976	989	P3	928	919	907	920
971	978	962	987	P2	923	912	900	914
954	959	952	984	P1	920	909	899	901

Distribution plots for each service and gender



Buttock height - Automatic measurement (mm)

Measuring instrument:

Anthroscan software.

Source:

Anthroscan.

Definition:

The vertical height of the Buttock Circumference measurement of the standing surface.

Landmark required:

None.

Posture required:

Scan position posture 2. Stand with feet shoulder width apart, trunk and head are erect with eyes looking forward. The upper arms are abducted away from the body with the forearms hanging vertically. All fingers are together and extended with the palm facing (medially) the thigh and the thumb facing forward.

Procedure:

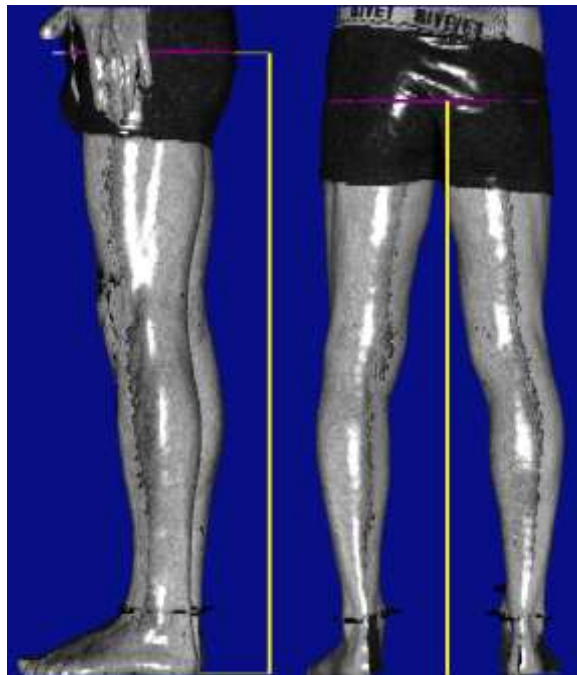
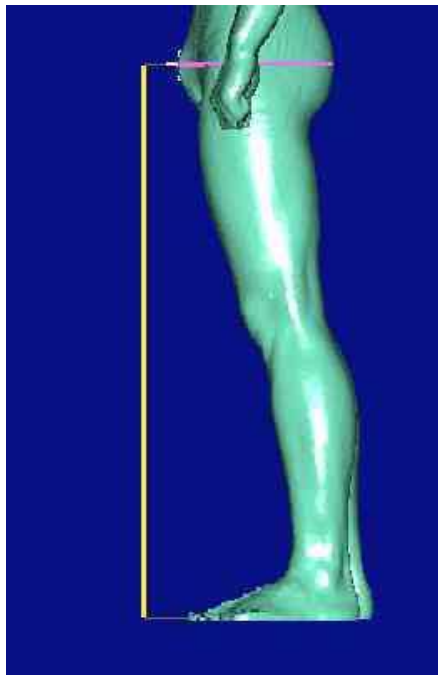
See Section 6 of Human Solutions (2015). Measurements are reported in mm.

Reference

Human Solutions, 2015. Anthroscan user guide version 3. Human Solutions GmbH, Kaiserslautern, Germany.

Notes:

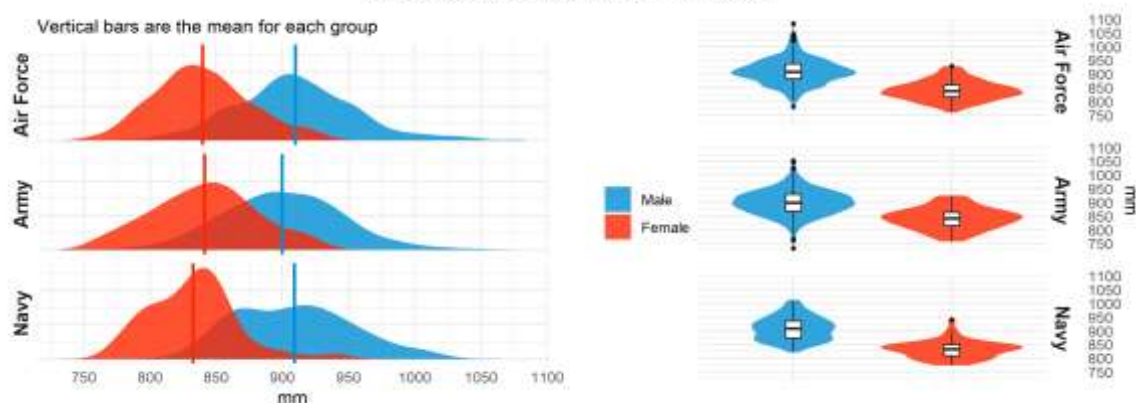
None.



Buttock height summary statistics - Automatic measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
904	910	900	909	Mean	840	841	832	839
46	47	46	44	SD	36	39	33	37
732	781	732	822	Min	759	758	774	758
1083	1083	1052	1012	Max	928	925	940	940
1023	1035	1014	1008	P99	920	919	925	924
1006	1022	997	1003	P98	917	918	911	918
997	1006	987	1001	P97	915	916	900	916
982	990	976	983	P95	906	913	884	909
960	962	956	966	P90	887	889	861	887
949	954	945	954	P85	882	881	858	877
940	948	938	946	P80	868	875	852	865
932	936	929	936	P75	860	864	849	861
927	930	924	932	P70	856	862	845	856
920	924	918	928	P65	851	857	844	851
915	919	913	918	P60	846	852	842	846
908	912	906	914	P55	840	847	838	843
904	907	898	908	P50	838	842	832	838
897	905	894	903	P45	834	837	831	834
892	898	888	898	P40	827	834	828	829
887	893	883	885	P35	825	826	823	825
880	888	876	875	P30	822	819	815	819
873	883	868	873	P25	817	815	809	814
864	869	862	867	P20	811	807	802	807
857	860	853	861	P15	801	799	796	797
848	853	842	855	P10	793	789	794	792
831	838	828	849	P5	788	777	783	781
819	825	816	846	P3	779	768	780	775
815	817	807	843	P2	777	764	778	769
796	809	793	833	P1	772	764	776	764

Distribution plots for each service and gender



Buttock-knee length sitting - Post-processed measurement (mm)

Measuring instrument:

CySlice.

Source:

ANSUR, NZDFAS

Definition:

Ensure that the participant is sitting with their knee bent at a 90° angle. This can be done by moving the body scanner seat up or down. This can also be facilitated by aligning the mid-point of the popliteal fossa (vertically) in line with Pternion (back of the foot). The horizontal distance between a buttock plate placed at the most posterior point on the buttock and the knee point anterior landmark.

Landmark required:

None.

Posture required:

Scan position posture 3. Ensure that the participant is sitting with their knee bent at a 90° angle. This can be done by moving the body scanner seat up or down. This can also be facilitated by aligning the popliteal fossa (vertically) in line with Pternion (back of the foot).

Procedure:

In CySlice use the caliper tool. View from the back of the participant. Highlight the right buttock as below. When the view is rotated to the front view the anterior aspect of the knee will also be highlighted. Select the X function (to create a coronal plan) to record the length. Measurements are reported in mm.

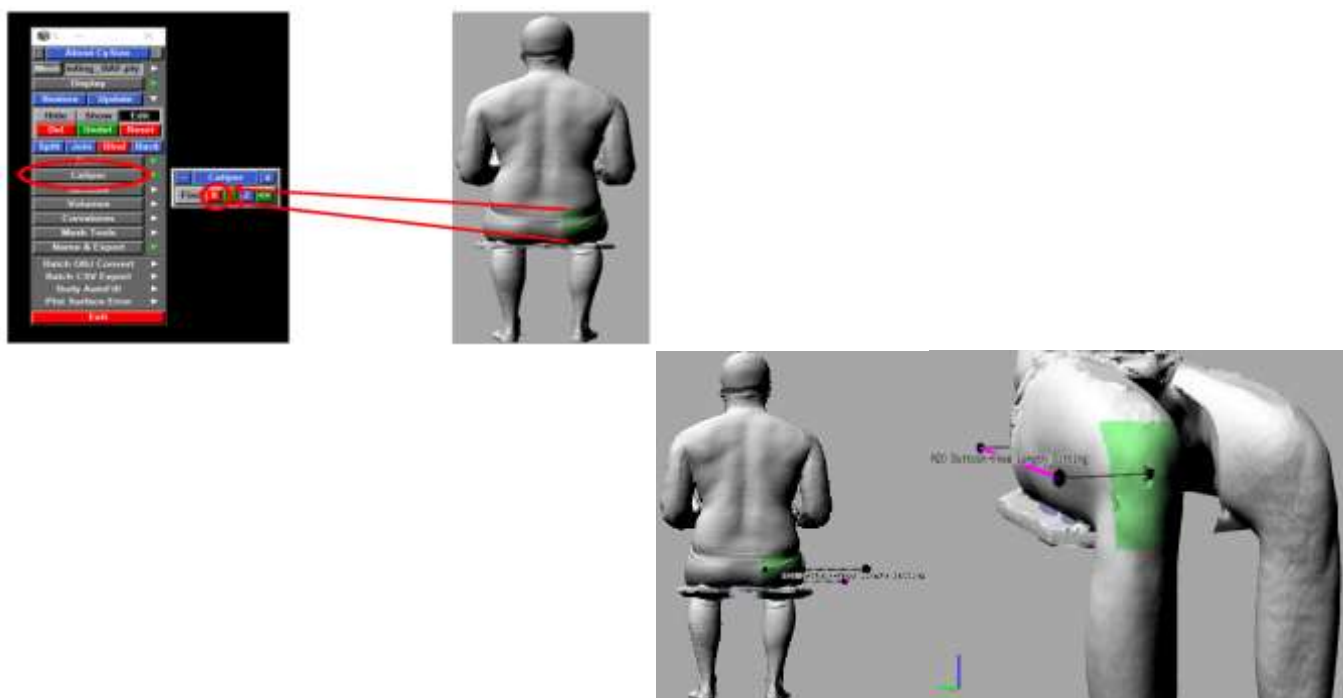
Reference:

Gordon, C.C., Blackwell, C.L., Bradtmiller, B., Parham, J.L., Barrientos, P., Paquette, S.P., Corner, B., Carson, J.M., Venezia, J.C., Rockwell, B.M., Mucher, M., Kristensen, S., 2014. 2012 Anthropometric survey of U.S. army personnel: Methods and summary statistics., Natick Soldier Research, Development of Engineering Center, Yellow Springs, Ohio, U.S.

Kolose, S., Hume, P.A., Tomkinson, G.R., Stewart, A., Stewart, T., Legg, S.J. (2021). Three-dimensional physique assessment in the military: New Zealand Defence Force Anthropometry Survey protocols and summary statistics., SPRINZ: Auckland, New Zealand.

Notes:

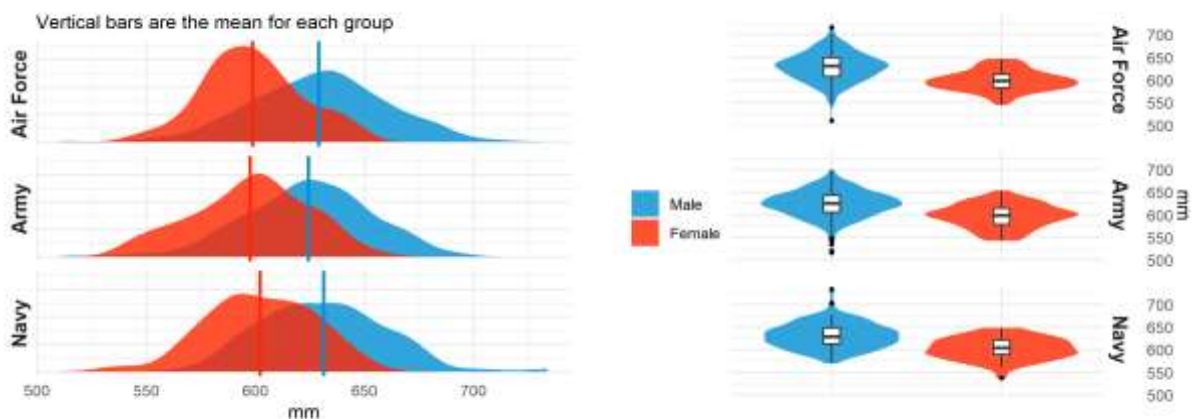
An alternative method is to view the participant from the right-side view, then highlight a narrow rectangle starting from the most posterior aspects of the right buttock to the most anterior aspect of the right knee then select the 'x' function.



Buttock-knee length sitting summary statistics - Post-processed measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
626	629	624	631	Mean	599	598	602	599
30	32	29	29	SD	23	26	24	25
511	511	517	570	Min	545	542	537	537
734	716	700	734	Max	647	654	648	654
690	700	687	706	P99	646	653	647	648
683	688	678	683	P98	645	641	646	646
679	684	675	676	P97	643	638	643	642
674	680	672	672	P95	638	637	637	637
664	667	662	668	P90	633	630	631	632
657	661	654	661	P85	622	628	628	627
651	654	648	654	P80	616	622	624	622
646	649	644	648	P75	612	615	621	615
641	644	640	644	P70	608	610	617	611
638	640	636	641	P65	605	607	612	607
634	637	632	639	P60	602	606	610	606
630	634	628	636	P55	599	602	607	602
627	631	626	629	P50	598	599	604	599
623	627	622	625	P45	596	598	595	597
620	623	619	622	P40	592	594	592	592
616	618	615	618	P35	588	590	591	590
612	613	611	616	P30	586	585	591	587
607	608	605	612	P25	583	580	590	583
601	604	600	606	P20	581	576	581	578
596	598	595	599	P15	578	568	576	575
588	589	587	598	P10	576	560	575	567
580	579	578	588	P5	565	550	567	556
570	574	569	586	P3	558	546	563	550
562	561	562	585	P2	554	544	557	545
548	551	547	582	P1	550	544	547	544

Distribution plots for each service and gender



Buttock-popliteal length sitting - Post-processed measurement (mm)

Measuring instrument:

CySlice

Source:

ANSUR, NZDFAS

Definition:

Ensure that the participant is sitting with their knee bent at a 90° angle. This can be done by moving the body scanner seat up or down. This can also be facilitated by aligning the popliteal fossa (vertically) in line with Pternion (back of the foot). The horizontal distance between a buttock plate placed at the most posterior point on either buttock and the back of the right knee (the popliteal fossa at the dorsal juncture of the calf and thigh).

Landmark required:

Buttock Point Sitting and Popliteal landmarks.

Posture required:

Scan position posture 3. Ensure that the participant is sitting with their knee bent at a 90° angle. This can be done by moving the body scanner seat up or down. This can also be facilitated by aligning the popliteal fossa (vertically) in line with Pternion (back of the foot).

Procedure:

This measure is the point to point distance between the Buttock Point Sitting and Popliteal landmarks. Measurements are reported in mm.

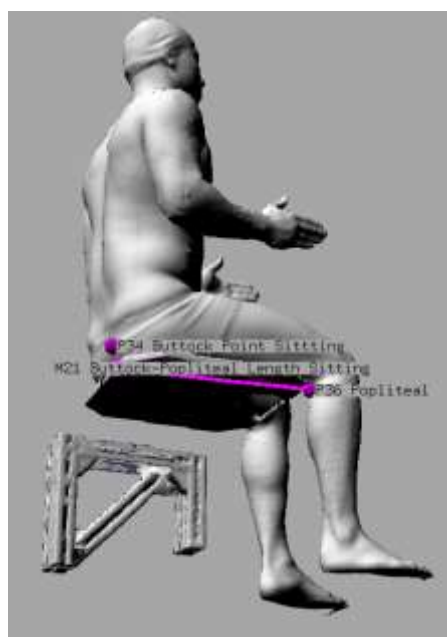
Reference:

Gordon, C.C., Blackwell, C.L., Bradtmiller, B., Parham, J.L., Barrientos, P., Paquette, S.P., Corner, B., Carson, J.M., Venezia, J.C., Rockwell, B.M., Mucher, M., Kristensen, S., 2014. 2012 Anthropometric survey of U.S. army personnel: Methods and summary statistics., Natick Soldier Research, Development of Engineering Center, Yellow Springs, Ohio, U.S.

Kolose, S., Hume, P.A., Tomkinson, G.R., Stewart, A., Stewart, T., Legg, S.J. (2021). Three-dimensional physique assessment in the military: New Zealand Defence Force Anthropometry Survey protocols and summary statistics., SPRINZ: Auckland, New Zealand.

Notes:

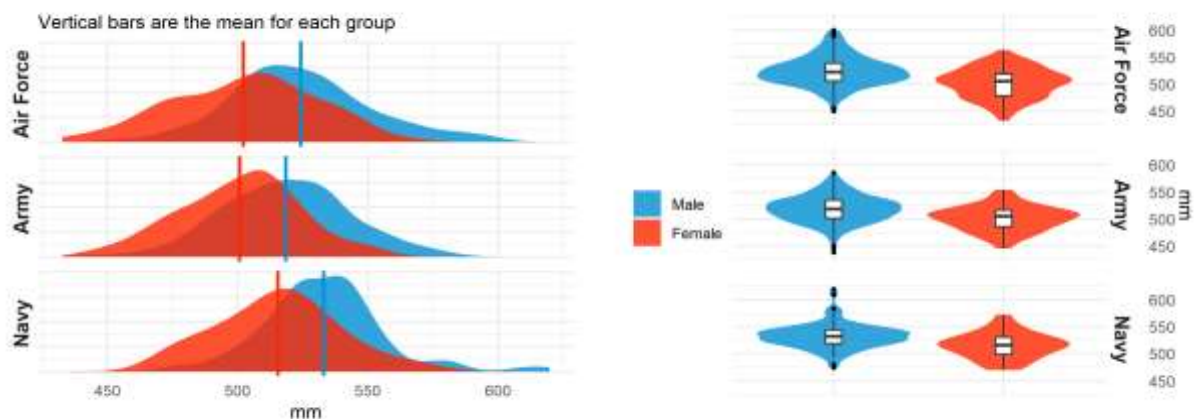
Note the illustration below does not show the 'point to point' line. The result will be correct upon final measurement export.



Buttock-popliteal length sitting summary statistics - Post-processed measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
522	524	519	533	Mean	502	501	516	504
26	27	25	24	SD	28	23	24	25
438	450	438	474	Min	433	446	470	433
620	600	586	620	Max	563	554	573	573
586	595	576	611	P99	554	550	568	561
579	588	571	590	P98	548	548	564	553
573	584	567	581	P97	545	545	560	549
566	575	560	576	P95	543	538	555	544
554	562	552	556	P90	539	527	544	537
547	552	544	552	P85	532	523	538	530
541	546	538	546	P80	527	518	532	524
537	539	534	544	P75	519	516	531	520
534	535	531	543	P70	516	512	525	517
531	532	528	539	P65	513	509	523	514
528	529	525	537	P60	511	508	521	511
525	525	522	537	P55	508	506	518	509
521	522	518	532	P50	505	505	516	507
518	518	516	528	P45	501	499	514	503
515	516	513	526	P40	498	495	511	499
512	513	509	525	P35	495	492	509	496
508	509	505	523	P30	488	490	504	492
505	506	501	519	P25	478	486	499	488
501	504	497	517	P20	476	479	496	479
496	499	494	511	P15	473	475	491	476
490	493	488	507	P10	468	470	482	470
480	481	480	497	P5	456	462	477	463
474	476	472	493	P3	449	458	476	456
470	473	467	489	P2	447	454	474	450
460	463	457	480	P1	442	446	472	446

Distribution plots for each service and gender



Calf girth - Automatic measurement (mm)

Measuring instrument:

Anthroscan.

Source:

UK Anthropometry Survey, Anthroscan.

Definition:

The maximum circumference of the calf while standing with legs straight, feet apart with weight evenly distributed).

Landmark required:

None.

Posture required:

Scan position posture 2. Stand with feet shoulder width apart, trunk and head are erect with eyes looking forward. The upper arms are abducted away from the body with the forearms hanging vertically. All fingers are together and extended with the palm facing (medially) the thigh and the thumb facing forward.

Procedure:

See Section 6 of Human Solutions (2015). Measurements are reported in mm.

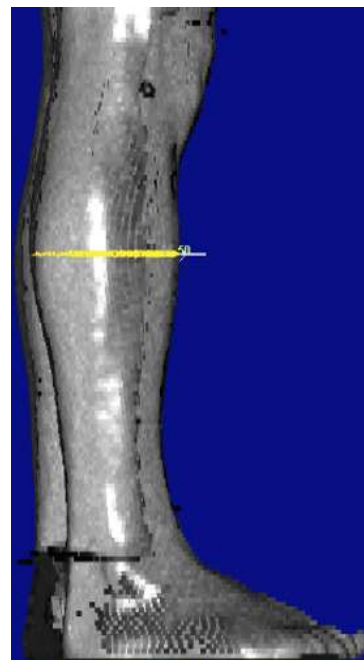
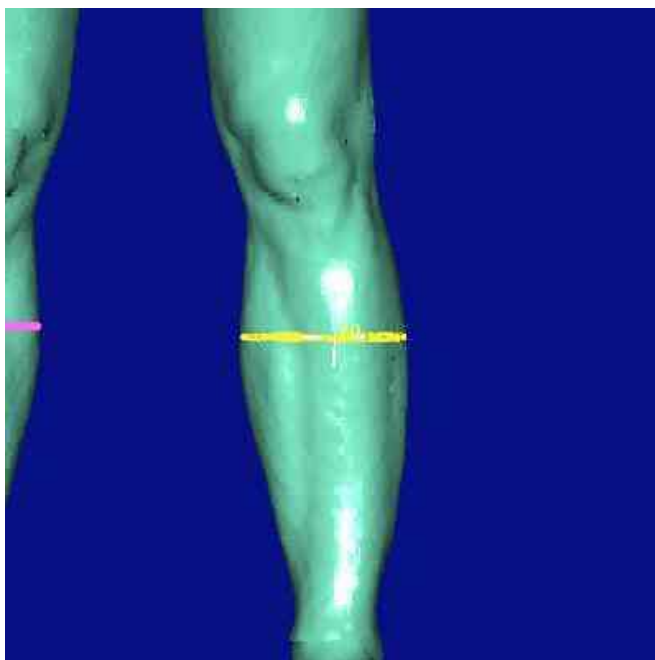
Reference:

Pringle, R. H., Puxley, A. J., Puxley, K. P. M., Turner, G. M., & Tyrell, A. K. (2011). Anthropometry Survey of UK Military Personnel 2006-7 (Issue 3) (QINETIQ/07/01821/3.0): QinetiQ Ltd.

Human Solutions, 2015. Anthroscan user guide version 3. Human Solutions GmbH, Kaiserslautern, Germany.

Notes:

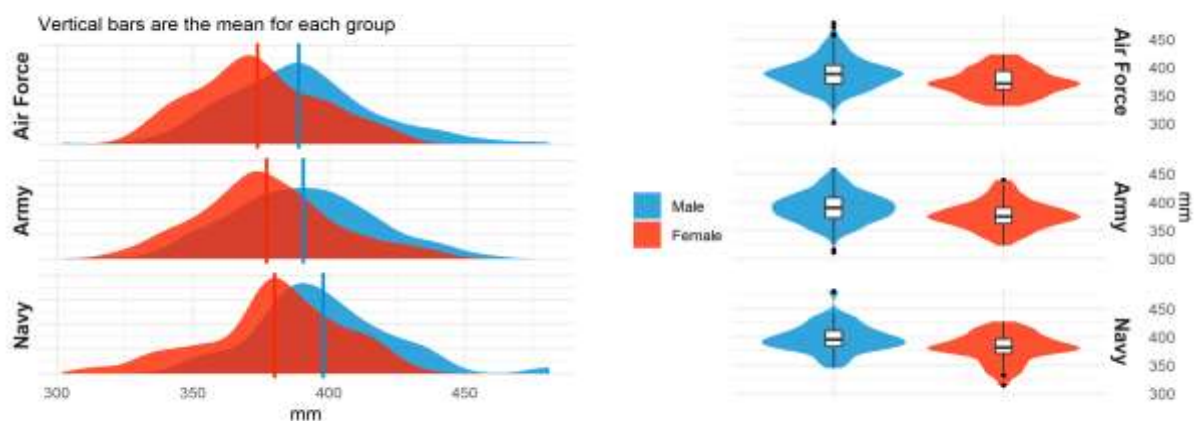
Check the digital tape (yellow line below) is horizontal and uniform around the calf. Confirm visually that the tape passes around the widest point of the calf whilst checking the tape value (increase or decrease) at the bottom of the window.



Calf girth summary statistics - Automatic measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
391	389	391	398	Mean	374	377	380	377
27	27	26	25	SD	23	25	25	24
302	302	311	345	Min	331	323	314	314
481	478	461	481	Max	423	439	427	439
457	458	451	480	P99	421	439	423	430
448	454	446	453	P98	420	431	420	427
442	444	441	440	P97	419	428	417	423
438	439	437	437	P95	416	424	415	418
425	424	424	431	P90	403	411	412	411
418	416	417	422	P85	398	402	406	401
412	408	413	418	P80	395	395	400	396
407	403	408	411	P75	393	390	396	393
403	400	404	407	P70	382	388	395	388
400	396	401	405	P65	379	385	387	384
396	392	397	400	P60	376	382	386	381
393	390	393	397	P55	374	377	383	378
390	388	390	395	P50	371	374	381	375
387	386	387	392	P45	371	374	378	374
384	382	383	390	P40	368	371	378	371
381	377	380	387	P35	365	370	376	369
377	374	376	385	P30	362	365	375	365
373	371	372	384	P25	360	362	371	361
369	367	368	380	P20	353	357	360	356
363	360	363	377	P15	348	352	354	351
358	357	356	370	P10	343	346	344	345
350	349	349	359	P5	339	338	335	338
346	346	346	353	P3	338	336	333	335
342	338	341	352	P2	337	334	329	332
335	333	335	351	P1	335	324	322	325

Distribution plots for each service and gender



Cervicale height sitting - Post-processed measurement (mm)

Measuring instrument:

CySlice.

Source:

ANSUR, NZDFAS.

Definition:

The vertical distance between the seated surface and the Cervicale landmark.

Landmark required:

Seventh cervical vertebra C7 and Seat Pan landmark.

Posture required:

Scan position posture 3. Ensure that the participant is sitting with their knee bent at a 90° angle. This can be done by moving the body scanner seat up or down. This can also be facilitated by aligning the popliteal fossa (vertically) in line with Pternion (back of the foot).

Procedure:

Look for the highest landmark on the upper back and look for the stickered landmarks. This measure is represented by the Y coordinate (mm on the Y or vertical axis) of the C7 landmark minus the Y coordinate (mm on the Y or vertical axis) of the Seat pan landmark in Posture 3. This calculation is performed in Excel. Measurements are reported in mm.

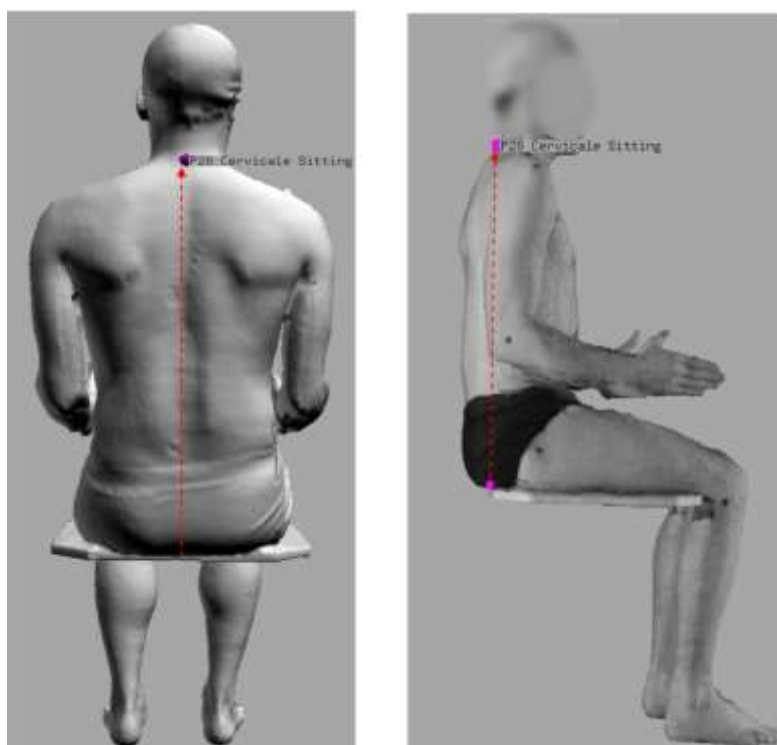
Reference:

Gordon, C.C., Blackwell, C.L., Bradtmiller, B., Parham, J.L., Barrientos, P., Paquette, S.P., Corner, B., Carson, J.M., Venezia, J.C., Rockwell, B.M., Mucher, M., Kristensen, S., 2014. 2012 Anthropometric survey of U.S. army personnel: Methods and summary statistics., Natick Soldier Research, Development of Engineering Center, Yellow Springs, Ohio, U.S.

Kolose, S., Hume, P.A., Tomkinson, G.R., Stewart, A., Stewart, T., Legg, S.J. (2021). Three-dimensional physique assessment in the military: New Zealand Defence Force Anthropometry Survey protocols and summary statistics., SPRINZ: Auckland, New Zealand.

Notes:

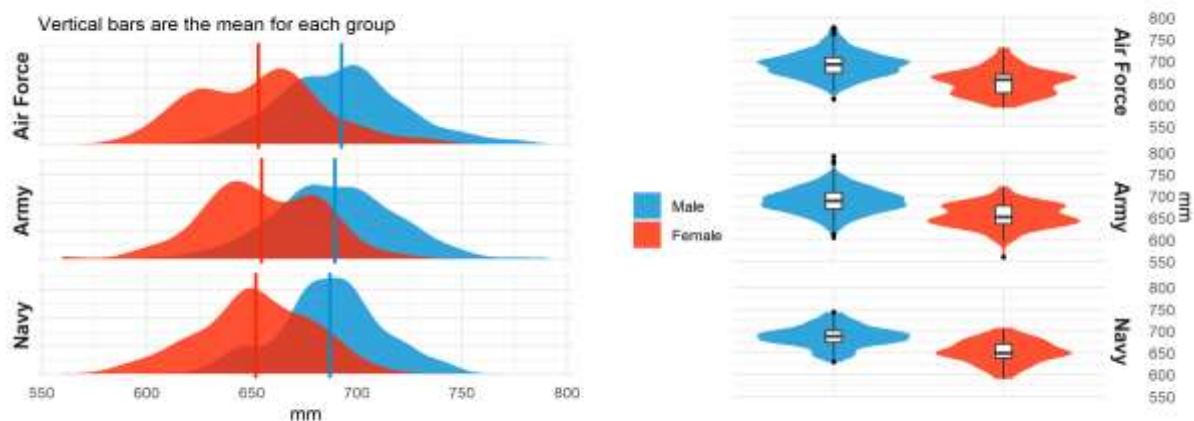
None.



Cervicale height sitting summary statistics - Post-processed measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
690	693	689	687	Mean	653	655	652	653
29	29	29	24	SD	30	28	26	28
605	613	605	629	Min	594	560	590	560
792	778	792	743	Max	732	722	707	732
759	770	755	741	P99	729	711	702	721
751	757	747	739	P98	719	709	697	709
745	752	744	734	P97	706	699	694	705
738	745	737	726	P95	702	694	691	698
725	729	726	719	P90	695	687	685	687
720	723	720	711	P85	679	684	680	681
713	716	714	706	P80	675	679	676	678
708	709	709	701	P75	669	678	671	675
703	705	704	697	P70	667	675	667	669
700	702	701	695	P65	666	671	661	666
697	699	697	693	P60	662	660	658	660
694	697	693	692	P55	660	658	652	658
690	693	689	688	P50	658	652	650	653
686	690	685	683	P45	652	650	649	649
681	684	681	681	P40	646	645	646	645
678	679	677	678	P35	636	641	645	642
675	676	675	676	P30	633	640	643	637
672	673	671	674	P25	627	637	638	635
668	669	666	672	P20	624	636	629	629
661	663	659	663	P15	620	629	623	624
654	656	654	656	P10	616	623	618	618
644	646	642	644	P5	611	609	609	609
637	643	635	643	P3	603	601	601	600
631	639	630	640	P2	600	599	597	599
625	634	623	634	P1	598	596	594	594

Distribution plots for each service and gender



Chest breadth - Post-processed measurement (mm)

Measuring instrument:

CySlice.

Source:

AWAS, NZDFAS.

Definition:

The maximum horizontal breadth at the height of Bust point, Right (females) or Thelion, Right (males).

Landmark required:

None.

Posture required:

Scan position posture 2. Stand with feet shoulder width apart, trunk and head are erect with eyes looking forward. The upper arms are abducted away from the body with the forearms hanging vertically. All fingers are together and extended with the palm facing (medially) the thigh and the thumb facing forward.

Procedure:

Use the caliper tool. Highlight a thin horizontal line across the chest. Ensure that the line passes through the centre of the Thelion right (male) and the bust point right (female). Best from the front. Use Y axis caliper. Chest breadth may also encompass the Latissimus dorsi muscle region. It may be easier to identify and place a marker on Thelion right. Then using the caliper tool highlight a thin line above and below the marker. For female participants, first identify the Best point then use the caliper to highlight a thin line above and below the marker then use the caliper tool to identify the chest breadth (see process below for females). Measurements are reported in mm.

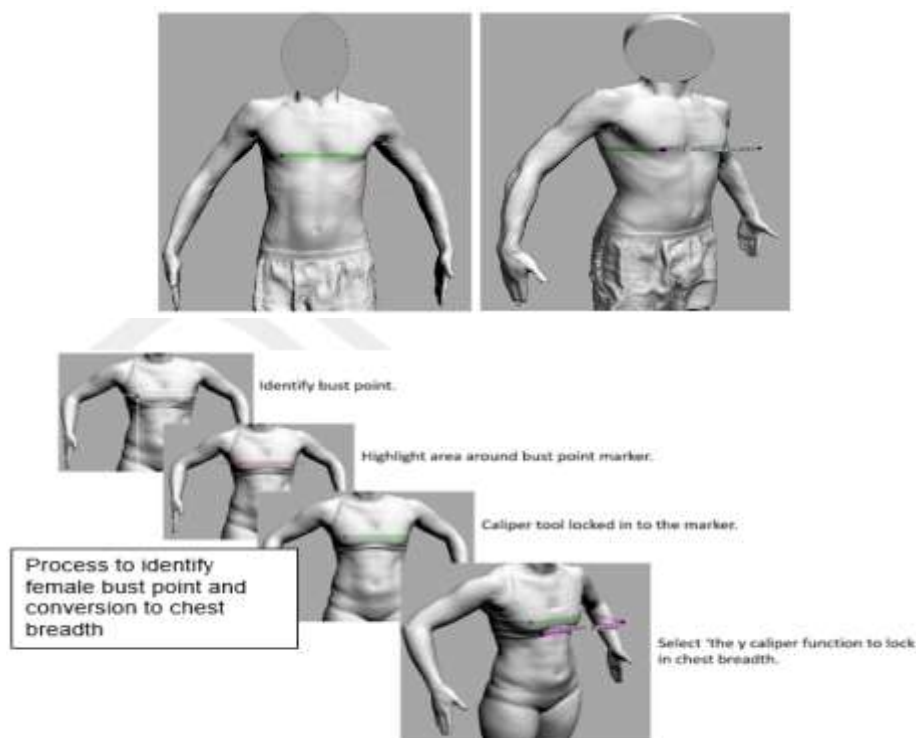
Reference:

Tomkinson, G. R., Daniell, N., Dale, M., & Bowler, T. (2012b). Australian Warfighters Anthropometry Survey (AWAS). Procedures Manual. Adelaide, Australia.: Health and Use of Time Group, Sansom Institute for Health Research, University of South Australia.

Kolose, S., Hume, P.A., Tomkinson, G.R., Stewart, A., Stewart, T., Legg, S.J. (2021). Three-dimensional physique assessment in the military: New Zealand Defence Force Anthropometry Survey protocols and summary statistics., SPRINZ: Auckland, New Zealand.

Notes:

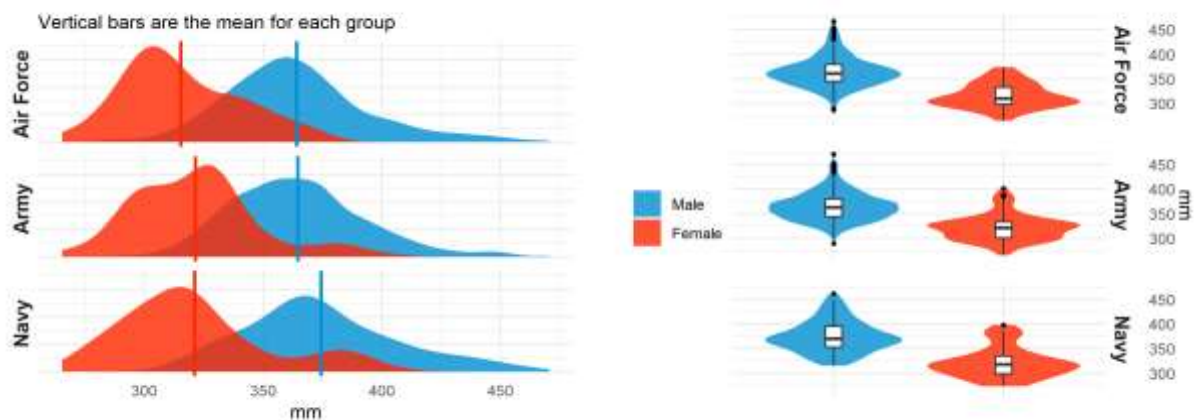
None.



Chest breadth summary statistics - Post-processed measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
366	364	365	374	Mean	315	321	321	319
29	30	28	32	SD	25	26	31	27
287	287	290	315	Min	265	265	274	265
470	467	470	461	Max	374	401	397	401
449	449	447	450	P99	371	388	393	388
442	441	435	448	P98	368	386	388	386
431	432	426	443	P97	367	385	386	382
420	422	415	435	P95	361	376	382	375
404	404	402	421	P90	350	353	378	355
395	392	392	407	P85	343	342	350	343
388	383	387	400	P80	340	337	340	339
381	379	379	395	P75	333	333	335	333
377	375	376	386	P70	326	331	324	329
373	371	373	379	P65	321	328	322	327
370	368	370	377	P60	316	328	321	323
366	364	366	375	P55	314	326	319	320
363	361	363	370	P50	310	322	318	317
360	358	358	366	P45	307	319	316	313
356	355	356	364	P40	306	313	312	309
353	352	352	363	P35	302	310	307	307
350	349	349	361	P30	300	307	302	302
345	345	344	353	P25	299	300	299	299
341	340	340	348	P20	297	298	297	297
337	336	336	342	P15	295	295	294	295
331	330	331	334	P10	287	293	288	289
324	321	324	328	P5	282	285	278	282
317	316	319	324	P3	280	283	278	278
316	310	316	321	P2	273	276	277	274
308	304	311	318	P1	267	270	276	268

Distribution plots for each service and gender



Chest depth - Post-processed measurement (mm)

Measuring instrument:

CySlice.

Source:

AWAS, NZDFAS.

Definition:

The horizontal distance between the Bust point (females) or Thelion (males), and the point on the dorsal surface at the same level, in the sagittal plane.

Landmarks required:

Thelion Bust point and Thelion Bust point projected landmarks.

Posture required:

Scan position posture 1. Stand with feet together, arms straight at the sides with the palms facing in towards the thigh. Fingers together and extended with the thumb facing forward. Stand with back erect and head in the Frankfort plane.

Procedure:

This measure is a derived measure (post analysis) that was not part of the original CySlice protocol. This procedure is performed in an Excel spreadsheet by adding the X coordinates for Thelion Bust point and Thelion Bust point projected to create a straight-line distance. Measurements are reported in mm.

Reference:

Tomkinson, G. R., Daniell, N., Dale, M., & Bowler, T. (2012a). Australian Warfighter Anthropometry Survey (AWAS): Landmarking and measurement manual. Adelaide, Australia: Health and Use of Time Group, Sansom Institute for Health Research, University of South Australia.

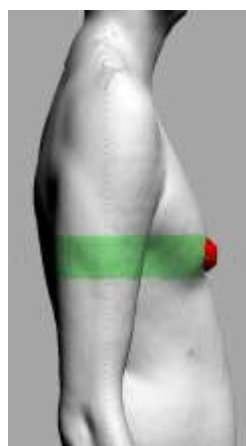
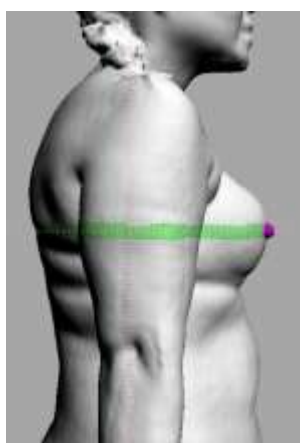
Kolose, S., Hume, P.A., Tomkinson, G.R., Stewart, A., Stewart, T., Legg, S.J. (2021). Three-dimensional physique assessment in the military: New Zealand Defence Force Anthropometry Survey protocols and summary statistics., SPRINZ: Auckland, New Zealand.

Notes:

All future Chest depth measurements should use the caliper tool. First identify the Thelion landmark. View the participant from the side. Use the Crosshair tool to correctly align the participants' posture. Highlight an area that is immediately above and below the Thelion landmark. Select the X function (to create a coronal plan) in the Caliper tool to calculate the depth.

There are three options for this measurement:

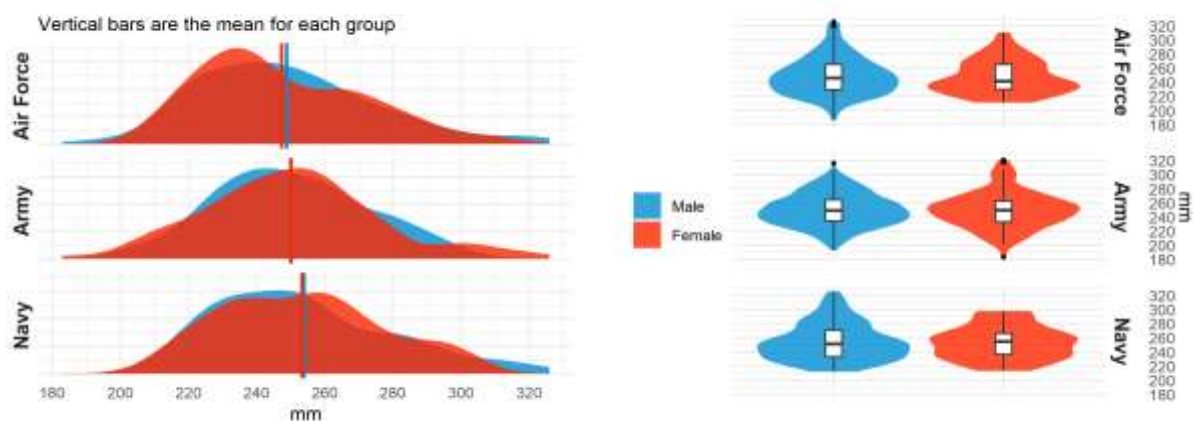
1. The anterior-posterior distance in a sagittal plane as described.
2. The point to point distance at the same level (i.e. on a transverse plane, but not in a sagittal plane).
3. The perpendicular planar distance which represents the theoretical minimum space occupancy for a person between the most anterior and most posterior points on the torso.



Chest depth summary statistics - Post-processed measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
250	249	250	254	Mean	247	250	253	250
24	26	23	26	SD	24	26	24	25
186	186	193	212	Min	211	183	213	183
326	326	316	326	Max	310	321	298	321
315	320	301	318	P99	308	317	298	310
304	317	296	315	P98	302	308	297	306
298	310	293	311	P97	296	305	297	301
292	297	289	304	P95	287	301	297	297
283	284	281	288	P90	283	279	289	283
277	278	276	284	P85	273	274	278	274
271	268	270	279	P80	268	271	273	271
265	265	265	271	P75	265	263	266	265
262	260	262	261	P70	261	260	264	261
258	255	259	258	P65	257	258	261	258
254	253	255	255	P60	248	256	259	256
251	249	251	253	P55	244	254	257	252
248	246	249	251	P50	241	250	255	247
245	242	246	248	P45	239	246	251	244
242	239	243	245	P40	236	244	243	240
238	236	239	238	P35	234	241	239	238
236	233	236	237	P30	232	237	237	235
233	229	234	233	P25	230	233	237	232
229	225	230	231	P20	227	231	233	230
226	222	227	229	P15	222	224	229	223
221	219	222	223	P10	221	217	222	220
215	215	214	221	P5	215	210	219	213
210	211	209	219	P3	214	205	218	211
206	205	206	218	P2	213	204	217	210
203	199	203	217	P1	212	201	215	205

Distribution plots for each service and gender



Chest height sitting - Post-processed measurement (mm)

Measuring instrument:

CySlice.

Source:

ANSUR, NZDFAS.

Definition:

The vertical distance between a horizontal sitting surface and the chest point anterior landmark.

Landmarks required:

Thelion (male)/Bust point (female) and Seat Pan top landmark.

Posture required:

Scan position posture 3. Ensure that the participant is sitting with their knee bent at a 90° angle. This can be done by moving the body scanner seat up or down. This can also be facilitated by aligning the popliteal fossa (vertically) in line with Pternion (back of the foot).

Procedure:

This measure is represented by the Y coordinate (mm on the Y or vertical axis) of the Thelion landmark in posture 3 minus the Y coordinate (mm on the Y or vertical axis) of the Seat pan marker. This calculation is performed in an Excel spreadsheet. Measurements are reported in mm.

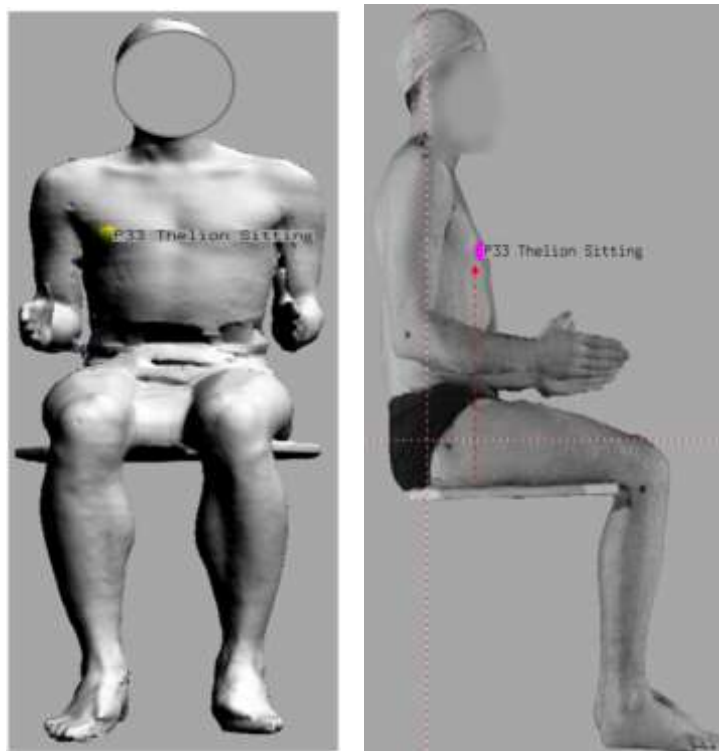
Reference:

Gordon, C.C., Blackwell, C.L., Bradtmiller, B., Parham, J.L., Barrientos, P., Paquette, S.P., Corner, B., Carson, J.M., Venezia, J.C., Rockwell, B.M., Mucher, M., Kristensen, S., 2014. 2012 Anthropometric survey of U.S. army personnel: Methods and summary statistics., Natick Soldier Research, Development of Engineering Center, Yellow Springs, Ohio, U.S.

Kolose, S., Hume, P.A., Tomkinson, G.R., Stewart, A., Stewart, T., Legg, S.J. (2021). Three-dimensional physique assessment in the military: New Zealand Defence Force Anthropometry Survey protocols and summary statistics., SPRINZ: Auckland, New Zealand.

Notes:

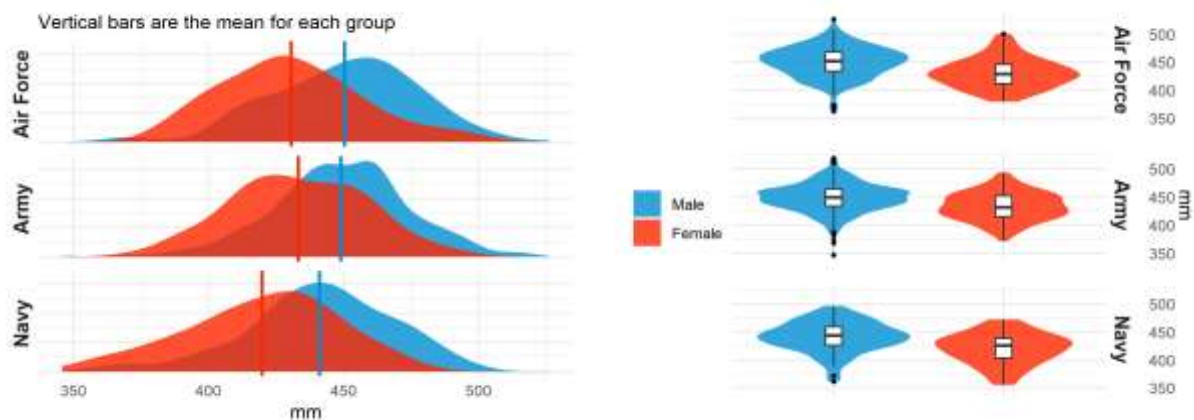
Ensure that the participant is sitting erect (and not leaning forward).



Chest height sitting summary statistics - Post-processed measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
448	450	449	441	Mean	431	433	420	430
26	28	25	27	SD	27	25	28	27
346	362	346	361	Min	379	372	355	355
526	526	518	497	Max	500	493	472	500
508	508	510	491	P99	496	487	470	493
498	500	498	490	P98	491	483	467	486
495	497	495	486	P97	486	477	466	480
491	492	491	481	P95	480	474	462	473
481	483	480	475	P90	464	463	452	463
474	478	473	470	P85	457	458	447	457
469	472	467	465	P80	451	456	440	452
465	468	464	459	P75	446	452	438	447
463	465	462	455	P70	444	448	437	444
460	463	459	452	P65	441	444	433	441
456	460	456	447	P60	434	441	428	436
453	455	453	445	P55	431	435	427	431
449	452	449	443	P50	429	432	425	428
446	449	446	439	P45	425	428	419	426
443	446	443	437	P40	424	426	413	424
439	441	441	433	P35	422	422	411	420
436	436	437	428	P30	415	420	408	415
432	433	434	426	P25	412	415	404	411
428	426	430	422	P20	408	412	397	408
422	420	424	417	P15	403	409	388	403
415	414	417	405	P10	398	400	382	395
406	408	407	394	P5	390	392	369	387
396	402	399	382	P3	388	388	365	382
390	393	394	371	P2	388	386	363	380
372	372	387	370	P1	385	384	359	368

Distribution plots for each service and gender



Crotch height - Post-processed measurement (mm)

Measuring instrument:

CySlice

Source:

AWAS.

Definition:

The vertical distance between the standing surface and the digitally identified crotch landmark.

Landmark required:

Crotch landmark.

Posture required:

Scan position posture 1. Stand with feet together, arms straight at the sides with the palms facing in towards the thigh. Fingers together and extended with the thumb facing forward. Stand with back erect and head in the Frankfort plane.

Procedure:

The Crotch landmark is the inferior point of the groin, on the right side of the male genitalia (if obstructing). With "Colour" mode off, identify the point on the crotch that a caliper coming in from the bottom would hit first (angle participant so that you are viewing their crotch from their foot). Add X-axis and Y-loops. Ensure the point marker is not on the upper thigh. Skip if it is unclear (due to crotch webbing caused by the upper thighs being too close together) or if the participant is wearing loose or 'baggy' shorts. Check from the side view using the Wire mesh mode. As measured in AWAS Section 7.1.19 of the Procedures Manual (Tomkinson et al., 2012). Measurements are reported in mm.

Reference:

Tomkinson, G. R., Daniell, N., Dale, M., & Bowler, T. (2012a). Australian Warfighter Anthropometry Survey (AWAS): Landmarking and measurement manual. Adelaide, Australia: Health and Use of Time Group, Sansom Institute for Health Research, University of South Australia.

Tomkinson, G. R., Daniell, N., Dale, M., & Bowler, T. (2012b). Australian Warfighters Anthropometry Survey (AWAS). Procedures Manual. Adelaide, Australia.: Health and Use of Time Group, Sansom Institute for Health Research, University of South Australia.

Notes:

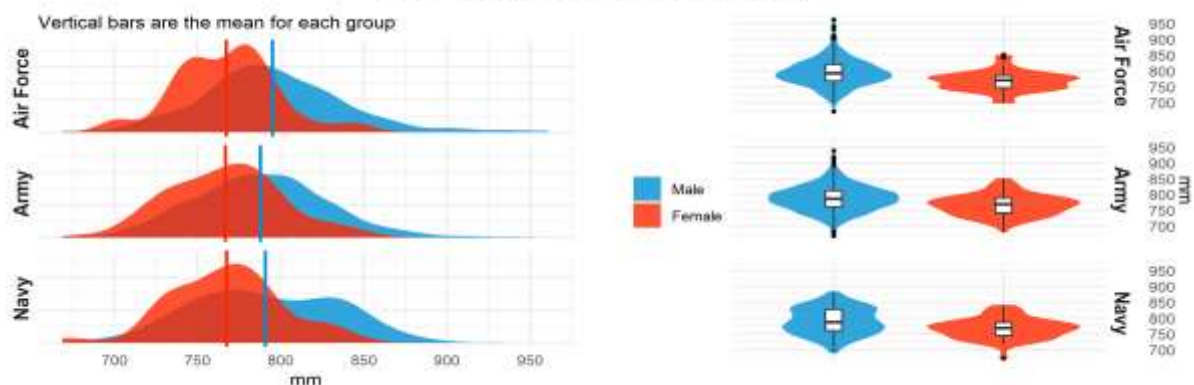
None.



Crotch height summary statistics - Post-processed measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
790	795	788	791	Mean	767	767	767	767
42	44	41	43	SD	31	34	34	33
668	671	668	689	Min	698	680	673	673
962	962	938	886	Max	851	852	842	852
904	929	888	870	P99	845	848	837	847
882	906	876	867	P98	842	836	832	842
869	890	868	864	P97	838	832	830	834
860	868	856	858	P95	819	831	827	829
841	848	838	842	P90	798	805	814	803
832	835	829	839	P85	794	798	793	796
824	825	820	834	P80	789	793	792	792
816	821	812	828	P75	784	789	786	787
809	815	808	817	P70	782	783	783	782
805	806	804	810	P65	778	779	780	779
799	801	798	806	P60	777	777	777	777
794	796	792	791	P55	774	771	770	773
788	793	787	787	P50	770	768	769	769
784	787	782	781	P45	765	764	763	763
779	783	779	776	P40	756	758	761	758
774	777	772	771	P35	755	751	757	754
768	774	767	766	P30	749	749	749	749
763	768	761	760	P25	747	742	746	744
756	763	754	751	P20	742	736	737	739
747	756	743	748	P15	739	731	733	733
737	741	737	736	P10	734	725	728	728
726	727	725	729	P5	720	714	726	714
716	722	715	717	P3	704	711	719	706
710	716	710	713	P2	701	705	710	703
703	706	703	706	P1	699	703	692	698

Distribution plots for each service and gender



Crotch length - Automatic measurement (mm)

Measuring instrument:

Anthroscan.

Source:

Anthroscan, UK Anthropometry Survey.

Definition:

The minimum surface distance between front waist level and back waist, (Code 6510) via the crotch.

Landmark required:

None.

Posture required:

Scan position posture 2. Stand with feet shoulder width apart, trunk and head are erect with eyes looking forward. The upper arms are abducted away from the body with the forearms hanging vertically. All fingers are together and extended with the palm facing (medially) the thigh and the thumb pointed forward.

Procedure:

See Section 6 of Human Solutions (2015). Measurements are reported in mm.

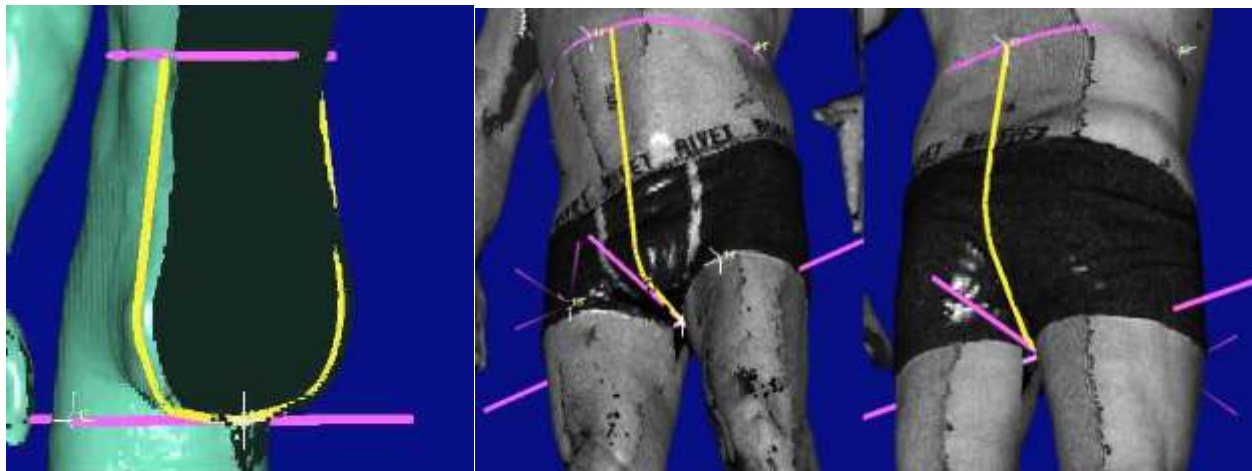
Reference:

Human Solutions, 2015. Anthroscan user guide version 3. Human Solutions GmbH, Kaiserslautern, Germany.

Pringle, R. H., Puxley, A. J., Puxley, K. P. M., Turner, G. M., & Tyrell, A. K. (2011). Anthropometry Survey of UK Military Personnel 2006-7 (Issue 3) (QINETIQ/07/01821/3.0): QinetiQ Ltd.

Notes:

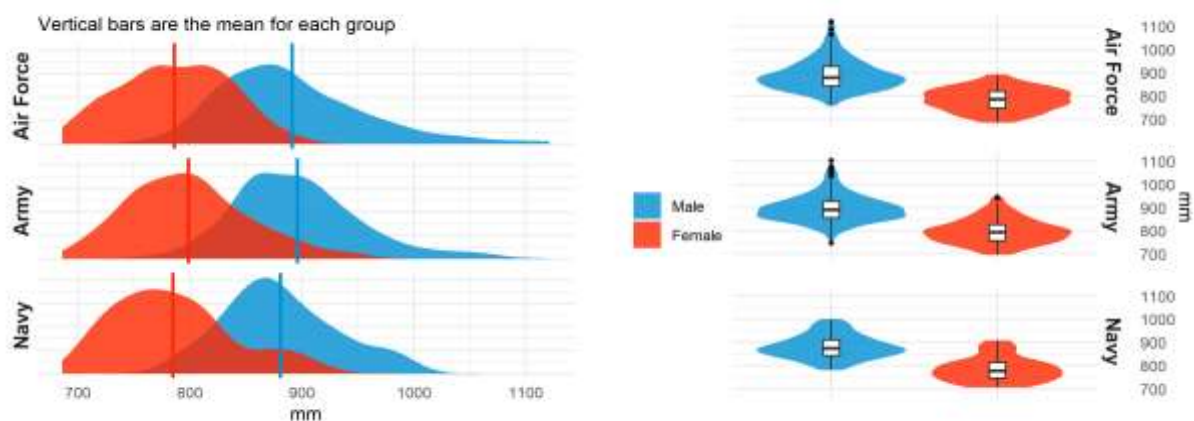
Check that the digital tape (yellow line below) is vertical on both the anterior and posterior ends.



Crotch length summary statistics - Automatic measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
893	891	896	881	Mean	786	799	785	792
59	66	57	50	SD	49	54	53	52
747	758	747	781	Min	686	697	707	686
1121	1121	1104	1000	Max	893	947	908	947
1065	1088	1064	987	P99	886	941	904	920
1047	1060	1046	984	P98	878	923	900	898
1029	1045	1029	983	P97	870	900	895	897
1003	1020	1005	978	P95	856	897	885	887
971	981	970	950	P90	848	867	869	861
951	958	951	936	P85	838	851	828	849
937	939	939	924	P80	831	846	817	834
926	928	927	911	P75	820	827	814	820
917	916	919	902	P70	817	820	808	816
907	902	911	894	P65	810	813	802	810
900	894	904	884	P60	803	808	791	804
892	886	898	878	P55	798	802	786	796
886	878	891	874	P50	785	794	777	790
878	874	883	869	P45	776	791	769	780
872	868	876	867	P40	770	781	766	773
867	862	870	859	P35	767	775	762	767
859	851	862	852	P30	763	766	753	763
852	843	856	844	P25	748	758	746	756
845	837	851	839	P20	742	756	740	745
837	831	844	834	P15	726	746	728	738
825	818	832	825	P10	722	737	722	724
808	806	816	804	P5	706	720	716	712
802	800	803	798	P3	700	709	712	707
795	789	798	792	P2	699	707	710	703
778	776	779	787	P1	695	705	709	698

Distribution plots for each service and gender



Crotch waist preferred anterior - Post-processed measurement (mm)

Measuring instrument:

CySlice.

Source:

AWAS, NZDFAS.

Definition:

The surface distance between the Crotch and Waist preferred anterior landmark.

Landmarks required:

Crotch and Waist preferred anterior landmarks.

Posture required:

Scan position posture 2. Stand with feet shoulder width apart, trunk and head are erect with eyes looking forward. The upper arms are abducted away from the body with the forearms hanging vertically. All fingers are together and extended with the palm facing (medially) the thigh and the thumb facing forward.

Procedure:

This measure is the surface distance (a function that mimics an anthropometric tape) between the Crotch and Waist preferred anterior landmarks. Measurements are reported in mm.

References:

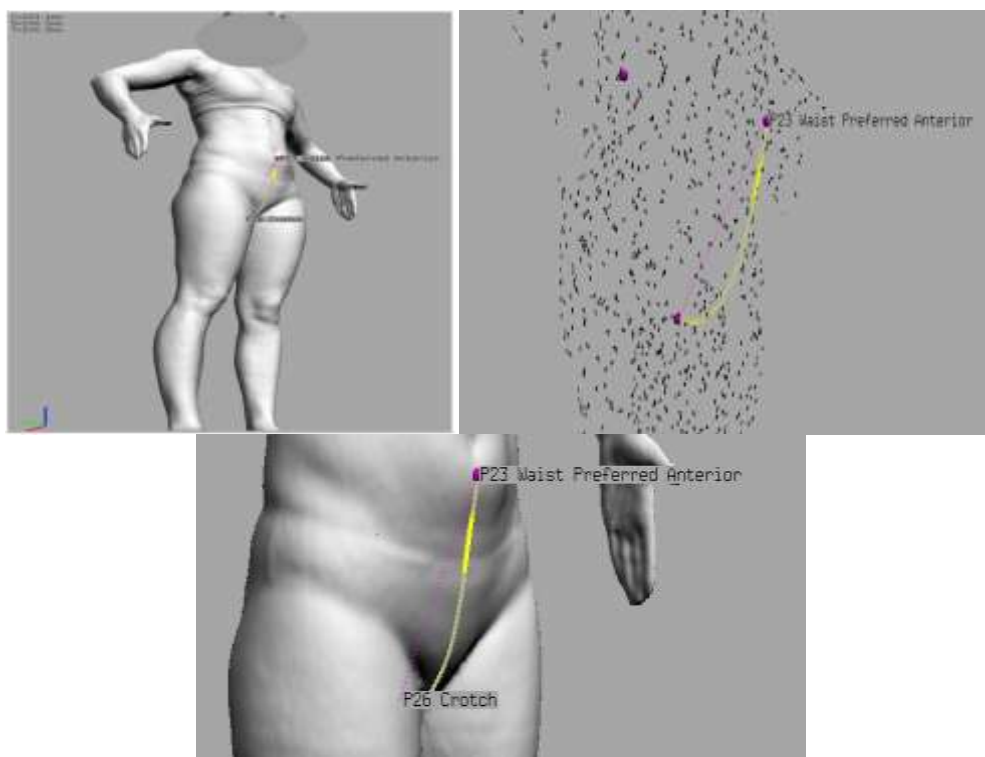
Tomkinson, G. R., Daniell, N., Dale, M., & Bowler, T. (2012a). Australian Warfighter Anthropometry Survey (AWAS): Landmarking and measurement manual. Adelaide, Australia: Health and Use of Time Group, Sansom Institute for Health Research, University of South Australia.

Tomkinson, G. R., Daniell, N., Dale, M., & Bowler, T. (2012b). Australian Warfighters Anthropometry Survey (AWAS). Procedures Manual. Adelaide, Australia.: Health and Use of Time Group, Sansom Institute for Health Research, University of South Australia.

Kolose, S., Hume, P.A., Tomkinson, G.R., Stewart, A., Stewart, T., Legg, S.J. (2021). Three-dimensional physique assessment in the military: New Zealand Defence Force Anthropometry Survey protocols and summary statistics., SPRINZ: Auckland, New Zealand.

Notes:

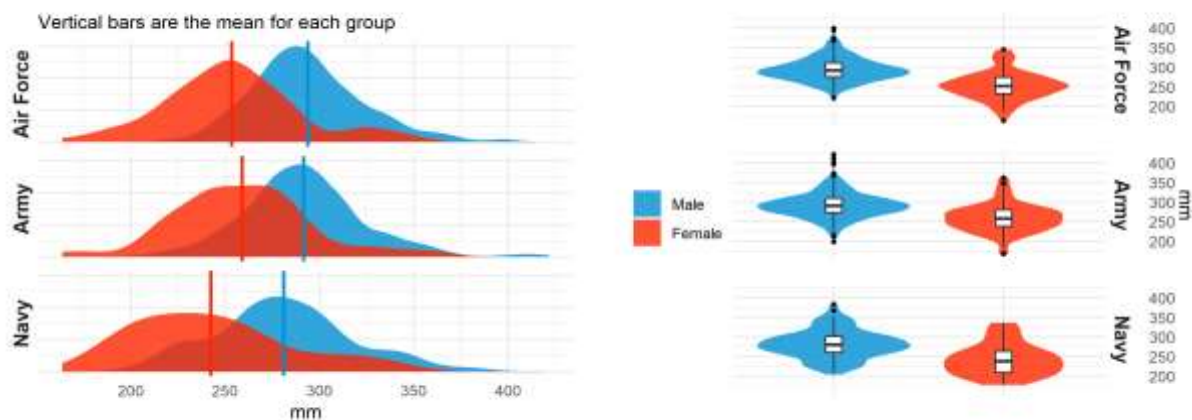
If crotch cannot be identified, then it will not be possible to acquire this measure.



Crotch waist preferred anterior summary statistics - Post-processed measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
291	294	292	281	Mean	254	259	242	254
32	30	32	37	SD	36	36	41	38
198	221	198	204	Min	164	168	177	164
422	399	422	383	Max	345	362	337	362
385	373	397	369	P99	345	360	335	347
367	366	365	355	P98	339	348	333	344
357	360	357	349	P97	329	340	331	335
348	347	351	345	P95	324	328	326	327
334	335	333	332	P90	290	298	303	302
321	322	320	315	P85	283	288	287	286
314	316	313	305	P80	278	284	268	282
309	311	310	301	P75	274	280	263	275
303	306	304	297	P70	265	275	260	270
299	300	300	294	P65	262	271	256	264
296	297	296	288	P60	257	267	248	261
293	294	294	281	P55	254	263	240	256
290	291	290	279	P50	252	258	237	252
286	288	287	277	P45	250	254	234	249
282	284	283	273	P40	247	249	228	243
279	281	279	266	P35	242	243	224	239
276	278	277	262	P30	237	240	213	236
272	275	272	260	P25	232	238	209	230
267	270	268	253	P20	226	232	206	223
261	266	262	240	P15	221	222	205	217
253	259	254	231	P10	212	218	196	207
240	250	241	223	P5	194	211	192	195
232	247	235	222	P3	189	200	183	187
224	242	226	219	P2	188	182	179	180
221	237	220	210	P1	180	168	178	169

Distribution plots for each service and gender



Crotch waist preferred posterior - Post-processed measurement (mm)

Measuring instrument:

CySlice

Source:

AWAS, NZDFAS.

Definition:

The surface distance between the Crotch and Waist preferred posterior landmark.

Landmarks required:

Crotch and Waist preferred posterior landmarks.

Posture required:

Scan position posture 2 Stand with feet shoulder width apart, trunk and head are erect with eyes looking forward. The upper arms are abducted away from the body with the forearms hanging vertically. All fingers are together and extended with the palm facing (medially) the thigh and the thumb facing forward.

Procedure:

This measure is the tape distance between the Crotch and Waist preferred posterior landmarks. Measurements are reported in mm.

Reference:

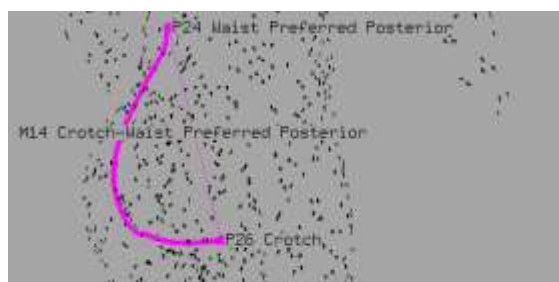
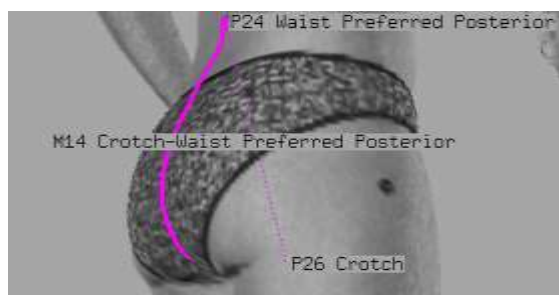
Tomkinson, G. R., Daniell, N., Dale, M., & Bowler, T. (2012a). Australian Warfighter Anthropometry Survey (AWAS): Landmarking and measurement manual. Adelaide, Australia: Health and Use of Time Group, Sansom Institute for Health Research, University of South Australia.

Tomkinson, G. R., Daniell, N., Dale, M., & Bowler, T. (2012b). Australian Warfighters Anthropometry Survey (AWAS). Procedures Manual. Adelaide, Australia.: Health and Use of Time Group, Sansom Institute for Health Research, University of South Australia.

Kolose, S., Hume, P.A., Tomkinson, G.R., Stewart, A., Stewart, T., Legg, S.J. (2021). Three-dimensional physique assessment in the military: New Zealand Defence Force Anthropometry Survey protocols and summary statistics., SPRINZ: Auckland, New Zealand.

Notes:

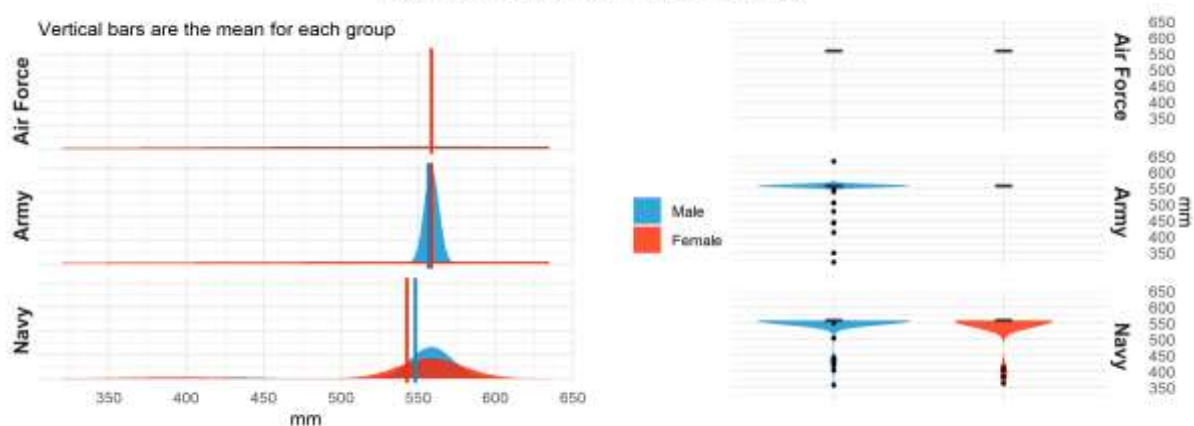
If crotch cannot be identified, then this measure will not be possible.



Crotch waist preferred posterior summary statistics - Post-processed measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
556	558	556	548	Mean	558	558	543	555
19	0	18	37	SD	0	0	50	23
320	558	320	357	Min	558	558	362	362
635	558	635	558	Max	558	558	558	558
558	558	558	558	P99	558	558	558	558
558	558	558	558	P98	558	558	558	558
558	558	558	558	P97	558	558	558	558
558	558	558	558	P95	558	558	558	558
558	558	558	558	P90	558	558	558	558
558	558	558	558	P85	558	558	558	558
558	558	558	558	P80	558	558	558	558
558	558	558	558	P75	558	558	558	558
558	558	558	558	P70	558	558	558	558
558	558	558	558	P65	558	558	558	558
558	558	558	558	P60	558	558	558	558
558	558	558	558	P55	558	558	558	558
558	558	558	558	P50	558	558	558	558
558	558	558	558	P45	558	558	558	558
558	558	558	558	P40	558	558	558	558
558	558	558	558	P35	558	558	558	558
558	558	558	558	P30	558	558	558	558
558	558	558	558	P25	558	558	558	558
558	558	558	558	P20	558	558	558	558
558	558	558	558	P15	558	558	558	558
558	558	558	558	P10	558	558	558	558
558	558	558	438	P5	558	558	403	558
558	558	558	428	P3	558	558	388	558
548	558	556	415	P2	558	558	380	558
441	558	473	398	P1	558	558	371	404

Distribution plots for each service and gender



Elbow girth - Automatic measurement (mm)

Measuring instrument:

Anthroscan.

Source:

Anthroscan, CFAS.

Definition:

Elbow perimeter measured on the right arm with a line passing the olecranon and the antecubital fossa (arm front hollow).

Landmark required:

None.

Posture required:

Scan position posture 2. Stand with feet shoulder width apart, trunk and head are erect with eyes looking forward. The upper arms are abducted away from the body with the forearms hanging vertically. All fingers are together and extended with the palm facing (medially) the thigh and the thumb facing forward.

Procedure:

See Section 6 of Human Solutions (2015). Measurements are reported in mm.

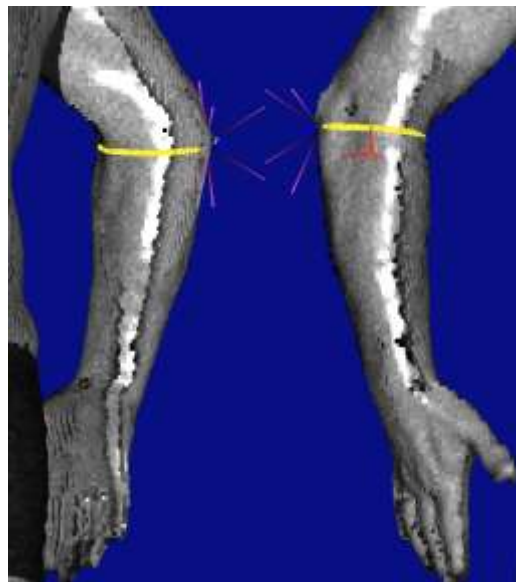
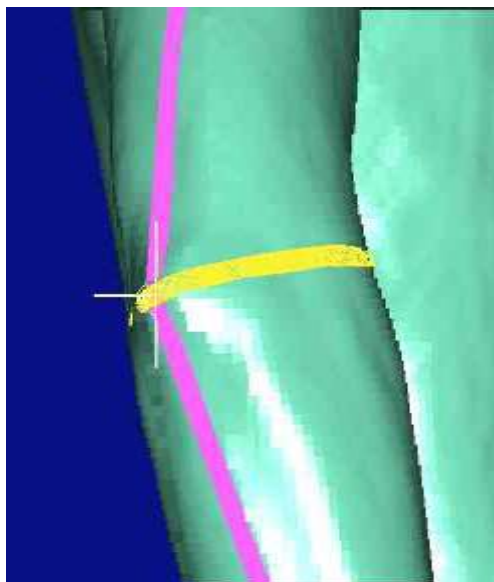
Reference:

Human Solutions, 2015. Anthroscan user guide version 3. Human Solutions GmbH, Kaiserslautern, Germany.

Keefe, A., H. Angel, and B. Mangan, 2012 Canadian Forces Anthropometric Survey (CFAS) – Final report. 2015, Défense Research and Development Canada: Toronto, Canada.

Notes:

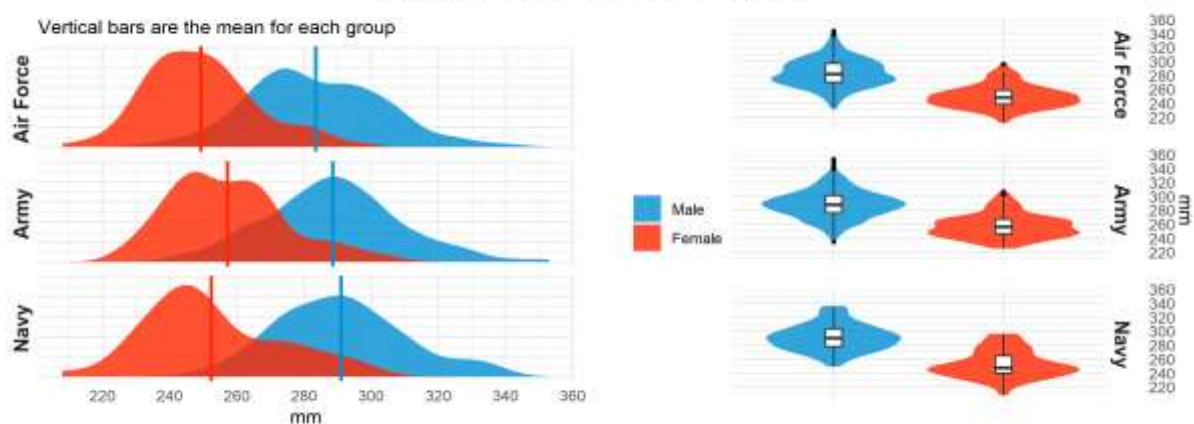
Check that the digital tape (yellow line below) is horizontal, ideally passing through the inner crease of the elbow and the olecranon process (tip of the elbow). The accuracy of this measurement is affected by the degree of flexion at the elbow.



Elbow girth summary statistics - Automatic measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
287	283	289	291	Mean	249	257	252	254
20	20	20	19	SD	16	17	20	18
232	232	235	249	Min	212	225	208	208
353	343	353	336	Max	296	306	296	306
338	334	340	335	P99	288	302	296	296
331	326	331	334	P98	284	296	295	296
328	324	328	331	P97	283	293	294	293
324	316	324	329	P95	282	289	291	287
312	308	314	316	P90	272	282	277	277
308	305	309	309	P85	265	271	277	271
303	300	304	307	P80	262	269	272	268
300	297	301	303	P75	258	267	264	264
297	294	298	300	P70	255	265	258	262
294	292	295	296	P65	254	263	254	258
292	288	293	294	P60	252	261	252	255
290	285	291	292	P55	250	258	248	254
287	282	288	290	P50	248	256	247	250
285	278	286	289	P45	247	252	247	248
282	277	284	285	P40	243	250	246	247
279	274	281	282	P35	242	248	243	246
277	272	278	279	P30	240	246	243	243
274	270	276	278	P25	239	246	240	241
271	267	272	275	P20	236	242	238	239
266	264	267	271	P15	234	240	233	236
262	261	263	269	P10	231	238	231	233
256	253	257	263	P5	228	234	228	230
251	248	253	258	P3	223	230	226	227
248	245	248	257	P2	222	229	222	225
243	240	245	256	P1	219	228	215	222

Distribution plots for each service and gender



Elbow grip length - Physical measurement (mm)

Measuring instrument:

Measurement rod, and a narrow cylindrical object with a known diameter such as a whiteboard pen. Full-length anthropometer, ideally made of solid steel. The anthropometer typically comes in 4 sections. When combined, one end of the rod contains a stationary or fixed arm or 'prong', the other prong is free to move up and down while at a right angles to the rod. There are typically two anthropometer scales that run opposite each other.

Source:

ISO 7250.

Definition:

The horizontal distance from a back wall to the grip centre point (defined as the centre of a measurement rod with a known diameter) grip with elbow bent at a 90 degree angle.

Landmark required:

None.

Posture required:

The assessor stands to the right side of the participant in front of the elbow. This position enables the assessor to support the weight of the anthropometer evenly, and be in a position to see both prongs (the fixed end and the measurement end).

Procedure:

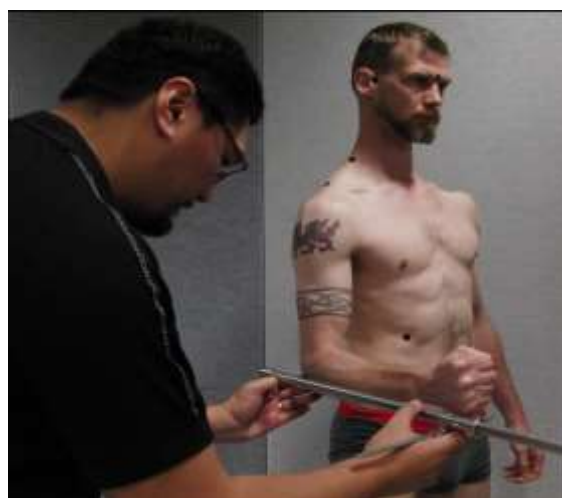
The 'inside' edge of the fixed prong touching the most posterior inferior aspect of the elbow (Olecranon), to the inside edge of the sliding prong touching the most anterior surface of the measurement rod. Extend the opposite prong 5 cm beyond the rod. Slowly push the prong towards the rod until it touches it. Check that anthropometer shaft is vertical, its arm is horizontal and then take the reading to the nearest 0.1 cm. Subtract the known radius of the measurement rod from the measurement (the measure should be from the Olecranon to the centre of the rod).

Reference:

ISO 7250-1. Basic Human Body Measurements for Technological Design. 2008, International Organization for Standardization: Geneva.

Notes:

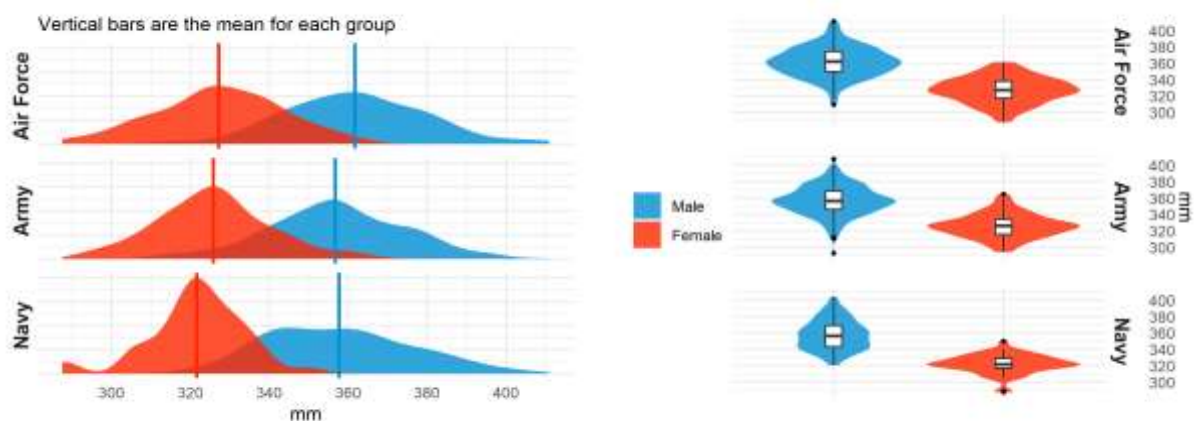
The right arm must be at a 90 degree angle. If the elbow position is difficult to locate, palpate the elbow with the left middle finger whilst holding the anthropometer horizontally (like Head depth caliper technique). The rod must be held tight and in a vertical position. If not, the rod will be unstable. This will result in the prong 'pushing' the rod backwards thus giving a false reading. Lengthen or shorten the anthropometer (by adding or removing sections of the rod) to suit the arm length of the participant. Ensure the prong is based securely, and square to the wall for stability. Be aware of handling the prong tip to avoid injuring the participant. The scribe observes and confirms whether the participant's arm is straight and horizontal to the floor immediately before the reading. The anthropometer and arm centre should be at the same height.



Elbow grip length summary statistics - Physical measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
358	362	357	358	Mean	327	326	322	325
18	18	18	18	SD	16	14	12	15
292	310	292	320	Min	288	294	288	288
411	411	408	404	Max	361	365	350	365
400	408	396	399	P99	360	360	346	360
396	402	394	396	P98	357	359	342	359
392	397	390	392	P97	354	358	340	354
387	390	385	388	P95	353	349	338	350
381	384	379	384	P90	348	344	335	344
378	380	376	378	P85	342	341	333	340
374	378	372	376	P80	340	337	331	338
370	374	368	369	P75	338	334	329	335
367	370	366	366	P70	337	331	327	332
364	367	363	364	P65	335	329	326	329
362	366	360	362	P60	331	328	324	328
360	363	358	360	P55	328	327	323	327
358	362	356	356	P50	327	326	322	326
356	359	356	354	P45	326	324	321	324
354	357	352	351	P40	325	323	320	322
351	355	350	348	P35	322	321	320	321
349	352	348	345	P30	321	318	318	318
346	349	346	343	P25	317	316	317	316
344	346	343	341	P20	313	314	314	314
340	343	339	339	P15	310	312	311	311
336	340	336	337	P10	305	307	307	306
329	334	326	333	P5	302	303	305	303
324	329	321	327	P3	297	299	293	296
320	327	318	327	P2	293	297	289	294
314	316	312	325	P1	290	294	288	289

Distribution plots for each service and gender



Elbow rest height standing - Physical measurement (mm)

Measuring instrument:

Anthropometer and anthropometry box. The stadiometer sits on the anthropometric box which is aligned with its long axis vertically.

Source:

ISO 7250.

Definition:

The horizontal distance from the back of the elbow to the grip with elbow flexed at a right angle.

Landmark required:

None.

Posture required:

The participant stands with feet together to the left side of the anthropometry box (outer right leg touching the left side of the box) with their arm in a 90 degree angle. The assessor kneels behind the participant and the box. Both participant and assessor are facing the same direction.

Procedure:

Measure from the most inferior surface of the elbow (Olecranon) to the most superior surface of the anthropometry box when the participant is at "end tidal" of the breathing cycle. Ensure the measure is taken from the 'outside' or superior edge of the sliding prong (whilst touching the olecranon). Measure to the nearest 0.1 cm. Apply a correction factor for elbow grip height = Olecranon to anthropometry box surface distance + anthropometer prong/arm width + box height.

Reference:

ISO 7250-1. Basic Human Body Measurements for Technological Design. 2008, International Organization for Standardization: Geneva.

Notes:

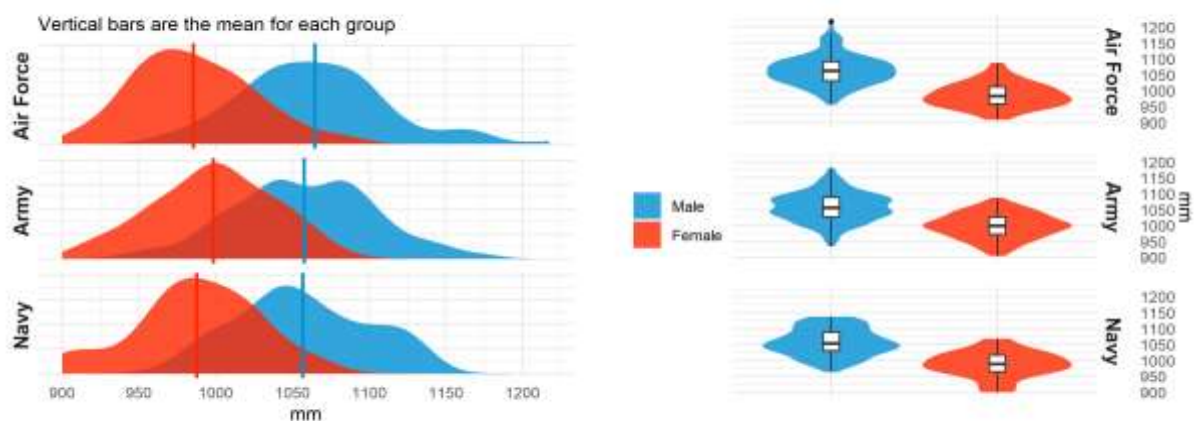
If the anthropometry box is too short consider using another object such as a sturdy desk or table. Make sure the fixed prong outer surface is square with the surface of the anthropometry box. Ensure the anthropometer is vertical. Participants with a wider than normal Latissimus Dorsi have elbows abducted from the body altering the height of the elbow. Take the measure at 'end tidal' to avoid inaccuracies due to breathing (vertical movements to the torso caused by fluctuations in the diaphragm). Participants are encouraged to relax throughout. The long axis of the tricep should ideally be perpendicular to the anthropometry box surface. However, the long axis of the triceps will only be perpendicular to the box surface if the participant is sufficiently slender or lean to enable the arm to hang vertically, a condition which is not the case in the example depicted.



Elbow rest height standing summary statistics - Physical measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
1059	1065	1058	1057	Mean	986	998	988	992
46	47	46	43	SD	39	40	40	40
934	956	934	964	Min	908	904	900	900
1218	1218	1181	1138	Max	1087	1087	1068	1087
1173	1180	1165	1134	P99	1081	1073	1065	1078
1162	1172	1150	1134	P98	1072	1070	1061	1069
1150	1166	1148	1129	P97	1062	1065	1058	1064
1138	1161	1137	1125	P95	1050	1060	1054	1059
1116	1120	1114	1122	P90	1035	1050	1031	1044
1105	1106	1103	1111	P85	1022	1041	1026	1034
1096	1096	1096	1100	P80	1016	1034	1022	1026
1090	1092	1089	1088	P75	1012	1027	1016	1020
1084	1088	1083	1080	P70	1007	1023	1008	1011
1078	1078	1078	1071	P65	999	1011	1003	1008
1072	1075	1072	1064	P60	992	1008	999	1002
1065	1068	1065	1058	P55	987	1004	996	998
1057	1062	1056	1052	P50	983	999	989	992
1051	1057	1050	1049	P45	976	995	984	988
1046	1050	1044	1044	P40	973	991	978	981
1040	1044	1038	1038	P35	967	986	975	974
1034	1039	1034	1033	P30	962	979	972	971
1029	1031	1026	1030	P25	959	972	964	964
1021	1026	1017	1020	P20	950	964	962	959
1011	1018	1009	1010	P15	947	956	953	950
1001	1007	999	997	P10	943	948	934	942
985	994	984	990	P5	925	929	907	924
975	982	969	986	P3	924	922	904	918
963	978	959	984	P2	917	918	903	909
955	964	952	982	P1	911	917	901	905

Distribution plots for each service and gender



Eye height - Post-processed measurement (mm)

Measuring instrument:

CySlice.

Source:

ISO 7250, NZDFAS

Definition:

The vertical distance from the floor to the lateral corner of the eye. The head is in the Frankfort plane.

Landmark required:

Ectocanthus landmark (lateral corner of the right eye).

Posture required:

Scan position posture 1. Stand with feet together, arms straight at the sides with the palms facing in towards the thigh. Fingers together and extended with the thumb facing forward. Stand with back erect and head in the Frankfort plane.

Procedure:

This measure is represented by the Y coordinate (mm on the Y or vertical axis) of the Ectocanthus landmark. Ensure that the point marker is NOT on the crease of the eye. Measurements are reported in mm. Located visually.

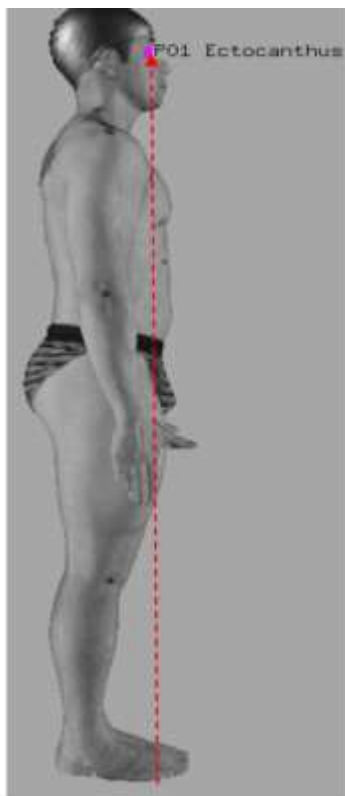
Reference:

ISO 7250-1. Basic Human Body Measurements for Technological Design. 2008, International Organization for Standardization: Geneva.

Kolose, S., Hume, P.A., Tomkinson, G.R., Stewart, A., Stewart, T., Legg, S.J. (2021). Three-dimensional physique assessment in the military: New Zealand Defence Force Anthropometry Survey protocols and summary statistics., SPRINZ: Auckland, New Zealand.

Notes:

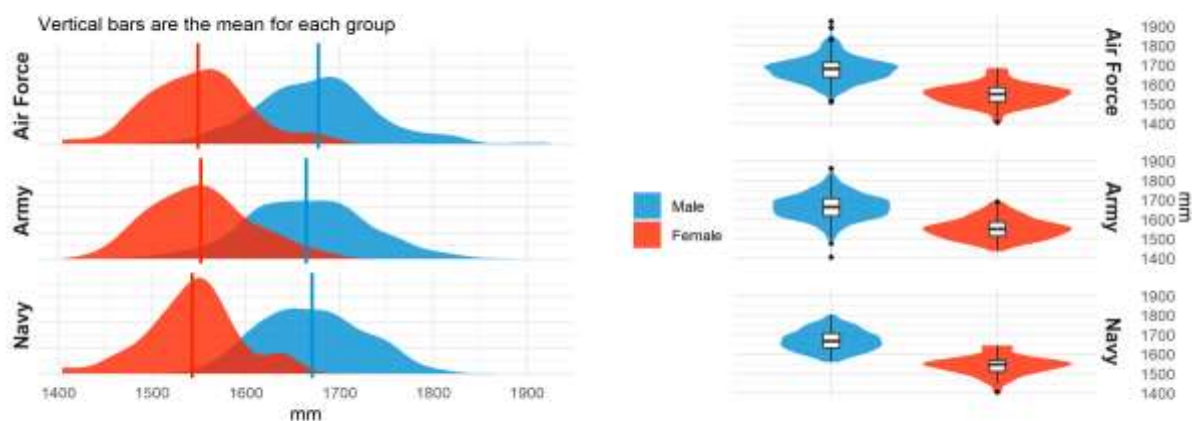
Ensure that the participant stands erect without 'hunching'.



Eye height summary statistics - Post-processed measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
1669	1677	1664	1671	Mean	1549	1552	1543	1549
64	65	65	54	SD	54	54	50	53
1404	1508	1404	1559	Min	1406	1436	1405	1405
1924	1924	1862	1804	Max	1684	1691	1645	1691
1824	1830	1817	1789	P99	1679	1678	1643	1677
1809	1823	1799	1768	P98	1673	1671	1641	1669
1795	1815	1790	1760	P97	1666	1657	1640	1659
1774	1794	1768	1756	P95	1646	1643	1638	1640
1751	1754	1751	1746	P90	1614	1624	1594	1621
1732	1734	1731	1734	P85	1592	1611	1588	1596
1719	1723	1716	1719	P80	1586	1591	1572	1587
1709	1713	1707	1707	P75	1583	1584	1568	1581
1701	1704	1699	1696	P70	1576	1577	1563	1571
1693	1700	1691	1691	P65	1568	1568	1561	1565
1685	1692	1681	1686	P60	1565	1561	1552	1561
1678	1684	1674	1681	P55	1557	1554	1549	1554
1667	1679	1663	1667	P50	1551	1550	1546	1549
1659	1669	1656	1659	P45	1540	1544	1543	1543
1651	1661	1647	1651	P40	1536	1537	1536	1536
1643	1651	1637	1645	P35	1529	1529	1532	1529
1634	1643	1628	1640	P30	1518	1521	1522	1519
1625	1636	1619	1632	P25	1513	1515	1512	1513
1615	1625	1612	1619	P20	1504	1504	1511	1504
1606	1612	1602	1611	P15	1495	1495	1499	1495
1593	1601	1585	1603	P10	1482	1486	1484	1482
1568	1571	1556	1592	P5	1474	1475	1464	1471
1549	1566	1546	1579	P3	1472	1464	1451	1464
1541	1559	1524	1571	P2	1446	1463	1440	1448
1515	1541	1506	1565	P1	1421	1451	1422	1428

Distribution plots for each service and gender



Eye height sitting - Post-processed measurement (mm)

Measuring instrument:

CySlice.

Source:

AWAS.

Definition:

Sitting surface to the Ectocanthus landmark.

Landmark required:

Ectocanthus.

Posture required:

Scan position posture 3. Ensure that the participant is sitting with their knee bent at a 90° angle. This can be done by moving the body scanner seat up or down. This can also be facilitated by aligning the popliteal fossa (vertically) in line with Pternion (back of the foot).

Procedure:

In CySlice use the Y coordinate (mm on the Y or vertical axis) of Ectocanthus. Measurements are reported in mm.

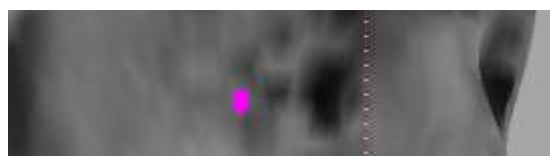
Reference:

Tomkinson, G. R., Daniell, N., Dale, M., & Bowler, T. (2012a). Australian Warfighter Anthropometry Survey (AWAS): Landmarking and measurement manual. Adelaide, Australia: Health and Use of Time Group, Sansom Institute for Health Research, University of South Australia.

Tomkinson, G. R., Daniell, N., Dale, M., & Bowler, T. (2012b). Australian Warfighters Anthropometry Survey (AWAS). Procedures Manual. Adelaide, Australia.: Health and Use of Time Group, Sansom Institute for Health Research, University of South Australia.

Notes:

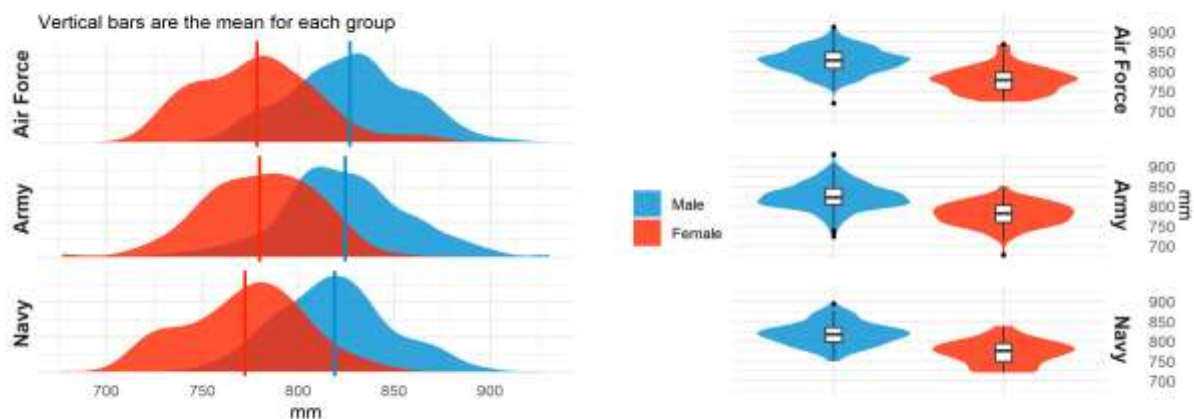
Ensure that the participant is sitting erect ideally with the head in the Frankfort plane.



Eye height sitting summary statistics - Post-processed measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
825	827	825	819	Mean	778	780	772	778
32	31	33	29	SD	31	30	30	30
720	720	724	750	Min	724	677	722	677
931	912	931	894	Max	868	851	839	868
901	893	903	879	P99	863	834	833	850
891	888	895	877	P98	855	829	826	838
886	882	888	875	P97	844	825	823	829
880	876	882	873	P95	827	823	820	824
866	867	867	860	P90	811	817	808	812
860	862	860	847	P85	809	809	799	808
851	856	851	841	P80	805	806	795	804
844	849	845	834	P75	797	802	794	798
839	840	839	832	P70	792	796	789	794
836	838	836	828	P65	787	793	786	789
831	836	830	827	P60	785	789	780	786
828	832	827	820	P55	782	786	778	783
824	828	823	817	P50	778	782	776	778
819	823	818	815	P45	776	777	770	776
815	820	815	813	P40	774	773	768	772
812	814	811	808	P35	764	767	765	766
808	810	807	804	P30	761	764	758	761
804	808	804	798	P25	755	760	749	758
800	801	800	794	P20	748	756	746	750
795	794	796	787	P15	744	751	735	745
784	784	785	783	P10	739	745	725	738
773	776	772	776	P5	732	731	723	728
764	771	762	766	P3	732	726	722	724
759	771	755	765	P2	731	721	722	722
749	763	745	762	P1	729	712	722	722

Distribution plots for each service and gender



Foot ball circumference - Physical measurement (mm)

Measuring instrument:

Anthropometry tape.

Source:

AWAS.

Definition:

The circumference around the first metatarsophalangeal protrusion and fifth metatarsophalangeal protrusion

Landmarks required:

None.

Posture required:

The participant assumes a relaxed standing position with the feet comfortably apart and body weight evenly distributed. The arms are hanging by the sides.

Procedure:

The assessor visually inspects the foot for the first and fifth metatarsophalangeal protrusion before placing the tape around these sites. The tape may require constant adjusting and will require a few prompts to the participant to raise their foot, reposition the tape then lower the foot. Take the reading to the nearest 0.1 cm. Measurements are reported in mm.

Reference:

Tomkinson, G. R., Daniell, N., Dale, M., & Bowler, T. (2012a). Australian Warfighter Anthropometry Survey (AWAS): Landmarking and measurement manual. Adelaide, Australia: Health and Use of Time Group, Sansom Institute for Health Research, University of South Australia.

Tomkinson, G. R., Daniell, N., Dale, M., & Bowler, T. (2012b). Australian Warfighters Anthropometry Survey (AWAS). Procedures Manual. Adelaide, Australia.: Health and Use of Time Group, Sansom Institute for Health Research, University of South Australia.

Notes:

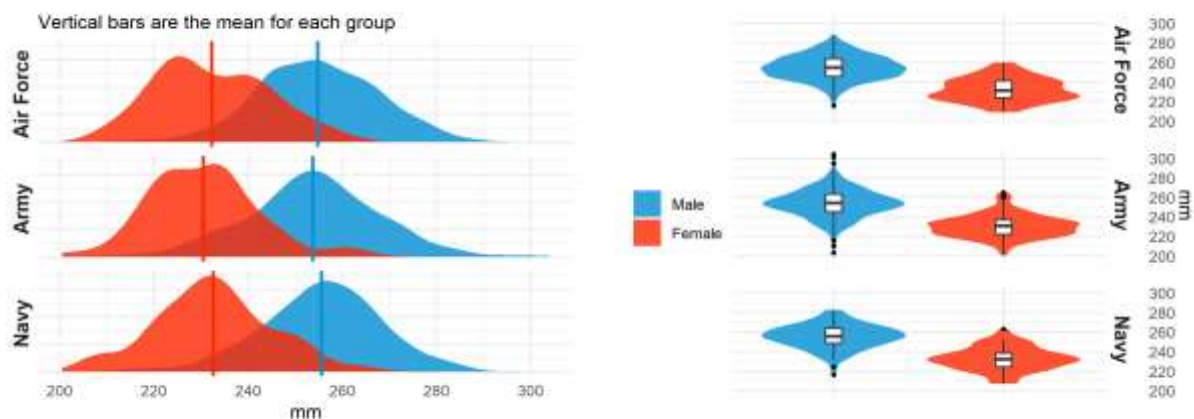
The first and fifth metatarsophalangeal protrusions are not necessarily horizontal in position, therefore the tape may not be perpendicular to the long axis of the foot.



Foot ball circumference summary statistics - Physical measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
254	255	254	256	Mean	232	230	233	232
14	13	14	13	SD	12	12	12	12
203	216	203	216	Min	209	200	207	200
304	288	304	283	Max	260	265	263	265
285	281	286	283	P99	259	261	259	261
283	279	284	281	P98	257	260	254	260
280	278	280	278	P97	255	258	252	257
276	276	275	275	P95	252	248	252	252
271	270	272	271	P90	249	244	249	247
268	268	268	266	P85	245	241	245	244
265	265	265	265	P80	242	238	243	241
263	264	263	264	P75	241	237	238	239
261	262	260	263	P70	240	235	238	237
259	260	258	260	P65	238	234	236	235
257	257	257	259	P60	235	233	235	234
256	256	255	257	P55	234	232	233	232
254	255	254	256	P50	231	231	232	231
253	253	253	255	P45	228	228	231	229
251	252	251	254	P40	227	226	230	227
250	250	250	252	P35	226	225	229	226
248	247	248	250	P30	225	224	228	225
246	245	245	248	P25	224	222	224	223
244	245	243	245	P20	222	221	222	222
240	244	240	243	P15	220	220	221	220
236	240	235	240	P10	219	218	219	218
231	235	230	235	P5	214	214	211	214
228	232	226	233	P3	212	213	209	211
226	229	225	229	P2	211	210	208	209
220	226	219	223	P1	210	206	207	207

Distribution plots for each service and gender



Foot ball length - Physical measurement (mm)

Measuring instrument:

Brannock device – AUT SPRINZ clinic.

Source:

ANSUR.

Definition:

The distance from the back of the heel to the landmark at the first metatarsophalangeal protrusion is measured with the Brannock device. The participant stands erect with the right foot in the Brannock device and the other foot on a board of equal height. Body weight is distributed equally on both feet. The medial side of the right foot is parallel with the long axis of the device.

Landmarks required:

None.

Posture required:

The participant assumes a relaxed standing position with the feet comfortably apart and body weight evenly distributed. The arms are hanging by the sides. The assessor will be kneeling and often change position to ensure the foot is positioned correctly.

Procedure:

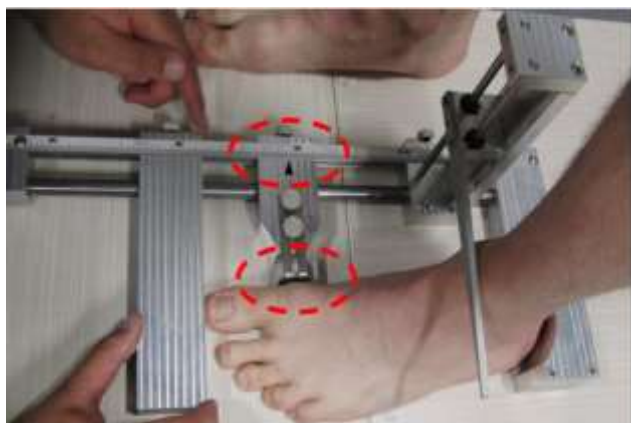
The heel is pressed lightly against the rear (curved) plate of the device, the side-sliding plate is positioned until it lightly touches the fifth metatarsophalangeal protrusion site (observed visually). An extension latch can also be used for increased accuracy. Take the reading when the etched marker (depicted as a black triangle below) meets the scale. Take the reading to the nearest 0.1 mm. Measurements are reported in mm.

Reference:

Gordon, C.C., Blackwell, C.L., Bradtmiller, B., Parham, J.L., Barrientos, P., Paquette, S.P., Corner, B., Carson, J.M., Venezia, J.C., Rockwell, B.M., Mucher, M., Kristensen, S., 2014. 2012 Anthropometric survey of U.S. army personnel: Methods and summary statistics., Natick Soldier Research, Development of Engineering Center, Yellow Springs, Ohio, U.S.

Notes:

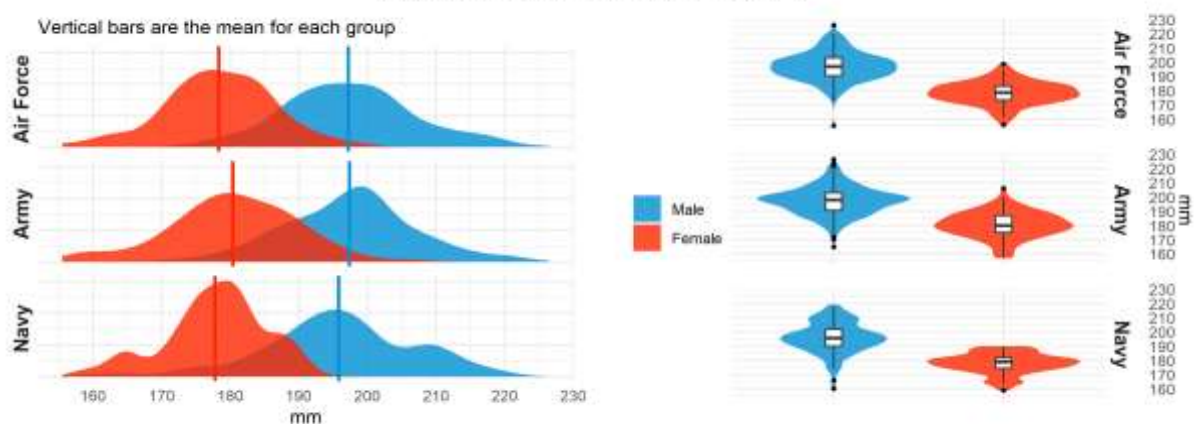
If the participant has a right foot injury then use the left foot. This may require a change of Brannock device type as in the figure.



Foot ball length summary statistics - Physical measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
197	197	197	196	Mean	178	180	178	179
10	10	10	11	SD	8	9	7	9
156	156	165	160	Min	156	157	159	156
226	226	226	219	Max	198	206	190	206
221	220	221	218	P99	196	200	190	198
219	218	219	217	P98	194	196	190	196
217	217	216	214	P97	193	196	189	194
214	215	214	213	P95	190	195	188	192
210	210	210	210	P90	188	191	187	190
207	207	207	208	P85	185	190	186	188
204	204	204	207	P80	185	188	183	186
203	203	203	202	P75	183	187	182	185
202	202	202	200	P70	183	185	181	183
200	200	201	199	P65	182	184	181	182
200	200	200	198	P60	180	183	180	181
198	198	199	196	P55	179	181	180	180
197	197	198	196	P50	178	180	179	180
196	195	197	195	P45	177	180	177	178
195	195	196	194	P40	177	179	177	177
194	194	194	192	P35	175	177	176	176
192	192	193	190	P30	175	176	175	175
190	190	191	190	P25	174	175	174	174
190	190	190	190	P20	172	174	173	173
187	188	187	186	P15	171	172	171	171
185	186	185	183	P10	169	170	166	169
181	182	181	175	P5	164	164	165	164
178	179	179	174	P3	162	160	164	161
176	178	177	172	P2	162	159	163	159
174	176	174	165	P1	160	157	161	158

Distribution plots for each service and gender



Foot breadth - Physical measurement (mm)

Measuring instrument:

Small bone caliper.

Source:

AWAS.

Definition:

The maximum horizontal distance between the first metatarsophalangeal protrusion and fifth metatarsophalangeal protrusion.

Landmarks required:

None.

Posture required:

The participant assumes a relaxed standing position with the feet comfortably apart and weight evenly distributed. The arms are hanging by the sides. The assessor will be kneeling in front and slightly to the side of the participant.

Procedure:

The caliper arms are held with the thumb and index finger. The assessor visually inspects the foot for the first and fifth metatarsophalangeal protrusion before placing the caliper plates on the sites. The plates are pressed firmly together. Take the reading to the nearest 0.1 cm. Measurements are reported in mm.

Reference:

Tomkinson, G. R., Daniell, N., Dale, M., & Bowler, T. (2012b). Australian Warfighters Anthropometry Survey (AWAS). Procedures Manual. Adelaide, Australia.: Health and Use of Time Group, Sansom Institute for Health Research, University of South Australia.

Notes:

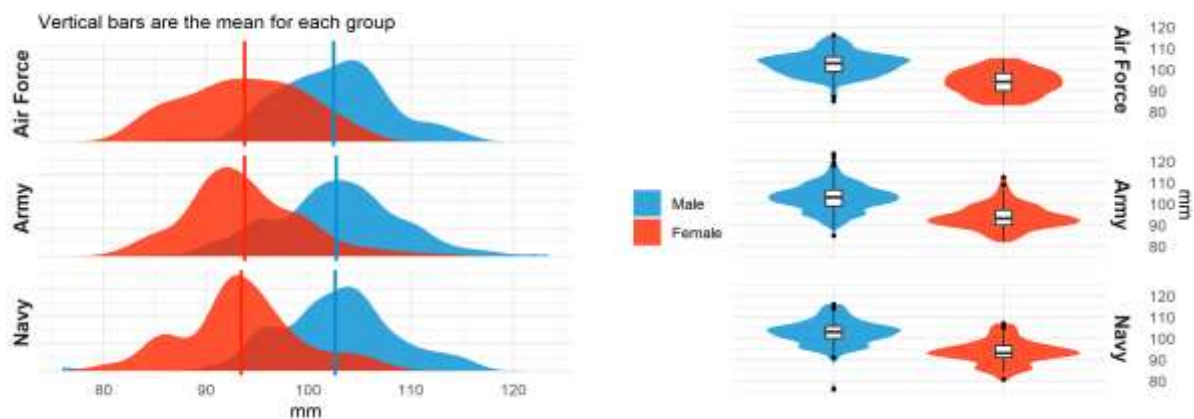
The first and fifth metatarsophalangeal protrusions may differ both distally in their elevation above the standing surface, therefore the calipers may offset both in a transverse plane and a coronal plane



Foot breadth summary statistics - Physical measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
103	102	103	103	Mean	94	94	93	94
6	5	6	6	SD	6	6	6	6
76	85	85	76	Min	83	82	80	80
124	116	124	116	Max	105	112	107	112
117	115	118	115	P99	105	109	106	107
115	114	116	115	P98	104	107	105	106
114	113	115	114	P97	104	106	105	105
112	112	113	112	P95	103	104	104	104
110	109	110	110	P90	101	100	101	101
108	108	109	108	P85	100	99	99	100
107	106	108	107	P80	99	99	97	99
106	106	106	106	P75	98	97	96	97
106	105	106	105	P70	97	96	95	96
105	105	105	105	P65	96	95	95	95
104	104	104	104	P60	96	94	95	95
103	103	104	103	P55	95	94	94	94
103	103	103	103	P50	94	93	93	93
102	102	102	102	P45	93	92	93	93
102	101	102	102	P40	92	92	92	92
100	100	100	100	P35	91	91	92	92
100	100	100	100	P30	91	91	92	91
99	99	99	100	P25	90	90	91	90
97	98	97	97	P20	88	90	89	90
96	97	95	97	P15	87	89	87	88
95	95	95	95	P10	85	88	86	86
93	95	92	95	P5	85	85	85	85
91	94	91	94	P3	84	85	84	84
90	93	90	92	P2	84	85	83	84
89	89	90	89	P1	84	83	82	83

Distribution plots for each service and gender



Foot length - Physical measurement (mm)

Measuring instrument:

Brannock device – AUT SPRINZ clinic. Measurements are in mm.

Source:

ISAK, ANSUR.

Definition:

Distance from the Akropodion (the tip of the longest toe — which may be the first or second phalanx) to the Pternion (most posterior point on the calcaneus of the foot).

Landmarks required:

None.

Posture required:

The participant assumes a relaxed standing position with the feet comfortably apart and weight evenly distributed. The arms are hanging by the sides. It is more convenient for the assessor if the participant stands on the box during this measurement. The assessor will be mostly kneeling but must change position to ensure the participant's foot is positioned correctly.

Procedure:

The heel is pressed lightly against the rear (curved) plate of the device, the sliding plate is moved towards the tip of the tip of the longest toe — which may be the first or second phalanx protrusion. Ensure that there is contact between the toe and the device, but with minimal pressure. The reading is taken where the sliding plate edge meets the scale. Take the reading to the nearest 0.1 cm. Measurements are reported in mm.

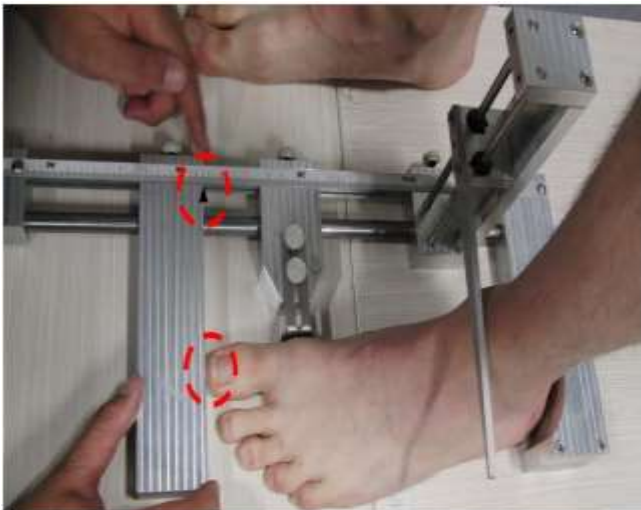
Reference:

Marfell-Jones, M.J., A.D. Stewart, and J.H. De Ridder, International Standards for Anthropometric Assessment. 2012.

Gordon, C.C., Blackwell, C.L., Bradtmiller, B., Parham, J.L., Barrientos, P., Paquette, S.P., Corner, B., Carson, J.M., Venezia, J.C., Rockwell, B.M., Mucher, M., Kristensen, S., 2014. 2012 Anthropometric survey of U.S. army personnel: Methods and summary statistics., Natick Soldier Research, Development of Engineering Center, Yellow Springs, Ohio, U.S.

Notes:

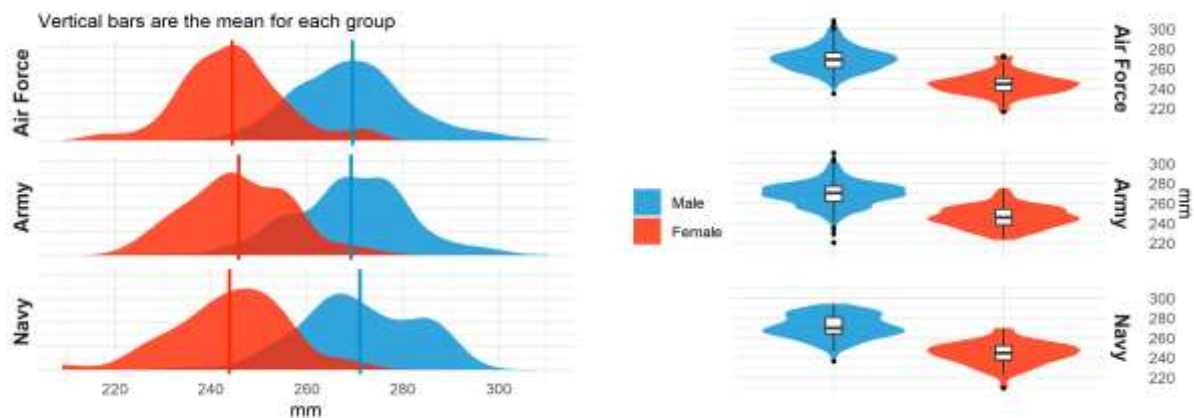
If the participant has a right foot injury then use the left foot. This may require a change of Brannock device type as in the figure.



Foot length summary statistics - Physical measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
269	270	269	271	Mean	244	246	244	245
12	12	13	12	SD	11	11	12	11
220	234	220	236	Min	216	223	209	209
310	308	310	294	Max	273	276	270	276
299	300	299	291	P99	273	270	268	272
296	298	296	291	P98	272	269	267	270
294	296	294	290	P97	271	268	265	269
290	292	289	288	P95	264	264	259	264
285	285	284	287	P90	256	257	256	257
281	281	280	286	P85	254	256	255	256
280	278	279	284	P80	252	256	253	254
277	276	277	281	P75	250	254	252	252
276	275	276	278	P70	248	253	250	250
274	274	275	276	P65	247	250	249	249
273	272	273	274	P60	246	248	248	247
271	271	271	272	P55	246	246	246	246
270	269	270	270	P50	244	246	244	245
268	267	268	269	P45	243	244	244	244
266	266	267	267	P40	241	244	242	242
265	265	266	266	P35	240	242	241	241
264	264	264	264	P30	239	240	239	239
262	261	262	264	P25	238	238	238	238
259	259	259	262	P20	236	237	234	236
256	257	256	260	P15	234	234	233	234
254	256	254	256	P10	233	232	228	231
250	251	250	253	P5	229	230	226	227
246	248	245	250	P3	226	227	223	226
245	246	243	249	P2	222	226	220	223
241	245	239	245	P1	218	224	215	220

Distribution plots for each service and gender



Forearm-fingertip length - Post-processed measurement (mm)

Measuring instrument:

CySlice

Source:

CySlice

Definition:

The horizontal distance from the posterior elbow to the tip of the middle finger, with elbow flexed to a 90 degree angle to the hand, extended.

Landmark required:

Olecranon rear (right) and Dactylion III landmark.

Posture required:

Scan position posture 3. Ensure that the participant is sitting with their knee bent at a 90° angle. This can be done by moving the body scanner seat up or down. This can also be facilitated by aligning the popliteal fossa (vertically) in line with Pternion (back of the foot).

Procedure:

This measure is the point-to-point distance between the Olecranon rear and Dactylion III (tip of the longest finger) landmarks. For the Centre of Dactylion III tip use X loop to narrow down to point but do not include fingernail. Measurements are reported in mm.

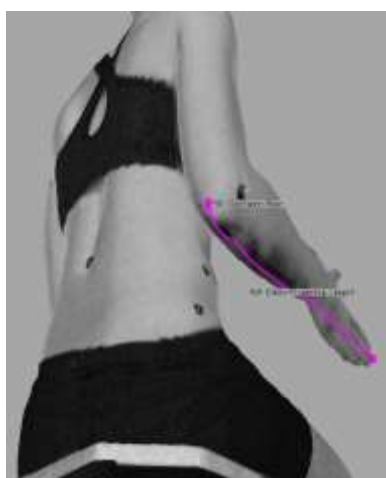
Reference:

DOD-HDBK-743. Military Handbook: Anthropometry of U.S. Military Personnel (13 FEB 1991). Department of Defense. United States.

Kolose, S., Hume, P.A., Tomkinson, G.R., Stewart, A., Stewart, T., Legg, S.J. (2021). Three-dimensional physique assessment in the military: New Zealand Defence Force Anthropometry Survey protocols and summary statistics., SPRINZ: Auckland, New Zealand.

Notes:

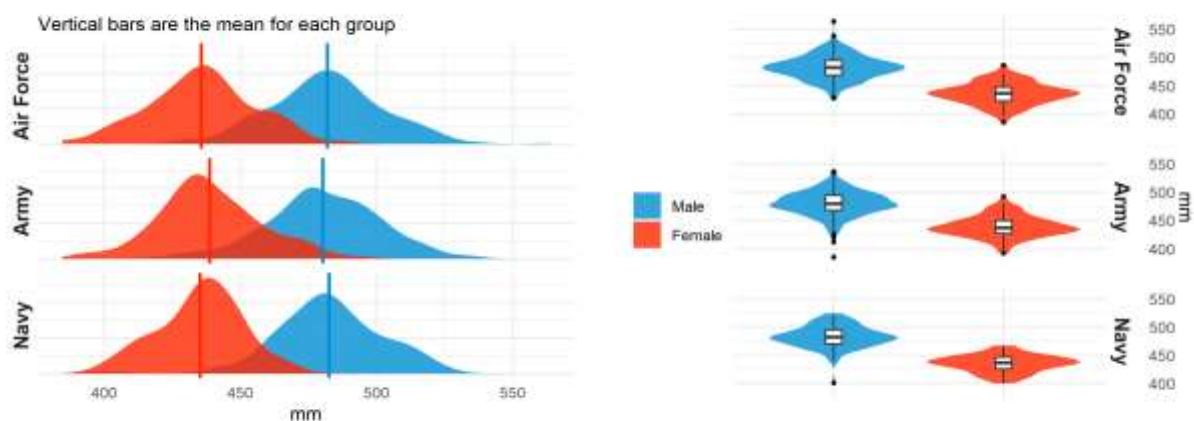
The olecranon bottom landmark is somewhat subjective. Check from the rear view that the olecranon landmark is in line with the 'belly' of the triceps and mid-line of the posterior aspect of the arm (see example below).



Forearm-fingertip length summary statistics - Post-processed measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
481	482	480	483	Mean	436	439	435	437
21	21	21	20	SD	19	19	15	18
384	428	384	401	Min	385	392	400	385
564	564	536	524	Max	486	492	467	492
528	530	529	522	P99	475	481	465	480
522	524	521	519	P98	469	478	464	473
519	521	518	516	P97	468	473	463	472
515	518	515	513	P95	466	472	460	469
508	511	506	509	P90	463	463	450	462
502	503	502	503	P85	457	458	449	456
498	500	498	498	P80	451	451	448	450
494	494	494	495	P75	447	450	446	448
491	491	491	491	P70	444	448	442	445
489	489	489	488	P65	442	444	440	442
486	486	486	485	P60	439	441	439	440
483	484	482	483	P55	437	438	437	437
481	482	480	482	P50	436	436	436	436
478	479	478	480	P45	434	435	436	435
477	477	476	479	P40	433	433	434	433
474	475	473	477	P35	430	432	433	432
472	473	471	474	P30	426	430	428	428
468	468	468	470	P25	423	427	426	426
465	466	464	468	P20	421	425	422	422
460	459	460	466	P15	416	422	418	418
455	455	454	460	P10	410	416	413	415
447	450	444	458	P5	404	411	410	406
439	444	437	445	P3	402	404	407	403
433	439	432	443	P2	399	402	405	400
428	431	425	435	P1	393	393	402	394

Distribution plots for each service and gender



Forearm-forearm breadth - Physical measurement (mm)

Measuring instrument:

Anthropometer or large sliding caliper, and anthropometric box.

Source:

ANSUR; AWAS.

Definition:

The maximum horizontal distance across the upper body between the lateral surfaces of the forearms, when seated with elbows flexed at a 90 degree angle.

Landmark required:

None.

Posture required:

The participant sits erect, looking straight ahead, on the anthropometry box. The shoulders and upper arms are relaxed, and the forearms and hands are extended forward horizontally with the palms facing each other (i.e. the elbow angle is at a 90 degree angle). The elbow and index finger are aligned horizontally on each arm. The assessor kneels behind the participant and the box. Both participant and assessor are facing the same direction.

Procedure:

The participant is asked to take a deep breath in, then slowly breathe out. The assessor applies traction to their wrists to extend their arm in sequence with the breathing motion. Measure from the most lateral points of the forearm region when the participant is at “end tidal” in the breath cycle. Ensure the measure is taken from the ‘outside’ or superior edge of the sliding prong (whilst touching the forearms). Measure to the nearest 0.1 cm. Measurements are reported in mm.

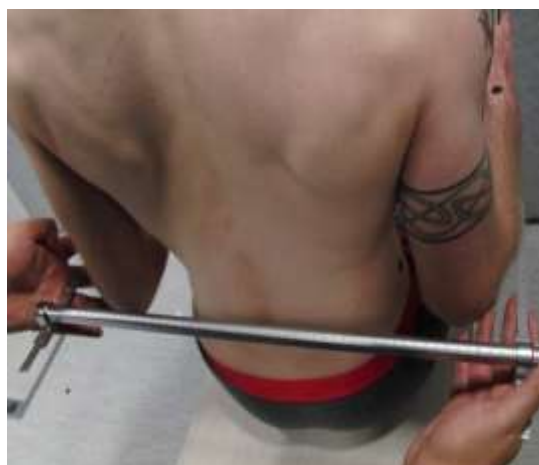
Reference

Gordon, C.C., Blackwell, C.L., Bradtmiller, B., Parham, J.L., Barrientos, P., Paquette, S.P., Corner, B., Carson, J.M., Venezia, J.C., Rockwell, B.M., Mucher, M., Kristensen, S., 2014. 2012 Anthropometric survey of U.S. army personnel: Methods and summary statistics., Natick Soldier Research, Development of Engineering Center, Yellow Springs, Ohio, U.S.

Tomkinson, G. R., Daniell, N., Dale, M., & Bowler, T. (2012b). Australian Warfighters Anthropometry Survey (AWAS). Procedures Manual. Adelaide, Australia.: Health and Use of Time Group, Sansom Institute for Health Research, University of South Australia.

Notes:

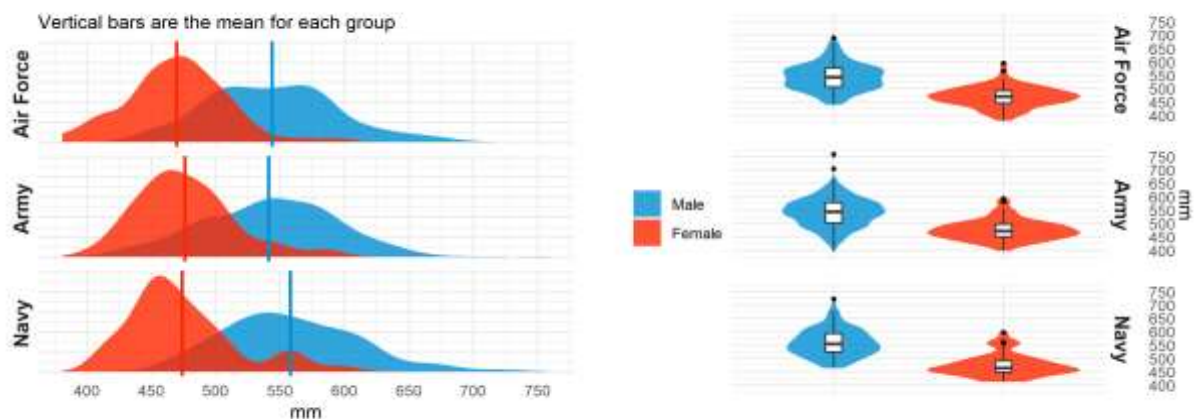
Participants with a wider than normal Latissimus Dorsi have elbows abducted from the body and variability in the positioning of the elbows. Participants’ forearms can differ in muscle and adipose tissue mass, affecting the measurements. The use of the anthropometer or large sliding caliper varies according to the forearm-forearm distance of the participant. Generally, use a large sliding caliper for forearm-forearm distances of 56 cm or less. For all other purposes, use an anthropometer. Take the measure at ‘end tidal’ position to avoid inaccuracies due to breathing (vertical movements to the torso caused by fluctuations in the diaphragm).



Forearm-forearm breadth summary statistics - Physical measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
544	544	541	558	Mean	470	476	474	474
52	50	53	51	SD	39	38	42	39
396	440	396	463	Min	381	398	412	381
759	690	759	722	Max	595	593	597	597
669	672	653	682	P99	574	584	582	592
653	657	644	671	P98	554	581	567	577
643	651	635	666	P97	537	559	561	561
629	630	627	651	P95	527	547	560	552
610	606	607	617	P90	512	520	545	518
595	588	593	613	P85	506	511	509	511
585	582	584	601	P80	500	501	500	501
579	577	578	593	P75	492	497	491	495
573	572	572	585	P70	487	494	485	489
565	565	565	573	P65	481	486	480	485
558	557	556	568	P60	478	481	473	479
550	549	549	561	P55	475	476	468	474
545	542	544	554	P50	470	472	463	471
538	536	537	546	P45	467	468	460	467
531	528	530	540	P40	460	463	459	460
524	519	524	533	P35	455	457	451	457
516	513	514	530	P30	452	456	450	452
507	507	502	523	P25	447	451	448	448
498	501	494	518	P20	444	445	445	444
489	492	484	505	P15	432	440	442	437
479	484	474	495	P10	414	432	427	428
456	462	449	481	P5	407	425	419	414
448	455	442	477	P3	404	420	416	411
441	451	432	471	P2	395	412	415	405
431	445	425	465	P1	386	410	413	399

Distribution plots for each service and gender



Grip reach - Physical measurement (mm)

Measuring instrument:

Measurement rod, as a cylindrical object with a 1 cm diameter such as a whiteboard pen. Full-length anthropometer, ideally made of solid steel. The anthropometer typically comes in 4 sections. When combined, one end of the rod contains a stationary or fixed arm or prong, the other prong is free to move up and down while at a right angle to the rod. There are typically two rod scales that run opposite each other.

Source:

ISO 7250.

Definition:

The horizontal distance from a back wall to the axis of the hand, with the arm extended horizontally and anteriorly.

The objective is to measure the distance between the wall and the grip centre point (defined as the centre of a measurement rod with a known diameter).

Landmark required:

None.

Posture required:

The participant stands erect against a wall with both the left and right shoulder blades touching the wall. Their right arm is raised as straight as possible anteriorly at a 90 degree angle to the body. Their arm must be in a relaxed and 'natural' position (i.e. do not ask them to fully reach forward or retract their shoulder/deltoid against the wall). They hold the measurement rod in a vertical orientation tight with their right hand (palm facing medially) outstretched. The assessor stands to the right side of the participant in front of the elbow. This position enables the assessor to support the weight of the anthropometer evenly, and be in a position to see both prongs (the fixed end and the measurement end).

Procedure:

The measure is taken at the most anterior face of the measurement rod immediately below the hand. Place the outer edge of the fixed prong against the wall. Extend the opposite prong 5 cm beyond the rod. Slowly push the prong towards the rod until it touches it. Check that both the arm and anthropometer are straight then take the reading to the nearest 0.1 cm. Apply a correction factor for grip reach = Wall to rod anterior face distance – (Rod diameter in cm/2).

Reference

ISO 7250-1. Basic Human Body Measurements for Technological Design. 2008, International Organization for Standardization: Geneva.

Notes:

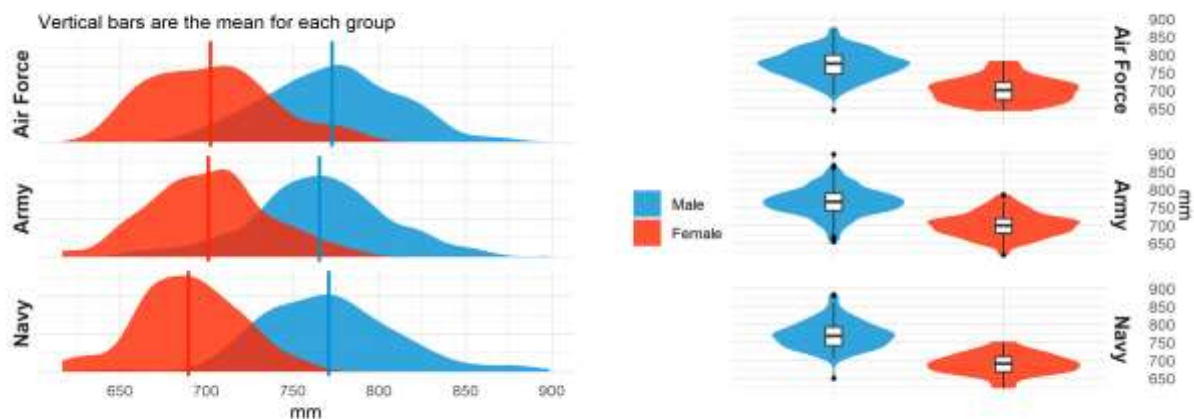
The rod must be held tight and in a vertical position. If not, the rod will be unstable. This will result in the prong 'pushing' the rod backwards thus giving a false reading. Lengthen or shorten the anthropometer (by adding or removing sections of the rod) to suit the arm length of the participant. Ensure the prong is based securely, and square to the wall for stability. Be aware of handling the prong tip to avoid injuring the participant. The scribe observes and confirms whether the participant's arm is straight and horizontal to the floor immediately before the reading. The anthropometer and arm centre should be at the same height. Ensure the data spreadsheet has the appropriate correction factor for the length of the anthropometer. Measurements are reported in mm.



Grip reach summary statistics - Physical measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
768	773	765	771	Mean	702	701	689	699
40	39	40	39	SD	35	34	29	34
646	646	654	650	Min	644	616	622	616
898	876	898	883	Max	783	786	752	786
862	865	855	880	P99	781	783	751	782
852	851	851	866	P98	779	769	749	777
843	835	843	852	P97	777	766	744	767
831	832	830	836	P95	770	763	730	759
821	821	820	821	P90	748	748	726	743
809	814	805	808	P85	738	736	722	732
800	808	796	802	P80	729	726	713	724
792	798	789	793	P75	722	718	710	719
786	792	785	786	P70	720	716	703	715
781	786	779	781	P65	715	714	699	713
777	782	774	777	P60	712	712	695	709
772	778	770	773	P55	705	706	691	702
768	775	766	768	P50	701	700	690	698
764	768	761	766	P45	696	697	687	692
758	764	756	762	P40	688	690	683	689
754	758	752	752	P35	685	688	677	685
748	753	746	748	P30	680	682	670	680
743	746	742	742	P25	676	678	668	675
738	740	736	738	P20	670	673	666	669
731	734	728	733	P15	662	667	666	666
719	723	713	730	P10	659	658	665	658
703	712	696	716	P5	655	649	639	649
692	702	683	713	P3	652	648	629	645
682	695	675	710	P2	649	642	625	639
664	693	660	698	P1	646	619	624	622

Distribution plots for each service and gender



Hand breadth - Physical measurement (mm)

Measuring instrument:

The Small bone caliper was used for NZDFA as opposed to the more traditional Segmometer. The Segmometer is not suitable for this measure as it requires firm pressure on the bone sites. The tape may also have a propensity to 'bend'. Measurements are in mm.

Source:

ANSUR, AWAS, CFAS.

Definition:

The breadth of the right hand between the metacarpale II and metacarpale V.

Landmarks required:

None.

Posture required:

The participant places the palm on a table with the fingers together and the thumb abducted. The middle finger is parallel to the long axis of the forearm. The two distal phalanges of the fingers are placed on a flat surface 8 mm higher than the table. The assessor stands facing the participant, perpendicular to the long axis of the hand.

Procedure:

The caliper plates are placed on the metacarpale II and metacarpale V. To ensure that outside surface of the hand is flat (thus reducing the 'cupping' propensity of the hand), a specially designed measurement board (of 8 mm thickness) was developed using stationary clipboards. The hand was placed so that the palm rested on the table surface while the fingers rested on the boards. Measurements are reported in mm.

Reference:

Gordon, C.C., Blackwell, C.L., Bradtmiller, B., Parham, J.L., Barrientos, P., Paquette, S.P., Corner, B., Carson, J.M., Venezia, J.C., Rockwell, B.M., Mucher, M., Kristensen, S., 2014. 2012 Anthropometric survey of U.S. army personnel: Methods and summary statistics., Natick Soldier Research, Development of Engineering Center, Yellow Springs, Ohio, U.S.

Tomkinson, G. R., Daniell, N., Dale, M., & Bowler, T. (2012a). Australian Warfighter Anthropometry Survey (AWAS): Landmarking and measurement manual. Adelaide, Australia: Health and Use of Time Group, Sansom Institute for Health Research, University of South Australia.

Keefe, A., H. Angel, and B. Mangan, 2012 Canadian Forces Anthropometric Survey (CFAS) – Final report. 2015, Défense Research and Development Canada: Toronto, Canada.

Notes:

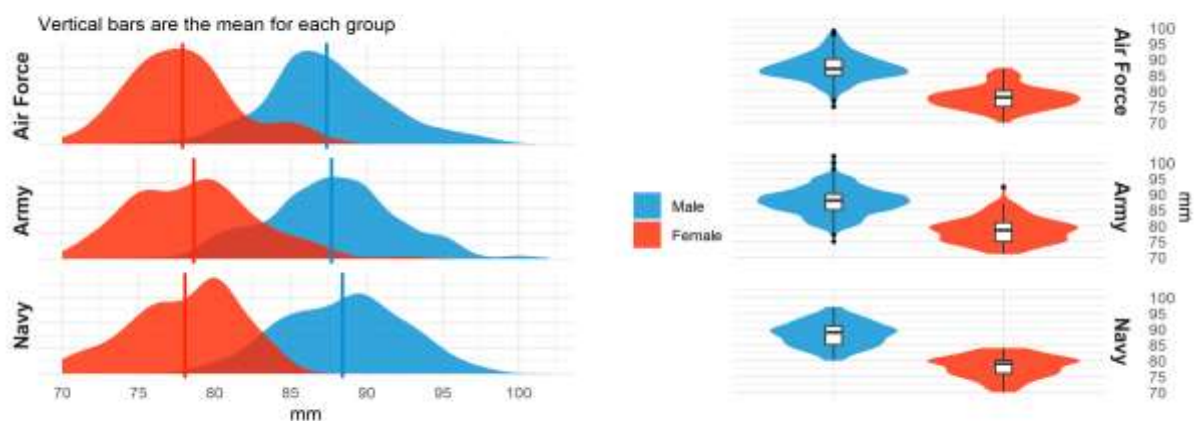
The caliper plates need to be applied firmly to the bony sites to compress the overlying soft tissue.



Hand breadth summary statistics - Physical measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
88	87	88	88	Mean	78	79	78	78
4	4	4	4	SD	4	4	4	4
75	75	75	80	Min	70	71	70	70
102	99	102	97	Max	87	92	84	92
97	97	98	97	P99	86	87	84	87
96	97	96	96	P98	86	87	84	87
95	96	95	95	P97	85	87	84	86
95	95	95	95	P95	85	86	83	85
93	92	93	93	P90	83	84	82	83
92	91	92	93	P85	81	83	82	82
91	90	91	92	P80	80	82	81	81
90	90	90	91	P75	80	81	80	80
90	89	90	90	P70	79	80	80	80
89	88	89	90	P65	79	80	80	80
89	88	89	90	P60	79	80	80	79
88	87	88	89	P55	78	79	79	79
88	87	88	89	P50	78	79	79	78
87	87	87	88	P45	77	78	78	78
87	86	87	87	P40	77	78	77	77
86	86	86	87	P35	76	77	77	76
85	85	86	86	P30	76	76	76	76
85	85	85	85	P25	75	75	76	75
85	85	84	85	P20	75	75	75	75
83	84	83	84	P15	75	75	74	75
82	82	82	83	P10	74	74	74	74
81	81	80	82	P5	73	72	72	72
80	80	80	81	P3	72	72	71	72
80	80	80	80	P2	72	72	71	72
79	78	79	80	P1	71	72	70	71

Distribution plots for each service and gender



Hand circumference - Physical measurement (mm)

Measuring instrument:

Anthropometric tape. Before measuring, ensure that the metal tape surface is not damaged and the scale is clear, and the tape can be retracted freely. There are various models. Tapes used in the NZDFAS were Cesorf and Rosscraft.

Source:

ANSUR.

Definition:

The circumference of the right hand is measured with a tape passing over the landmarks at metacarpale II and metacarpale V. The participant places the palm on a table with the fingers together and the thumb abducted. The middle finger is parallel to the long axis of the forearm. The two distal phalanges of the fingers lie on a flat surface 8 mm higher than the table.

Landmark required:

None.

Posture required:

The participant places the palm on a table with the fingers together and the thumb abducted. The middle finger is parallel to the long axis of the forearm. The two distal phalanges of the fingers lie on a flat surface 8 mm higher than the table. The assessor stands facing the participant, perpendicular to the hand. Measurements are reported in mm.

Procedure: The tape is placed around the palm passing through the metacarpale II and metacarpale V. To ensure that outside surface of the hand is flat (thus reducing the 'cupping' propensity of the hand), a specially designed measurement board (of 8mm thickness) was developed using stationary clipboards. The hand was placed so that the palm rested on the table surface while the fingers rested on the boards.

Reference:

Gordon, C.C., Blackwell, C.L., Bradtmiller, B., Parham, J.L., Barrientos, P., Paquette, S.P., Corner, B., Carson, J.M., Venezia, J.C., Rockwell, B.M., Mucher, M., Kristensen, S., 2014. 2012 Anthropometric survey of U.S. army personnel: Methods and summary statistics., Natick Soldier Research, Development of Engineering Center, Yellow Springs, Ohio, U.S.

Notes:

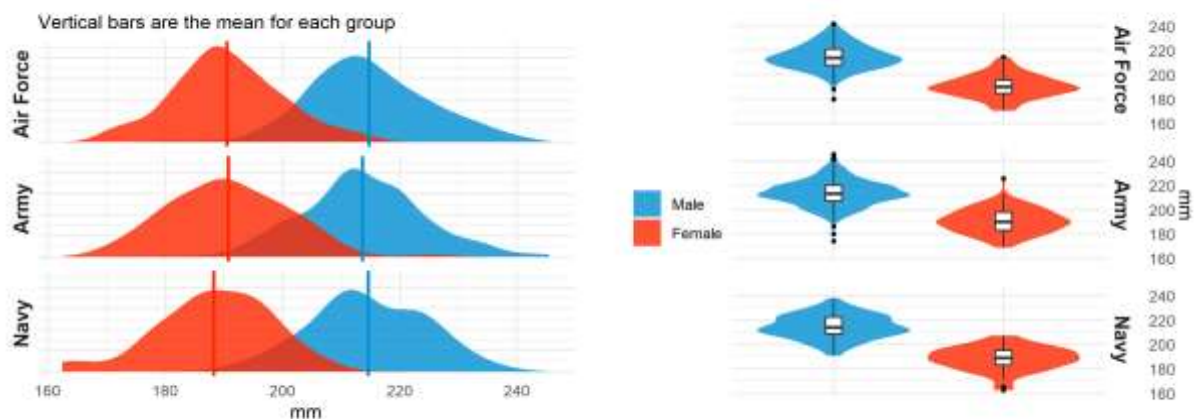
Check that the palm is flat against the table surface. Ensure the tape conforms to the skin surface without indentation.



Hand circumference summary statistics - Physical measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
214	215	214	215	Mean	191	191	188	190
10	10	11	10	SD	9	10	10	10
174	180	174	191	Min	170	169	162	162
246	242	246	238	Max	214	226	208	226
239	239	239	235	P99	212	213	206	213
236	236	236	233	P98	211	208	205	210
234	235	234	231	P97	210	208	204	208
232	233	232	230	P95	206	207	203	206
228	229	227	227	P90	202	204	199	203
225	226	224	225	P85	200	201	197	200
222	224	222	224	P80	199	199	197	199
220	221	220	223	P75	196	198	195	196
219	220	219	222	P70	195	195	195	195
218	218	218	219	P65	194	195	192	194
216	216	216	216	P60	193	193	192	192
215	215	215	215	P55	190	191	191	191
214	214	213	214	P50	190	190	189	190
212	213	212	213	P45	189	190	187	189
211	212	211	211	P40	188	189	186	188
210	210	210	211	P35	187	187	186	187
209	209	209	210	P30	186	185	185	185
207	208	207	209	P25	185	183	183	184
206	206	205	206	P20	183	182	180	182
204	205	203	205	P15	182	181	179	181
201	204	200	201	P10	180	178	177	178
198	199	197	200	P5	176	175	172	175
195	197	195	197	P3	173	174	167	172
194	196	194	195	P2	172	172	165	171
190	193	190	193	P1	171	171	164	169

Distribution plots for each service and gender



Hand length - Physical measurement (mm)

Measuring instrument:

Segmometer.

Source:

ANSUR.

Definition:

The length of the right hand between the stylium landmark on the wrist and the tip of the middle finger is measured with a Segmometer. The participant places the hand on the table (palm facing up) with the fingers together and the thumb abducted. The middle finger is parallel to the long axis of the forearm. The two distal phalanges of the fingers lie on a flat surface 8 mm higher than the table.

Landmark required:

None.

Posture required:

The participant places the lateral surface of the right forearm and the back of the right-hand flat against the table surface. The palm is open and facing up. Fingers and thumb are together. The assessor stands facing the participant, perpendicular to the hand.

Procedure:

Measurement is taken on the palmar surface of the hand between the mid-stylium landmark and the tip of the Dactylion (middle finger). The fixed end of the segmometer is placed on the centre wrist landmark, the sliding end is pressed lightly against the tip of the middle finger. Measurements are reported in mm.

Reference:

Gordon, C.C., Blackwell, C.L., Bradtmiller, B., Parham, J.L., Barrientos, P., Paquette, S.P., Corner, B., Carson, J.M., Venezia, J.C., Rockwell, B.M., Mucher, M., Kristensen, S., 2014. 2012 Anthropometric survey of U.S. army personnel: Methods and summary statistics., Natick Soldier Research, Development of Engineering Center, Yellow Springs, Ohio, U.S.

Notes:

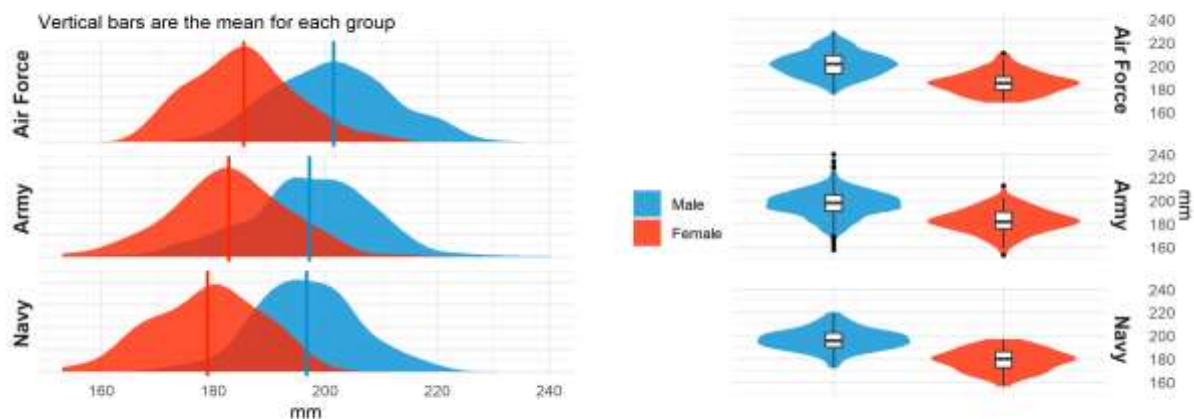
Ensure that the palm and all fingers are together and rigid (no cupping of the hands). Ensure the back of the hand and fingers are fully extended and flat against the table surface. Ensure that the measure is on the distal finger surface and not the fingernail.



Hand length summary statistics - Physical measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
198	201	197	197	Mean	185	183	179	183
11	10	12	9	SD	9	10	9	10
158	176	158	172	Min	168	153	156	153
240	230	240	220	Max	211	213	197	213
224	223	225	217	P99	208	203	196	207
221	222	220	216	P98	206	202	194	202
219	222	216	215	P97	204	201	193	201
216	220	214	211	P95	201	200	192	200
211	216	210	209	P90	198	195	191	195
210	212	209	205	P85	194	194	190	193
207	210	206	204	P80	193	191	187	191
205	209	205	202	P75	190	190	186	190
204	207	203	201	P70	189	187	184	188
202	205	202	200	P65	188	186	182	186
201	204	200	199	P60	187	185	181	185
200	202	199	198	P55	186	184	181	184
199	202	198	196	P50	185	182	180	183
197	200	196	195	P45	184	182	179	182
195	199	195	194	P40	183	180	178	180
194	197	194	193	P35	181	180	175	180
193	195	192	192	P30	180	178	175	178
191	194	191	190	P25	179	176	172	176
190	192	189	190	P20	177	174	169	174
187	190	185	188	P15	175	173	169	173
184	188	182	186	P10	174	170	166	170
180	185	176	184	P5	172	166	164	166
176	184	174	180	P3	170	163	164	164
174	182	173	178	P2	169	162	163	163
171	180	169	175	P1	169	159	159	159

Distribution plots for each service and gender



Head breadth - Physical measurement (mm)

Measuring instrument:

Large sliding caliper. This has two straight branches attached to a rigid scale that allow measurements of large bone or soft tissue to be measured to 0.1 or 0.05 cm. Before measuring, the distance between the branches should be verified to ensure it has been assembled correctly.

Source:

ISO 7250, ANSUR.

Definition:

Maximum horizontal breadth of the head above the ears, measured perpendicular to the mid-sagittal plane. This measurement is taken from behind the participant. The scale end of the caliper is above the participants' head with the reading made from behind the participant.

Landmark required:

None.

Posture required:

The participant sits erect, looking straight ahead with eyewear removed. The assessor stands behind the participant and observes the head at eye level. The scale side of the caliper is above the participants head and facing towards the rear.

Procedure:

Viewed directly from in behind, identify the most lateral aspects of the head. Opening the large sliding caliper beyond the anticipated distance, and bracing the fingers on the skull surface above each ear, slowly move the branches towards one another until they rest on the skin surface no lower than the height of the Helix (top of the ear). Record the measurement to 0.1 cm or 0.05 cm precision. Measurements are reported in mm.

Reference:

ISO 7250-1. Basic Human Body Measurements for Technological Design. 2008, International Organization for Standardization: Geneva.

Gordon, C.C., Blackwell, C.L., Bradtmiller, B., Parham, J.L., Barrientos, P., Paquette, S.P., Corner, B., Carson, J.M., Venezia, J.C., Rockwell, B.M., Mucher, M., Kristensen, S., 2014. 2012 Anthropometric survey of U.S. army personnel: Methods and summary statistics., Natick Soldier Research, Development of Engineering Center, Yellow Springs, Ohio, U.S.

Notes:

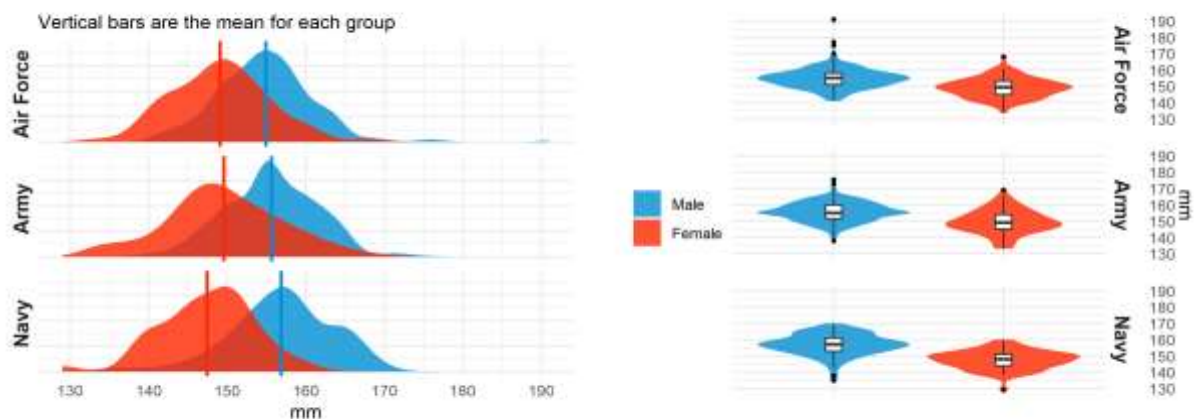
This is a bony measurement with a limited depth of superficial tissue. The position of the head has no influence on the measurement.



Head breadth summary statistics - Physical measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
156	155	156	157	Mean	149	150	147	149
6	6	6	7	SD	6	7	6	7
135	141	138	135	Min	134	133	129	129
191	191	176	170	Max	168	169	160	169
170	174	170	168	P99	163	166	159	165
168	168	166	168	P98	160	165	158	163
166	165	166	167	P97	160	164	157	162
165	164	165	166	P95	160	162	156	160
163	162	163	165	P90	156	159	155	158
162	160	162	164	P85	155	157	152	155
160	160	160	163	P80	154	156	152	154
160	158	160	161	P75	153	154	151	153
158	158	159	160	P70	152	153	151	152
158	157	158	159	P65	151	152	150	151
157	156	157	159	P60	150	151	150	150
156	155	156	158	P55	150	150	149	150
155	155	155	157	P50	149	149	148	149
155	154	155	156	P45	148	148	147	148
154	154	154	156	P40	148	148	146	148
154	152	154	155	P35	147	147	146	146
152	152	153	154	P30	146	146	145	146
152	151	152	153	P25	145	145	144	145
150	150	150	152	P20	144	144	143	144
150	149	150	151	P15	142	143	141	142
148	148	148	149	P10	142	141	140	141
146	145	146	146	P5	140	137	139	138
145	144	145	143	P3	139	135	139	136
143	143	144	141	P2	139	134	137	134
141	142	142	138	P1	137	133	133	133

Distribution plots for each service and gender



Head girth - Automatic measurement (mm)

Measuring instrument:

Anthroscan.

Source:

Anthroscan.

Definition:

Maximal circumference around the cranium at the level of the forehead. The measurement passes in a sagittal plane just above the bony brow ridges and across the external occipital protuberance (the most protruding point of the back of the head). The measurement is close to horizontal when the head is positioned in the Frankfort plane.

Landmark required:

None.

Posture required:

Scan position posture 2. Stand with feet shoulder width apart, trunk and head are erect with eyes looking forward. The upper arms are abducted away from the body with the forearms hanging vertically. All fingers are together and extended with the palm facing (medially) the thigh and the thumb facing forward.

Procedure:

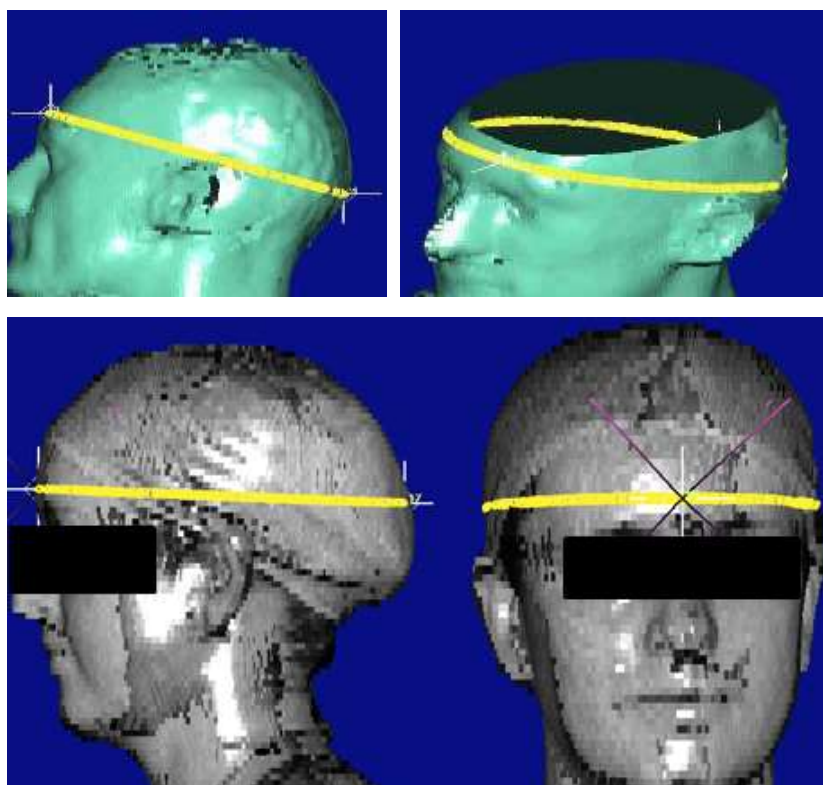
See Section 6 of Human Solutions (2015). Measurements are reported in mm.

Reference:

Human Solutions, 2015. Anthroscan user guide version 3. Human Solutions GmbH, Kaiserslautern, Germany.

Notes:

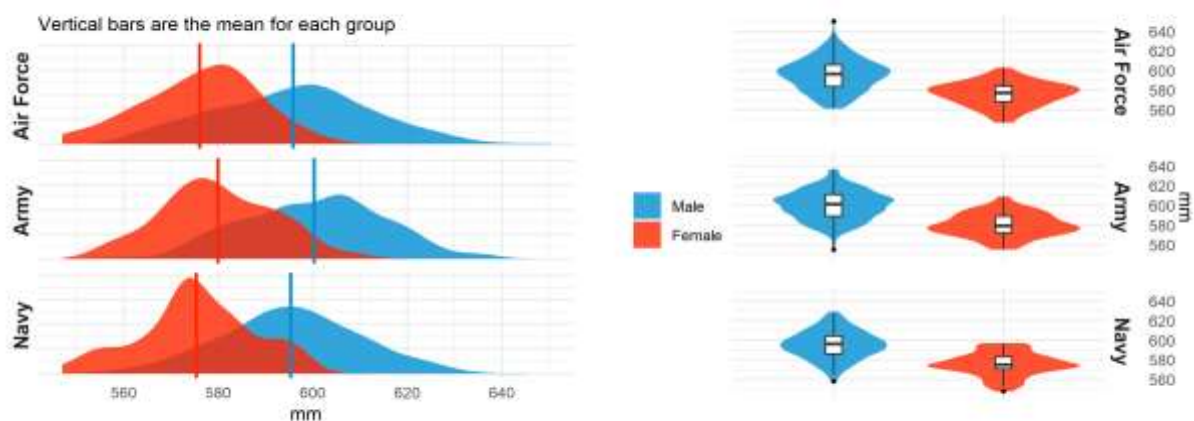
Check that the tape is horizontal at the bony brow ridge. For females, check the tape is not hindered by hair arrangement. Ideally, females should have their hair bun below the top of the ear, or alternatively gathered above the measurement plane. Unless one of these conditions is met, then this measurement cannot be taken. If the head is oriented high or low (looking up or down) or in a position other than Frankfort position, then manoeuvre the tape accordingly.



Head girth summary statistics - Automatic measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
599	596	600	595	Mean	576	580	575	578
15	17	15	14	SD	12	12	12	12
555	561	555	558	Min	547	555	548	547
650	650	637	629	Max	603	609	597	609
634	631	635	625	P99	599	608	597	603
628	629	629	623	P98	597	604	597	598
626	626	627	622	P97	596	599	597	598
623	623	624	621	P95	595	598	596	597
618	617	619	612	P90	590	596	592	594
614	613	616	612	P85	588	593	588	590
612	610	613	608	P80	586	590	585	589
609	606	611	604	P75	584	589	583	586
607	604	608	603	P70	582	587	582	584
605	602	607	600	P65	582	583	579	582
603	601	605	598	P60	581	582	577	581
601	599	603	597	P55	579	580	575	579
599	596	601	596	P50	577	579	575	578
597	594	598	593	P45	576	578	574	576
595	592	596	592	P40	573	577	573	575
593	590	594	590	P35	572	574	572	573
591	587	593	589	P30	571	574	572	572
588	584	589	586	P25	568	572	571	571
585	580	586	584	P20	566	571	565	568
581	578	584	579	P15	563	569	564	565
578	573	580	577	P10	559	566	558	562
573	568	576	572	P5	555	560	554	557
570	566	574	569	P3	551	558	553	554
568	564	573	566	P2	549	557	552	553
564	562	569	564	P1	548	556	550	548

Distribution plots for each service and gender



Head length - Physical measurement (mm)

Measuring instrument:

Large sliding caliper. This has two straight branches attached to a rigid scale that allow measurements of large bone or soft tissue to be measured to 0.1 or 0.05 cm. Before measuring, the distance between the branches should be verified to ensure it has been assembled correctly.

Source:

ISO 7250.

Definition:

The straight line distance between the glabella and the opistocranium (the posterior extremity of the longest diameter of the skull, measured from the glabella). The position of the head has no influence on the measurement.

Landmark required:

None.

Posture required:

The participant sits erect, looking straight ahead with eyewear removed. The assessor stands at the side of the participant and observes the head in the Frankfort plane.

Procedure:

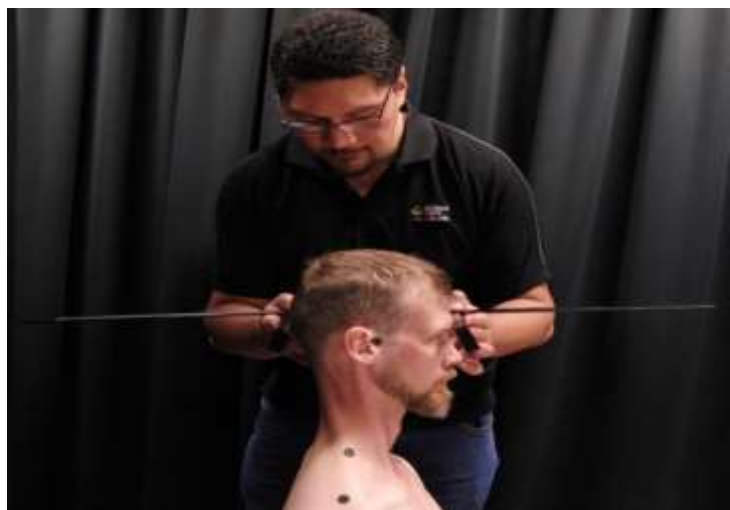
Viewed directly from the side. Opening the large sliding caliper beyond the anticipated distance, rest the device on the back of the hands and using the thumbs and index fingers, slowly move the branches towards one another until the anterior branch lightly touches the glabella landmark. Hold this in position. The posterior branch should then be aligned with and moved towards the opistocranium until it touches. It may help to palpate the opsticranion with either the second or third finger of the posterior hand. Record the measurement to 0.1 cm or 0.05 cm precision. Measurements are reported in mm.

Reference:

ISO 7250-1. Basic Human Body Measurements for Technological Design. 2008, International Organization for Standardization: Geneva.

Notes:

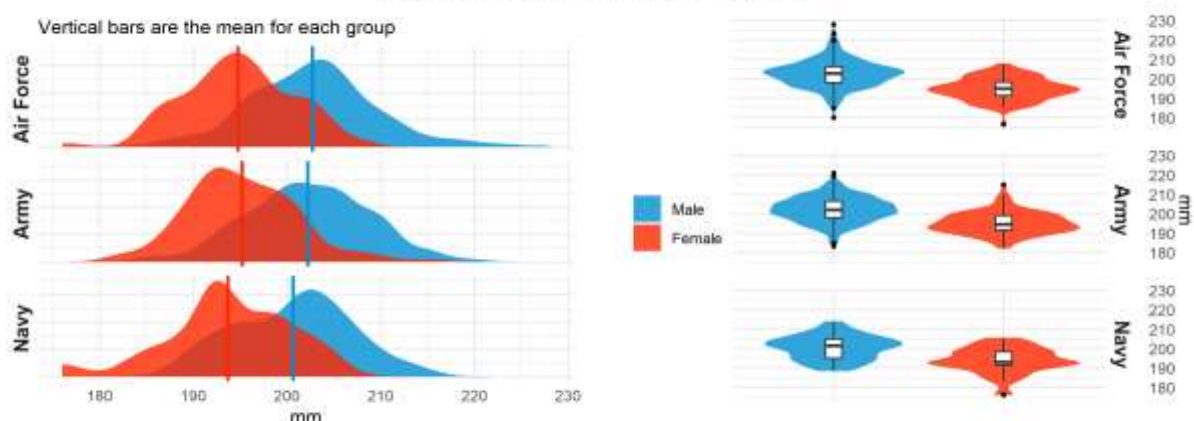
This is a soft tissue measurement; therefore, the caliper branches must be placed on the skin, but not indent the skin. The position of the head has no influence on the measurement.



Head length summary statistics - Physical measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
202	203	202	201	Mean	195	195	194	195
7	7	7	6	SD	6	6	7	6
180	180	183	188	Min	176	182	176	176
228	228	221	214	Max	208	215	206	215
219	223	217	214	P99	207	210	205	208
216	219	215	213	P98	205	209	204	207
215	218	215	212	P97	204	207	204	206
213	214	212	210	P95	204	205	203	204
210	211	210	208	P90	203	202	203	202
209	209	210	206	P85	202	201	200	201
208	208	208	206	P80	200	200	199	200
206	206	206	205	P75	198	199	198	199
206	206	206	204	P70	197	198	198	198
205	205	205	203	P65	197	197	197	197
204	204	204	203	P60	196	196	195	196
203	204	203	202	P55	196	196	194	195
202	203	202	202	P50	195	194	193	194
202	202	202	201	P45	194	194	192	194
200	201	200	200	P40	193	193	192	193
200	200	200	199	P35	193	192	192	192
199	199	199	197	P30	192	192	192	192
198	198	198	195	P25	191	192	192	192
196	197	197	195	P20	190	191	189	190
195	196	195	194	P15	189	190	187	189
194	195	194	192	P10	187	188	185	187
192	191	192	190	P5	186	187	183	186
190	189	190	190	P3	186	186	178	184
188	189	188	190	P2	186	184	176	183
186	186	186	189	P1	183	182	176	177

Distribution plots for each service and gender



Hip breadth sitting - Post-processed measurement (mm)

Measuring instrument:

CySlice

Source:

ANSUR, NZDFAS.

Definition:

The horizontal distance in a coronal plane between two parallel sagittal planes defining the left and right lateral extent of a seated participant with knees together. a “buttock plate” placed at the most posterior point on either buttock and the back of the right knee (the popliteal fossa at the dorsal juncture of the calf and thigh).

Landmark required:

None.

Posture required:

Scan position posture 3. Ensure that the participant is sitting with their knee bent at a 90° angle. This can be done by moving the body scanner seat up or down. This can also be facilitated by aligning the popliteal fossa (vertically) in line with Pternion (back of the foot).

Procedure:

In CySlice use the caliper tool. View from the right side of the participant. Highlight the hip and upper thigh area. Select the Z function (to identify the breadth along a coronal plane) to calculate the breadth. Measurements are reported in mm.

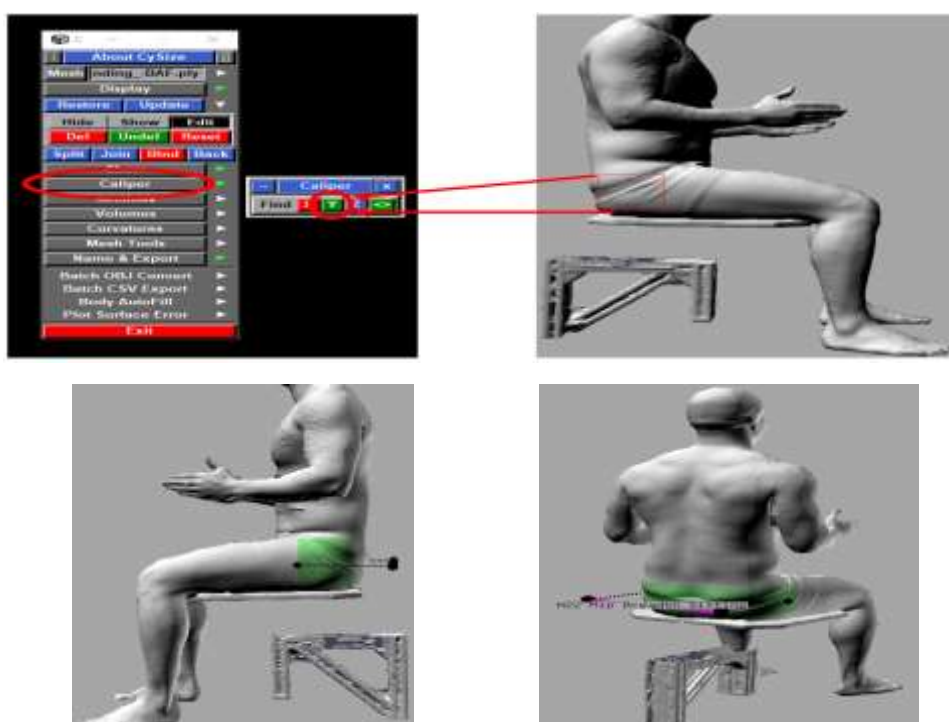
Reference:

Gordon, C.C., Blackwell, C.L., Bradtmiller, B., Parham, J.L., Barrientos, P., Paquette, S.P., Corner, B., Carson, J.M., Venezia, J.C., Rockwell, B.M., Mucher, M., Kristensen, S., 2014. 2012 Anthropometric survey of U.S. army personnel: Methods and summary statistics., Natick Soldier Research, Development of Engineering Center, Yellow Springs, Ohio, U.S.

Kolose, S., Hume, P.A., Tomkinson, G.R., Stewart, A., Stewart, T., Legg, S.J. (2021). Three-dimensional physique assessment in the military: New Zealand Defence Force Anthropometry Survey protocols and summary statistics., SPRINZ: Auckland, New Zealand.

Notes:

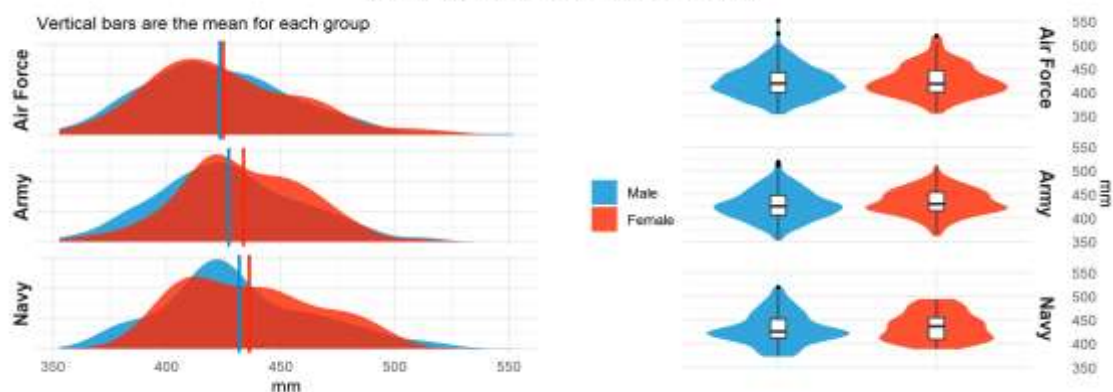
Another method is to view from the back and highlight the left and right buttocks. However, this should be used with caution as the caliper may highlight areas of the midthigh. This is caused by participants who sit in a ‘wide’ stance i.e. their knees are pointing laterally as opposed to straight forward.



Hip breadth sitting summary statistics - Post-processed measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
427	423	427	432	Mean	425	434	436	431
32	34	31	33	SD	33	27	29	30
353	354	353	372	Min	356	363	388	356
552	552	518	519	Max	520	512	494	520
512	521	512	511	P99	509	489	492	504
496	494	494	508	P98	501	484	490	493
489	486	487	498	P97	494	483	488	488
483	482	482	489	P95	474	477	487	482
470	465	471	480	P90	467	469	478	471
462	460	461	467	P85	461	463	474	464
454	449	455	462	P80	457	457	464	460
447	442	448	451	P75	447	454	455	451
440	440	441	446	P70	435	448	449	447
436	435	436	436	P65	433	446	447	444
431	429	432	432	P60	430	443	445	436
428	424	428	429	P55	422	433	441	432
424	419	425	426	P50	418	430	436	428
421	415	422	423	P45	417	426	428	424
417	411	418	420	P40	413	424	421	419
412	407	414	418	P35	410	421	420	418
409	405	410	417	P30	404	418	414	414
405	400	406	412	P25	400	416	409	411
400	394	401	408	P20	400	412	407	405
393	388	395	402	P15	396	411	405	401
386	382	387	388	P10	390	400	403	396
377	376	378	381	P5	380	392	400	386
374	372	374	378	P3	375	382	395	381
367	362	367	375	P2	371	381	393	376
361	360	362	374	P1	365	370	391	369

Distribution plots for each service and gender



Hip breadth standing - Post-processed measurement (mm)

Measuring instrument:

CySlice

Source:

JIS Z 8500, AWAS.

Definition:

The maximum horizontal distance in a coronal plane between the right and left protrusions of the hip.

Landmark required:

None.

Posture required:

Scan position posture 1. Stand with feet together, arms straight at the sides with the palms facing in towards the thigh. Fingers together and extended with the thumb facing forward. Stand with back erect and head in the Frankfort plane.

Procedure:

In CySlice use the caliper tool. View from the right side. Highlight an area from the back or the front, at a height between the iliocrestale and crotch landmark. Take care not to select any webbing that may exist between the thigh and the hands. Select the Y function (to create a coronal plan from the front view) to calculate breadth. Measurements are reported in mm.

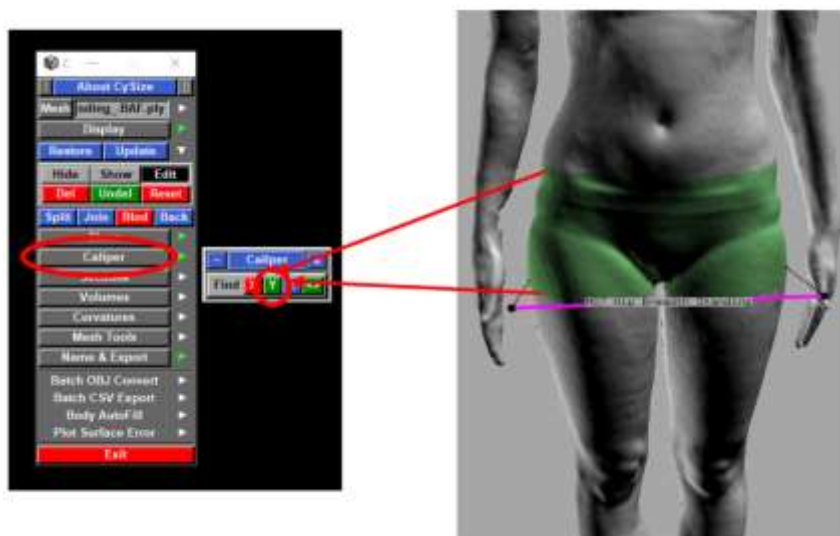
Reference:

JIS Z 8500 Ergonomics Basic Human Body Measurements for Technological Design (2002). Japanese Industrial Standard: Tokyo, Japan.

Tomkinson, G. R., Daniell, N., Dale, M., & Bowler, T. (2012b). Australian Warfighters Anthropometry Survey (AWAS). Procedures Manual. Adelaide, Australia.: Health and Use of Time Group, Sansom Institute for Health Research, University of South Australia.

Notes:

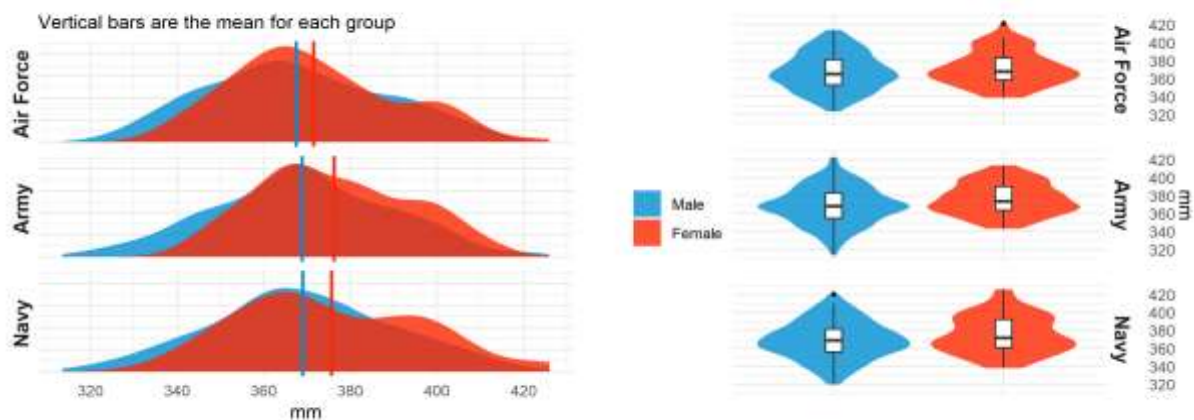
Use the Crosshair tool to align the participant's posture. Ensure clothing is smooth at the defined measurement points.



Hip breadth standing summary statistics - Post-processed measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
368	367	369	369	Mean	372	376	376	375
21	21	21	21	SD	19	17	21	19
314	324	314	320	Min	339	343	338	338
423	414	423	420	Max	421	414	426	426
415	410	417	410	P99	411	411	424	420
409	408	410	409	P98	405	410	422	411
407	407	405	408	P97	403	409	417	408
403	403	403	406	P95	403	404	404	403
396	396	397	395	P90	401	400	401	401
391	392	391	394	P85	396	398	400	399
388	388	387	387	P80	387	395	397	394
383	381	383	381	P75	383	390	392	389
379	379	380	380	P70	379	384	389	383
375	375	375	376	P65	378	382	386	381
372	371	372	373	P60	373	380	380	378
370	368	371	371	P55	369	379	372	374
368	365	368	369	P50	368	374	371	371
366	364	367	364	P45	367	371	369	369
363	360	365	363	P40	366	369	367	367
361	358	362	361	P35	363	368	365	366
358	356	358	360	P30	361	365	363	364
355	353	355	356	P25	358	364	361	361
350	347	351	352	P20	356	361	359	358
346	345	346	347	P15	353	358	354	355
342	341	342	342	P10	351	354	350	351
334	334	334	336	P5	345	349	347	346
331	333	330	331	P3	341	348	345	344
327	332	326	328	P2	341	346	343	343
324	328	323	325	P1	340	344	340	340

Distribution plots for each service and gender



Hip girth maximum - Post-processed measurement (mm)

Measuring instrument:

CySlice

Source:

AWAS.

Definition:

The maximum horizontal circumference of the body (excluding the appendages) at or about the height of the hip. This measure must be taken below the height of the iliac crest.

Landmark required:

None.

Posture required:

It is vital that the participant is wearing smooth, well fitted clothing to reduce measurements error (e.g. clothing creases). Scan position posture 1. Stand with feet together, arms straight at the sides with the palms facing in towards the thigh. Fingers together and extended with the thumb facing forward. Stand with back erect and head in the Frankfort plane.

Procedure:

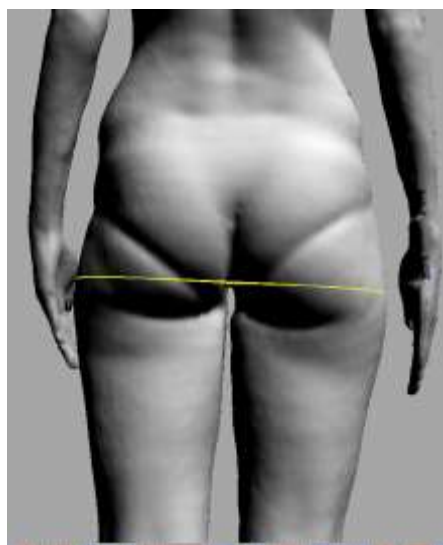
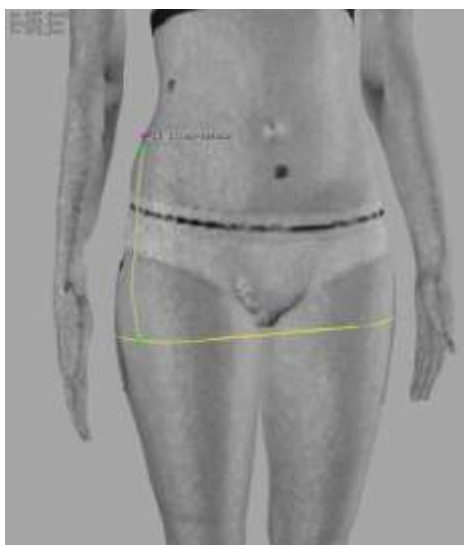
Eyeball the hip region. Add two-point markers, one above and one below this region (green dots on the image) what is clearly the widest part. Join the two points, press spacebar, add Z-loop on guideline (i.e. forming a dotted line). Toggle between the min/max girth by pressing Shift with '-' or '+' key. If circumference is incomplete (i.e. only covering a part of the cross-section), press = with the cursor on the guideline. Check that the measure has been recorded by placing the cursor on the dotted line and then pressing 'i' to bring up measurements text view. Next, press 't' (for toggle) to see the measurements. Save by double clicking Hip girth (on the names list window) then single click on the 'dotted' line and then Space bar to save. As per AWAS section 7.2.16 of the Procedures Manual (Tomkinson et al., 2012). Measurements are reported in mm.

Reference:

Tomkinson, G. R., Daniell, N., Dale, M., & Bowler, T. (2012b). Australian Warfighters Anthropometry Survey (AWAS). Procedures Manual. Adelaide, Australia.: Health and Use of Time Group, Sansom Institute for Health Research, University of South Australia.

Notes:

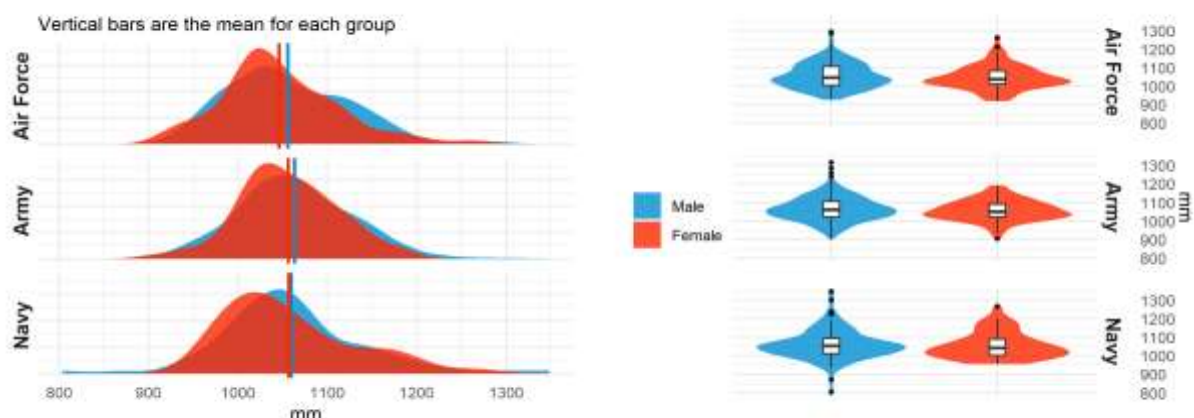
If the measure is taken on a fold or crease in the briefs, consider remeasuring.



Hip girth maximum summary statistics - Post-processed measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
1061	1056	1064	1060	Mean	1046	1057	1057	1053
68	69	65	83	SD	66	56	73	63
803	926	902	803	Min	920	903	955	903
1349	1292	1315	1349	Max	1262	1193	1267	1267
1244	1251	1226	1306	P99	1225	1183	1239	1209
1210	1196	1197	1253	P98	1200	1174	1211	1197
1191	1184	1190	1229	P97	1185	1163	1200	1185
1177	1171	1176	1192	P95	1168	1151	1195	1172
1149	1147	1149	1159	P90	1124	1128	1168	1135
1132	1129	1132	1142	P85	1109	1115	1147	1116
1118	1117	1118	1116	P80	1098	1102	1112	1102
1106	1107	1106	1094	P75	1082	1091	1090	1089
1092	1092	1093	1081	P70	1070	1085	1078	1080
1080	1075	1083	1072	P65	1061	1077	1072	1071
1072	1067	1074	1064	P60	1050	1069	1051	1061
1063	1052	1068	1056	P55	1042	1061	1047	1050
1054	1044	1059	1052	P50	1036	1050	1042	1046
1048	1036	1051	1046	P45	1029	1046	1031	1035
1039	1032	1045	1035	P40	1024	1036	1023	1030
1032	1025	1036	1031	P35	1019	1033	1020	1024
1024	1017	1028	1024	P30	1013	1028	1012	1020
1016	1005	1021	1012	P25	1010	1020	1003	1012
1008	994	1012	1005	P20	1002	1013	995	1006
992	983	1002	992	P15	987	1007	991	997
978	974	982	979	P10	970	998	979	985
958	958	959	945	P5	944	974	968	960
943	950	948	939	P3	938	954	967	944
938	940	938	919	P2	928	939	964	938
926	935	928	862	P1	921	931	960	922

Distribution plots for each service and gender



Iliocristale height - Post-processed measurement (mm)

Measuring instrument:

CySlice

Source:

ANSUR, NZDFAS.

Definition:

The vertical distance between a standing surface and the right Iliocristale landmark.

Landmark required:

Iliocristale landmark.

Posture required:

Scan position posture 1. Stand with feet together, arms straight at the sides with the palms facing in towards the thigh. Fingers together and extended with the thumb facing forward. Stand with back erect and head in the Frankfort plane.

Procedure:

This measure is represented by the Y coordinate (mm on the Y or vertical axis) of the Iliocristale landmark in posture 1. Measurements are reported in mm.

Reference:

Gordon, C.C., Blackwell, C.L., Bradtmiller, B., Parham, J.L., Barrientos, P., Paquette, S.P., Corner, B., Carson, J.M., Venezia, J.C., Rockwell, B.M., Mucher, M., Kristensen, S., 2014. 2012 Anthropometric survey of U.S. army personnel: Methods and summary statistics., Natick Soldier Research, Development of Engineering Center, Yellow Springs, Ohio, U.S.

Kolose, S., Hume, P.A., Tomkinson, G.R., Stewart, A., Stewart, T., Legg, S.J. (2021). Three-dimensional physique assessment in the military: New Zealand Defence Force Anthropometry Survey protocols and summary statistics., SPRINZ: Auckland, New Zealand.

Notes:

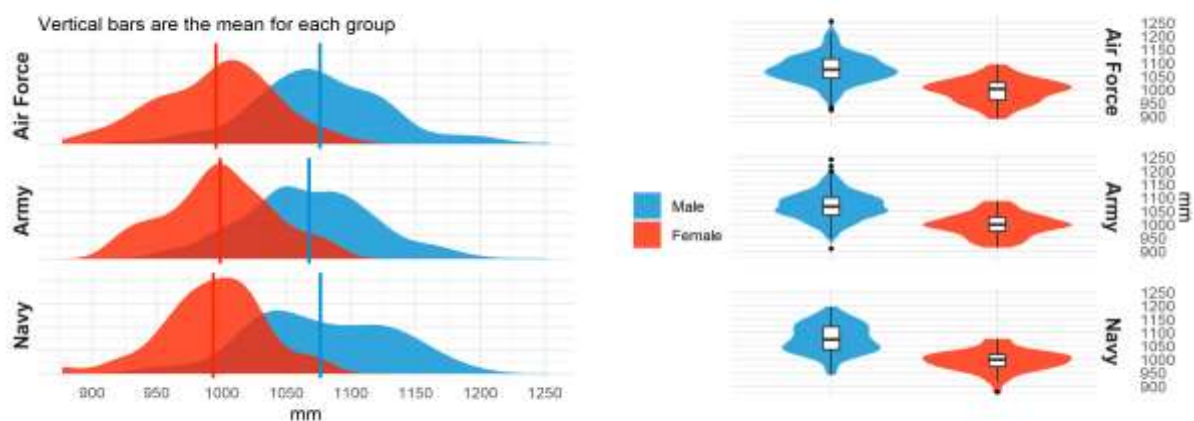
None.



Iliocristale height summary statistics - Post-processed measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
1071	1076	1068	1077	Mean	996	999	994	997
52	53	51	55	SD	45	41	40	42
909	922	909	941	Min	889	914	877	877
1254	1254	1242	1195	Max	1093	1088	1076	1093
1196	1212	1185	1180	P99	1085	1085	1075	1085
1179	1201	1175	1175	P98	1080	1083	1073	1081
1174	1192	1170	1171	P97	1077	1079	1069	1077
1160	1173	1156	1161	P95	1064	1069	1058	1069
1135	1136	1131	1146	P90	1050	1054	1036	1053
1124	1125	1117	1136	P85	1038	1039	1027	1038
1115	1118	1109	1128	P80	1033	1032	1021	1031
1106	1114	1099	1121	P75	1026	1025	1018	1025
1097	1101	1094	1113	P70	1020	1020	1014	1019
1090	1092	1088	1100	P65	1013	1010	1013	1012
1082	1086	1081	1094	P60	1009	1005	1004	1007
1076	1077	1074	1081	P55	1004	1002	998	1003
1069	1073	1066	1073	P50	1002	999	998	998
1062	1068	1058	1064	P45	996	996	993	996
1055	1063	1053	1054	P40	992	993	987	991
1050	1057	1047	1048	P35	986	988	981	984
1044	1050	1042	1040	P30	972	979	977	977
1037	1042	1035	1035	P25	961	974	973	970
1030	1035	1028	1031	P20	954	964	964	960
1020	1029	1015	1024	P15	949	951	958	951
1008	1014	1004	1019	P10	934	942	948	940
987	984	987	998	P5	923	927	924	926
972	971	972	972	P3	904	926	918	917
965	969	963	962	P2	902	925	910	914
954	942	956	953	P1	898	917	894	902

Distribution plots for each service and gender



Index finger breadth distal - Physical measurement (mm)

Measuring instrument:

Small bone caliper. The Rosscraft small bone caliper is 18 cm with pressure plates that are 10 mm diameter. Before measuring, the distance between the plates when touching should be verified as 0 cm to ensure it has been assembled correctly.

Source:

JIS Z 8500.

Definition:

The maximum distance between medial and lateral surfaces of the second finger in the region of the joint between middle and distal phalanges. The participant holds the forearm horizontal with hand stretched out flat and fingers spread, palm up.

Landmark required:

None.

Posture required:

Participants are seated at a table. The right hand is placed palm down on a measurement board. The centre wrist and medial side of the forearm are flat on the table. Fingers are spread apart. The assessor stands next to the hand (facing the participant).

Procedure:

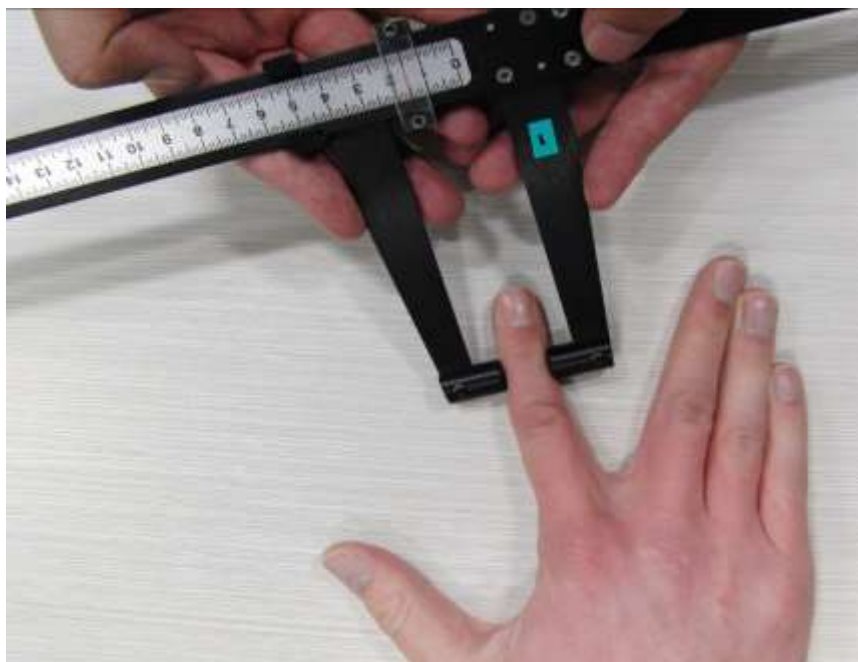
The plates of the small caliper are pressed firmly on the left and right side of the joint between the middle and distal phalanges. Measurements are reported in mm.

Reference:

JIS Z 8500 Ergonomics Basic Human Body Measurements for Technological Design (2002). Japanese Industrial Standard: Tokyo, Japan.

Notes:

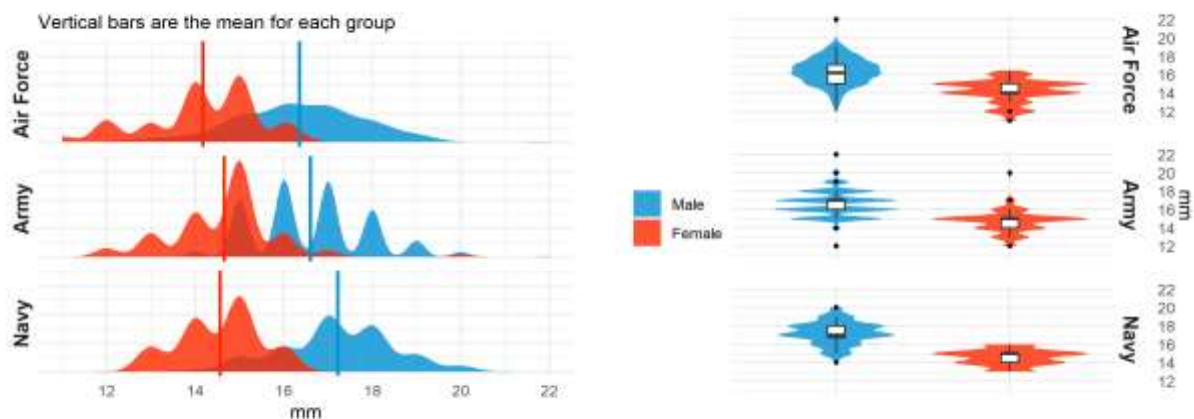
For greatest accuracy press firmly in this measure. Ensure that the palm and all fingers are pressed flat against the table.



Index finger breadth distal summary statistics - Physical measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
17	16	17	17	Mean	14	15	15	14
1	1	1	1	SD	1	1	1	1
12	12	12	14	Min	11	12	13	11
22	22	22	20	Max	16	20	16	20
20	19	20	20	P99	16	17	16	17
19	19	19	20	P98	16	17	16	16
19	19	19	19	P97	16	17	16	16
19	19	19	19	P95	16	16	16	16
18	18	18	19	P90	16	16	16	16
18	18	18	18	P85	15	16	15	15
18	18	18	18	P80	15	15	15	15
17	17	17	18	P75	15	15	15	15
17	17	17	18	P70	15	15	15	15
17	17	17	18	P65	15	15	15	15
17	17	17	18	P60	15	15	15	15
17	17	17	17	P55	14	15	15	15
17	16	17	17	P50	14	15	15	15
16	16	16	17	P45	14	15	15	15
16	16	16	17	P40	14	15	14	14
16	16	16	17	P35	14	14	14	14
16	16	16	17	P30	14	14	14	14
16	15	16	17	P25	14	14	14	14
15	15	15	16	P20	13	14	14	14
15	15	15	16	P15	13	13	14	13
15	15	15	16	P10	12	13	13	13
15	14	15	15	P5	12	13	13	12
14	13	15	15	P3	12	12	13	12
14	13	15	15	P2	11	12	13	12
14	13	14	15	P1	11	12	13	12

Distribution plots for each service and gender



Index finger breadth proximal - Physical measurement (mm)

Measuring instrument:

Small bone caliper. The Rosscraft small bone caliper is 18 cm with pressure plates that are 10 mm diameter. Before measuring, the distance between the plates when touching should be verified as 0 cm to ensure it has been assembled correctly.

Source:

JIS Z 8500.

Definition:

The maximum distance between medial and lateral surfaces of the second finger in the region of the joint between middle and proximal phalanges. The participant holds the forearm horizontal with hand stretched out flat and fingers spread, palm up.

Landmark required:

None.

Posture required:

Participants are seated at a table. The right hand is placed palm down on a measurement board. The centre wrist and medial side of the forearm are flat on the table. Fingers are spread apart. The assessor stands next to the hand (facing the participant).

Procedure:

The plates of the small caliper are pressed firmly on the left and right side of the joint between the middle and proximal phalanges. Measurements are reported in mm.

Reference:

JIS Z 8500 Ergonomics Basic Human Body Measurements for Technological Design (2002). Japanese Industrial Standard: Tokyo, Japan.

Notes:

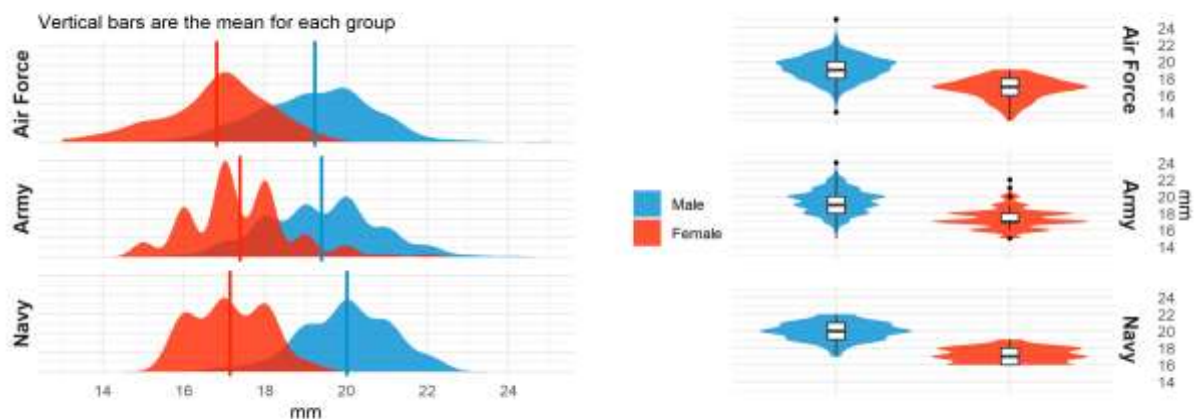
For greatest accuracy press firmly in this measure. Ensure that the palm and all fingers are pressed flat against the table.



Index finger breadth proximal summary statistics - Physical measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
19	19	19	20	Mean	17	17	17	17
1	1	1	1	SD	1	1	1	1
14	14	15	17	Min	13	15	16	13
25	25	24	22	Max	19	22	19	22
23	23	23	22	P99	19	21	19	20
22	22	22	22	P98	19	20	19	20
22	22	22	22	P97	19	20	19	19
22	21	22	22	P95	19	20	18	19
21	21	21	21	P90	18	19	18	18
21	21	21	21	P85	18	18	18	18
21	20	20	21	P80	18	18	18	18
20	20	20	21	P75	18	18	18	18
20	20	20	21	P70	17	18	18	18
20	20	20	20	P65	17	18	18	18
20	20	20	20	P60	17	18	17	17
20	20	20	20	P55	17	17	17	17
20	19	19	20	P50	17	17	17	17
19	19	19	20	P45	17	17	17	17
19	19	19	20	P40	17	17	17	17
19	19	19	20	P35	17	17	17	17
19	19	19	19	P30	16	17	17	17
18	18	18	19	P25	16	17	16	16
18	18	18	19	P20	16	16	16	16
18	18	18	19	P15	15	16	16	16
18	17	18	19	P10	15	16	16	16
17	17	17	18	P5	15	16	16	15
17	17	17	18	P3	14	15	16	15
17	16	17	18	P2	14	15	16	15
16	16	16	17	P1	14	15	16	14

Distribution plots for each service and gender



Index finger reach - Physical measurement (mm)

Measuring instrument:

Full-length anthropometer, ideally made of solid steel. The anthropometer typically comes in 4 separate sections. When combined, one end of the rod contains a stationary or fixed arm or prong, the other prong is free to move up and down while at a right angle to the rod. There are typically two scales on the rod that run opposite to each other.

Source:

CFAS.

Definition:

The horizontal distance between the vertical plane of the back and the tip of the right index finger.

Landmark required:

None.

Posture required:

The participant stands erect against a wall with both the left and right shoulder blades touching the wall. Their right arm is raised as straight as possible to the front at a 90 degree angle to the body with the index finger pointing medially to the opposite wall. Their arm must be in a relaxed and 'natural' position (i.e. do not ask them to fully reach forward or retract their shoulder/deltoid against the wall). The assessor stands to the right side of the participant in front of the elbow. This position enables the assessor to support the weight of the anthropometer evenly, and be in a position to see both prongs (the fixed end and the measurement end).

Procedure:

Place the outer edge of the fixed prong against the wall. Extend the opposite prong 50 mm beyond the fingertip. Slowly push the prong towards the hand until it touches the tip of the index finger. Check that both the arm and anthropometer are straight and horizontal then take the reading to the nearest 0.1 cm. Measurements are reported in mm.

Reference:

Keefe, A., H. Angel, and B. Mangan, 2012 Canadian Forces Anthropometric Survey (CFAS) – Final report. 2015, Defense Research and Development Canada: Toronto, Canada.

Notes:

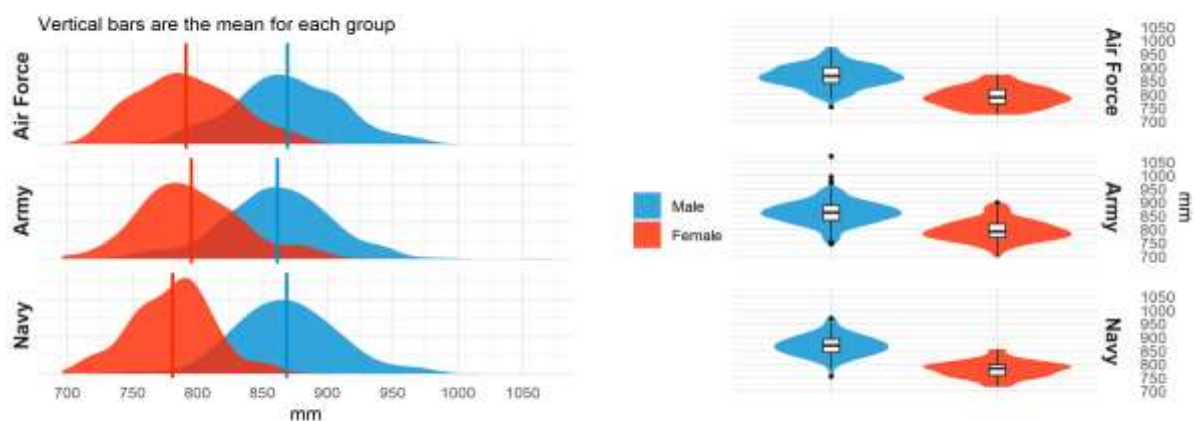
Lengthen or shorten the anthropometer (by adding or removing sections of the rod) to suit the arm length of the participant. Ensure that the prong is based securely, and square to the wall for stability. Be aware of handling the prong tip to avoid injuring the participant. Ask the scribe to observe and confirm whether the participant's arm is straight and horizontal to the floor immediately before taking the reading. The anthropometer and the centre of the arm should be at the same height.



Index finger reach summary statistics - Physical measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
864	869	861	869	Mean	791	795	781	791
42	41	43	39	SD	37	39	31	37
744	754	744	754	Min	724	696	716	696
1070	976	1070	970	Max	874	898	855	898
967	966	953	970	P99	872	886	851	884
950	959	947	956	P98	870	885	847	874
945	949	942	945	P97	867	880	840	872
934	938	934	933	P95	857	873	822	857
915	916	912	916	P90	836	842	817	836
906	909	904	904	P85	831	834	809	828
898	906	894	900	P80	825	828	802	820
891	900	888	893	P75	818	820	798	815
884	890	883	885	P70	810	814	795	807
879	883	876	881	P65	802	805	794	801
874	878	871	878	P60	799	801	791	798
869	874	866	872	P55	795	796	789	794
864	869	862	868	P50	789	792	784	789
858	861	856	862	P45	782	788	781	784
854	857	850	857	P40	780	782	773	780
850	854	847	854	P35	776	777	769	774
844	849	842	849	P30	771	773	764	770
838	842	834	843	P25	766	770	759	766
830	835	828	838	P20	756	762	756	759
823	829	820	832	P15	749	759	749	753
812	814	810	825	P10	742	753	747	748
795	796	790	810	P5	735	734	724	733
784	794	771	806	P3	732	733	720	732
769	789	766	799	P2	732	731	719	723
757	784	755	781	P1	729	716	717	717

Distribution plots for each service and gender



Interpupillary breadth - Physical measurement (mm)

Measuring instrument:

A standard transparent ruler. The transparency enables the assessor to place the ruler close to the eyes without contact.

Source:

ANSUR, AWAS.

Definition:

The distance between the Centre of the Pupil R) and the Centre of the Pupil L.

Landmark required:

None.

Posture required:

The participant stands erect, with gaze focussed on a hypothetical position on the wall behind the assessor, with glasses removed. The assessor stands in front and slightly to the side of the participant.

Procedure:

Place the ruler directly in front of the nose with the zero point of the ruler in line with the centre of the left Pupil. For stability and safety, hold the ruler with the thumb and index finger and use the middle fingers to anchor the hands to the head. Take the reading at the centre of the right pupil. Movement of the eyes must be kept to a minimum. Measure to the nearest 0.1 cm. Measurements are reported in mm.

Reference:

Gordon, C.C., Blackwell, C.L., Bradtmiller, B., Parham, J.L., Barrientos, P., Paquette, S.P., Corner, B., Carson, J.M., Venezia, J.C., Rockwell, B.M., Mucher, M., Kristensen, S., 2014. 2012 Anthropometric survey of U.S. army personnel: Methods and summary statistics., Natick Soldier Research, Development of Engineering Center, Yellow Springs, Ohio, U.S.

Tomkinson, G. R., Daniell, N., Dale, M., & Bowler, T. (2012a). Australian Warfighter Anthropometry Survey (AWAS): Landmarking and measurement manual. Adelaide, Australia: Health and Use of Time Group, Sansom Institute for Health Research, University of South Australia.

Notes:

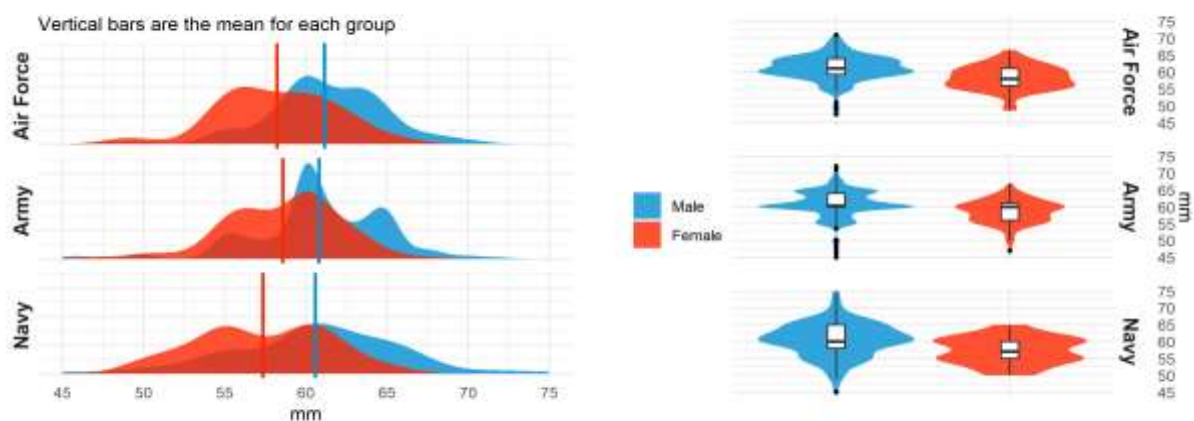
The position of the head has no influence on the measurement. Ensure that the jaw is still and the head is in the Frankfort plane.



Interpupillary breadth summary statistics - Physical measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
61	61	61	61	Mean	58	59	57	58
4	4	4	5	SD	4	3	4	4
45	48	45	45	Min	48	47	50	47
75	71	72	75	Max	66	67	65	67
70	70	70	72	P99	65	65	65	65
69	69	68	71	P98	65	65	65	65
68	68	68	69	P97	65	64	64	65
67	67	67	67	P95	63	64	63	64
65	65	65	66	P90	63	63	62	63
65	64	65	65	P85	62	62	62	62
64	64	64	65	P80	61	61	61	61
64	64	64	65	P75	61	61	60	61
63	63	63	63	P70	60	60	60	60
62	63	62	62	P65	60	60	60	60
62	62	62	62	P60	59	60	60	60
61	62	61	61	P55	59	60	58	60
61	61	60	60	P50	58	60	57	59
60	61	60	60	P45	58	59	57	58
60	60	60	60	P40	57	58	55	57
60	60	60	60	P35	56	57	55	57
60	60	60	60	P30	56	57	55	56
60	59	60	58	P25	56	56	55	55
58	59	58	55	P20	55	56	55	55
57	58	57	55	P15	55	55	53	55
55	57	55	55	P10	55	55	52	54
55	55	55	52	P5	54	53	50	52
51	54	52	51	P3	50	51	50	50
50	52	50	50	P2	49	50	50	50
48	49	47	48	P1	49	50	50	49

Distribution plots for each service and gender



Knee circumference - Post-processed measurement (mm)

Measuring instrument:

CySlice.

Source:

AWAS, NZDFAS.

Definition:

The circumference of the knee at the height of the digitally extracted Midpatella landmark.

Landmark required:

Midpatella landmark.

Posture required:

Scan position posture 1. Stand with feet together, arms straight at the sides with the palms facing in towards the thigh. Fingers together and extended with the thumb facing forward. Stand with back erect and head in the Frankfort plane.

Procedure:

As per AWAS Section 7.2.28 of the Procedures Manual (Tomkinson et al., 2012). Alternatively, use CySlice to draw an X-axis (a digital circumference) around the Midpatella (anterior point midway between the top and bottom of the right patella) landmark. Look for the stickered landmark (kneecap mid-point). If absent the midpoint may still be derived by placing the point marker in the centre of the knee, then use an X-axis loop. Measurements are reported in mm.

Reference:

Tomkinson, G. R., Daniell, N., Dale, M., & Bowler, T. (2012b). Australian Warfighters Anthropometry Survey (AWAS). Procedures Manual. Adelaide, Australia.: Health and Use of Time Group, Sansom Institute for Health Research, University of South Australia.

Kolose, S., Hume, P.A., Tomkinson, G.R., Stewart, A., Stewart, T., Legg, S.J. (2021). Three-dimensional physique assessment in the military: New Zealand Defence Force Anthropometry Survey protocols and summary statistics., SPRINZ: Auckland, New Zealand.

Notes:

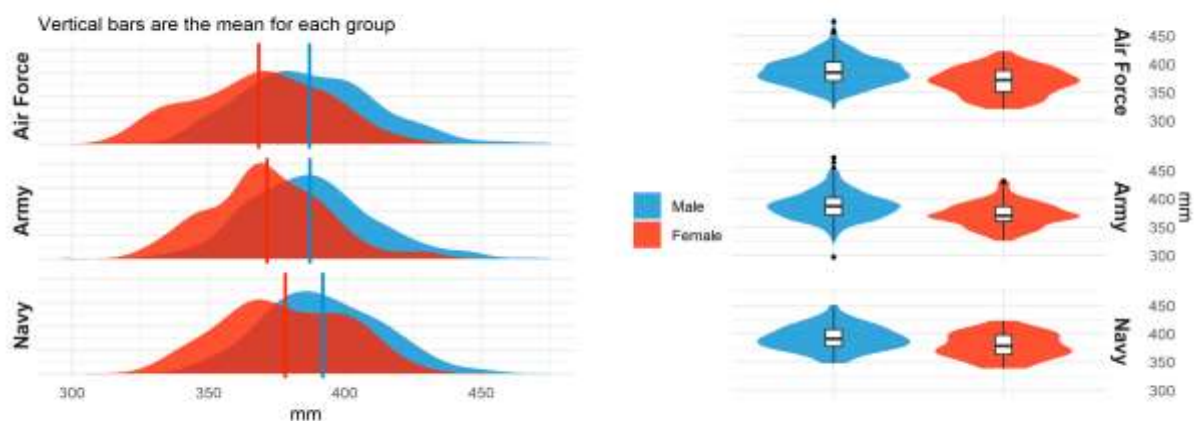
Ensure that there is no 'webbing' (a digital error that occurs when parts of the body are too close together and the software interprets this as one item) between the left and right knee. If so, then skip this measure.



Knee circumference summary statistics - Post-processed measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
388	387	387	392	Mean	368	371	378	372
24	25	24	21	SD	24	21	22	22
296	321	296	348	Min	320	326	338	320
475	475	472	450	Max	422	432	423	432
447	454	447	441	P99	416	429	420	423
441	438	443	433	P98	412	422	416	420
435	433	438	430	P97	409	413	414	413
429	429	428	428	P95	405	403	409	408
418	419	417	419	P90	396	396	406	401
412	411	411	415	P85	395	391	402	396
406	406	405	410	P80	389	388	401	391
402	403	401	407	P75	388	386	397	388
399	400	397	402	P70	382	382	392	385
395	396	394	400	P65	377	378	389	380
392	393	392	395	P60	374	376	383	377
389	389	389	392	P55	372	372	381	372
387	385	386	391	P50	371	370	378	371
383	382	383	389	P45	367	368	370	368
381	379	380	384	P40	363	367	370	367
378	376	378	382	P35	360	365	368	364
374	372	374	379	P30	356	362	366	362
371	370	371	377	P25	351	360	363	356
368	367	367	375	P20	345	352	360	351
364	361	363	369	P15	340	348	355	347
360	357	360	367	P10	334	344	351	343
351	348	353	358	P5	331	339	341	334
346	346	345	353	P3	329	334	339	331
344	345	343	351	P2	327	332	339	330
339	344	335	349	P1	324	331	338	326

Distribution plots for each service and gender



Knee height - Automatic measurement (mm)

Measuring instrument:

Anthroscan software.

Source:

Anthroscan.

Definition:

The vertical height of the front level of the knee girth height (codes 9520/9521) to the standing surface.

Landmark required:

None.

Posture required:

Scan position posture 2. Stand with feet shoulder width apart, trunk and head are erect with eyes looking forward. The upper arms are abducted away from the body with the forearms hanging vertically. All fingers are together and extended with the palm facing (medially) the thigh and the thumb facing forward.

Procedure:

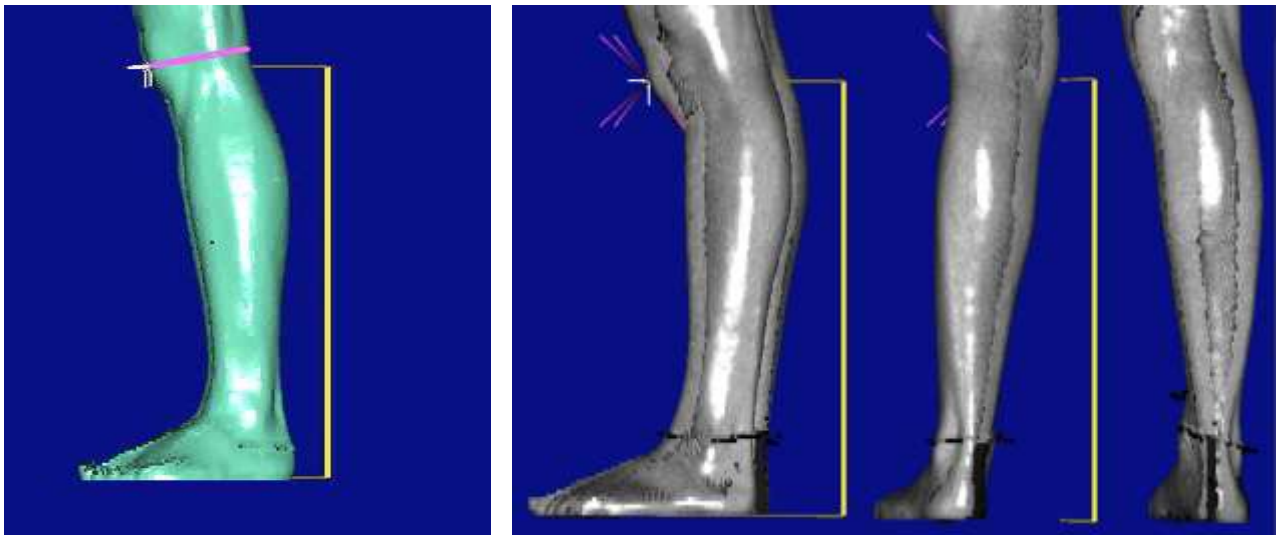
See Section 6 of Human Solutions (2015). Measurements are reported in mm.

Reference:

Human Solutions, 2015. Anthroscan user guide version 3. Human Solutions GmbH, Kaiserslautern, Germany.

Notes:

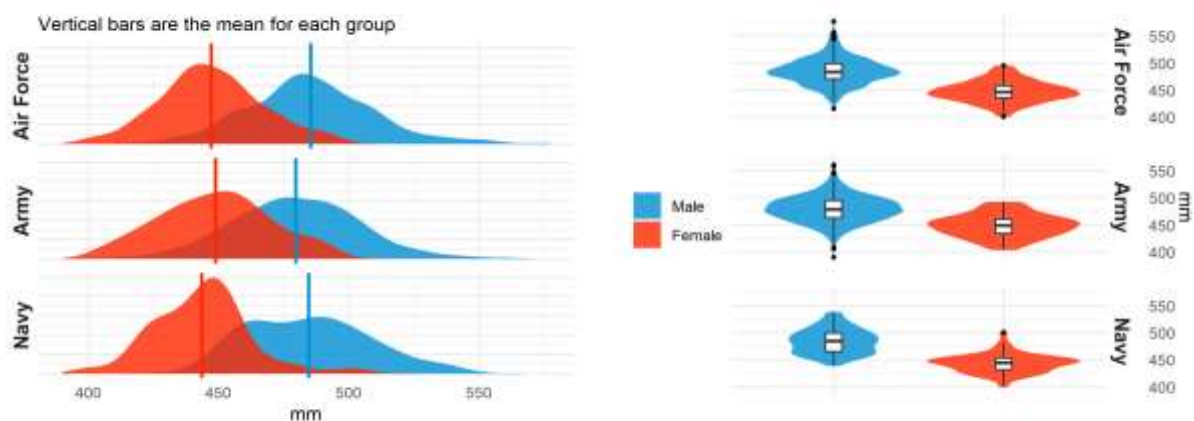
None.



Knee height summary statistics - Automatic measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
482	485	480	485	Mean	447	449	444	447
25	25	25	23	SD	20	21	18	20
390	416	390	438	Min	401	404	400	400
577	577	561	539	Max	495	493	501	501
545	552	541	537	P99	491	491	493	493
536	545	532	535	P98	489	490	485	490
532	536	526	534	P97	488	488	479	488
524	528	521	524	P95	483	487	472	485
512	514	510	515	P90	473	476	459	473
506	509	504	508	P85	470	471	457	468
501	506	500	504	P80	462	467	454	462
497	499	495	499	P75	458	461	453	459
494	496	492	497	P70	457	459	450	457
491	494	489	495	P65	454	457	450	454
488	490	486	489	P60	451	455	448	452
484	487	483	487	P55	448	452	447	450
482	484	479	484	P50	446	449	444	447
478	482	476	481	P45	445	445	443	445
476	480	474	479	P40	441	444	441	442
473	476	471	472	P35	440	440	439	440
469	474	467	466	P30	438	437	435	436
465	471	463	465	P25	436	434	432	434
461	464	459	462	P20	432	430	427	430
457	459	454	459	P15	427	426	424	425
452	454	449	456	P10	423	420	423	422
442	447	441	453	P5	417	414	418	415
436	439	435	451	P3	414	409	416	410
434	436	430	449	P2	409	407	413	407
424	432	423	444	P1	404	407	406	404

Distribution plots for each service and gender



Knee height sitting - Post-processed measurement (mm)

Measuring instrument:

CySlice

Source:

CFAS, NZDFAS.

Definition:

The vertical distance between a footrest surface and the Suprapatella landmark.

Landmark required:

Suprapatella landmark.

Posture required:

Scan position posture 3. Ensure that the participant is sitting with their knee bent at a 90° angle. This can be done by moving the body scanner seat up or down. This can also be facilitated by aligning the popliteal fossa (vertically) in line with Pternion (back of the foot).

Procedure:

This measure is represented by the Y coordinate (mm on the vertical axis) of the Suprapatella landmark in posture 3. Measurements are reported in mm.

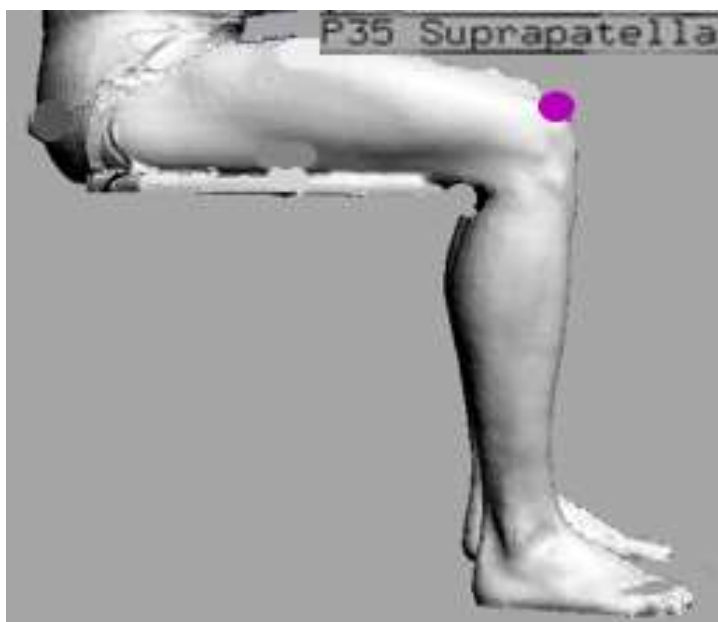
Reference:

Keefe, A., H. Angel, and B. Mangan, 2012 Canadian Forces Anthropometric Survey (CFAS) – Final report. 2015, Defense Research and Development Canada: Toronto, Canada.

Kolose, S., Hume, P.A., Tomkinson, G.R., Stewart, A., Stewart, T., Legg, S.J. (2021). Three-dimensional physique assessment in the military: New Zealand Defence Force Anthropometry Survey protocols and summary statistics., SPRINZ: Auckland, New Zealand.

Notes:

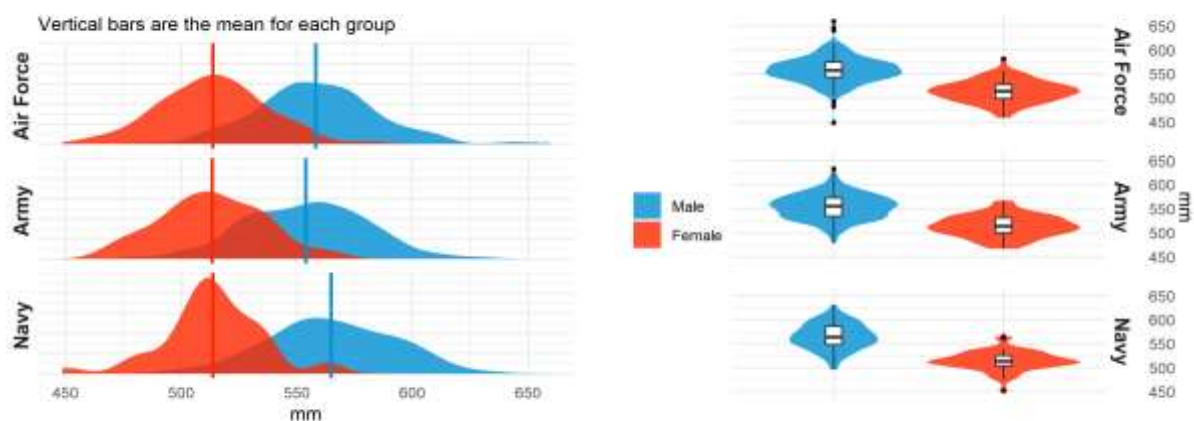
None



Knee height sitting summary statistics - Post-processed measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
556	558	554	565	Mean	514	513	514	514
27	28	27	27	SD	23	22	21	22
448	448	478	496	Min	458	466	451	451
659	659	633	631	Max	581	567	565	581
617	637	615	618	P99	564	563	564	565
611	612	608	612	P98	556	561	562	562
608	610	604	610	P97	553	560	556	559
599	605	595	608	P95	550	549	539	550
591	592	587	599	P90	545	538	536	539
583	583	581	595	P85	534	536	534	536
578	578	577	590	P80	532	534	530	532
574	575	573	586	P75	528	531	525	528
570	571	569	580	P70	525	526	523	525
567	568	564	574	P65	521	522	520	522
563	565	561	572	P60	519	517	516	518
560	560	558	568	P55	517	516	514	516
557	557	555	563	P50	514	514	513	514
553	553	551	560	P45	510	510	512	510
549	551	547	557	P40	508	508	510	508
546	549	543	554	P35	508	504	509	506
542	545	538	550	P30	502	502	507	502
537	543	534	548	P25	498	500	504	500
533	537	531	545	P20	494	495	501	496
528	533	526	537	P15	491	490	498	491
523	524	522	530	P10	488	482	488	485
513	514	510	523	P5	477	477	481	476
506	511	504	517	P3	473	473	476	473
502	507	501	507	P2	468	471	471	470
492	494	491	504	P1	463	470	461	465

Distribution plots for each service and gender



Medial malleolus-hallux length - Post-processed measurement (mm)

Measuring instrument:

CySlice.

Source:

NZDFAS.

Definition:

The distance between the centre of the Medial Malleolus and the tip of the Hallux (big toe).

Landmark required:

Medial Malleolus and Hallux landmarks.

Posture required:

Scan position posture 3. Ensure that the participant is sitting with their knee bent at a 90° angle. This can be done by moving the body scanner seat up or down. This can also be facilitated by aligning the popliteal fossa (vertically) in line with Pternion (back of the foot).

Procedure:

This measure is the point to point distance between the Medial Malleolus (inner ankle) and Hallux (most anterior point of the big toe) landmarks. For the Medial Malleolus place point on medial surface of inner ankle. Use Y loop to identify the most medial protruding point of the malleolus. For the Hallux place point on anterior surface of Hallux. Use X loop to identify this. Measurements are reported in mm.

Reference:

Kolose, S., Hume, P.A., Tomkinson, G.R., Stewart, A., Stewart, T., Legg, S.J. (2021). Three-dimensional physique assessment in the military: New Zealand Defence Force Anthropometry Survey protocols and summary statistics., SPRINZ: Auckland, New Zealand.

Notes:

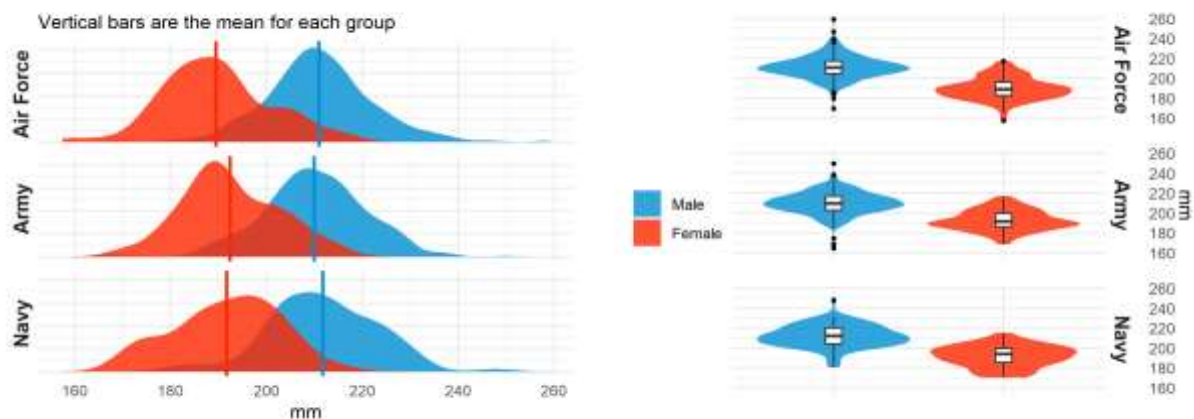
The scan quality is often poor for feet and hands. If the Hallux is not visible, then skip this measure. The Malleolus can be identified visually but for accuracy, place a point in the centre and identify the most lateral aspect using the Y section tool. The Y section tool identifies the 'peak' or the widest point of the media Malleolus.



Medial malleolus-hallax length summary statistics - Post-processed measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
210	211	210	212	Mean	189	192	192	191
11	12	11	11	SD	11	10	11	11
164	169	164	180	Min	157	169	170	157
259	259	250	248	Max	217	217	215	217
237	239	236	233	P99	215	214	212	215
233	236	230	231	P98	214	213	209	214
230	234	229	230	P97	213	212	208	213
229	229	227	230	P95	208	211	208	208
224	224	224	225	P90	204	206	204	205
222	222	221	224	P85	204	204	203	204
219	219	219	222	P80	198	202	201	201
217	217	217	220	P75	196	200	199	199
216	216	215	217	P70	193	198	199	197
214	214	214	215	P65	192	196	197	194
213	213	213	214	P60	191	193	195	193
212	212	211	213	P55	190	192	194	192
210	210	210	212	P50	189	191	194	191
209	209	209	210	P45	188	191	190	189
208	208	207	208	P40	186	189	190	188
207	207	206	207	P35	185	188	187	187
205	206	205	205	P30	183	187	186	186
204	204	203	204	P25	183	186	185	184
202	203	202	203	P20	181	185	183	183
200	201	200	202	P15	179	183	179	181
197	197	196	200	P10	177	180	175	178
193	193	192	194	P5	174	178	174	174
189	192	189	190	P3	172	175	173	172
187	189	188	185	P2	168	172	172	171
184	185	185	183	P1	163	171	171	169

Distribution plots for each service and gender



Neck girth base - Automatic measurement (mm)

Measuring instrument:

Anthroscan software.

Source:

Anthroscan.

Definition:

Circumference measurement at the level of the base of the neck, just on the transition between the torso and neck.

Landmark required:

None.

Posture required:

Scan position posture 2. Stand with feet shoulder width apart, trunk and head are erect with eyes looking forward. The upper arms are abducted away from the body with the forearms hanging vertically. All fingers are together and extended with the palm facing (medially) the thigh and the thumb facing forward.

Procedure:

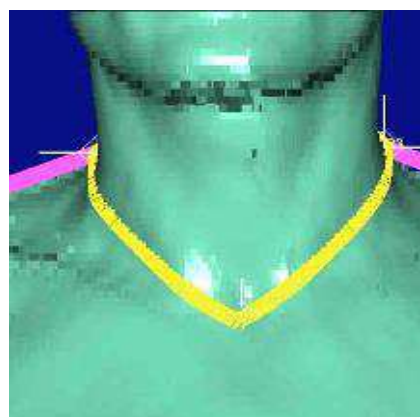
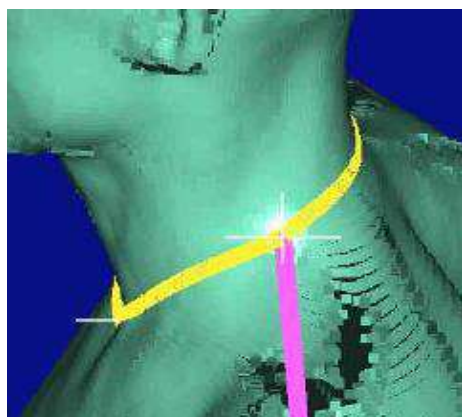
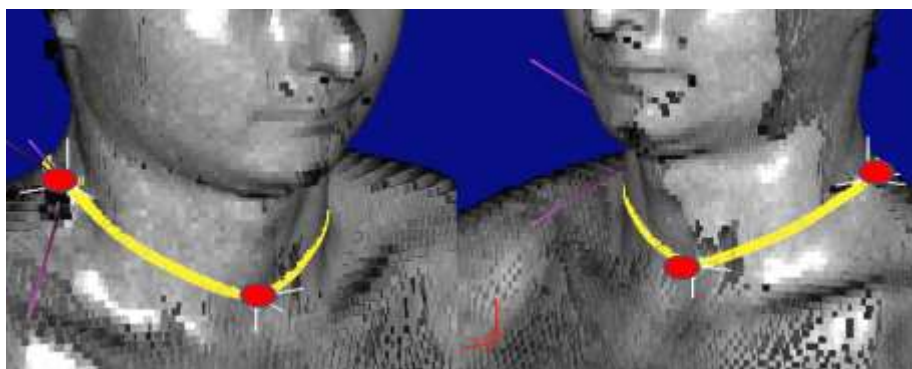
See Section 6 of Human Solutions (2015). Measurements are reported in mm.

Reference:

Human Solutions, 2015. Anthroscan user guide version 3. Human Solutions GmbH, Kaiserslautern, Germany.

Notes:

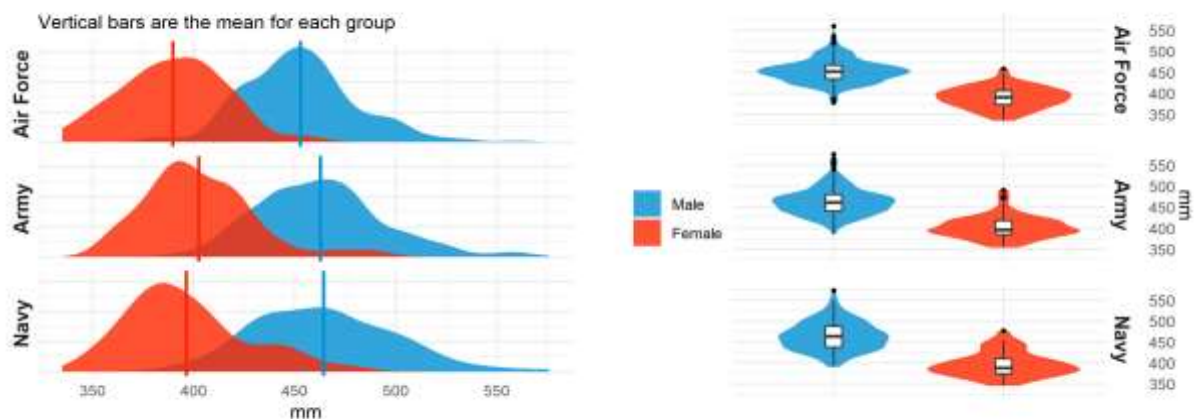
This measure often requires slight adjustment as sometimes the software produces a sharp 'edge' at the base of the throat (it does not behave like a standard tape). To adjust, place the cursor on the tape (depicted as red dots), left mouse click and hold, then manually move the tape to create a more round profile. The tape can also be adjusted using points on the left and right side of the neck (to conform around the neck circumference).



Neck girth base summary statistics - Automatic measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
460	453	463	464	Mean	390	403	396	397
32	28	32	35	SD	26	27	30	28
378	378	385	391	Min	335	354	346	335
576	560	576	573	Max	458	490	477	490
557	529	559	551	P99	452	489	468	477
536	518	541	541	P98	441	476	459	468
526	508	526	531	P97	430	471	454	457
518	502	522	519	P95	426	446	449	443
502	492	504	509	P90	421	431	441	429
491	480	495	501	P85	418	425	430	422
484	473	486	495	P80	410	422	416	418
478	467	480	487	P75	405	418	409	414
473	464	476	480	P70	404	415	405	408
469	461	473	474	P65	402	409	403	405
465	457	469	468	P60	400	406	399	402
462	454	464	466	P55	393	402	396	398
458	452	461	463	P50	390	396	388	395
455	449	458	460	P45	387	395	387	391
450	445	454	455	P40	384	394	385	388
446	443	448	448	P35	381	391	384	385
443	438	444	441	P30	376	389	383	383
438	435	441	438	P25	372	385	374	378
434	428	436	433	P20	368	382	372	375
428	424	429	431	P15	362	377	369	370
422	420	423	426	P10	355	371	366	364
415	414	416	417	P5	350	364	355	355
409	409	412	405	P3	343	361	353	352
404	400	405	402	P2	340	359	352	349
397	387	403	398	P1	337	359	349	342

Distribution plots for each service and gender



Palm length - Physical measurement (mm)

Measuring instrument:

Segmometer.

Source:

ISO 7250.

Definition:

Distance from a line drawn between the styloid processes mid-stylian landmark to the proximal finger crease of the middle finger on the palm of the hand.

Landmark required:

None.

Posture required:

The participant places the lateral surface of the right forearm and the back of the right-hand flat against the table surface. The palm is open and facing up. Fingers and thumb are together. The assessor stands in a position that is perpendicular to the hand.

Procedure:

Measurement is taken on the palmar surface of the hand between the mid-stylian landmark and the proximal crease of the middle finger. The fixed end of the segmometer is placed on the centre wrist landmark, the sliding end is on the crease. Measurements are reported in mm.

Reference:

ISO 7250-1. Basic Human Body Measurements for Technological Design. 2008, International Organization for Standardization: Geneva.

Notes:

Ensure that the palm and all fingers are together and rigid (no cupping of the hands).

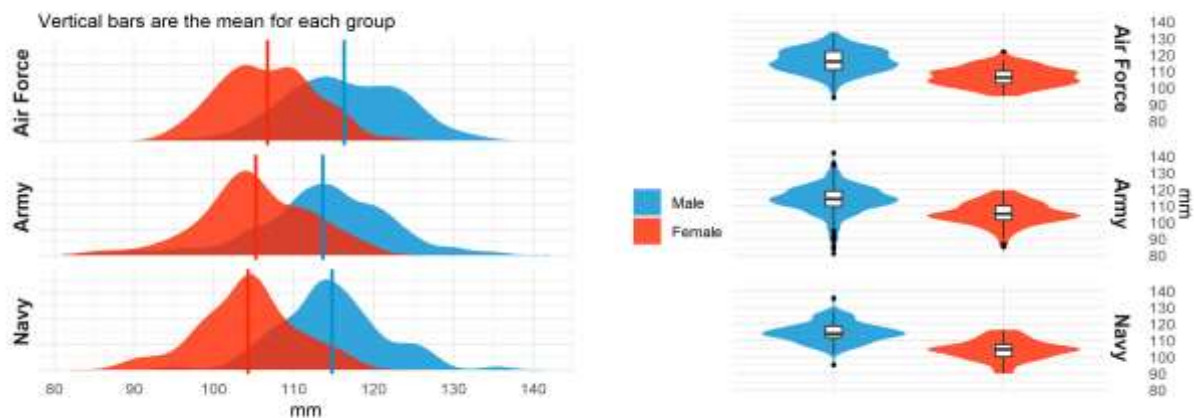
Ensure the back of the hand and fingers are flat against the table surface.



Palm length summary statistics - Physical measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
114	116	114	115	Mean	107	105	104	106
8	7	9	7	SD	6	7	6	6
81	94	81	95	Min	95	85	90	85
142	134	142	136	Max	122	119	116	122
133	132	135	129	P99	118	119	116	119
130	130	130	127	P98	116	119	116	117
130	130	130	127	P97	116	117	115	116
126	127	126	126	P95	116	116	114	116
124	125	123	124	P90	114	114	112	114
122	124	122	121	P85	113	112	111	112
121	123	120	119	P80	111	111	109	111
120	122	119	118	P75	110	110	108	110
119	120	118	117	P70	110	109	106	109
117	120	117	116	P65	110	107	105	108
116	118	116	116	P60	109	106	105	106
115	117	115	115	P55	108	105	105	106
115	116	114	114	P50	106	105	104	105
114	115	113	114	P45	105	104	104	104
113	114	112	113	P40	105	104	104	104
112	114	112	112	P35	104	103	103	103
111	112	110	112	P30	103	102	102	103
110	111	110	112	P25	103	102	100	102
109	110	108	109	P20	102	101	99	101
107	109	106	109	P15	101	99	99	100
105	107	103	107	P10	100	97	98	98
100	105	97	105	P5	98	93	94	96
96	103	93	104	P3	97	93	92	93
94	101	91	103	P2	96	90	91	91
90	100	89	101	P1	95	87	90	90

Distribution plots for each service and gender



Popliteal height sitting - Post-processed measurement (mm)

Measuring instrument:

CySlice.

Source:

ANSUR, NZDFAS.

Definition:

The vertical distance from a footrest surface to the back of the right knee (the popliteal fossa at the dorsal juncture of the calf and thigh).

Landmark required:

Popliteal landmark.

Posture required:

Scan position posture 3. Ensure that the participant is sitting with their knee bent at a 90° angle. This can be done by moving the body scanner seat up or down. This can also be facilitated by aligning the popliteal fossa (vertically) in line with Pternion (back of the foot).

Procedure:

The Popliteal is the crease between the bottom of the thigh and top of the calf on right leg when in seated position. With "Colour" mode off, this point is best accessed when viewed from inferior e.g. looking up to the knee crease as if viewed from the participants heel. The marker should be placed in the middle of the crease. The measure is represented by the Y coordinate (mm on the vertical axis) of the Popliteal landmark in posture 3. Measurements are reported in mm.

Reference:

Gordon, C.C., Blackwell, C.L., Bradtmiller, B., Parham, J.L., Barrientos, P., Paquette, S.P., Corner, B., Carson, J.M., Venezia, J.C., Rockwell, B.M., Mucher, M., Kristensen, S., 2014. 2012 Anthropometric survey of U.S. army personnel: Methods and summary statistics., Natick Soldier Research, Development of Engineering Center, Yellow Springs, Ohio, U.S.

Kolose, S., Hume, P.A., Tomkinson, G.R., Stewart, A., Stewart, T., Legg, S.J. (2021). Three-dimensional physique assessment in the military: New Zealand Defence Force Anthropometry Survey protocols and summary statistics., SPRINZ: Auckland, New Zealand.

Notes:

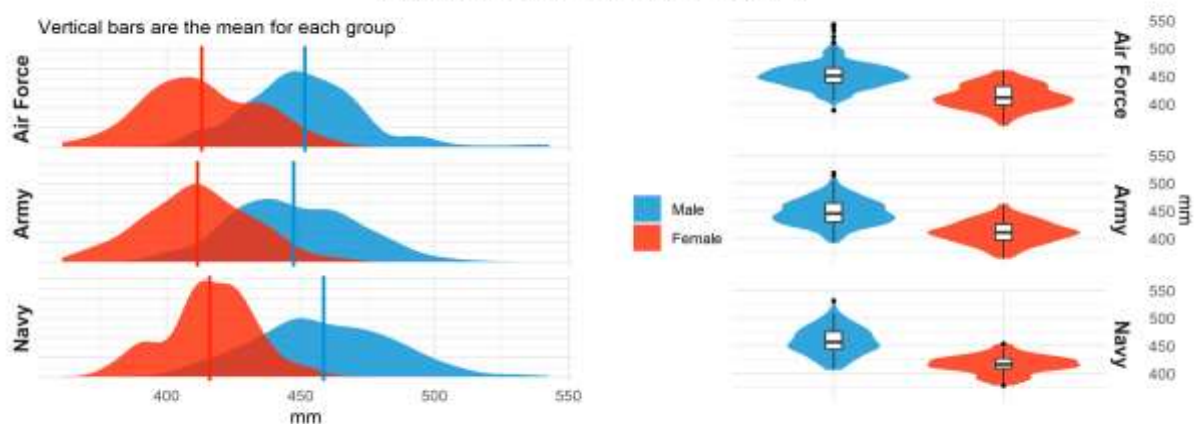
Ensure that the popliteal landmark is placed in the centre (underneath) the thigh and not on the lateral side (near the tibiale laterale). Use different views (e.g. wire view) to increase visibility. If not visible remove this measure.



Popliteal height sitting summary statistics - Post-processed measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
450	452	447	459	Mean	413	412	416	413
24	23	23	25	SD	21	20	16	20
388	388	392	406	Min	361	364	379	361
543	543	518	531	Max	460	463	454	463
509	530	503	512	P99	458	460	450	459
502	508	495	508	P98	455	448	447	453
496	498	491	505	P97	451	446	444	448
490	492	486	500	P95	447	443	440	445
480	476	478	490	P90	438	436	435	437
474	470	472	485	P85	437	434	431	435
469	468	468	481	P80	435	428	427	431
465	464	464	475	P75	431	425	427	427
462	461	461	473	P70	424	422	426	423
459	459	458	469	P65	418	418	423	419
455	455	453	466	P60	416	415	422	417
451	452	449	461	P55	414	413	419	414
448	450	445	456	P50	411	411	416	412
445	448	442	452	P45	410	409	414	411
442	445	440	450	P40	407	408	412	409
440	443	437	448	P35	401	405	411	406
437	440	434	446	P30	400	402	410	402
432	438	430	444	P25	398	397	409	399
429	432	427	437	P20	395	394	405	395
426	429	424	432	P15	394	392	398	393
422	426	420	426	P10	389	386	392	388
413	414	412	417	P5	380	377	388	380
409	411	404	413	P3	378	373	386	375
404	411	402	412	P2	373	372	384	373
398	408	397	411	P1	367	371	381	370

Distribution plots for each service and gender



Radiale-styilion length - Post-processed measurement (mm)

Measuring instrument:

CySlice

Source:

ISAK, AWAS.

Definition:

The point-to-point distance between the digitally extracted Radiale and Styilion landmarks. Note that despite the appearance of a contour distance in the figure, CySlice extracts this measurement as a point-to-point distance.

Landmark required:

Radiale right and Styilion right landmarks.

Posture required:

Scan position posture 1. Stand with feet together, arms straight at the sides with the palms facing in towards the thigh. Fingers together and extended with the thumb facing forward. Stand with back erect and head in the Frankfort plane.

Procedure:

Identify and select the digital Radiale right and Styilion (most distal point on the lateral margin of the styloid process of the radius) right landmarks. Look for the stickered landmark and skip if absent. Measurements are reported in mm.

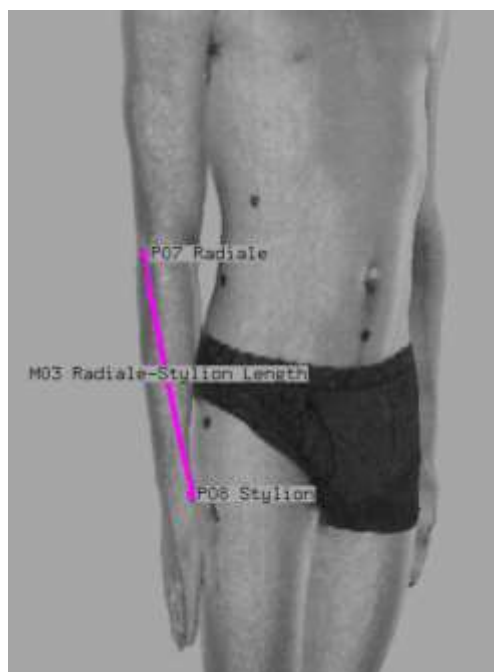
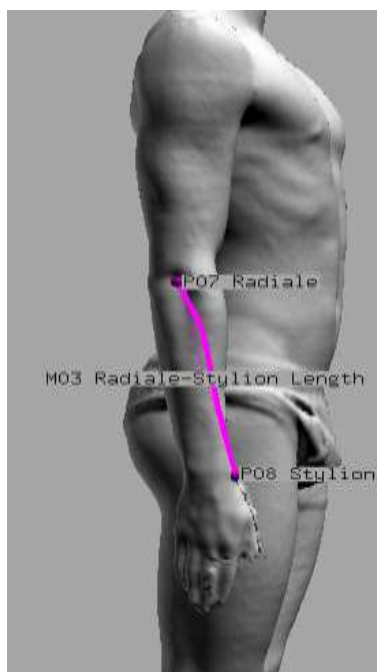
Reference:

Marfell-Jones, M.J., A.D. Stewart, and J.H. De Ridder, International Standards for Anthropometric Assessment. 2012.

Tomkinson, G. R., Daniell, N., Dale, M., & Bowler, T. (2012a). Australian Warfighter Anthropometry Survey (AWAS): Landmarking and measurement manual. Adelaide, Australia: Health and Use of Time Group, Sansom Institute for Health Research, University of South Australia.

Notes:

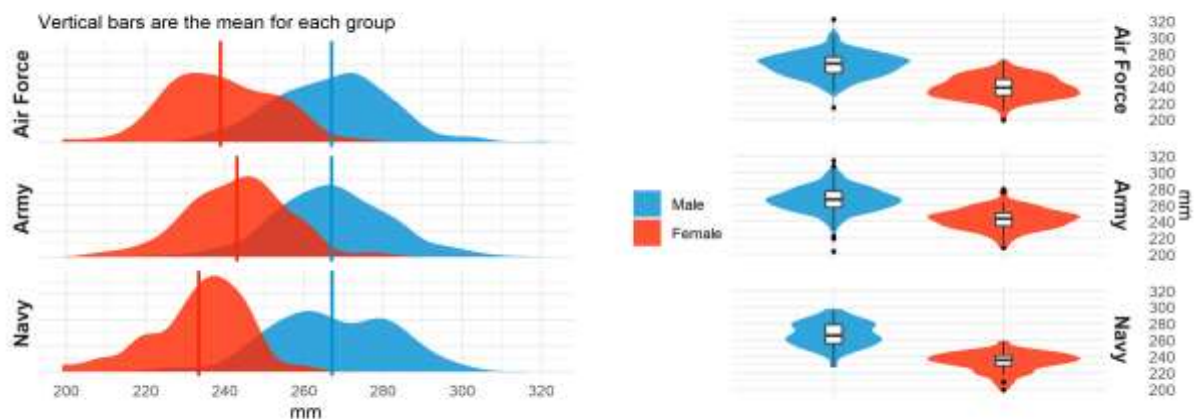
Ignore the curved line produced by CySlice. The export function will correct this to the point to point distance.



Radiale-stylian length summary statistics - Post-processed measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
267	267	267	267	Mean	239	243	233	240
15	15	15	15	SD	14	13	12	13
204	215	204	227	Min	199	208	199	199
322	322	314	298	Max	273	279	259	279
303	303	302	297	P99	266	276	255	272
298	300	299	296	P98	262	266	251	263
296	295	296	294	P97	259	262	249	261
291	289	292	289	P95	259	261	247	260
285	284	285	286	P90	256	260	246	257
283	282	283	283	P85	255	255	245	254
279	279	279	281	P80	251	252	244	251
277	276	277	279	P75	249	251	241	249
275	275	274	278	P70	247	250	241	247
273	273	272	276	P65	244	248	239	245
270	272	270	272	P60	240	247	237	243
269	270	268	267	P55	240	245	236	241
267	268	267	266	P50	239	244	236	240
265	265	265	264	P45	237	242	235	238
263	264	263	262	P40	234	241	233	236
261	261	261	261	P35	232	238	230	235
259	259	259	259	P30	230	236	230	233
257	257	257	256	P25	229	235	229	230
255	254	255	254	P20	228	233	223	229
252	252	253	251	P15	226	230	220	227
249	249	250	248	P10	224	229	218	223
243	243	242	245	P5	220	222	210	218
239	238	239	242	P3	218	219	209	214
236	237	236	237	P2	214	217	207	209
230	236	230	228	P1	208	212	203	208

Distribution plots for each service and gender



Seated height - Physical measurement (mm)

Measuring instrument:

Stadiometer and anthropometry box. Only the bottom half of the stadiometer is required unless the participant has a sitting height in excess of 1300 mm. The stadiometer sits on the anthropometry box on its long axis.

Source:

ISAK.

Definition:

The height from the sitting platform to the Vertex® when the head is held in the Frankfort plane. The technique uses stretched stature methods to avoid repeated measures having to be taken as near as possible to the same time of day as the original measurement.

Landmark required:

None.

Posture required:

The participant is seated on a measuring box or level platform. Their arms and hands are by relaxed by their side. The assessor stands in front of the participant and observes at eye level the head in the Frankfort plane. The scale end of the caliper is near the participants head.

Procedure:

The participant is instructed to take and hold a deep breath, and while keeping the head in the Frankfort plane, the assessor applies gentle upward lift through the mastoid processes. Both thumbs of the assessor are below each Orbitale, and the index fingers are placed below the base of the skull. The recorder places the headboard firmly down on the Vertex®, crushing the hair as much as possible. Care must be taken to ensure the participant does not contract the gluteal muscles nor push with the legs. Measurements are reported in mm.

Reference:

Marfell-Jones, M.J., A.D. Stewart, and J.H. De Ridder, International Standards for Anthropometric Assessment. 2012.

Notes:

If the anthropometry box is too short consider using another object such as a sturdy desk or table.

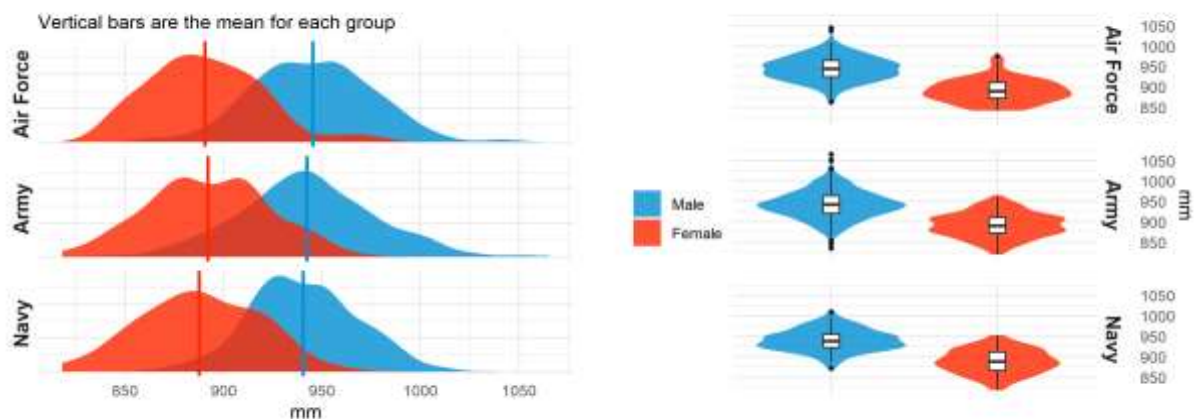
Their knees should be at a right angle. If the seat surface does not enable this angle, then ask the participant to sit straight with their back straight and against the Stadiometer (without leaning on it). The posterior-inferior end of the buttocks must be pushed back against the base of the ruler (as far as their body allows). Care must be taken to ensure the participant does not contract the gluteal muscles nor push with the legs.



Seated height summary statistics - Physical measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
943	945	942	940	Mean	891	892	888	891
33	30	35	27	SD	29	30	30	30
836	863	836	871	Min	842	820	818	818
1066	1045	1066	1010	Max	976	965	952	976
1026	1011	1026	998	P99	969	951	945	964
1010	1007	1012	990	P98	962	950	938	952
1005	998	1007	988	P97	953	948	934	949
998	994	1002	985	P95	932	941	929	940
986	984	988	976	P90	924	935	925	927
976	976	978	972	P85	918	920	921	919
970	972	970	963	P80	915	916	914	915
964	965	964	955	P75	911	911	912	911
959	961	958	953	P70	902	910	909	909
954	957	953	951	P65	901	907	895	904
950	954	950	949	P60	896	904	894	899
945	951	944	945	P55	892	899	892	893
942	945	942	938	P50	890	890	888	889
938	941	939	932	P45	885	885	886	885
933	936	933	931	P40	879	883	880	880
931	932	930	929	P35	877	879	875	878
926	928	926	927	P30	875	874	874	874
922	925	921	922	P25	872	873	866	872
916	920	915	919	P20	866	867	862	865
910	914	908	915	P15	859	861	856	859
902	909	900	911	P10	855	852	849	851
890	898	886	899	P5	848	844	845	845
883	890	878	890	P3	845	840	836	842
875	886	874	889	P2	844	834	831	836
868	872	868	884	P1	843	827	824	828

Distribution plots for each service and gender



Shoulder-elbow length - Post-processed measurement (mm)

Measuring instrument:

CySlice

Source:

ANSUR, NZDFAS.

Definition:

The distance between the right acromion landmark and the right olecranon bottom landmark.

Landmark required:

Acromiale Right and Olecranon bottom (right) landmark.

Posture required:

Scan position posture 3. Ensure that the participant is sitting with their knee bent at a 90° angle. This can be done by moving the body scanner seat up or down. This can also be facilitated by aligning the popliteal fossa (vertically) in line with Pternion (back of the foot).

Procedure:

This measure is the point to point distance between the Acromiale Right and Olecranon bottom (right) landmark. Measurements are reported in mm.

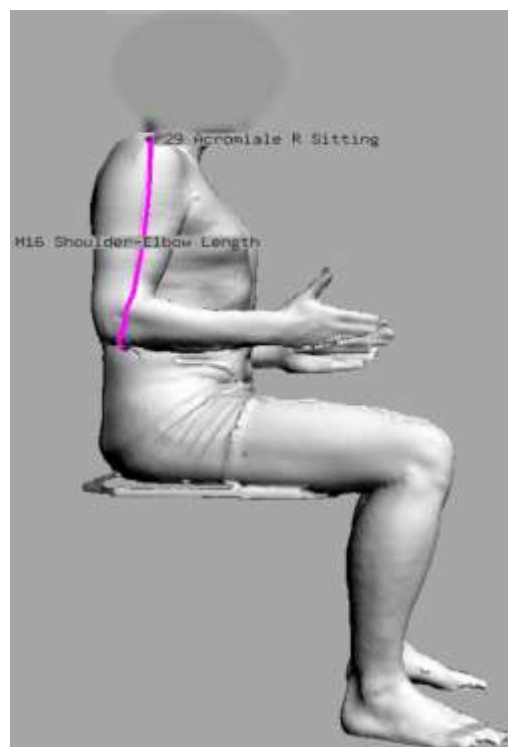
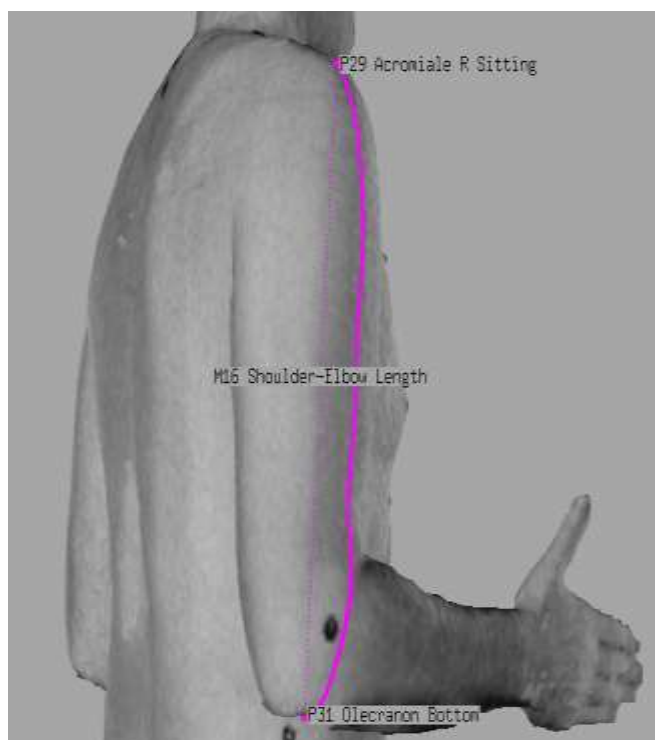
Reference:

Gordon, C.C., Blackwell, C.L., Bradtmiller, B., Parham, J.L., Barrientos, P., Paquette, S.P., Corner, B., Carson, J.M., Venezia, J.C., Rockwell, B.M., Mucher, M., Kristensen, S., 2014. 2012 Anthropometric survey of U.S. army personnel: Methods and summary statistics., Natick Soldier Research, Development of Engineering Center, Yellow Springs, Ohio, U.S.

Kolose, S., Hume, P.A., Tomkinson, G.R., Stewart, A., Stewart, T., Legg, S.J. (2021). Three-dimensional physique assessment in the military: New Zealand Defence Force Anthropometry Survey protocols and summary statistics., SPRINZ: Auckland, New Zealand.

Notes:

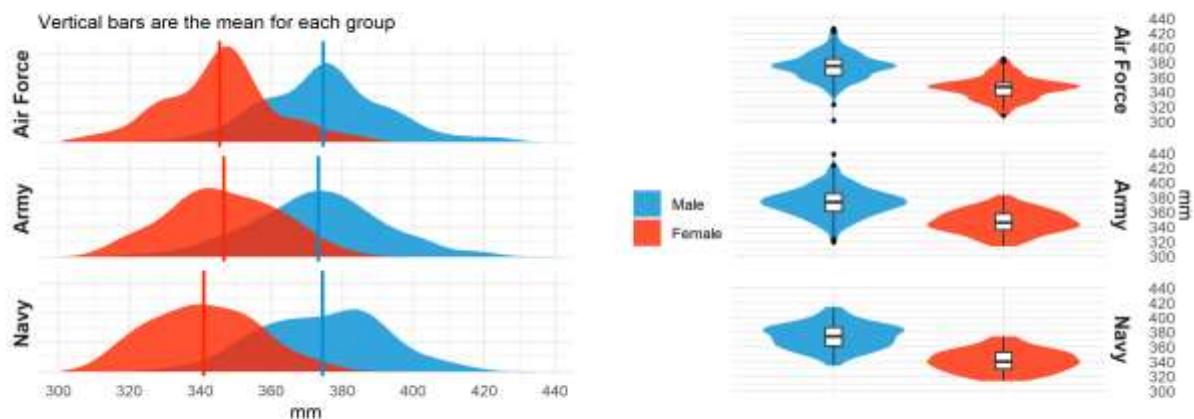
None.



Shoulder-elbow length summary statistics - Post-processed measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
374	375	373	374	Mean	345	347	341	345
19	18	19	17	SD	15	15	15	15
301	301	319	334	Min	307	313	314	307
438	426	438	414	Max	385	383	374	385
419	423	419	411	P99	382	380	372	380
414	415	415	408	P98	379	376	371	376
409	411	408	405	P97	375	374	369	374
404	403	404	403	P95	370	370	365	370
397	397	398	394	P90	367	368	358	367
392	393	392	390	P85	358	363	356	361
388	389	388	388	P80	356	361	353	357
385	385	385	386	P75	352	357	352	355
382	382	382	385	P70	351	356	351	353
380	379	380	382	P65	350	353	347	351
378	378	378	381	P60	349	350	344	349
376	376	376	377	P55	347	348	342	347
374	375	373	374	P50	347	346	340	345
372	373	371	374	P45	345	344	339	343
370	372	369	369	P40	343	342	337	341
368	370	367	367	P35	342	340	336	339
365	367	365	365	P30	341	339	331	337
361	362	361	361	P25	335	336	330	334
358	360	358	358	P20	334	334	327	331
355	357	354	357	P15	329	331	325	329
350	353	348	353	P10	327	326	322	325
344	346	342	348	P5	322	321	320	320
338	342	337	346	P3	316	319	317	317
335	341	335	341	P2	315	318	315	315
328	334	327	335	P1	312	315	314	314

Distribution plots for each service and gender



Sitting elbow rest height sitting - Post-processed measurement (mm)

Measuring instrument: CySlice

Source:

ANSUR, NZDAS.

Definition:

The vertical distance between a sitting surface and the olecranon, bottom landmark on the flexed right elbow.

Landmark required:

Olecranon bottom and Seat pan height landmarks.

Posture required:

Scan position posture 3.

Procedure:

This measure is represented by the Y coordinate (mm on the Y or vertical axis) of the Olecranon bottom landmark minus the Y coordinate of the Seat pan height landmark in posture 3. Measurements are reported in mm.

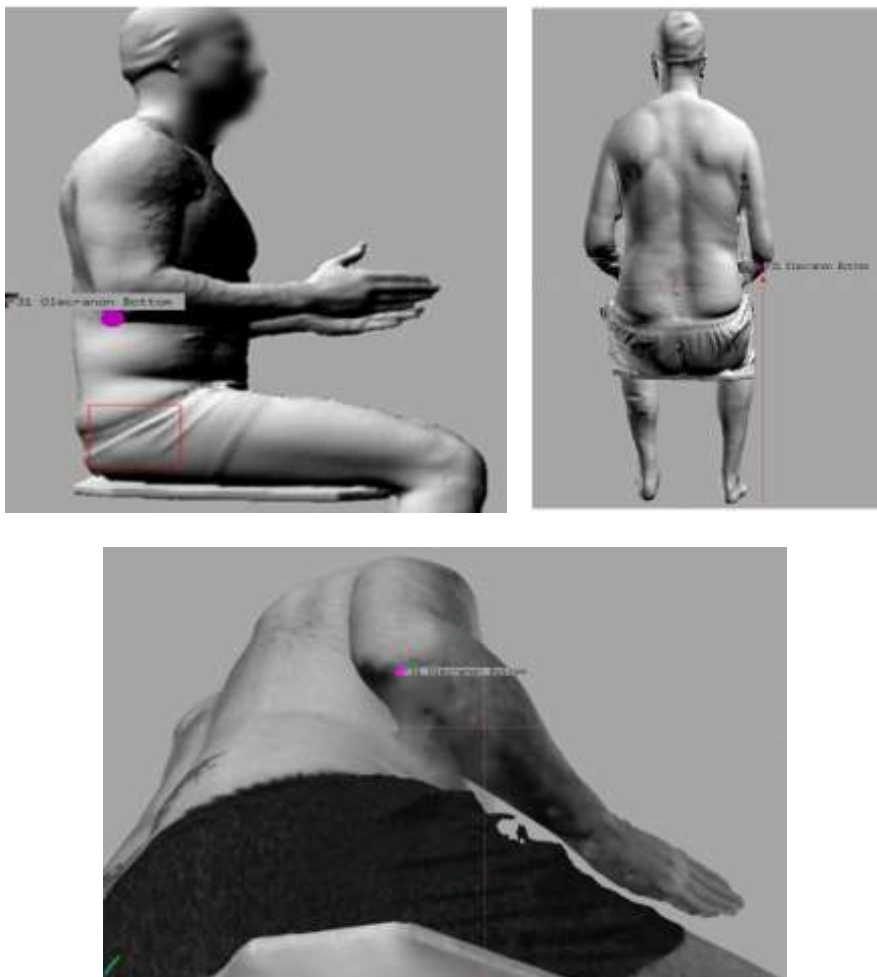
Reference:

Gordon, C.C., Blackwell, C.L., Bradtmiller, B., Parham, J.L., Barrientos, P., Paquette, S.P., Corner, B., Carson, J.M., Venezia, J.C., Rockwell, B.M., Mucher, M., Kristensen, S., 2014. 2012 Anthropometric survey of U.S. army personnel: Methods and summary statistics., Natick Soldier Research, Development of Engineering Center, Yellow Springs, Ohio, U.S.

Kolose, S., Hume, P.A., Tomkinson, G.R., Stewart, A., Stewart, T., Legg, S.J. (2021). Three-dimensional physique assessment in the military: New Zealand Defence Force Anthropometry Survey protocols and summary statistics., SPRINZ: Auckland, New Zealand.

Notes:

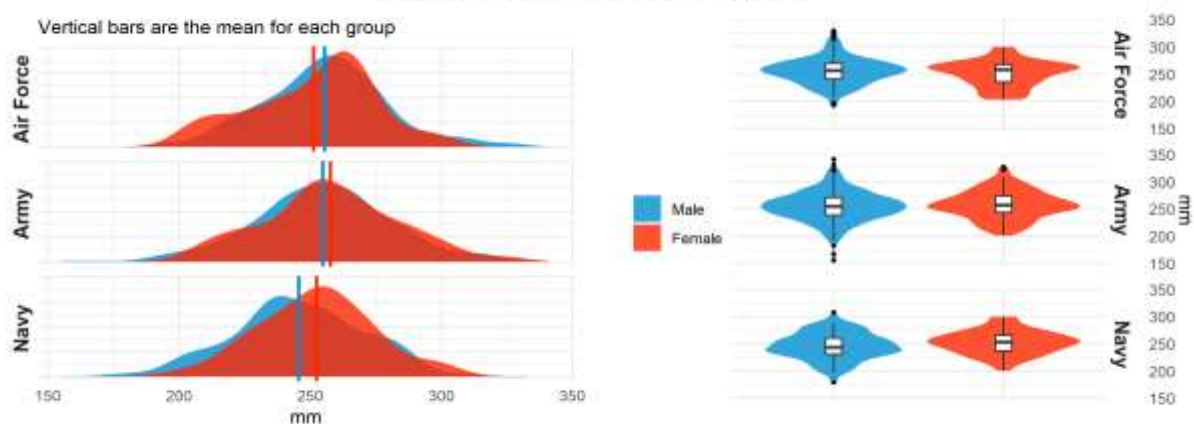
Ensure that the forearm is horizontal and parallel with the ground.



Sitting elbow rest height sitting summary statistics - Post-processed measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
254	256	255	246	Mean	251	258	252	254
26	24	27	25	SD	24	26	22	25
155	193	155	179	Min	204	201	201	201
341	330	341	308	Max	300	327	300	327
320	319	321	291	P99	300	322	299	308
311	309	315	287	P98	297	309	299	302
308	308	309	287	P97	294	304	297	300
298	297	299	285	P95	289	302	291	298
287	282	288	280	P90	274	290	277	286
279	277	283	272	P85	269	286	273	277
275	273	276	268	P80	268	279	270	273
270	270	271	260	P75	267	274	265	268
266	266	267	258	P70	266	269	262	267
264	264	264	254	P65	263	265	259	263
260	261	261	252	P60	261	263	258	261
257	258	257	250	P55	259	260	255	258
254	257	255	243	P50	258	257	253	256
252	253	252	241	P45	256	253	252	253
248	251	249	239	P40	249	251	248	251
244	248	245	236	P35	247	250	245	248
241	244	242	234	P30	238	247	243	244
237	241	238	231	P25	236	243	237	237
233	235	235	229	P20	232	234	235	233
228	232	228	219	P15	222	230	230	226
220	223	221	213	P10	215	222	224	220
209	217	209	204	P5	208	215	219	211
204	212	203	200	P3	207	210	215	209
198	208	198	197	P2	205	210	212	207
193	198	192	195	P1	204	209	207	204

Distribution plots for each service and gender



Sleeve outseam - Post-processed measurement (mm)

Measuring instrument:

CySlice.

Source:

ANSUR, AWAS.

Definition:

The contour (surface) distance between the digitally extracted Acromion Right and Centre Wrist marker landmarks, passing over the Radiale landmark.

Landmark required:

Digitally extracted Acromiale R and Centre Wrist and Radiale landmarks.

Posture required:

Scan position posture 1.

Procedure:

Identify and select the digital Acromiale R, Centre Wrist (centre point of the right wrist) and Radiale landmarks. Measurements are reported in mm. For the Centre Wrist add 'Z-loop' around the Stylium landmark. Visually identify the mid-point at the top of the wrist (when viewed straight on from the side). Look for the stickered landmark and skip if absent. This landmark is reliant on the presence of the Stylium.

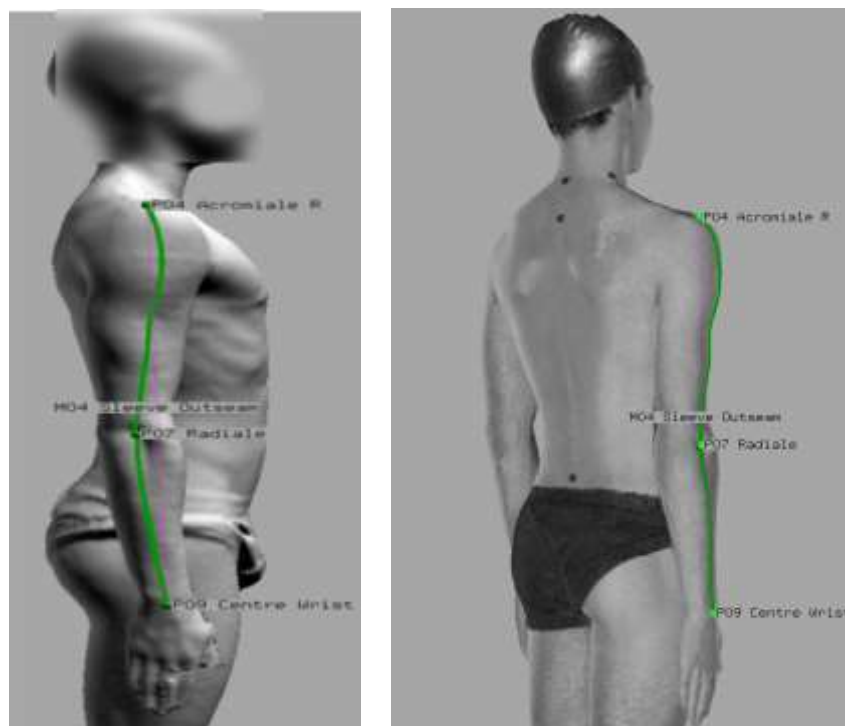
Reference:

Gordon, C.C., Blackwell, C.L., Bradtmiller, B., Parham, J.L., Barrientos, P., Paquette, S.P., Corner, B., Carson, J.M., Venezia, J.C., Rockwell, B.M., Mucher, M., Kristensen, S., 2014. 2012 Anthropometric survey of U.S. army personnel: Methods and summary statistics., Natick Soldier Research, Development of Engineering Center, Yellow Springs, Ohio, U.S.

Tomkinson, G. R., Daniell, N., Dale, M., & Bowler, T. (2012a). Australian Warfighter Anthropometry Survey (AWAS): Landmarking and measurement manual. Adelaide, Australia: Health and Use of Time Group, Sansom Institute for Health Research, University of South Australia.

Notes:

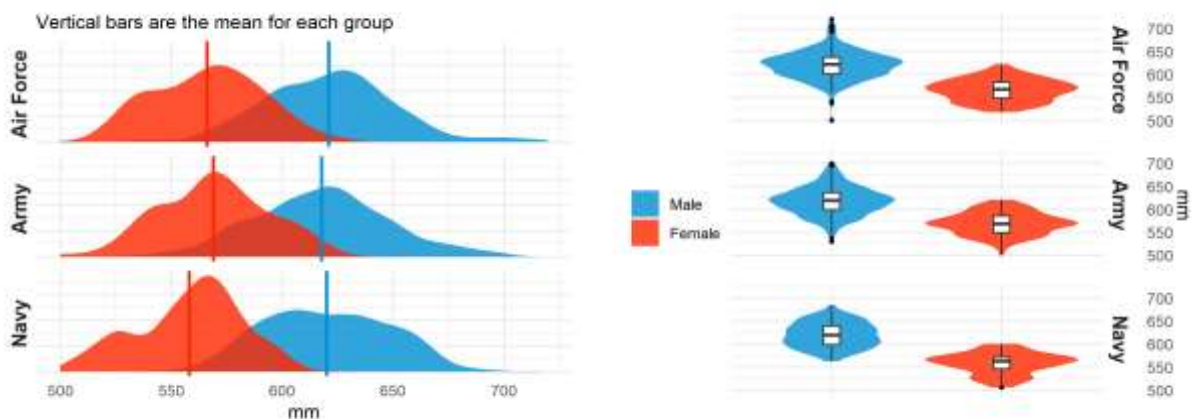
None.



Sleeve outseam summary statistics - Post-processed measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
619	621	618	620	Mean	566	569	558	566
30	30	30	27	SD	24	25	23	24
501	501	530	563	Min	518	500	506	500
720	720	699	685	Max	623	621	600	623
695	706	692	667	P99	617	619	598	618
685	693	684	664	P98	611	614	597	613
678	681	679	663	P97	606	612	596	608
669	668	671	662	P95	604	608	595	606
657	657	655	660	P90	596	605	585	597
649	648	649	651	P85	591	597	580	591
644	644	643	648	P80	587	590	577	587
637	638	637	640	P75	583	586	572	582
634	636	632	635	P70	580	582	571	578
630	631	629	634	P65	576	577	570	575
626	629	624	628	P60	574	575	566	571
623	626	622	626	P55	569	571	563	569
620	622	619	619	P50	568	568	563	567
615	618	614	612	P45	565	566	561	565
612	615	611	610	P40	562	565	556	563
607	610	606	608	P35	558	563	551	558
603	603	603	604	P30	552	558	549	552
599	601	599	599	P25	548	550	547	548
594	598	593	593	P20	540	545	535	544
587	592	585	589	P15	537	543	528	538
581	584	578	586	P10	534	538	525	533
573	574	571	581	P5	530	531	517	526
566	570	562	575	P3	526	529	514	524
560	567	557	572	P2	525	525	512	517
548	545	548	569	P1	522	517	509	514

Distribution plots for each service and gender



Suprasternale height - Automatic measurement (mm)

Measuring instrument:

Anthroscan software.

Source:

Anthroscan.

Definition:

The vertical height of the nape landmark to the standing surface.

Landmark required.

None.

Procedure:

See Section 6 of Human Solutions (2015). Measurements are reported in mm.

Posture required:

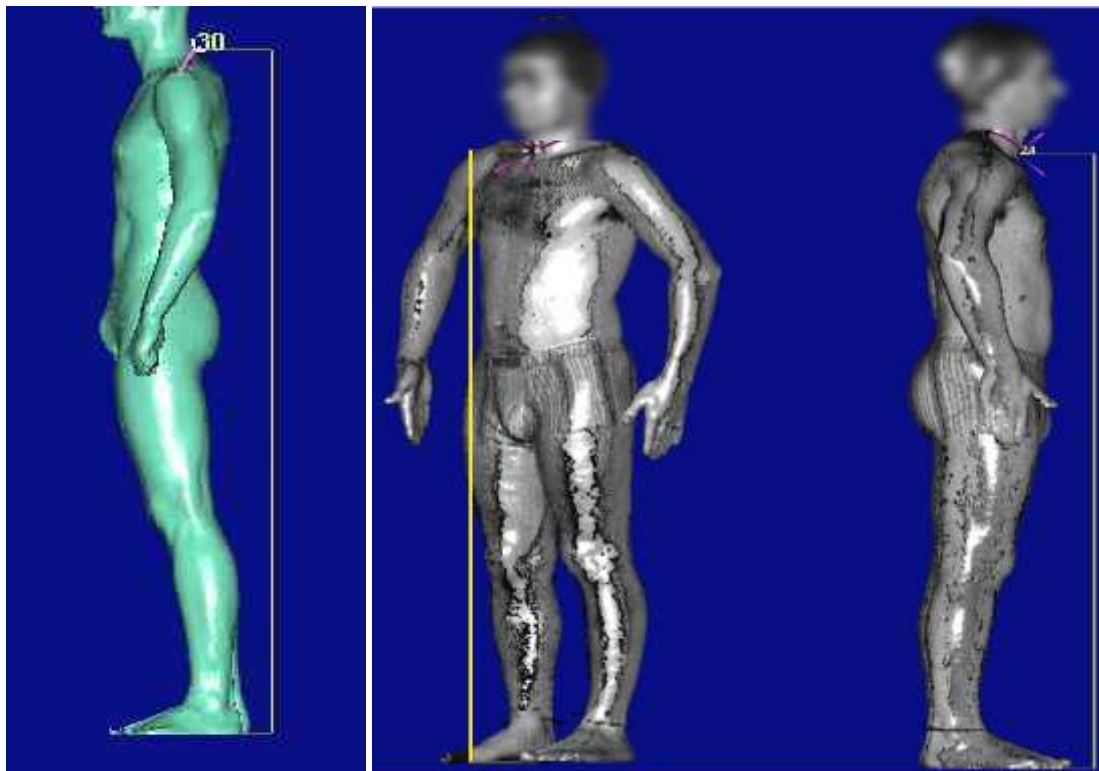
Scan position posture 2. Stand with feet shoulder width apart, trunk and head are erect with eyes looking forward. The upper arms are abducted away from the body with the forearms hanging vertically. All fingers are together and extended with the palm facing (medially) the thigh and the thumb facing forward.

Reference:

Human Solutions, 2015. Anthroscan user guide version 3. Human Solutions GmbH, Kaiserslautern, Germany.

Notes:

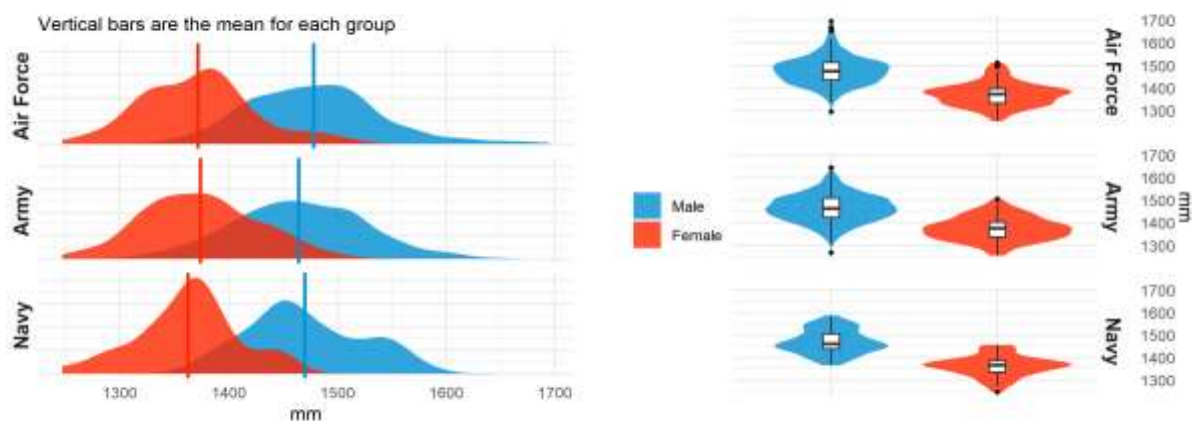
Ensure the participant stands straight (ideally in Frankfort position).



Suprasternale height summary statistics - Automatic measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
1469	1478	1465	1470	Mean	1372	1374	1363	1371
61	62	61	53	SD	52	52	47	51
1268	1294	1268	1366	Min	1254	1254	1247	1247
1695	1695	1644	1587	Max	1511	1506	1457	1511
1616	1661	1604	1577	P99	1500	1489	1454	1495
1602	1619	1596	1571	P98	1488	1479	1450	1478
1588	1616	1583	1560	P97	1478	1468	1448	1474
1567	1579	1562	1554	P95	1472	1464	1445	1461
1547	1560	1542	1551	P90	1435	1442	1424	1438
1528	1529	1522	1543	P85	1416	1433	1404	1428
1517	1522	1514	1526	P80	1405	1424	1390	1409
1511	1514	1509	1505	P75	1396	1402	1386	1400
1502	1507	1500	1497	P70	1392	1400	1381	1392
1493	1500	1488	1486	P65	1388	1390	1378	1388
1482	1495	1479	1478	P60	1384	1384	1373	1381
1475	1485	1473	1471	P55	1377	1377	1370	1377
1467	1475	1464	1460	P50	1373	1375	1366	1373
1459	1470	1456	1457	P45	1370	1364	1363	1366
1452	1460	1448	1450	P40	1356	1356	1359	1358
1445	1452	1441	1446	P35	1347	1351	1356	1351
1438	1446	1432	1442	P30	1344	1343	1341	1342
1427	1435	1424	1439	P25	1333	1337	1336	1336
1417	1423	1413	1422	P20	1326	1328	1330	1326
1409	1416	1403	1413	P15	1319	1319	1321	1319
1395	1410	1388	1405	P10	1316	1313	1299	1311
1373	1383	1366	1392	P5	1296	1295	1284	1291
1362	1375	1352	1383	P3	1281	1284	1276	1277
1352	1366	1342	1374	P2	1277	1269	1269	1270
1334	1353	1332	1373	P1	1269	1267	1258	1256

Distribution plots for each service and gender



T2 height - Post-processed measurement (mm)

Measuring instrument:

CySlice

Source:

AWAS, NZDFAS.

Definition:

Standing surface to T2 landmark. Identified as the Y coordinate (mm on the Y or vertical axis) of the T2 landmark.

Landmark required:

Second thoracic vertebra T2 landmark.

Posture required:

Scan position posture 1.

Procedure:

Use the second highest landmark on the upper back. See Section 6 of Human Solutions (2015). Measurements are reported in mm.

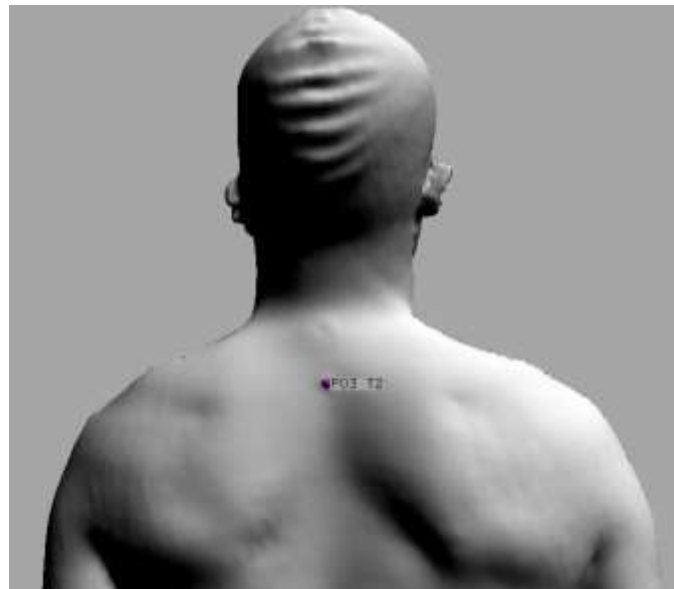
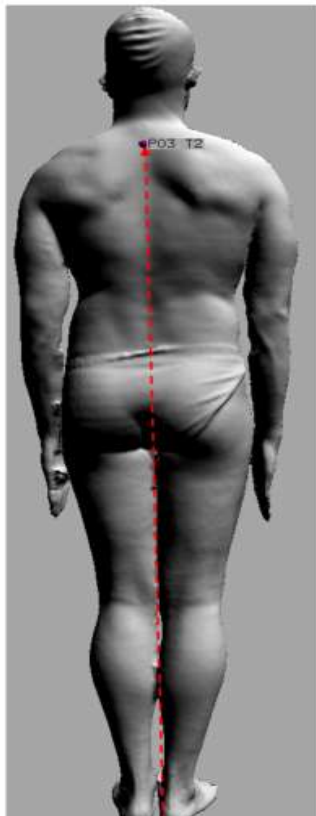
Reference:

Tomkinson, G. R., Daniell, N., Dale, M., & Bowler, T. (2012a). Australian Warfighter Anthropometry Survey (AWAS): Landmarking and measurement manual. Adelaide, Australia: Health and Use of Time Group, Sansom Institute for Health Research, University of South Australia.

Kolose, S., Hume, P.A., Tomkinson, G.R., Stewart, A., Stewart, T., Legg, S.J. (2021). Three-dimensional physique assessment in the military: New Zealand Defence Force Anthropometry Survey protocols and summary statistics., SPRINZ: Auckland, New Zealand.

Notes:

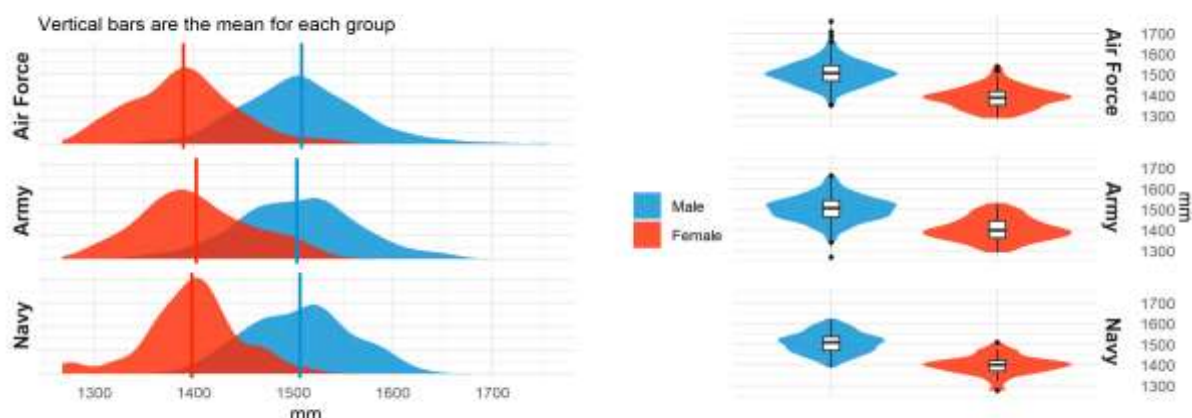
None.



T2 height summary statistics - Post-processed measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
1505	1509	1504	1507	Mean	1390	1403	1398	1397
60	62	61	51	SD	52	55	48	53
1268	1352	1268	1386	Min	1289	1292	1275	1275
1757	1757	1664	1624	Max	1539	1532	1509	1539
1652	1681	1645	1606	P99	1524	1511	1495	1517
1642	1652	1637	1600	P98	1508	1510	1480	1509
1623	1634	1624	1598	P97	1493	1509	1474	1507
1604	1613	1602	1588	P95	1474	1502	1474	1493
1580	1582	1580	1577	P90	1450	1480	1461	1472
1565	1567	1563	1561	P85	1439	1466	1438	1452
1553	1555	1553	1549	P80	1429	1451	1426	1439
1542	1543	1542	1536	P75	1417	1443	1421	1428
1534	1535	1534	1533	P70	1410	1428	1419	1419
1526	1525	1528	1526	P65	1406	1416	1411	1410
1520	1517	1521	1523	P60	1399	1408	1407	1406
1512	1510	1514	1518	P55	1396	1403	1404	1401
1506	1506	1506	1509	P50	1388	1399	1400	1396
1499	1502	1496	1504	P45	1382	1391	1400	1389
1490	1494	1488	1494	P40	1379	1385	1392	1383
1482	1485	1480	1480	P35	1377	1378	1385	1378
1474	1476	1471	1476	P30	1364	1372	1382	1372
1466	1469	1463	1470	P25	1354	1362	1371	1362
1457	1458	1455	1466	P20	1339	1359	1366	1357
1445	1446	1443	1446	P15	1333	1351	1358	1344
1431	1436	1427	1442	P10	1328	1335	1355	1330
1409	1415	1405	1422	P5	1304	1319	1322	1306
1397	1406	1388	1417	P3	1302	1305	1288	1302
1381	1389	1376	1416	P2	1301	1303	1276	1301
1361	1371	1358	1410	P1	1297	1301	1276	1289

Distribution plots for each service and gender



Tenth rib height - Post-processed measurement (mm)

Measuring instrument:

CySlice.

Source:

AWAS, NZDFAS.

Definition:

The standing surface to the 10th rib landmark vertical distance.

Landmark required:

Tenth rib landmark.

Posture required:

Scan position posture 1.

Procedure:

This measure is represented by the Y coordinate (mm on the Y or vertical axis) of the tenth rib landmark in posture 1. Measurements are reported in mm.

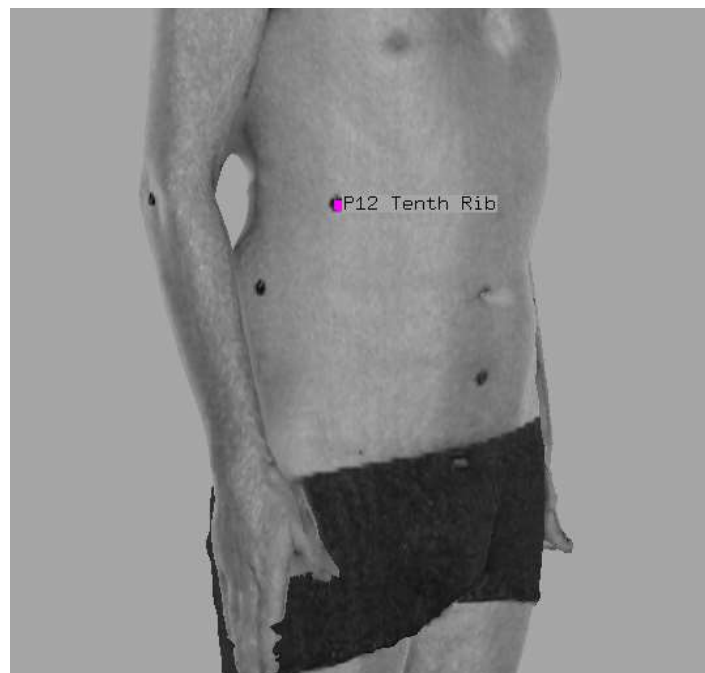
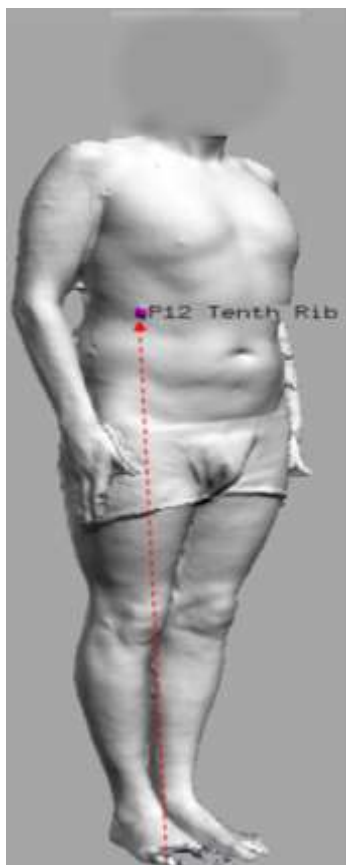
Reference:

Tomkinson, G. R., Daniell, N., Dale, M., & Bowler, T. (2012a). Australian Warfighter Anthropometry Survey (AWAS): Landmarking and measurement manual. Adelaide, Australia: Health and Use of Time Group, Sansom Institute for Health Research, University of South Australia.

Kolose, S., Hume, P.A., Tomkinson, G.R., Stewart, A., Stewart, T., Legg, S.J. (2021). Three-dimensional physique assessment in the military: New Zealand Defence Force Anthropometry Survey protocols and summary statistics., SPRINZ: Auckland, New Zealand.

Notes:

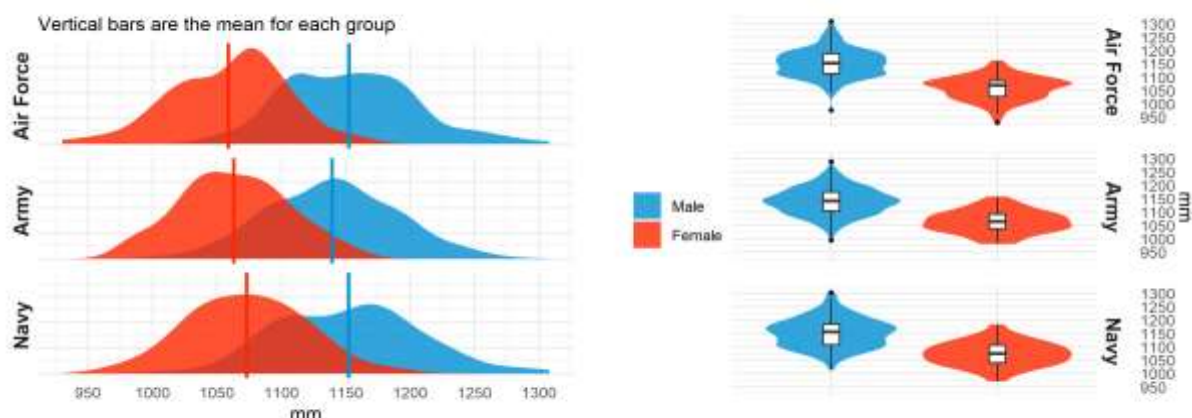
If the landmark is not present, then skip this measure. Ensure that the landmark is not confused with the Iliocristale landmark.



Tenth rib height summary statistics - Post-processed measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
1145	1153	1140	1152	Mean	1059	1063	1073	1064
52	52	51	55	SD	45	42	45	44
976	976	994	1012	Min	930	980	971	930
1308	1308	1289	1303	Max	1162	1157	1185	1185
1268	1284	1254	1286	P99	1153	1154	1173	1157
1255	1264	1244	1272	P98	1146	1153	1160	1153
1244	1259	1237	1253	P97	1138	1137	1151	1147
1233	1243	1221	1236	P95	1122	1132	1138	1134
1208	1212	1204	1224	P90	1109	1123	1131	1121
1197	1200	1194	1208	P85	1102	1106	1119	1107
1188	1194	1183	1193	P80	1095	1098	1109	1101
1180	1188	1174	1185	P75	1085	1092	1105	1093
1173	1181	1166	1178	P70	1081	1085	1099	1085
1163	1173	1158	1176	P65	1077	1082	1089	1082
1156	1165	1151	1168	P60	1074	1074	1084	1076
1151	1156	1146	1162	P55	1072	1066	1079	1071
1144	1152	1141	1155	P50	1070	1064	1074	1066
1138	1145	1134	1146	P45	1064	1056	1065	1062
1130	1137	1127	1138	P40	1051	1047	1063	1054
1123	1127	1121	1126	P35	1042	1043	1054	1044
1116	1117	1112	1117	P30	1035	1039	1045	1039
1107	1113	1103	1108	P25	1028	1037	1040	1035
1101	1108	1095	1103	P20	1023	1026	1036	1026
1092	1103	1086	1094	P15	1014	1023	1030	1022
1079	1097	1075	1089	P10	1002	1010	1022	1008
1063	1078	1056	1071	P5	990	993	1006	992
1050	1066	1045	1064	P3	966	984	998	984
1044	1051	1039	1059	P2	963	983	991	980
1027	1045	1026	1044	P1	953	981	981	964

Distribution plots for each service and gender



Thigh clearance - Post-processed measurement (mm)

Measuring instrument:

CySlice.

Source:

AWAS, NZDFAS.

Definition:

The vertical distance between a horizontal sitting surface and the Thigh Point Top landmark.

Landmark required:

Thigh Point Top and Seat Pan Height landmarks.

Posture required:

Scan position posture 3. Ensure that the participant is sitting with their knee bent at a 90° angle. This can be done by moving the body scanner seat up or down. This can also be facilitated by aligning the popliteal fossa (vertically) in line with Pternion (back of the foot).

Procedure:

This measure is represented by the Y coordinate (mm on the Y or vertical axis) of the Thigh Point Top (most superior point of the middle surface of the right thigh) landmark minus the Y coordinate of the Seat Pan Height landmark in posture 3. This calculation is performed in an Excel spreadsheet. Ensure that the seat height is positioned so that the legs are at a 90 degree angle and that the popliteal is not contacting the front edge of the seat. Measurements are reported in mm.

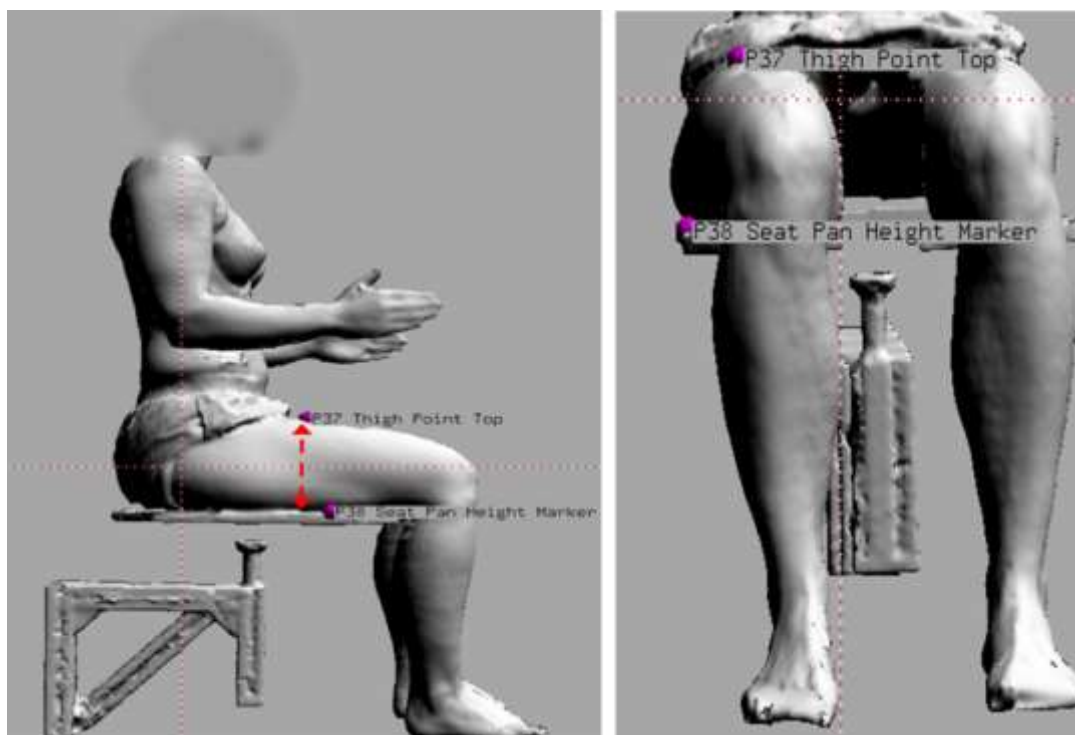
Reference:

Tomkinson, G. R., Daniell, N., Dale, M., & Bowler, T. (2012a). Australian Warfighter Anthropometry Survey (AWAS): Landmarking and measurement manual. Adelaide, Australia: Health and Use of Time Group, Sansom Institute for Health Research, University of South Australia.

Kolose, S., Hume, P.A., Tomkinson, G.R., Stewart, A., Stewart, T., Legg, S.J. (2021). Three-dimensional physique assessment in the military: New Zealand Defence Force Anthropometry Survey protocols and summary statistics., SPRINZ: Auckland, New Zealand.

Notes:

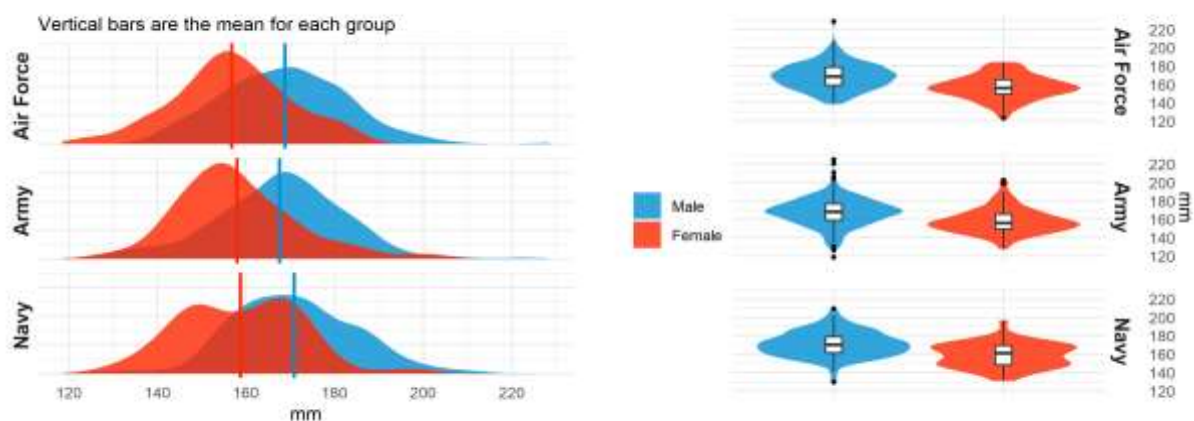
It is important that the participant is seated with their legs at right angles. Before the scan, raise or lower the seat until the bottom of the right thigh is horizontal and parallel to the floor. Next, ensure that the popliteal fold is in vertical line with the back of the heel. Ensure both feet are facing forward.



Thigh clearance summary statistics - Post-processed measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
168	169	168	171	Mean	157	158	159	158
15	14	15	14	SD	13	14	13	13
118	138	118	130	Min	123	127	131	123
228	228	225	209	Max	184	203	197	203
204	201	204	202	P99	183	199	190	196
198	198	196	199	P98	182	190	183	187
195	196	193	197	P97	182	188	179	183
191	191	189	193	P95	179	182	175	181
186	186	185	187	P90	173	176	172	174
183	182	182	186	P85	170	171	171	171
180	181	180	185	P80	167	168	170	169
178	179	177	179	P75	165	166	169	166
175	175	175	176	P70	162	163	169	164
174	173	173	175	P65	161	161	165	162
172	172	171	174	P60	160	159	163	160
170	171	170	172	P55	158	157	162	158
168	168	168	170	P50	156	156	161	156
167	168	167	168	P45	155	155	155	155
165	165	166	167	P40	154	153	154	154
163	163	163	165	P35	154	153	151	153
161	161	161	163	P30	151	151	150	150
159	159	159	161	P25	149	149	148	149
157	156	156	160	P20	146	147	147	147
154	154	153	157	P15	145	146	146	146
150	151	149	155	P10	139	143	143	142
144	146	141	153	P5	136	140	138	137
139	144	136	151	P3	133	137	137	136
136	143	133	148	P2	130	136	136	132
132	142	132	139	P1	126	131	133	128

Distribution plots for each service and gender



Thigh girth - Automatic measurement (mm)

Measuring instrument:

Anthroscan software.

Source:

Anthroscan.

Definition:

Maximum horizontal circumference measurement around the left leg beneath crotch. The circumference is measured parallel to the standing surface.

Landmark required:

None.

Posture required:

Scan position posture 2. Stand with feet shoulder width apart, trunk and head are erect with eyes looking forward. The upper arms are abducted away from the body with the forearms hanging vertically. All fingers are together and extended with the palm facing (medially) the thigh and the thumb facing forward.

Procedure:

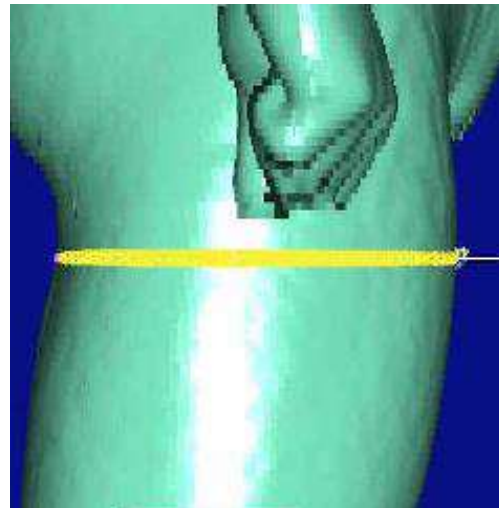
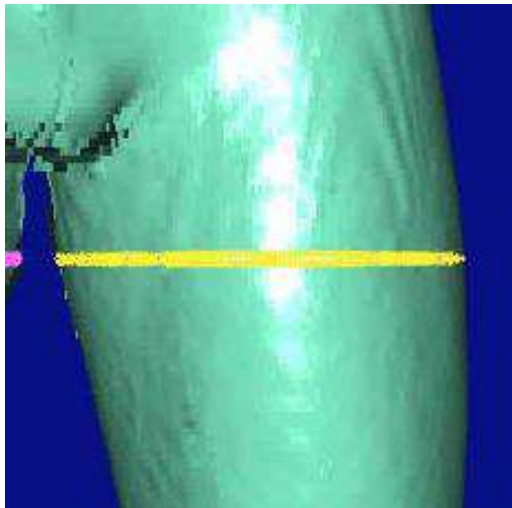
See Section 6 of Human Solutions (2015). Measurements are reported in mm.

Reference:

Human Solutions, 2015. Anthroscan user guide version 3. Human Solutions GmbH, Kaiserslautern, Germany.

Notes:

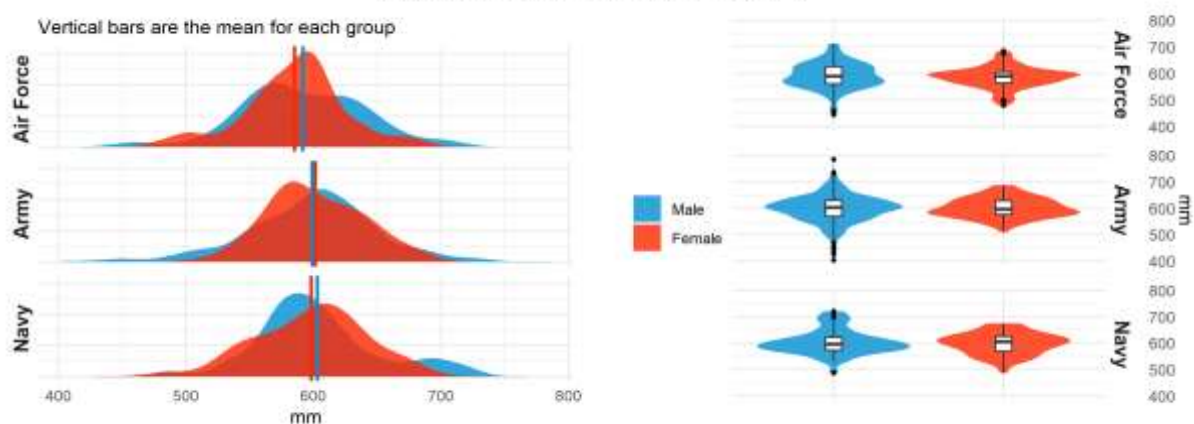
Check that the digital tape (yellow line below) is horizontal. Sometimes the software will draw the girth around both legs if they are too close together. Check that the tape follows the curvature of the thigh. Sometimes the tape can be 'bent' (picture far right) possibly due to drawing around an unknown object of the artefact. The tape should be below the gluteal fold when viewed from the side. If not, adjust accordingly.



Thigh girth summary statistics - Automatic measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
597	592	599	603	Mean	585	602	598	595
51	49	52	48	SD	40	37	42	40
403	444	403	486	Min	478	510	487	478
785	713	785	720	Max	685	687	675	687
717	707	722	720	P99	678	686	674	684
707	698	707	717	P98	672	680	673	675
696	691	693	709	P97	666	673	672	673
683	667	682	696	P95	649	665	669	665
658	652	657	680	P90	635	652	649	645
644	641	644	653	P85	617	642	636	637
635	635	636	632	P80	610	637	630	629
628	626	630	622	P75	605	628	625	621
622	619	624	616	P70	602	622	620	613
615	612	617	610	P65	599	614	617	609
610	605	611	603	P60	597	610	610	603
604	596	606	599	P55	593	603	607	599
599	589	602	596	P50	590	597	605	596
593	581	598	592	P45	584	592	597	590
587	575	592	589	P40	580	587	595	585
579	571	585	582	P35	575	583	586	582
572	567	578	577	P30	570	580	581	576
568	560	569	574	P25	563	576	568	571
560	554	561	570	P20	559	572	563	564
549	546	549	567	P15	551	565	549	558
540	539	538	550	P10	538	557	540	545
512	518	508	537	P5	506	544	537	533
499	504	496	528	P3	500	538	531	514
483	470	483	517	P2	496	533	522	505
456	459	450	488	P1	489	532	505	494

Distribution plots for each service and gender



Thumb tip reach - Physical measurement (mm)

Measuring instrument:

Full-length anthropometer, ideally made of solid steel. The anthropometer typically comes in 4 separate sections. When combined, one end of the rod contains a stationary or fixed arm or prong, the other prong is free to move up and down while at a right angle to the rod. There are typically two scales on the rod that run opposite to each other.

Source:

ANSUR.

Definition:

The horizontal distance from a back wall to the tip of the right thumb.

Landmark required:

None.

Posture required:

The participant stands erect against a wall with both the left and right shoulder blades touching the wall. Their right arm is raised as straight as possible to the front at a 90 degree angle to the body. Their arm must be in a relaxed and 'natural' position (i.e. do not ask them to fully reach forward or retract their shoulder/deltoid against the wall). They form a relaxed but extended 'pinch' position with the tips of their thumb gently touching the index finger with the palm facing down (index finger superior to thumb). The assessor stands to the right side of the participant in front of the elbow. This position enables the assessor to support the weight of the anthropometer evenly and be in a position to see both prongs (the fixed end and the measurement end).

Procedure:

Place the outer edge of the fixed prong against the wall. Extend the opposite prong 5 cm beyond the fingertip. Slowly push the prong towards the hand until it touches the tip of the thumb (excluding the fingernail). Check that both the arm and anthropometer are straight and horizontal then take the reading to the nearest 0.1 cm. Measurements are reported in mm.

Reference:

Gordon, C.C., Blackwell, C.L., Bradtmiller, B., Parham, J.L., Barrientos, P., Paquette, S.P., Corner, B., Carson, J.M., Venezia, J.C., Rockwell, B.M., Mucher, M., Kristensen, S., 2014. 2012 Anthropometric survey of U.S. army personnel: Methods and summary statistics., Natick Soldier Research, Development of Engineering Center, Yellow Springs, Ohio, U.S.

Notes:

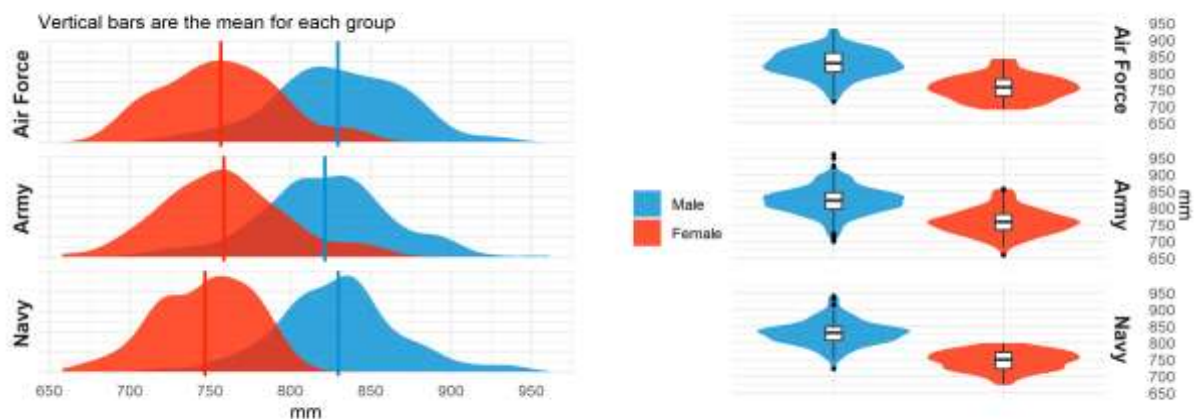
Lengthen or shorten the anthropometer (by adding or removing sections of the rod) to suit the arm length of the participant. Ensure the prong is based securely, and square to the wall for stability. Be aware of handling the prong tip to avoid injuring the participant. Ask the scribe to observe and confirm whether the participant's arm is straight and horizontal to the floor immediately before taking the reading. The anthropometer and arm centre should be at the same height. Ensure that the data spreadsheet has the appropriate correction factor for the length of the anthropometer.



Thumb tip reach summary statistics - Physical measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
825	830	822	830	Mean	757	759	747	756
41	41	41	38	SD	36	39	29	36
700	714	700	722	Min	690	658	674	658
961	934	961	940	Max	842	857	798	857
924	926	910	932	P99	841	854	795	847
905	910	904	918	P98	837	848	792	839
899	899	899	907	P97	833	839	790	836
891	888	892	890	P95	825	836	787	820
878	879	873	878	P90	796	803	781	798
866	870	861	864	P85	792	797	776	791
858	866	852	854	P80	787	787	774	782
850	860	846	849	P75	782	781	771	779
844	853	842	842	P70	776	778	768	772
839	846	837	840	P65	768	767	759	768
835	840	832	838	P60	765	763	754	763
830	835	826	836	P55	762	761	753	760
825	829	823	830	P50	757	758	750	755
820	822	817	827	P45	748	755	748	750
814	818	811	820	P40	746	750	745	747
810	814	806	814	P35	744	740	737	741
804	810	802	811	P30	736	737	724	736
800	803	798	807	P25	732	734	722	731
794	798	788	801	P20	723	727	721	723
786	791	782	798	P15	713	722	721	718
774	779	772	785	P10	711	712	714	711
755	761	752	773	P5	703	702	695	700
742	745	738	759	P3	697	694	693	694
731	742	727	753	P2	696	690	690	691
723	729	721	749	P1	694	683	682	685

Distribution plots for each service and gender



Tibiale laterale height - Post-processed measurement (mm)

Measuring instrument:

CySlice.

Source:

ISAK, NZDFAS.

Definition:

The vertical distance between a standing surface and the Tibiale laterale landmark.

Landmark required:

Tibiale laterale.

Posture required:

Scan position posture 1.

Procedure:

This measure is represented by the Y coordinate (mm on the Y or vertical axis) of the Tibiale laterale (most superior point on the lateral border of the head of the tibia) landmark in posture 1. Look for the stickered landmark (side of knee) and skip if absent. Measurements are reported in mm.

Reference:

Marfell-Jones, M.J., A.D. Stewart, and J.H. De Ridder, International Standards for Anthropometric Assessment. 2012.

Kolose, S., Hume, P.A., Tomkinson, G.R., Stewart, A., Stewart, T., Legg, S.J. (2021). Three-dimensional physique assessment in the military: New Zealand Defence Force Anthropometry Survey protocols and summary statistics., SPRINZ: Auckland, New Zealand.

Notes:

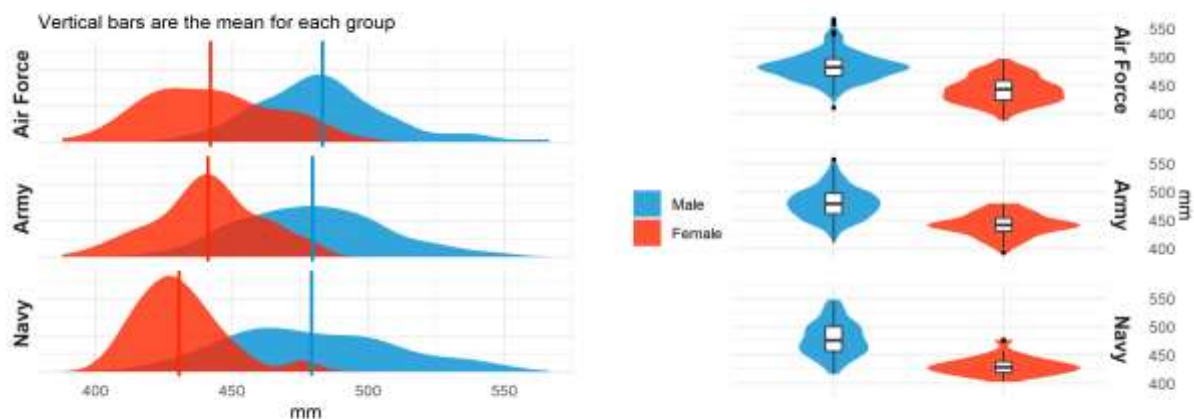
None.



Tibiale laterale height summary statistics - Post-processed measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
481	483	480	479	Mean	442	441	431	439
27	25	27	30	SD	24	19	16	21
409	410	409	416	Min	388	392	403	388
566	566	557	548	Max	497	479	477	497
549	556	549	547	P99	489	479	476	483
541	544	539	542	P98	485	479	476	479
538	541	533	540	P97	483	479	471	479
530	532	527	533	P95	480	475	457	477
515	514	514	525	P90	474	466	448	470
507	506	506	509	P85	472	463	445	463
501	500	502	506	P80	466	456	440	457
498	496	498	500	P75	458	454	438	451
493	492	493	497	P70	454	449	438	448
490	489	490	493	P65	449	447	434	446
486	486	486	486	P60	447	445	432	444
482	484	482	478	P55	444	443	430	441
480	482	479	476	P50	443	442	429	438
476	479	475	473	P45	436	439	427	436
473	477	471	467	P40	433	438	426	433
469	474	468	464	P35	430	436	424	431
465	471	464	460	P30	428	433	421	428
462	467	461	457	P25	424	431	419	425
457	462	456	453	P20	420	427	418	421
452	459	451	449	P15	419	421	416	418
447	455	446	443	P10	414	416	413	414
439	446	439	435	P5	407	409	410	409
435	442	434	431	P3	404	404	409	404
431	436	429	425	P2	404	401	408	403
424	433	424	423	P1	399	400	405	400

Distribution plots for each service and gender



Trochanterion height - Post-processed measurement (mm)

Measuring instrument:

CySlice.

Source:

ANSUR, AWAS, NZDFAS.

Definition:

The vertical distance between a standing surface and the Trochanterion landmark.

Landmark required:

Trochanterion.

Posture required:

Scan position posture 2.

Procedure:

This measure is represented by the Y coordinate (mm on the Y or vertical axis) of the Trochanterion (most superior point on the greater trochanter of the femur) landmark in posture 1. Look for the stickered landmark (right hip close to pant line) and skip if absent. Measurements are reported in mm.

Reference:

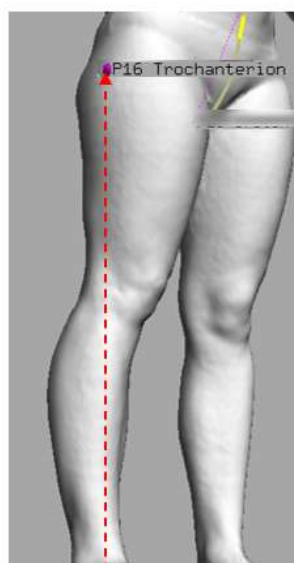
Gordon, C.C., Blackwell, C.L., Bradtmiller, B., Parham, J.L., Barrientos, P., Paquette, S.P., Corner, B., Carson, J.M., Venezia, J.C., Rockwell, B.M., Mucher, M., Kristensen, S., 2014. 2012 Anthropometric survey of U.S. army personnel: Methods and summary statistics., Natick Soldier Research, Development of Engineering Center, Yellow Springs, Ohio, U.S.

Tomkinson, G. R., Daniell, N., Dale, M., & Bowler, T. (2012a). Australian Warfighter Anthropometry Survey (AWAS): Landmarking and measurement manual. Adelaide, Australia: Health and Use of Time Group, Sansom Institute for Health Research, University of South Australia.

Kolose, S., Hume, P.A., Tomkinson, G.R., Stewart, A., Stewart, T., Legg, S.J. (2021). Three-dimensional physique assessment in the military: New Zealand Defence Force Anthropometry Survey protocols and summary statistics., SPRINZ: Auckland, New Zealand.

Notes:

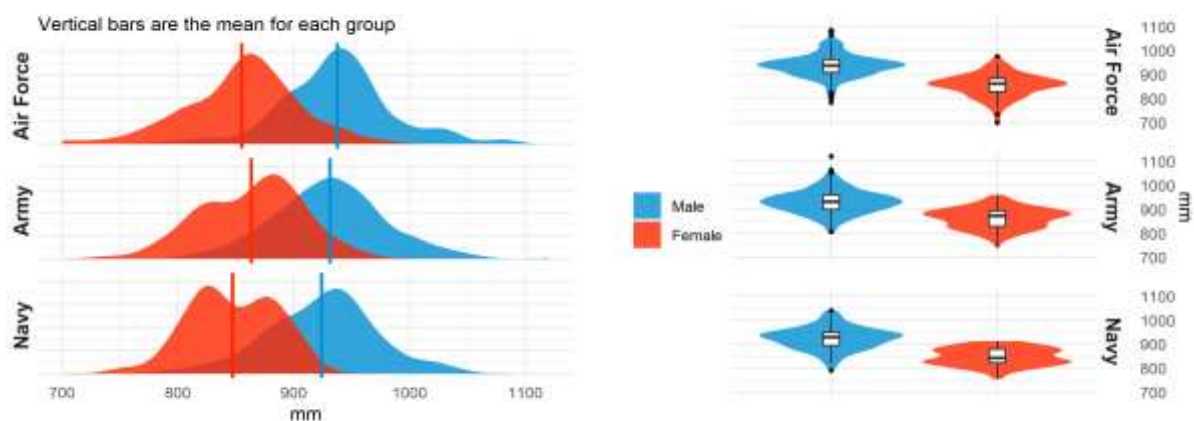
This requires the participant to be scanned with feet together and cannot be measured when a participant is scanned in a wide stance.



Trochanterion height summary statistics - Post-processed measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
932	938	931	924	Mean	855	863	847	857
48	49	48	47	SD	49	43	37	44
783	783	805	791	Min	700	740	755	700
1121	1084	1121	1039	Max	975	959	912	975
1049	1078	1045	1026	P99	952	954	909	953
1038	1039	1034	1021	P98	943	940	907	942
1030	1037	1027	1018	P97	942	937	905	936
1016	1029	1013	1000	P95	933	932	903	931
993	995	993	977	P90	908	915	897	907
976	981	977	972	P85	899	905	881	900
966	966	968	956	P80	892	899	879	894
960	962	960	950	P75	884	893	878	886
954	957	954	947	P70	877	887	876	881
948	951	948	944	P65	871	883	870	878
942	946	941	937	P60	865	879	862	874
937	941	935	933	P55	863	876	855	866
932	938	931	929	P50	861	873	842	862
928	934	925	921	P45	857	862	835	857
922	930	920	918	P40	851	856	829	849
916	923	913	910	P35	846	846	829	841
909	920	908	901	P30	841	835	827	831
901	908	900	894	P25	828	830	822	827
894	900	892	886	P20	812	824	817	820
883	894	882	876	P15	808	817	812	811
873	883	870	869	P10	799	809	800	801
852	864	852	843	P5	775	791	794	782
840	841	842	832	P3	760	781	792	776
830	827	831	820	P2	745	779	785	761
816	814	819	816	P1	725	773	770	742

Distribution plots for each service and gender



Vertical trunk circumference - Post-processed measurement (mm)

Measuring instrument:

CySlice

Source:

AWAS.

Definition:

The circumference of the trunk on a plane passing through the Crotch landmark and over Bust point (females)/Thelion (males), Midshoulder, and Buttock Point, Posterior landmarks.

Landmark required:

Crotch, Thelion (males)/Bust point (females), Midshoulder and Buttock Point posterior landmarks.

Posture required:

Scan position posture 2. Stand with feet shoulder width apart, trunk and head are erect with eyes looking forward. The upper arms are abducted away from the body with the forearms hanging vertically. All fingers are together and extended with the palm facing (medially) the thigh and the thumb facing forward.

Procedure:

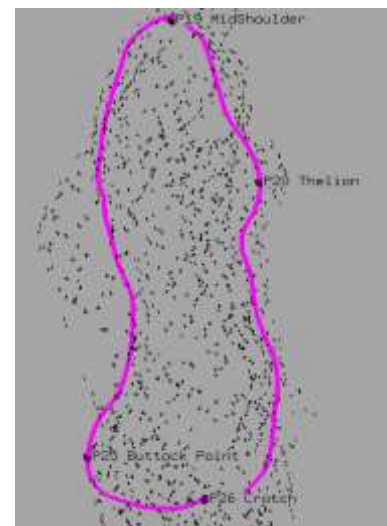
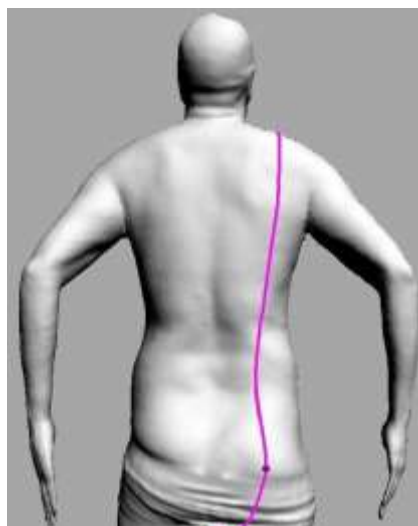
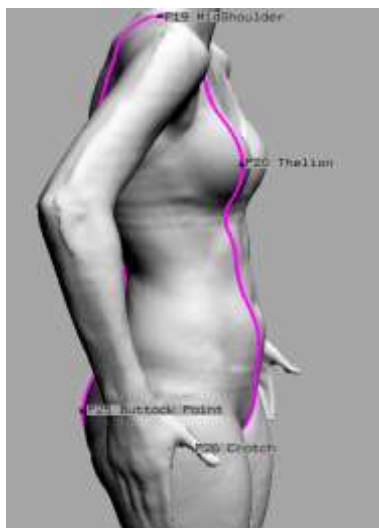
The Midshoulder is the top of the right shoulder midway between Trapezius Point and Acromiale right landmarks. Look for the stickered landmark (midpoint on right shoulder) and if the landmark is missing place a landmark on the midway point between the neck/trap crease and acromion. The Buttock Point is the most posterior point of the right buttock. View from the side. Place the point marker on the most posterior-protruding region of the right buttock. Add X-loop around the point to refine the point. Skip if the participant is wearing baggy shorts. If there is no clear protrusion or sign of curvature change to rear view (view from the back). Place a point marker in the centre of the right buttock then use a X-loop to refine the point. As per AWAS Section 7.2.13 of the Procedures Manual (Tomkinson et al., 2012). Measurements are reported in mm.

Reference:

Tomkinson, G. R., Daniell, N., Dale, M., & Bowler, T. (2012b). Australian Warfighters Anthropometry Survey (AWAS). Procedures Manual. Adelaide, Australia.: Health and Use of Time Group, Sansom Institute for Health Research, University of South Australia.

Notes:

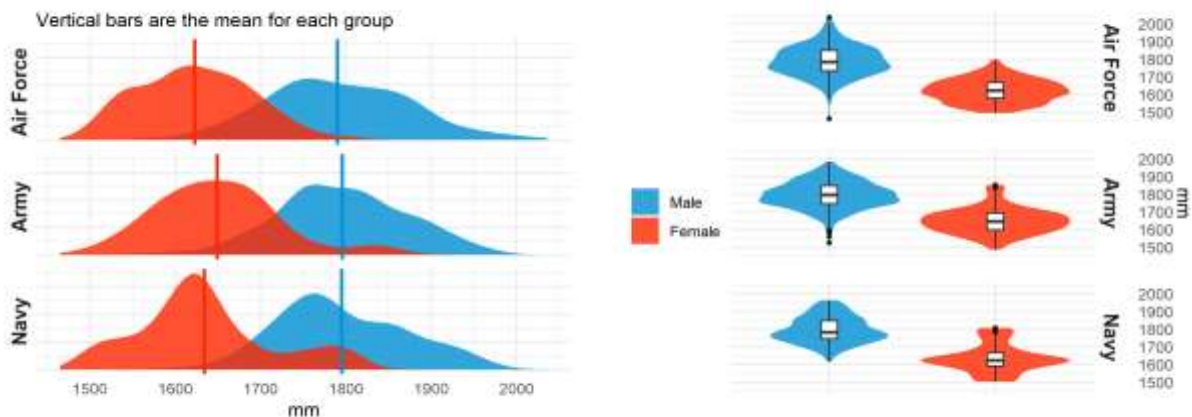
If crotch cannot be identified, then this measure will not be possible.



Vertical trunk circumference summary statistics - Post-processed measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
1794	1790	1796	1795	Mean	1623	1649	1634	1637
79	86	77	74	SD	65	73	79	72
1465	1465	1524	1616	Min	1497	1487	1503	1487
2036	2036	1984	1963	Max	1798	1852	1806	1852
1968	1999	1967	1952	P99	1769	1851	1803	1834
1950	1967	1944	1940	P98	1747	1836	1799	1811
1940	1957	1937	1934	P97	1734	1825	1797	1798
1929	1934	1926	1930	P95	1730	1778	1795	1765
1898	1893	1899	1908	P90	1702	1726	1758	1728
1879	1878	1881	1873	P85	1692	1710	1724	1703
1862	1861	1864	1860	P80	1678	1700	1686	1693
1849	1851	1848	1848	P75	1669	1692	1665	1681
1836	1838	1836	1840	P70	1661	1681	1644	1671
1825	1826	1824	1827	P65	1649	1673	1639	1661
1813	1813	1814	1801	P60	1641	1665	1636	1647
1802	1798	1804	1792	P55	1624	1658	1631	1640
1790	1785	1794	1780	P50	1623	1644	1623	1631
1779	1774	1783	1771	P45	1612	1636	1620	1623
1769	1764	1772	1769	P40	1604	1627	1618	1618
1759	1751	1763	1759	P35	1596	1618	1606	1610
1752	1745	1755	1757	P30	1588	1612	1599	1598
1742	1734	1746	1744	P25	1581	1598	1590	1589
1732	1726	1735	1732	P20	1552	1584	1579	1580
1718	1708	1721	1720	P15	1549	1579	1553	1561
1694	1687	1699	1713	P10	1536	1564	1543	1544
1672	1657	1673	1689	P5	1530	1539	1513	1530
1651	1637	1656	1675	P3	1522	1532	1506	1518
1632	1629	1640	1671	P2	1520	1526	1503	1513
1605	1586	1604	1659	P1	1512	1516	1503	1503

Distribution plots for each service and gender



Waist breadth - Post-processed measurement (mm)

Measuring instrument:

CySlice

Source:

ANSUR, NZDFAS.

Definition:

The maximum horizontal breadth of the waist in a transverse plane at the level of Omphalion.

Landmark required:

None.

Posture required:

Scan position posture 2. Stand with feet shoulder width apart, trunk and head are erect with eyes looking forward. The upper arms are abducted away from the body with the forearms hanging vertically. All fingers are together and extended with the palm facing (medially) the thigh and the thumb facing forward.

Procedure:

Using the caliper tool highlight across the omphalion as close to the omphalion as possible. Best viewed from the front. Use the Y axis caliper (to create a 'digital' circumference) to identify and record the measurement. Beware of hand webbing. If present, skip both breadth markers. Use only if the Omphalion is visible. Omphalion is not a landmark in this posture as it is located visually. Measurements are reported in mm.

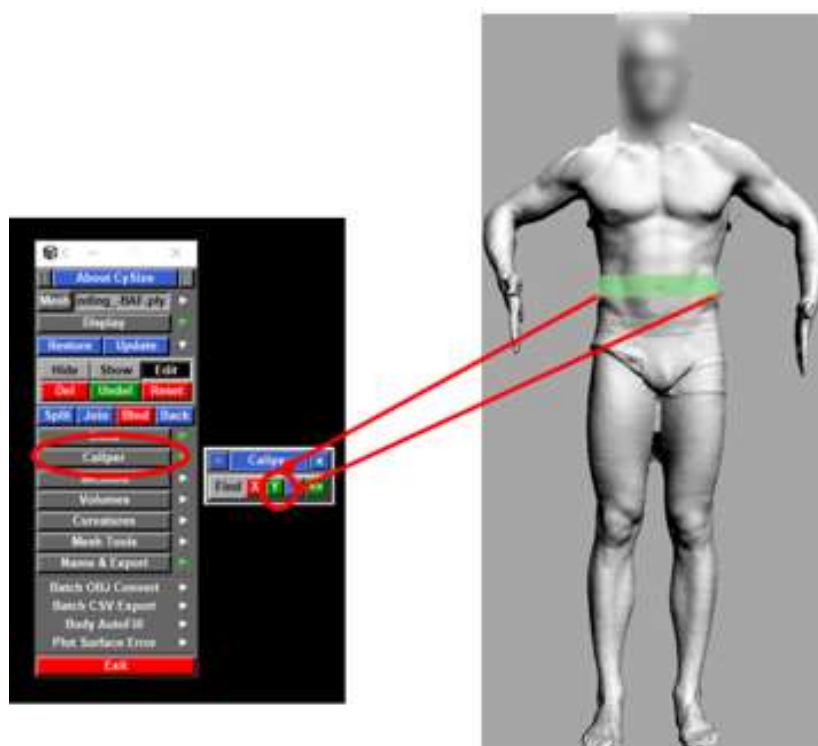
Reference:

Gordon, C.C., Blackwell, C.L., Bradtmiller, B., Parham, J.L., Barrientos, P., Paquette, S.P., Corner, B., Carson, J.M., Venezia, J.C., Rockwell, B.M., Mucher, M., Kristensen, S., 2014. 2012 Anthropometric survey of U.S. army personnel: Methods and summary statistics., Natick Soldier Research, Development of Engineering Center, Yellow Springs, Ohio, U.S.

Kolose, S., Hume, P.A., Tomkinson, G.R., Stewart, A., Stewart, T., Legg, S.J. (2021). Three-dimensional physique assessment in the military: New Zealand Defence Force Anthropometry Survey protocols and summary statistics., SPRINZ: Auckland, New Zealand.

Notes:

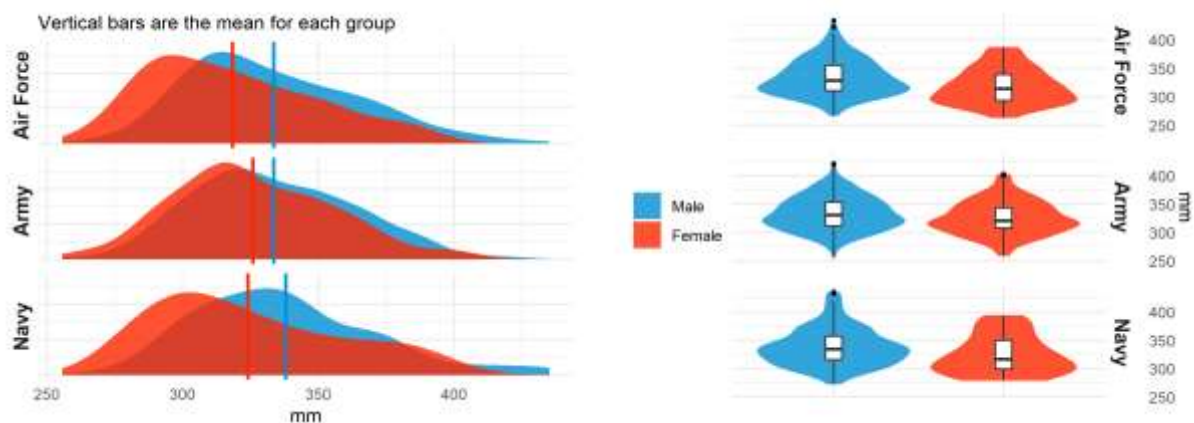
None.



Waist breadth summary statistics - Post-processed measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
334	334	334	338	Mean	318	326	324	323
31	32	30	34	SD	31	30	34	31
256	266	256	272	Min	263	259	279	259
435	434	422	435	Max	387	403	394	403
414	413	405	432	P99	387	400	392	394
404	405	394	423	P98	386	395	390	389
394	401	391	416	P97	384	384	389	387
386	392	385	402	P95	378	375	388	380
376	378	373	380	P90	357	363	378	367
368	369	366	371	P85	354	359	366	357
361	361	361	369	P80	350	352	357	353
355	355	354	357	P75	339	344	350	344
350	348	350	348	P70	333	342	338	339
344	343	345	343	P65	328	339	330	332
340	338	340	342	P60	322	330	326	327
335	333	335	338	P55	316	324	323	322
331	328	331	334	P50	314	321	316	318
326	324	326	332	P45	311	319	311	315
322	320	323	324	P40	305	317	307	311
319	317	320	322	P35	299	311	301	308
316	313	316	318	P30	296	310	300	301
311	310	311	316	P25	293	308	300	299
307	306	307	308	P20	289	300	298	295
303	303	303	304	P15	287	297	288	291
297	298	297	300	P10	285	291	284	286
291	291	290	295	P5	280	285	281	281
285	288	284	291	P3	276	280	279	279
282	283	282	288	P2	273	271	279	272
273	274	274	283	P1	269	267	279	268

Distribution plots for each service and gender



Waist circumference preferred - Post-processed measurement (mm)

Measuring instrument:

CySlice

Source:

AWAS.

Definition:

The horizontal circumference of the torso at the height of the Waist Preferred Posterior landmark.

Landmark required:

Waist circumference posterior preferred.

Posture required:

Scan position posture 1.

Procedure:

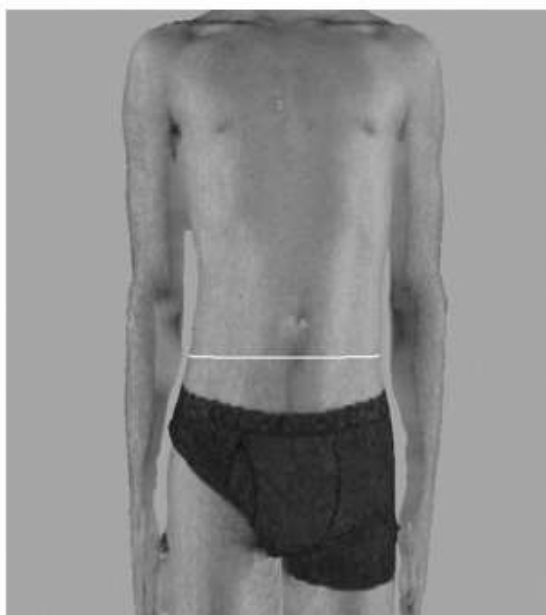
Use CySlice to create an X section loop (a 'digital' circumference) around the Waist Preferred Posterior landmark (preferred waist location for belts/trousers on posterior). Look for the stickered landmark (lower back) and skip if absent as there is no way to determine this feature. Measurements are reported in mm.

Reference:

Tomkinson, G. R., Daniell, N., Dale, M., & Bowler, T. (2012b). Australian Warfighters Anthropometry Survey (AWAS). Procedures Manual. Adelaide, Australia.: Health and Use of Time Group, Sansom Institute for Health Research, University of South Australia.

Notes:

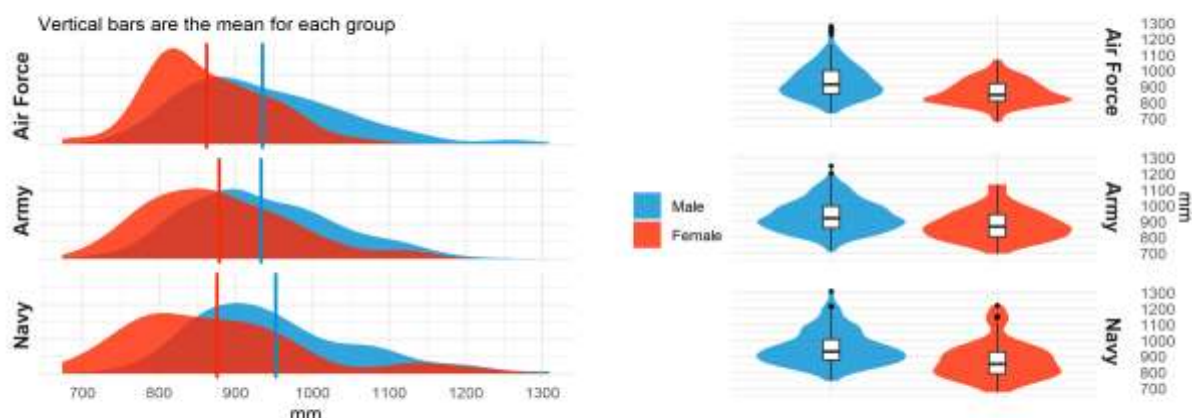
Use the Crosshair tool to align the participant in the correct X, Y, and Z plane. This measurement will be repeated if the participant is not standing vertical, due to postural sway.



Waist circumference preferred summary statistics - Post-processed measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
935	935	933	952	Mean	862	878	875	872
102	106	98	109	SD	76	95	120	95
709	732	709	746	Min	677	696	673	673
1309	1280	1248	1309	Max	1070	1133	1219	1219
1211	1262	1169	1227	P99	1045	1131	1191	1140
1164	1205	1149	1211	P98	1021	1123	1162	1129
1144	1150	1127	1195	P97	1002	1109	1149	1108
1121	1131	1113	1160	P95	987	1039	1138	1033
1077	1076	1072	1095	P90	965	1002	992	985
1044	1044	1040	1071	P85	949	969	970	965
1019	1025	1015	1049	P80	927	953	956	947
998	998	996	1004	P75	917	942	927	928
982	985	980	985	P70	892	923	921	912
966	963	967	972	P65	886	904	905	897
951	949	951	954	P60	877	892	894	885
934	933	933	940	P55	855	873	881	873
920	912	919	928	P50	846	867	850	855
908	906	908	922	P45	833	855	843	847
897	892	897	912	P40	828	849	826	834
887	882	888	895	P35	822	835	811	823
874	868	874	880	P30	815	817	795	814
860	856	860	875	P25	808	804	790	804
847	842	846	863	P20	803	794	777	793
834	830	831	846	P15	793	787	766	785
816	816	813	841	P10	786	770	759	771
794	800	792	819	P5	768	745	720	747
775	773	773	803	P3	752	732	717	725
767	768	765	789	P2	725	730	710	716
747	762	741	780	P1	698	721	691	698

Distribution plots for each service and gender



Waist depth standing - Post-processed measurement (mm)

Measuring instrument:

CySlice

Source:

NZDFAS.

Definition:

The maximum depth of the waist area located between the iliocrestale and tenth rib. Measurement taken at the point of 'end-tidal' expiration.

Landmark required:

None.

Posture required:

Scan position posture 1.

Procedure:

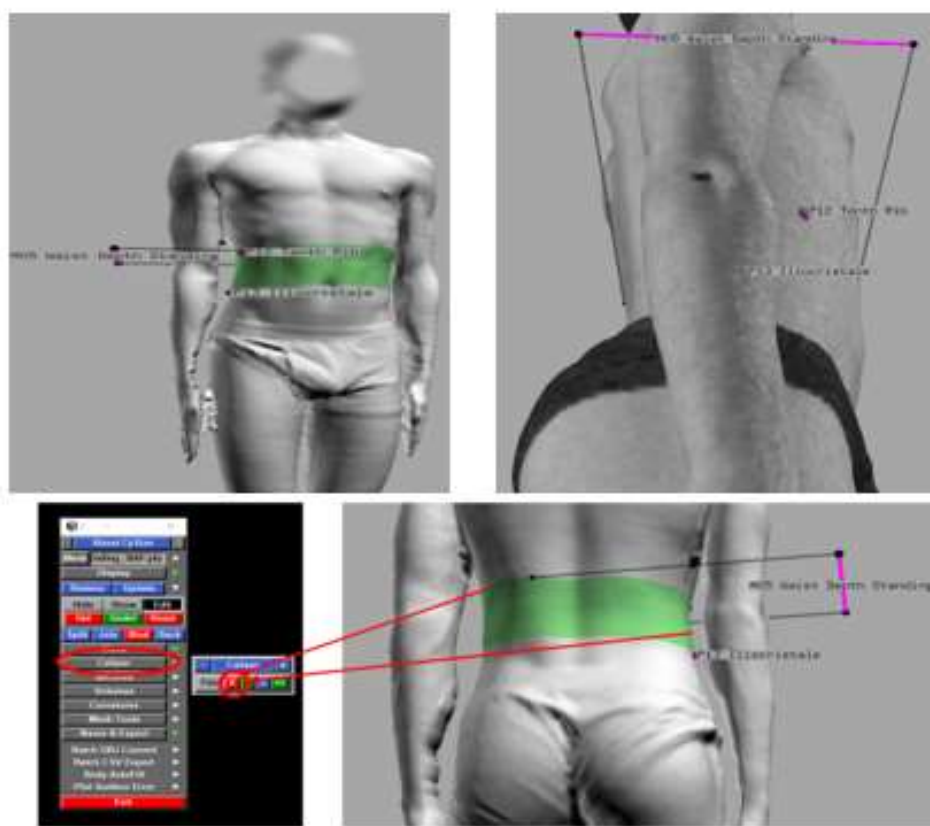
Use the CySlice caliper tool to highlight waist area between iliocrestale and the tenth rib. Select the X function (to create a coronal plan) to record the depth measure. Measurements are reported in mm.

Reference:

Kolose, S., Hume, P.A., Tomkinson, G.R., Stewart, A., Stewart, T., Legg, S.J. (2021). Three-dimensional physique assessment in the military: New Zealand Defence Force Anthropometry Survey protocols and summary statistics., SPRINZ: Auckland, New Zealand.

Notes:

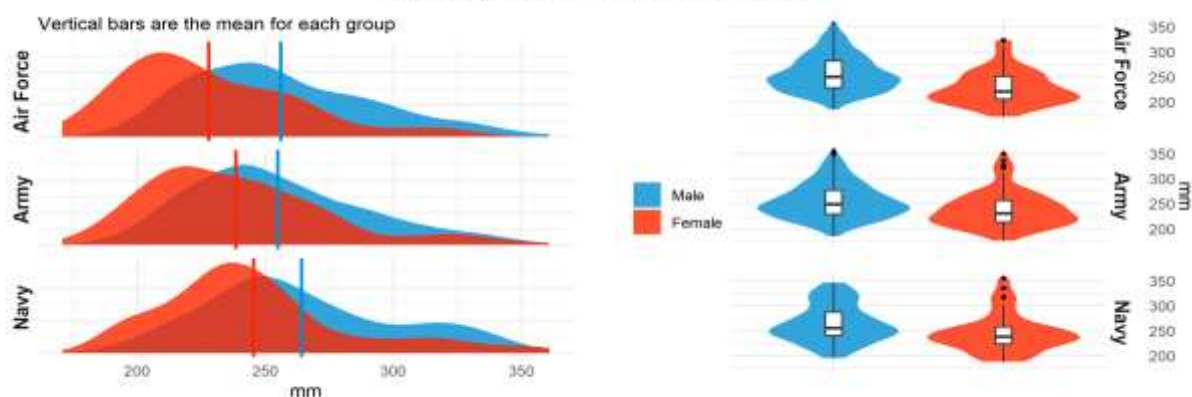
If the tenth rib and/or iliocrestale landmark is missing, the measure can be determined by identifying the distance between the Omphalion and Omphalion projected to the back.



Waist depth standing summary statistics - Post-processed measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
256	256	255	264	Mean	228	239	246	236
35	36	34	37	SD	34	35	38	36
184	184	185	195	Min	171	176	188	171
361	361	356	346	Max	323	350	355	355
345	345	342	344	P99	323	337	346	336
336	332	335	338	P98	318	327	338	326
331	330	331	334	P97	311	324	330	323
326	326	320	330	P95	294	315	317	315
307	304	305	321	P90	265	278	299	278
294	295	291	313	P85	261	272	277	268
286	285	285	301	P80	258	265	261	261
278	282	277	287	P75	251	256	258	255
272	273	269	279	P70	241	250	254	250
265	264	264	273	P65	236	247	251	246
260	260	259	266	P60	230	242	247	240
255	253	254	261	P55	222	240	239	236
250	250	249	256	P50	221	230	238	230
247	247	245	252	P45	217	227	236	226
242	242	242	247	P40	211	225	235	222
239	238	239	247	P35	210	219	232	219
236	235	234	243	P30	207	215	226	214
230	228	229	240	P25	205	214	224	210
225	223	225	237	P20	201	211	218	206
221	220	221	227	P15	196	206	211	201
214	216	214	220	P10	191	198	201	196
209	209	208	212	P5	188	196	196	190
203	205	202	207	P3	184	189	194	188
200	201	198	203	P2	179	187	192	185
195	196	194	199	P1	175	184	190	177

Distribution plots for each service and gender



Waist girth - Automatic measurement (mm)

Measuring instrument:

Anthroscan software.

Source:

Human Solutions.

Definition:

The circumference of the waist is measured at the height of the natural waist (maximum indentation when viewed from the front). The circumference is measured parallel to the standing surface.

Landmark required:

None.

Posture required:

Scan position posture 2. Stand with feet shoulder width apart, trunk and head are erect with eyes looking forward. The upper arms are abducted away from the body with the forearms hanging vertically. All fingers are together and extended with the palm facing (medially) the thigh and the thumb facing forward.

Procedure:

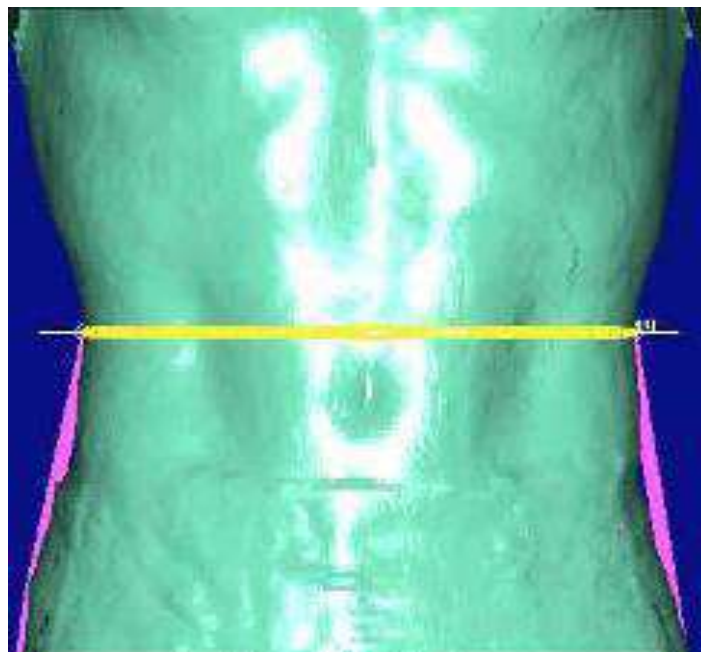
See Section 6 of Human Solutions (2015). Measurements are reported in mm.

Reference:

Human Solutions, 2015. Anthroscan user guide version 3. Human Solutions GmbH, Kaiserslautern, Germany.

Notes:

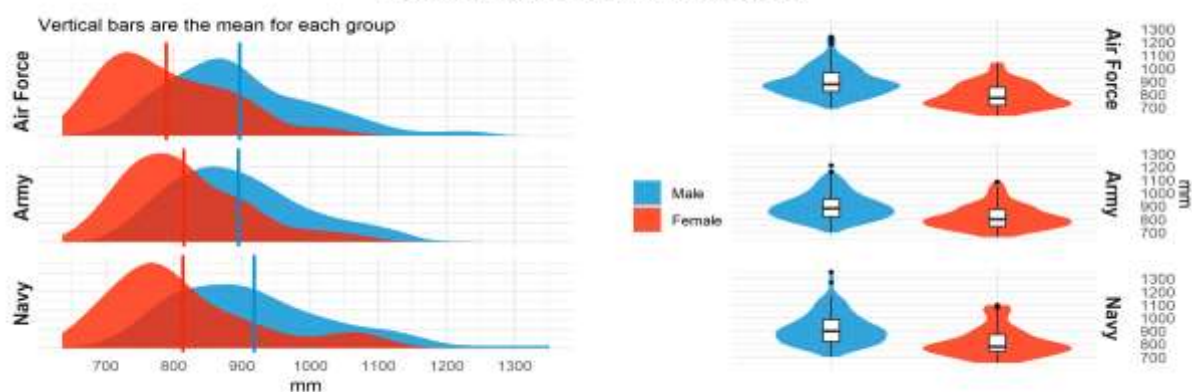
Visually check that the digital tape (yellow line below) is horizontal. If there is no natural indentation (most narrow point of the waist) then consider A) removing this measurement or B) drag the yellow line so that it is positioned above the iliac crest and below the 10th rib (or bottom of the rib cage if it is visible).



Waist girth summary statistics - Automatic measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
898	897	895	917	Mean	789	815	813	806
105	108	100	122	SD	91	90	110	95
689	689	696	701	Min	636	662	656	636
1351	1241	1210	1351	Max	1044	1086	1096	1096
1168	1233	1134	1281	P99	1021	1054	1088	1073
1134	1176	1123	1193	P98	1006	1048	1079	1050
1122	1134	1111	1150	P97	990	1013	1069	1046
1093	1092	1086	1127	P95	932	1002	1050	1003
1046	1042	1042	1092	P90	910	921	973	927
1013	1012	1004	1035	P85	888	908	917	904
982	980	977	1015	P80	871	885	889	882
959	966	953	986	P75	854	872	872	869
940	931	938	960	P70	837	843	829	839
921	911	921	936	P65	816	825	818	823
907	902	907	916	P60	799	820	803	814
896	890	896	908	P55	786	812	794	799
884	876	882	898	P50	772	799	778	792
870	870	869	889	P45	757	793	776	777
858	858	855	869	P40	744	778	768	767
846	846	844	852	P35	738	768	758	757
836	836	835	839	P30	731	760	752	744
820	822	820	819	P25	719	745	744	738
805	804	805	810	P20	708	738	730	727
790	787	792	796	P15	699	733	712	710
775	771	775	786	P10	690	715	701	701
754	751	752	770	P5	671	702	685	682
742	742	742	763	P3	661	680	676	672
729	736	729	761	P2	661	675	670	662
718	713	721	747	P1	654	671	663	661

Distribution plots for each service and gender



Waist height preferred - Post-processed measurement (mm)

Measuring instrument:

CySlice.

Source:

AWAS.

Definition:

The vertical distance between the standing surface and the digitally extracted Waist Preferred, Anterior landmark.

Landmark required:

Waist height preferred anterior landmark.

Posture required:

Scan position posture 1.

Procedure:

As measured in AWAS Section 7.1.19 of the Procedures Manual (Tomkinson et al., 2012). Measurements are reported in mm.

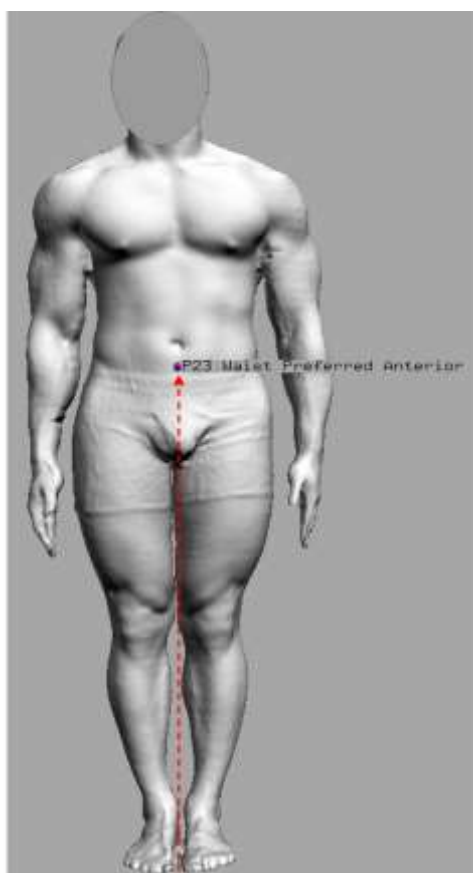
Reference:

Tomkinson, G. R., Daniell, N., Dale, M., & Bowler, T. (2012a). Australian Warfighter Anthropometry Survey (AWAS): Landmarking and measurement manual. Adelaide, Australia: Health and Use of Time Group, Sansom Institute for Health Research, University of South Australia.

Tomkinson, G. R., Daniell, N., Dale, M., & Bowler, T. (2012b). Australian Warfighters Anthropometry Survey (AWAS). Procedures Manual. Adelaide, Australia.: Health and Use of Time Group, Sansom Institute for Health Research, University of South Australia.

Notes:

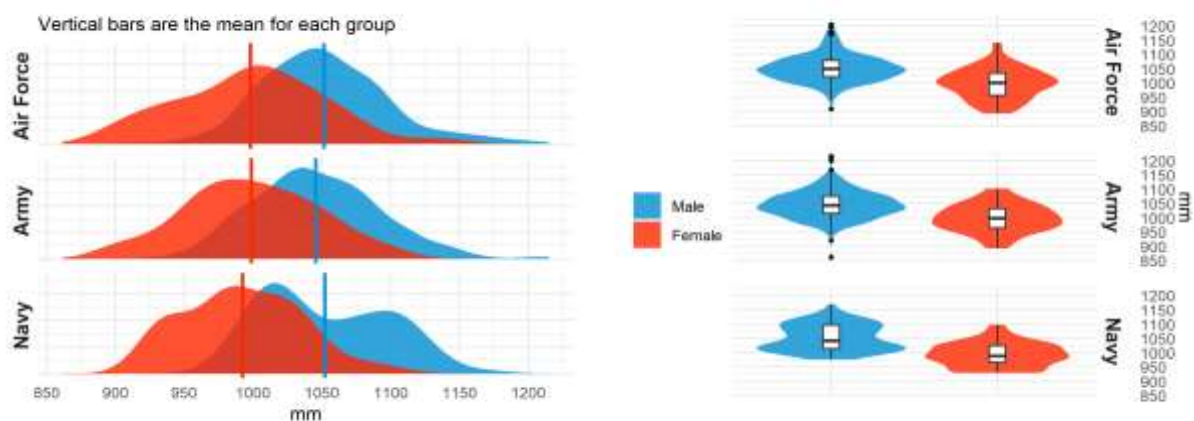
None.



Waist height preferred summary statistics - Post-processed measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
1048	1052	1046	1052	Mean	998	999	992	997
47	47	47	46	SD	54	48	42	49
861	909	861	975	Min	893	892	929	892
1215	1204	1215	1170	Max	1141	1103	1098	1141
1170	1178	1155	1143	P99	1133	1101	1089	1103
1152	1167	1144	1135	P98	1113	1099	1081	1098
1141	1158	1138	1133	P97	1089	1089	1072	1089
1129	1139	1124	1126	P95	1078	1077	1056	1077
1109	1108	1106	1112	P90	1061	1060	1037	1058
1096	1094	1091	1107	P85	1052	1051	1032	1050
1086	1086	1082	1101	P80	1040	1041	1029	1037
1079	1080	1076	1097	P75	1034	1032	1024	1030
1072	1073	1068	1081	P70	1025	1027	1019	1024
1063	1063	1062	1075	P65	1017	1019	1012	1016
1058	1058	1057	1067	P60	1009	1010	1000	1008
1051	1053	1049	1056	P55	1007	1002	996	1002
1045	1049	1043	1042	P50	1000	999	988	997
1038	1043	1037	1034	P45	994	992	983	991
1034	1037	1033	1029	P40	992	983	983	984
1029	1033	1026	1021	P35	983	976	978	979
1021	1027	1020	1018	P30	971	972	972	972
1015	1021	1015	1013	P25	957	965	965	964
1008	1013	1005	1006	P20	949	961	947	953
1001	1007	997	1005	P15	940	952	938	942
991	998	987	1001	P10	920	938	934	932
978	988	976	990	P5	912	918	930	918
972	972	968	985	P3	906	905	930	907
963	964	959	982	P2	899	901	930	902
954	956	951	976	P1	894	898	930	895

Distribution plots for each service and gender



Weight body mass - Automatic measurement (kg)

Measuring instrument:

Anthroscan software.

Source:

Human Solutions.

Definition:

Body mass as assessed by standing weight in kilograms acquired using load cell integrated into the scanner platform.

Landmark required:

None.

Posture required:

Scan position posture 2. Stand with feet shoulder width apart, trunk and head are erect with eyes looking forward. The upper arms are abducted away from the body with the forearms hanging vertically. All fingers are together and extended with the palm facing (medially) the thigh and the thumb facing forward.

Procedure:

See Section 6 of Human Solutions (2015). Measurements are reported in mm.

Reference

Human Solutions, 2015. Anthroscan user guide version 3. Human Solutions GmbH, Kaiserslautern, Germany.

Notes:

From time to time the SECA scales underneath the platform can fail to record the weight value. Prior to scanning

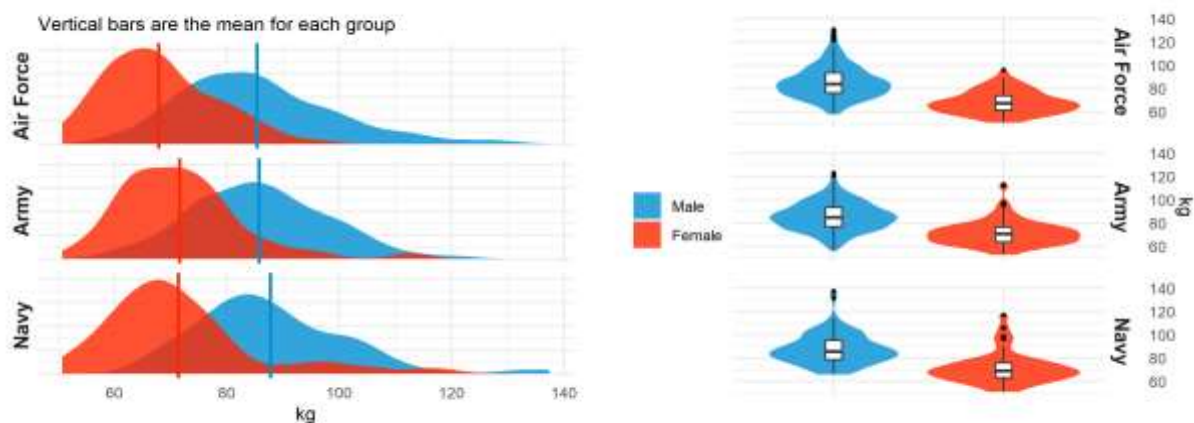
- Ensure that the scale is plugged into the wall and the wall switch is activated.
- Prior to performing the calibration (at the start of each data collection day), weigh the orange calibration pole by placing it in the middle of the black platform. The SECA scale LCD unit should read 6.6 kg every time. Values above or below this may indicate a hardware or software issue thus manual laser realignment is required.
- If the 'weight.raw' file is not created by Anthroscan (see participants scan folder) after a scan, try the following remedies (in no order)
 - Remove and re-plug all connections which include the following:
 - Power cable entry into the black scale platform.
 - Network cable port in the black scale platform.
 - Serial port cable from the serial port of the PC and the serial adapter (black square box that resides underneath the platform).
 - Press and hold the 'TARE' button for 3 seconds then release.
 - Re-start the body scanner power unit and scanner PC.
 - If weight recording errors persist, record the weight from the SECA scale LCD. These can be entered manually into Anthroscan later. **It is important to constantly check the participant folder after each scan to make sure the weights.raw file is created.**



Weight body mass summary statistics - Automatic measurement (kg)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
86	85	86	88	Mean	68	72	71	70
13	14	12	13	SD	10	11	14	11
56	58	56	66	Min	51	53	51	51
137	130	123	137	Max	96	113	117	117
121	125	115	133	P99	91	112	112	111
114	120	112	119	P98	88	99	108	98
112	114	109	112	P97	87	96	104	96
108	112	106	107	P95	85	90	98	89
102	103	102	104	P90	82	85	88	83
99	99	99	102	P85	78	80	79	80
96	97	96	99	P80	77	78	77	77
94	93	93	95	P75	74	77	76	76
91	90	91	92	P70	72	76	74	74
90	88	90	91	P65	70	74	72	73
88	87	88	88	P60	69	73	71	71
86	85	87	87	P55	68	71	69	70
85	84	85	85	P50	67	71	69	69
83	82	84	85	P45	65	69	68	68
82	81	82	83	P40	65	68	68	66
80	79	81	82	P35	63	66	65	65
78	77	79	80	P30	62	65	64	64
76	76	77	79	P25	61	64	63	63
75	74	75	78	P20	59	63	62	62
73	71	73	76	P15	58	62	60	60
71	70	71	72	P10	57	60	59	58
67	67	66	69	P5	55	58	55	56
64	64	64	69	P3	53	56	53	54
62	61	62	68	P2	52	54	53	53
60	60	60	67	P1	51	54	52	51

Distribution plots for each service and gender



Wrist girth - Automatic measurement (mm)

Measuring instrument:

Anthroscan software.

Source:

Human Solutions.

Definition:

Circumference of wrist at the level of the styloid processes of the radius and ulna, with the hand outstretched, and straight with fingers closed.

Landmark required:

None.

Posture required:

Scan position posture 2. Stand with feet shoulder width apart, trunk and head are erect with eyes looking forward. The upper arms are abducted away from the body with the forearms hanging vertically. All fingers are together and extended with the palm facing (medially) the thigh and the thumb facing forward.

Procedure:

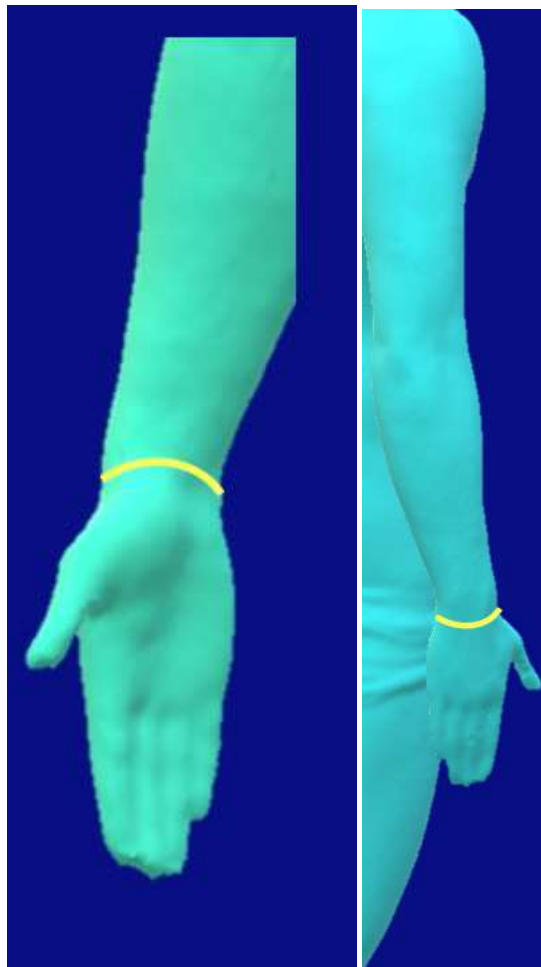
See Section 6 of Human Solutions (2015). Measurements are reported in mm.

Reference:

Human Solutions, 2015. Anthroscan user guide version 3. Human Solutions GmbH, Kaiserslautern, Germany.

Notes:

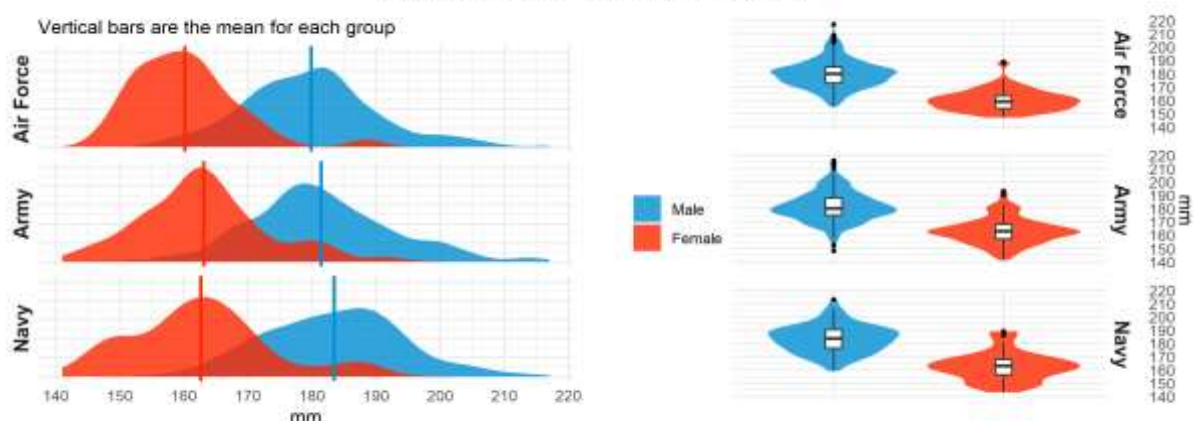
Ensure the yellow line is perpendicular to the long axis of the forearm.



Wrist girth summary statistics - Automatic measurement (mm)

Male					Female			
All	Air Force	Army	Navy		Air Force	Army	Navy	All
790	216	486	88	N	72	97	43	212
181	180	181	183	Mean	160	163	163	162
11	10	11	10	SD	8	10	11	10
148	155	148	159	Min	147	141	143	141
217	217	216	213	Max	189	193	189	193
213	206	213	207	P99	188	190	189	189
205	205	205	205	P98	183	184	188	188
204	203	204	204	P97	176	183	187	185
201	200	201	201	P95	172	181	186	181
195	193	197	195	P90	170	178	175	173
192	189	193	194	P85	167	172	170	170
190	187	190	191	P80	166	170	170	169
188	185	188	190	P75	163	168	168	167
186	184	186	189	P70	163	166	166	165
184	183	184	188	P65	163	165	165	164
183	182	183	187	P60	161	164	164	163
182	181	182	186	P55	160	163	164	163
180	180	180	184	P50	159	163	163	161
179	179	179	182	P45	158	162	161	161
178	177	178	181	P40	158	161	160	159
177	176	177	179	P35	156	160	159	158
176	175	176	178	P30	156	159	158	157
174	173	175	176	P25	154	157	156	156
172	171	173	173	P20	153	155	153	154
170	170	170	172	P15	152	153	150	153
168	167	168	170	P10	152	152	148	151
165	164	165	167	P5	150	148	147	148
162	161	162	165	P3	149	146	147	147
159	159	159	165	P2	148	146	146	146
158	158	157	163	P1	147	144	145	144

Distribution plots for each service and gender



REFERENCES

1. Stewart, A.D. and P.A. Hume *Bideltoid Breadth Measurement*. J.E. Lindsay Carter Kinanthropometry Archive 3D Scanning Protocols, 2014. 2.
2. Roebuck, J.A., *Anthropometric Methods: Designing to Fit the Human Body*. null. Vol. null. 1995. null.
3. Marfell-Jones, M., A. Stewart, and T. Olds, *Kinanthropometry IX: Proceedings of the 9th International Conference of the International Society for the Advancement of Kinanthropometry*. 2006: Taylor & Francis.
4. Stewart, A., *Kinanthropometry and Body Composition: A Natural Home for Three-Dimensional Photonic Scanning*. Journal of sports sciences, 2010. **28**: p. 455-7.
5. Pheasant, S. and C. Haslegrave, *Bodyspace: Anthropometry, ergonomics and the design of work. Third edition*. 2006: Taylor & Francis Group. null.
6. Norton, K., *Standards for Anthropometry Assessment*. 2018. p. 68-137.
7. Heuberger, R., T. Domina, and M. MacGillivray, *Body scanning as a new anthropometric measurement tool for health-risk assessment*. International Journal of Consumer Studies, 2007. **0**(0): p. 070924015744003-???
8. Hume, P.A., D.A. Kerr, and T.R. Ackland, *Best practice protocols for physique assessment in sport*. 2018: Springer.
9. Veitch, D., V. Blewett, and D. Caple, *Sizing Up Australia: What Use Have Designers Made of Anthropometric Data?* 2009.
10. Mellow, P., et al., *Digital Photogrammetry Versus ISAK Anthropometry in Determining Body Segment Lengths of Powerlifters*. Vol. 6. 2003. 25.
11. Shu, C., P. Xi, and A. Keefe, *Data Processing and Analysis for the 2012 Canadian Forces 3D Anthropometric Survey*. Procedia Manufacturing, 2015. **3**: p. 3745-3752.
12. DOD-HDBK-743A, *Military handbook anthropometry of U.S. military personnel*. 1991, U.S. Army Natick RD&E Center: Natick, Massachusetts, U.S.
13. International Standards for Anthropometric Assessment, *International Standards for Anthropometric Assessment*. 2001, South Australia, Australia: International Society for the Advancement of Kinanthropometry.
14. Robinette, K.M. and H.A.M. Daanen, *Lessons learnt from CAESER: A 3-D anthropometric survey*. 2003, Air Force Research Laboratory: Wright-Patterson Air Force Base, Ohio, U.S.
15. Control, C.f.D. and Prevention, *National Health and Nutrition Examination Survey (NHANES): Anthropometry Procedures Manual*. Atlanta: Centers for Disease Control and Prevention, 2007.
16. ISO, *Basic Human Body Measurements for Technological Design: Part 2: Statistical summaries of body measurements from national populations*. 2010.
17. Gordon, C.C., et al. *2012 Anthropometric Survey of U.S. Army Pilot Personnel: Methods and Summary Statistics*. 2016.
18. Marfell-Jones, M., A.D. Stewart, and T. Olds, *International Standards for Anthropometric Assessment*, in *International Standards for Anthropometric Assessment*. 2001, International Society for the Advancement of Kinanthropometry.
19. Gordon, C., et al., *2010 Anthropometric survey of U.S. Marine corps personnel: Methods and summary statistics*. 2013, Anthrotech: Natick Soldier Research, Development of Engineering Center, Yellow Springs, Ohio, U.S.
20. Viviani, C., et al., *Accuracy, Precision and Reliability in Anthropometric Surveys for Ergonomics Purposes in Adult Working Populations: A Literature Review*. International Journal of Industrial Ergonomics, 2018. **65**: p. 1-16.
21. Marfell-Jones, M. and T. Olds, *Kinanthropometry X: Proceedings of the 10th International Society for the Advancement of Kinanthropometry Conference, held in conjunction with the 13th Commonwealth International Sport Conference*. 2007: Routledge.
22. Stewart, A. and T. Ackland, *Anthropometry in Physical Performance and Health*. Body Composition: Health and Performance in Exercise and Sport., 2017: p. 89-108.
23. Robinette, K.M., et al., *Anthropometry Resource (Caesar) Final Report, Volume I: Summary*. 2002.
24. Harrison, C.R. and D.B. Burnsides, *A Method of Comparing 3-D Image Consistency and Quality Between Commercially Available 3-D Scanners*. 2003, SAE International.
25. Veitch, D. and K.M. Robinette. *World Engineering Anthropometry Resource WEAR: A Review*. in *Human Factors and Ergonomics Society of Australia Inc. Annual Conference*. 2006.
26. Zakaria, N. and W. Ruznan, *4 - Developing apparel sizing system using anthropometric data: Body size and shape analysis, key dimensions, and data segmentation*, in *Anthropometry, Apparel Sizing and Design (Second Edition)*, N. Zakaria and D. Gupta, Editors. 2020, Woodhead Publishing. p. 91-121.

27. Bravo, G., et al., *A Literature Review of Anthropometric Studies OF School Students For ergonomics Purposes: are Accuracy, Precision aND Reliability Being Considered?* Work, 2018. **60**: p. 3-17.
28. Apeagyei, P., *Application of 3D body scanning technology to human measurement for clothing Fit*. JDCTA, 2010. **4**: p. 58-68.
29. Bullas, A.M., *The Importance of Complex Anthropometrics in the Assessment of Cyclists*. 2017, Sheffield Hallam University.
30. Simmons, K.P., *Body Measurement Techniques: A Comparison of Three-Dimensional Body Scanning and Physical Anthropometric Methods.*, in *TTM Graduate Faculty, College of Textiles*. 2001, North Carolina State University: Raleigh, North Carolina.
31. Daniell, N., *Three-dimensional scanning in anthropometry- Bringing new techniques and applications to an old science.*, in *Health and Use of Time Group, Sansom Institute for Health Research*. 2011, University of South Australia: Adelaide.
32. Sicotte, M., et al., *Reliability of Anthropometric Measures in A Longitudinal Cohort of Patients Initiating Art in West Africa*. BMC Medical Research Methodology., 2010. **10**(1): p. 102.
33. Fairclough, J.A., et al., *Abdominal Girth: An Unreliable Measure of Intra-Abdominal Bleeding*. Injury, 1984. **16**(2): p. 85-87.
34. Maylia, E., et al., *Can Thigh Girth be Measured Accurately? A Preliminary Investigation*. Journal of Sport Rehabilitation, 1999. **8**: p. 43-49.
35. Katch, F.I. and V.L. Katch, *Measurement and Prediction Errors in Body Composition Assessment And The Search for the Perfect Prediction Equation*. Research Quarterly for Exercise and Sport, 1980. **51**(1): p. 249-260.
36. Lohman, T., A. Roche, and R. Martorell, *Anthropometric Standardization Reference Manual*. null. Vol. null. 1988. null.
37. Heuberger, R., T. Domina, and M. MacGillivray, *Body Scanning as a New Anthropometric Measurement Tool for Health-Risk Assessment*. International Journal of Consumer Studies, 2007. **32**: p. 34-40.
38. Simenko, J. and I. Cuk, *Reliability and Validity of NX-16 3D Body Scanner*. International journal of Morphology, 2016. **34**(4).
39. Wells, J.C., P. Treleaven, and T.J. Cole, *BMI compared with 3-dimensional body shape: the UK National Sizing Survey*. American Journal of Clinnical Nutrition, 2007. **85**(2): p. 419-25.
40. Keefe, A., H. Angel, and B. Mangan, *2012 Canadian Forces Anthropometric Survey (CFAS) – Final report*. 2015, Defense Research and Development Canada: Toronto, Canada.
41. Olds, T., *The rise and fall of anthropometry*. J Sports Sci, 2004. **22**(4): p. 319-20.
42. Njoku, C.O., et al., *Non-imaging Method: 3D Scanning*, in *Best Practice Protocols for Physique Assessment in Sport*, P.A. Hume, D.A. Kerr, and T.R. Ackland, Editors. 2018, Springer Singapore: Singapore. p. 71-85.
43. Istook, C.L. and S.J. Hwang, *3D body scanning systems with application to the apparel industry*. Journal of Fashion Marketing and Management: An International Journal, 2001. **5**(2): p. 120-132.
44. Kumar, L., et al., *Rapid Manufacturing: Classification and Recent Development*. International Journal of Advanced Engineering Research and Science., 2017. **4**(3): p. 237070.
45. Straub, J. and S. Kerlin, *Development of a Large, Low-Cost, Instant 3D Scanner*. Technologies, 2014. **2**(2): p. 76-95.
46. Ares, M., et al. *3D Scanning System for In-Vivo Imaging of Human Body*. in *Fringe 2013 - 7th International Workshop on Advanced Optical Imaging and Metrology*. 2014.
47. Schievano, S., et al., *Reconstruction of Fetal and Infant Anatomy Using Rapid Prototyping of Post-Mortem Mr Images*. Insights Into Imaging, 2010. **1**(4): p. 281-286.
48. Haleem, A. and M. Javaid, *3D Scanning Applications in the Medical Field: A Literature-Based Review*. Clinical Epidemiology and Global Health, 2019. **7**(2): p. 199-210.
49. Daanen, H. and T. Haar, *3D whole body scanners revisited*. Displays, 2013. **34**(4): p. 270-275.
50. Olds, T., P. Blanchonette, and D. Stratton, *Fitting the man to the machine: the ADAPT project*. Australian Defence Force Journal, 2007(172): p. 95.
51. Hemaraju, S., K. Yermal, and A. Ms, *Ergonomic Evaluation through Digital Human Modelling: A Review*. 2019.
52. Schranz, N., et al., *Three-Dimensional Anthropometric Analysis: Differences Between Elite Australian Rowers and the General Population*. Journal of Sports Sciences, 2010. **28**(5): p. 459-469.
53. <Schutz Cardello and Winterhalter 2005 Perceptions of fiber ad fabric uses and the factors contributing to military clothing comfort and satisfaction.pdf>.
54. Schueler, A., I. Fichtner, and O. Ueberschär, *Using the 3D Body Scanner in Elite Sports*. 2018. 216-221.

55. Gorea, A. and F. Baytar, *Using 3D Body Scanning to Measure Compression Variations in a Seamless Knitted Sports Bra*. International Journal of Fashion Design, Technology and Education, 2020. **13**(2): p. 111-119.
56. Petrak, S., M.M. Naglić, and J. Geršak, *Sizing and Fit for Swimsuits and Diving Suits*, in *Anthropometry, Apparel Sizing and Design*. 2020, Elsevier. p. 255-287.
57. Wannop, J.W., et al., *Development of a Footwear Sizing System in the National Football League*. Sports health, 2019. **11**(1): p. 40-46.
58. Friel, K., et al., *The Use of 3d Scanning for Sporting Applications*. Proceedings of SPIE, 2015. **9495**: p. 949517-949517-8.
59. Braganca, S., P. Arezes, and M. Carvalho, *An overview of the current three-dimensional body scanners for anthropometric data collection*, in *Occupational Safety and Hygiene III*. 2015, CRC Press 2015.
60. Robinette, K.M. and H.A. Daanen, *Precision of the CAESAR scan-extracted measurements*. Appl Ergon, 2006. **37**(3): p. 259-65.
61. D'Apuzzo, N., *Recent Advances in 3D Full Body Scanning with Applications to Fashion and Apparel*, in *Optical 3-D Measurement Techniques IX*, A. Gruen and H. Kahmen, Editors. 2009: Vienna, Austria.
62. Mark, W., et al., *3-D Scene Reconstruction with a Handheld Stereo Camera*. 2007.
63. Paquette, S., *3D scanning in apparel design and human engineering*. IEEE Computer Graphics and Applications, 1996. **16**(5): p. 11-15.
64. Buxton, B.F., et al., *Reconstruction and Interpretation of 3D Whole Body Surface Images*. 2000, Department of Computer Science University College London.
65. Wang, J., et al., *Validation of a 3-Dimensional Photonic Scanner for the Measurement of Body Volumes, Dimensions, and Percentage Body Fat*. American Journal of Clinical Nutrition, 2006. **83**(4): p. 809-816.
66. Jaeschke, L., A. Steinbrecher, and T. Pischon, *Measurement of Waist and Hip Circumference with a Body Surface Scanner: Feasibility, Validity, Reliability, and Correlations with Markers of the Metabolic Syndrome*. PLoS One, 2015. **10**(3): p. e0119430.
67. Choi, K. and S.P. Ashdown, *3D Body Scan Analysis of Dimensional Change in Lower Body Measurements for Active Body Positions*. Textile Research Journal, 2011. **81**(1): p. 81-93.
68. Glock, F., et al., *Validity and intraobserver reliability of three-dimensional scanning compared with conventional anthropometry for children and adolescents from a population-based cohort study*. Pediatr Res, 2017. **81**(5): p. 736-744.
69. Zhang, K., et al., *Rapid-Accurate Anthropometric Body Shape Assessment With Low-Cost Novel 3d Imaging System*. The FASEB Journal, 2014. **28**(Supplement).
70. Wells, J., et al., *Acceptability, Precision and Accuracy of 3D Photonic Scanning for Measurement of Body Shape in a Multi-Ethnic Sample of Children Aged 5-11 Years: the SLIC study*. PloS one, 2015. **10**(4): p. e0124193.
71. Kuehnappel, A., et al., *Reliability of 3D laser-based anthropometry and comparison with classical anthropometry*. Sci Rep, 2016. **6**: p. 26672.
72. Lu, J.M., M.J. Wang, and R. Mollard, *The Effect of Arm Posture on the Scan-Derived Measurements*. Applied Ergonomics, 2010. **41**(2): p. 236-241.
73. Lu, J. and M.J.J. Wang, *The Evaluation of Scan-Derived Anthropometric Measurements*. IEEE Transactions on Instrumentation and Measurement, 2010. **59**(8): p. 2048-2054.
74. Beazley, A. and T. Bond, *Computer-aided Pattern Design and Product Development*. 2009: Wiley.com.
75. Suikerbuijk, R., et al., *Automatic Feature Detection in 3D Human Body Scans*. 2004, SAE International.
76. Ulijaszek and C.G.N. Mascie-Taylor, *Anthropometry the individual and the population*. 1994: Cambridge University Press.
77. Tomkinson, G.R., et al., *Time changes in the body dimensions of male Australian Army personnel between 1977 and 2012*. Appl Ergon, 2017. **58**: p. 18-24.
78. Ulijaszek, S.J. and C.G.N. Mascie-Taylor, *Anthropometry: The Individual and the Population*. 2005: Cambridge University Press.
79. Friedl, K.E., *Body Composition and Military Performance: Origins of Army Standards*, in *Body Composition and Military Performance*. 1992, National Academy of Sciences.: Washington.
80. Furnell, A. and J. Coleman. *Trends in Military Anthropometry*. 2015. Melbourne.
81. Cole, T.J., *The Secular Trend In Human Physical Growth: A Biological View*. Economics & Human Biology, 2003. **1**(2): p. 161-168.
82. Baten, J. and M. Blum, *Growing Tall But Unequal: New Findings and New Background Evidence on Anthropometric Welfare in 156 Countries, 1810–1989*. Economic History of Developing Regions, 2012. **27**(sup1): p. S66-S85.

83. Iqbal, M., et al., *Body Segment Dimensions of Indonesian Male Army*. IOP Conference Series: Materials Science and Engineering, 2020. **931**: p. 012013.
84. Tomkinson, G.R., A.J. Clark, and P. Blanchonette, *Secular Changes in Body Dimensions of Royal Australian Air Force Aircrew (1971-2005)*. Ergonomics, 2010. **53**(8): p. 994-1005.
85. Robinette, K.M., S. Blackwell, and H.A.M. Daanen. *Civilian American and European surface anthropometry resource (CAESAR) final report, Volume I; Summary*. 2002. Ohio.
86. Tomkinson, G.R., et al., *Australian Warfighter Anthropometry Survey (AWAS). Methods, temporal changes and summary statistics*. 2012, Health and Use of Time Group, Sansom Institute for Health Research, University of South Australia: Adelaide, Australia.
87. Olds, T., et al., *Fitting the Man to the Machine: The Adapt [Australian Defence Anthropometric Personnel Testing] Project*. Australian Defence Force Journal 2007. **172**: p. 95-102.
88. Blanchonette, P. and A. Smith. *Comparison of the Size of the ADF Aircrew and US Army Personnel*. 2013.
89. Blachonette, P., *Australian Defence Force Anthropometry A Summary of Historic Surveys 2017*, Defence Science and Technology Group.
90. Olds, T., et al., *ADAPT Procedures Manual*. 2004, University of South Australia: Adelaide.
91. Pringle, R.H., et al., *Anthropometry Survey of UK Military Personnel 2006-7 (Issue 3)*. 2011, QinetiQ Ltd.
92. Allen, R., *Review of Scanning Technologies*. 2003, Unreferenced Shape Analysis Customer
93. ISO, *Garment Construction and Anthropometric Surveys*. 1989, International Organization for Standardization
94. Pourtaghi, G., et al., *Anthropometric characteristics of Iranian military personnel and their changes over recent years*. International Journal of Occupational Environmental Medicine,, 2014. **5**: p. 115 - 124.
95. McDowell, M.A., et al., *Anthropometric Reference Data for Children and Adults: United States, 2003–2006*. National Health Statistics Reports, 2008(10): p. 1-48.
96. Kennedy, S.J., R.M. White, and W. Hendrix, *Anthropometric Survey of the Imperial Iranian Armed Forces. Phase III. Technical Summary*. 1971, Ft. Belvoir: Army Natick Labs, M. A.. Defense Technical Information Center.
97. Gordon, C., et al., *Anthropometric Survey of U.S. Army Personnel: Summary Statistics, Interim Report for 1988*. 1989.
98. Gordon, C.C., et al., *2012 Anthropometric survey of U.S. army personnel: Methods and summary statistics*. 2014: Natick Soldier Research, Development of Engineering Center, Yellow Springs, Ohio, U.S.
99. Furnell, A., et al., *Sizing Up the ADF: The Australian Warfighter Anthropometry Survey*. 2014.
100. Tomkinson, G.R., et al., *Validation Trial Report*. 2013, Health and Use of Time Group, School of Health Sciences, University of South Australia.
101. Keefe, A., H. Angel, and B. Mangan, *2012 Canadian Forces Anthropometric Survey (CFAS)*. 2012, Defense Research and Development Canada.
102. Da Silva, G.V., M. Halpern, and C.C. Gordon, *Anthropometry of Brazilian Air Force pilots*. Ergonomics, 2017: p. 1-13.
103. Hotzman, J.L., et al. *Measurer's Handbook: US Army and Marine Corps Anthropometric Surveys, 2010-2011*. 2011.
104. Furnell, A., et al. *Scoping Analyses for the Anthropometric Survey of the Royal Australian Navy (ASRAN)*. in *Proceedings 19th Triennial Congres of the IEA, Melbourne 9-14 August 2015*. 2015.
105. Ponton, K., et al., *Revised Anthropometry Guidance for the Royal Australian Navy*, M. Division., Editor. 2019, Maritime Division. Defence Science and Technology Group.
106. Ponton, K., et al., *Sizing up Royal Australian Navy Sailors*. 2016, Maritime Division, Defence Science Technology Group, Australia Defence Force: Melbourne, Australia.
107. ISO, *ISO 15535:2006: General Requirements for Establishing Anthropometric Databases*. 2006.
108. Blackwell, S., et al. *Civilian American and European Surface Anthropometry Resource (CAESAR), C: F41624-93-C-6001 Final Report, Volume II: Descriptions*. 2002. Dayton, Ohio.
109. Tomkinson, G.R., et al., *Australian Warfighters Anthropometry Survey (AWAS). Procedures Manual*. 2012, Health and Use of Time Group, Sansom Institute for Health Research, University of South Australia.: Adelaide, Australia.
110. Legg, S., *New Zealand Army Anthropometry Project Pre-scoping Report. A pre-scoping report for the Human Systems Group of the New Zealand Defence Technology Agency*. 2008, Massey University: Palmerston North, New Zealand.
111. Slappendel, C. and B.D. Wilson, *Anthropometric Estimates for New Zealand Adults*. Ergonomics NZ, 1992. **7**(3): p. 5-7.
112. Pheasant, S., *Bodyspace: anthropometry, ergonomics and design*. 1986: Taylor & Francis.

113. Toulson, P.K., *Report on the Anthropometric Survey of RNZAF Aircrew, Royal New Zealand Air Force*. 1973, Royal New Zealand Air Force.: Auckland.
114. NZDF personal summary online. *Personnel summary* (<http://www.nzdf.mil.nz/personnel-records/personnel-branch/default.htm>). 2019; Available from: <http://www.nzdf.mil.nz/personnel-records/personnel-branch/default.htm>.
115. International Standards Organisation (ISO), *General requirements for establishing anthropometric databases*. 2006, International Organization for Standardization: Geneva, Switzerland.
116. Statistics New Zealand, *2013 Census QuickStats about culture and identity*. 2014, Statistics New Zealand: Wellington, New Zealand.
117. Tomkinson, G.R., et al., *Australian Warfighter Anthropometry Survey (AWAS): Landmarking and Measurement Manual*. 2012, Health and Use of Time Group, Sansom Institute for Health Research, University of South Australia.
118. Tomkinson, G.R., et al., *Australian Warfighter Anthropometry Survey (AWAS): Landmarking and measurement manual*. 2012, Health and Use of Time Group, Sansom Institute for Health Research, University of South Australia: Adelaide, Australia.
119. Stewart, A.D., et al., *International standards for anthropometric assessment*. 2011, Lower Hutt, New Zealand: ISAK. 125.
120. Tomkinson, G.R., et al., *AWAS Methods, Temporal Changes and Summary Statistics*. 2012, Health and Use of Time Group, Sansom Institute for Health Research, University of South Australia.



Digital Receipt

This receipt acknowledges that Turnitin received your paper. Below you will find the receipt information regarding your submission.

The first page of your submissions is displayed below.

Submission author: **Stephven Kolose**
Assignment title: **Check my research**
Submission title: **NEW ZEALAND DEFENCE FORCE ..**
File name: **S_Kolose_Thesis.docx**
File size: **15.24M**
Page count: **265**
Word count: **61,778**
Character count: **344,291**
Submission date: **22-Mar-2021 09:55AM (UTC+1300)**
Submission ID: **1538110727**



