PART III – AN OVERVIEW OF MILITARY ANTHROPOMETRY SURVEYS 2000–2020

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Preface

PART II 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 anthropometric surveys have used the technology. The purpose of PART III 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.

Overview

The military has an extensive track record of conducting anthropometric surveys. Part III will 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.

Keywords

Military, anthropometric surveys, 3D scanning.

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 [92]. 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 [93].

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 tuberculous, or simply to identify factors that explain why soldiers may be unfit for military service [94].

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 [95]. 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 [95].

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

Table 1. A chronological review of early military anthropometric surveys.

Year	Population	Sample size	Source	No. of measures
1861–65	US Volunteers	1,232,256	Gould (1869) [96]	(# not stated)
1863–65	US Draftees	501,068	Baxter (1875) [97]	(# not stated)
1917–18	US Draftees	1,961,692	Davenport & Love (1921) [98]	(# not stated)
1919	US Seperates	103,909	Davenport & Love (1921) [98]	(# not stated)
1946	US Army Men	105,062	Newman & White (1951)[99]	66
1946	US Army Women	8864	Randall & Munro (1949) [100]	66
1950	US Air Force Flyers	4063	Hertzberg et. al (1954) [101]	132
1959	US Army Aviators	500	US DOD HDBK 743A	(# not stated)
1964	US Navy Aviators	549	Gifford et. al (1965)[102]	98
1965	US Ground Personnel	3869	US DOD HDBK 743A [103]	161
1966	US Army Men	682	US DOD HDBK 743A [103]	73
1966	US Marines	2008	White & Churchill (1978) [104]	73
1966	US Army Basic Trainees	2639	US DOD HDBK 743A [103]	70
1967	US Air Force Flyers	2420	Grunhhofer & Kroh (1975)[105]	189
1968	US Air Force Women	1905	Clauser et al. (1972) [106]	139
1970	US Army Aviators	1482	Churchill et al. (1971)[107]	88
1977	US Army Women	1331	Churchill et al. (1977) [108]	(# not stated)
1988	US Army Men	1774	US DOD HDBK 743A [103]	240
1988	US Army Women	2208	US DOD HDBK 743A [103]	240
1989	US ANSUR I	3982	Gordon et. al (1989)[109]	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 [11]. 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 [11].

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 [11].

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 [11].

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 [11]. 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 [110].

The panel consisted of content experts in military anthropometry. The panel were also survey leaders for their respective countries. A summary [110] 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 [111]. 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 [111, 112]. By comparison, people from South-east Asian countries (e.g., Indonesia) are regarded as some of the shortest in the world [113]. 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 [114]. There have been limited studies looking at the secular trends for military personnel for measurements other than height and weight [93]. Tomkinson et al [93] 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 [115]. 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.

Secular trends are usually estimated from age-corrected data derived from temporally sequential studies from the 'same' population [92]. This is acceptable for countries that have a consistent history of anthropometric surveys such as the US, but not for countries that have conducted limited anthropometric surveys. The make-up of military anthropometry populations is based on ethnicity and immigration [92] of the country's current population. Meaningful changes in immigration may influence the ethnic mix within the population (country). This in turn, will influence the military populations ethnic mix. Furthermore, increased height may be important for some military roles but not for others. For example, a 10-year, 10 mm difference in seated height may be irrelevant for clothing design, but it may be significant for a young Air Force cadet who is a borderline fit for their crew station anthropometry assessment. Alternatively, once accepted into the program, the cadet may end up flying an aircraft that was designed using anthropometric data that are several decades old [115]. Of greater concern, the cadet may have grown considerably over the course of their basic training.

To summarise, there are several trends and challenges in military anthropometry surveys. Small-scale rather than large-scale anthropometry surveys are potentially a more practical and viable alternative. This can help ease logistical burden. Sharing of anthropometric findings especially amongst military organisations is and will always be difficult. More research should be conducted on digital human modelling, dynamic and encumbered anthropometry, and sampling strategies/procedures that are 'military-friendly'. Secular trends of military personnel body sizes will have implications for future acquisition of equipment or platforms and may influence how they are operated.

The next part describes international military anthropometric surveys that have been conducted between 2000 and 2020. Many other studies were not available for review due to confidentiality or proprietary reasons.

Contemporary surveys

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 2).

Combined variable list

All measurements used in the surveys (except for the Iranian survey) were recorded and condensed (according to nomenclature) in Appendix A. 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 A 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 [116]. The demographic information for CAESAR will not be covered.

The following observations were made during the development and interrogation of the list in Appendix A. 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 undoubtably 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 2. Summary of selected anthropometric surveys conducted between 2000 and 2020 showing sample, measurement, demographic, and technology descriptives.

COUNTRY	SAMPLE PARAMETERS	# LM; P; DIGITAL (A, P, D)	ETHNICITY	TRADE	SCANNER
2002 Civilian American and European Surface Anthropometry Resource - CAESAR	4431 18 to 65 years 2094 Male 2332 Female 54% North America 28% Netherlands 18% Italy	99; 72; 40; (-, 99, -)	North America: 77% White 11% Black 12% Other Netherlands: 82% White 18% Other Italy: 96% Italian 4.0% Other	(# not stated)	Cyberware (US, ITA) WB4 Whole Body Scanner Laser <2mm Human Solutions, Vitus Pro Laser <2mm
2006-7 Anthropometry Survey of UK Military Personnel Tri-service	**2470** 17 to 55 years 2160 Male 311 Female 44% Army 26% Air Force 30% Navy	96; -; 18; (71, -, 6)	Only minority groups presented 1.5% Black 1.0% Caribbean 0.9% Black African 0.72% Fijian 0.2% Indian 0.16% East African 8.0% Gurkas	(# not stated)	Textile Clothing Technology Corporation [TC]² KX-16 Cyberware Laser Head Scanner Infrared Laser 1 mm
2010 Anthropometric Survey of Iranian Military Personnel	12635 18 to 30 years Male (# not stated) Female (# not stated)	90; -; 90; (-, -, -)	(# not stated)	(# not stated)	MANUAL ONLY
2012 Anthropometric Survey of U.S. Army Personnel - ANSUR II Army only	**7435** 17 – 58 years 7435 Male 3922 Female 64% Active Duty 33% National Guard 3% Reserves	135; 53; 94; (-, -, 41)	62% White 21% Black 11% Hispanic 3.0% Asian 1.0% Native American 1.0% Pacific Islander	27% Quartermaster supply 15% Signal, COMS & Info systems 10% Medical 8.0% Intelligence 8.0% Ordinance/Mechanical	Cyberware WBX and PX and INFOOT foot scanner Laser <2mm
2012 Australian Warfighter Anthropometry Survey - AWAS Army only	**2138** 18 to 40 years 1861 Male 277 Female	84; 25; 40; (-, 44, -)	Country of birth 92% Australia 1.3% New Zealand 1.3% Other 1.1% South-East Asia 1% Europe (ex. UK) 1% UK 0.7% Pacific Islands	24% Rifleman 7.6% Driver 5.9% Combat Engineer 5.7% Crewman ASLAV 5.0% Operator Supply 3.5% Operator Admin 3.4% Gun Number	Human Solutions, Vitus XXL Whole body scanner Laser 27 cm³

2012 Canadian Forces Anthropometry Survey - CFAS Tri service	**2205** 17 to 60 years 38.4% Army 21.9% Navy 39.7% Air Force 1890 Male 315 Female	91; 44; 48; (-, -, 43)	Racial distribution 92.7% Caucasian 2% Other 1% Black 0.8% Filipino 0.7% Latin American 0.6% Metis 0.6% Chinese	8.8% Pilot 8.4% Infantry 6.1% Aviation Technician 5.8% Combat Engineer 4.7% Crewman Armoured 4.1% Resource Support Clerk 3.9% Supply Technician 3.4% Air Combat Officer 2.9% Avionics System Tech	Human Solutions, Vitus XXL Whole body scanner Laser 27 cm³ Human Solutions, VITUS aHead Head Scanner Laser 30 cm³ FootIn3D Scanner Laser 35 cm³ VisImage Inc BoSS XXI Body Sizing system Photo
2014 Anthropometric Survey of Brazilian Air Force Air Force only	**2339** 16 to 52 years Brazilian Pilot population 44% Potential pilots 56% Current pilots 2133 Male 206 Female	39; -; 39; (-, -, -)	Racial distribution 72% White 22.3% Brown 4.4% Black 1% Asian 0.22% Indigenous 0.08% Other	Officers (top 4 only) 14.5% Transport 6.5% Fighter 5.7% Helicopter 4.1% Instructor Cadets and students 20.5% Trainees 8.7% Students 7.1% Admin 3.5% Infantry	MANUAL ONLY
2015 Anthropometric Survey of the Royal Australian Navy - ASRAN Navy only	**1332** 18 to 54 years 1090 Male 232 Female	87; 69; 43; (-, 44, -)			Human Solutions, Vitus XXL Whole body scanner Laser 27 cm³

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 cm^2).

Summary of military surveys 2000 to 2019

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 [117].

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 [30].

The dataset was used to identify recruitment guidelines for aircrew, to optimise cockpit human-machine interface and improve the fit of clothing and equipment [118]. 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/cm^2. 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) [119, 120]. 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 [120]. 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 [120, 121].

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) [122].

Prior to this survey, the previous published dataset was the Defence Standard 00-25 Part 17 developed from surveys conducted between 1970 and 1995 [122]. 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 [122].

Two Textile Clothing Corporation [TC]^2 3D body light scanners were used. The scanners used infrared as opposed to laser technology (see Part 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 [123] and from ISO 8559 [124]. 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 [122].

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 [122].

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 ethic group with known anthropometric differences from the general UK army [122].

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 [125]. The measurement protocol and definitions were based on the 2008 National Health and Nutrition Examination Survey (NHANES) [126]. 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 personal 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, 5^{th} to 95^{th} 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 [127], 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 [125].

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

The 2012 Anthropometric Survey of US army personnel (ANSUR II) [16] 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 [109]. 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 [128].

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%).

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 [129].

The previous anthropometric survey was the Australian Tri-Service Anthropometric Survey in 1977 [130] 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 [115].

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 [117].

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/cm^2 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 [131].

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 [129].

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 [131].

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 [132].

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 [132].

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/cm^2, the VITUS AHead Scanner (±1 mm accuracy at a point density of 30 points/cm^2) and the FootIn 3D (± 1 mm accuracy at a point density of 35 cm points/cm^2). 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 fontal 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 [133].

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) [133].

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 [134]. The measurements were specifically relevant to the design of aircraft cockpits, protective gear, uniform sizing, and computerised digital human modelling [133]. 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 [11, 15].

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 [135-137].

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 [138]. 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, 50^{th}, and 95th). The limited percentile data would not be helpful for designing equipment or platforms for a section of the population outside these values [135, 137]. 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 section.

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 [136].

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

Part III 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 TC^2) 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 A 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 over-sample 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.

Part IV will describe the methodology of the 2016–2018 New Zealand Defence Force Anthropometry Survey.