ASSESSING AGILITY IN NETBALL PLAYERS

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

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Primary Supervisor: Professor John Cronin

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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 - 12 of this thesis represent 11 separate papers that have been submitted to peer-reviewed journals for consideration for publication. My contribution and the contribution by the various co-authors to each of these papers are outlined in the candidate contribution to co-authored papers table and at the beginning of each chapter. All co-authors have approved the inclusion of the joint work in this doctoral thesis.

Jennifer K. Hewit

5th April 2011

CANDIDATE CONTRIBUTIONS TO CO-AUTHORED PAPERS

Chapter publication reference	**Author %**
CHAPTER 2: Hewit, J., Cronin, J.B., & Hume, P.A. *Kinematic comparison of straight and change of direction acceleration tasks*. Submitted to *Journal of Strength and Conditioning Research.*	JH = 85%; JC = 10%; PH = 5%.
CHAPTER 3: Hewit, J., Cronin, J.B., Button, C., & Hume, P.A. (2011). *Understanding deceleration in sport.* Strength and Conditioning Journal. 33(1): 47-52.	JH = 83%; JC = 10%; CB = 2%; PH = 5%
CHAPTER 4: Hewit, J., Cronin, J.B., Hume, P.A., & Button, C. (2010). *Understanding change of direction performance via the 90˚ turn and sprint test*. Strength and Conditioning Journal. 32(6): 82-88.	JH = 85%; JC = 10%; PH = 5%.
CHAPTER 5: Hewit, J., Cronin, J.B., & Hume, P.A. *Understanding change of direction performance: A technical analysis of a 180˚ ground-based turn and sprint task.* Submitted to *International Journal of Sports Science and Coaching.*	JH = 85%; JC = 10%; PH = 5%.
CHAPTER 6: Hewit, J., Cronin, J.B., & Hume, P.A. (2010). *Understanding ground-based change of direction in sport.* To be submitted to *Strength and Conditioning Journal*.	JH = 85%; JC = 10%; PH = 5%.
CHAPTER 7: Hewit, J., Cronin, J.B., & Hume, P.A. *Understanding change of direction performance: A technical analysis of a 180˚ aerial catch and turn task.* Submitted to *International Journal of Sports Science and Coaching.*	JH = 86%; JC = 8%; PH = 6%.

CHAPTER 8: Hewit, J., Cronin, J.B., & Hume, P.A. *Understanding aerial change of direction performance in sport.* To be submitted to *Strength and Conditioning Journal*.	JH = 86%; JC = 8%; PH = 6%.
CHAPTER 9: Hewit, J., Cronin, J.B., & Hume, P.A. *Leg power assessment in sport: Multi-direction leg asymmetry.* Submitted to *Physical Therapy in Sport.*	JH = 85%; JC = 10%; PH = 5%.
CHAPTER 10: Hewit, J., Cronin, J.B., & Hume, P.A. Asymmetry in multi-directional jumping tasks. Submitted to *Strength and Conditioning Journal.*	JH = 85%; JC = 10%; PH = 5%.
CHAPTER 12: Hewit, J., Button, C., Hume, P.A., & Cronin, J.B. Developing a sport-specific perceptual assessment for agility: A reactive decision-making passing task for court-based team sports. To be submitted to *Journal of Science and Medicine in Sport.*	JH = 85%; CB = 9%; PH = 4%; JC = 2%.
APPENDIX 2: Hewit, J., Cronin, J.B., Button, C., & Hume, P.A., (2009). Needs analysis of agility in netball players: A technical report for Netball New Zealand. Technical Report No. 1 submitted to Netball New Zealand. 7 pages.	JH = 83%; JC = 10%; PH = 5%; CB = 2%.
APPENDIX 3: Hewit, J., Cronin, J.B., Button, C., & Hume, P.A., (2008). Netball-specific agility assessment battery testing protocol and initial results: A technical report for Netball New Zealand. Technical Report No. 2 submitted to Netball New Zealand. 10 pages.	JH = 83%; JC = 10%; PH = 5%; CB = 2%.
APPENDIX 4: Hewit, J., Cronin, J.B., Button, C., & Hume, P.A., (2010). Needs Analysis of Agility in New Zealand Netball Players: A technical report for Netball New Zealand. Fact Sheet No. 1 to be sent to Netball New Zealand. 2 pages.	JH = 83%; JC = 10%; PH = 5%; CB = 2%.
APPENDIX 5: Hewit, J., Cronin, J.B., Button, C., & Hume, P.A., (2009). Preliminary change of direction assessment and initial findings: A technical report for Netball New Zealand. Technical Report No. 3 submitted to Netball New Zealand. 7 pages.	JH = 83%; JC = 10%; PH = 5%; CB = 2%.

APPENDIX 6: Hewit, J., Cronin, J.B., Button, C., & Hume, P.A., (2008). Assessing change of direction techniques in netball players. Sport and Exercise Science Conference, Dunedin.	JH = 83%; JC = 10%; PH = 5%; CB = 2%.
APPENDIX 7: Hewit, J., Cronin, J.B., Button, C., & Hume, P.A., (2010). 90˚ ground-based change of direction in netball: A fact sheet for Netball New Zealand. Fact Sheet No. 2 to be sent to Netball New Zealand. 2 pages.	JH = 83%; JC = 10%; PH = 5%; CB = 2%.
APPENDIX 8: Hewit, J., Cronin, J.B., Button, C., & Hume, P.A., (2010). 180˚ ground-based change of direction in netball: A fact sheet for Netball New Zealand. Fact Sheet No. 3 to be sent to Netball New Zealand. 2 pages.	JH = 83%; JC = 10%; PH = 5%; CB = 2%.
APPENDIX 9: Hewit, J., Cronin, J.B., Button, C., & Hume, P.A., (2009). Developing an aerial change of direction test for netball players: A technical report for Netball New Zealand. Technical Report No. 4 submitted to Netball New Zealand. 12 pages.	JH = 83%; JC = 10%; PH = 5%; CB = 2%.
APPENDIX 10: Hewit, J., Cronin, J.B., Button, C., & Hume, P.A., (2008). Developing a netball-specific aerial change of direction assessment task. Sport Performance Research Institute New Zealand Conference, Auckland.	JH = 83%; JC = 10%; PH = 5%; CB = 2%.
APPENDIX 11: Hewit, J., Cronin, J.B., Button, C., & Hume, P.A., (2010). 180˚ aerial change of direction in netball: A fact sheet for Netball New Zealand. Fact Sheet No. 4 to be sent to Netball New Zealand. 3 pages.	JH = 83%; JC = 10%; PH = 5%; CB = 2%.

APPENDIX 12: Hewit, J., Cronin, J.B., Button, C., & Hume, P.A., (2010). Assessing leg power capabilities in netball players: A technical report for Netball New Zealand. Technical Report No. 5 submitted to Netball New Zealand. 11 pages.	JH = 83%; JC = 10%; PH = 5%; CB = 2%.
APPENDIX 13: Hewit, J., Cronin, J.B., Button, C., & Hume, P.A., (2009). Leg asymmetries between various direction-based movement tasks in netball players. Sport and Exercise Science Conference, Rotorua.	JH = 83%; JC = 10%; PH = 5%; CB = 2%.
APPENDIX 14: Hewit, J., Cronin, J.B., Button, C., & Hume, P.A., (2010). Leg power asymmetry: A fact sheet for Netball New Zealand. Fact Sheet No. 5 to be sent to Netball New Zealand. 2 pages.	JH = 85%; JC = 9%; PH = 4%; CB = 2%.
APPENDIX 15: Hewit, J., Button, C., Hume, P.A., and Cronin, J.C., (2010). Developing a reactive decision-making passing test for netball players: A technical report for Netball New Zealand. Technical Report No. 6 submitted to Netball New Zealand. 11 pages.	JH = 85%; CB = 9%; PH = 4%; JC = 2%.
APPENDIX 16: Hewit, J., Button, C., Hume, P.A., and Cronin, J.C., (2010). Reactive decision-making in netball: A fact sheet for Netball New Zealand. Fact Sheet No. 6 to be sent to Netball New Zealand. 3 pages.	JH = 85%; CB = 9%; PH = 4%; JC = 2%.
APPENDIX 17: Hewit, J., Cronin, J.B., Button, C., & Hume, P.A., (2010). A compilation of regional netball testing feedback for the netball-specific agility assessment battery: A technical report for Netball New Zealand. Technical Report No. 7 submitted to Netball New Zealand. 18 pages.	JH = 85%; JC = 10%; CB = 3%; PH = 2%.
APPENDIX 18: Hewit, J., Cronin, J.B., Button, C., & Hume, P.A., (2010). An individualized agility profile for netball players: A technical report for Netball New Zealand. Technical Report No. 8 submitted to Netball New Zealand. 20 pages.	JH = 85%; JC = 10%; CB = 3%; PH = 2%.

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Enormous thanks go to my supervisors Professor John Cronin, Professor Patria Hume, Dr. Chris Button and Leigh Gibbs. You've helped me develop this thesis from a rough idea into a comprehensive assessment battery, and have supported me continuously throughout doctoral challenges as well as my pregnancy and motherhood challenges.

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ABSTRACT

Determinants of agility performance include change of direction factors (technical and physical qualities) and perceptual/decision-making factors. This thesis aimed to address the gap in agility literature by developing a netball-specific agility assessment battery which incorporated analyses of various ground-based and aerial change of direction movement strategies/kinematics (technical), multi-directional leg power and leg asymmetry profiles (physical) and pass appropriateness in response to target player movements (perceptual/decision-making).

A survey developed and administered to 52 New Zealand netball coaches and staff identified the areas within agility that were of importance to the development of netball players. Feedback from the netball coaches and staff identified several tasks which were thought to be of greatest importance for the performance development of netball players; 1) fast and sharp change of direction movements inclusive of rapid decelerations and explosive accelerations; 2) aerial changes of direction (i.e. the ability to turn fully in the air prior to landing); 3) single-leg jumping ability; 4) awareness of the ball, teammate and opponents; and 5) interception timing and accuracy. A netball-specific agility assessment battery and the associated individual tasks (5.0 m straight acceleration, 90˚ and 180˚ ground-based changes of direction, 180˚ aerial catch and turn task, multi-directional single-leg countermovement jumping, and a reactive passing task) were developed based off of this feedback and further analysed in the experimental studies presented in this thesis. When comparing kinematics of straight and change of direction (COD) acceleration performances, COD acceleration was associated with a more upright torso (28 - 30%, $p < 0.001$), shorter step length (19 - 22%, $p < 0.001$) and lower knee lift (21 - 22%, $p = 0.00$). Faster straight acceleration players were associated with smaller step lengths (3 – 5%, $p = 0.02$ to 0.05), lower knee lift (7 – 15%, $p = 0.02$ to 0.05) and greater forward lean than slower players while faster COD accelerations had increased step frequencies (4%, $p = 0.03$). Technical characteristics of sub-elite netball players that were likely to contribute to more proficient ground-based and aerial COD performances included decreased rotational inertia and large takeoff distance (ground-based COD) and aggressive driving action of the arms/legs at takeoff, rapid head turn and lower body rotation while airborne (aerial COD).

Single-leg power profiles/imbalances (average symmetry index – ASI) when performing multi-directional unilateral countermovement jumps were investigated in 22 players. Individual ASI's ranged from 0.0 to 32.7% while averaged ASI's ranged from 3.1% (peak force) to 11.4% (peak power). There were ASI differences between vertical force and power (3.1% and 9.2%, $p = 0.02$), horizontal power and jump distance (11.3% and 4.6%, $p < 0.00$), horizontal force and distance (8.0% and 4.6%, $p < 0.00$) and lateral power and jump distance (10.0% and 6.2%, $p = 0.05$).

Increased ecological validity of the reactive decision-making assessment task resulted in relatively high variability (CV = 22.7 to 35.1%, ICC = -0.60 to -0.14) for all three performance times. Decision times to move right or left (0.209 and 0.210 s, $p = 0.00$) were faster decisions for vertical and upper right locations (0.263 and 0.261 s, $p = 0.00$). Movement times (0.171 to 0.176 s, $p = 0.00$ to 0.01) in vertical, upper right, and upper left directions were slower when compared to right and left directions (0.147 to 0.154 s). Passes to the right were faster than passes to the left (0.147 and 0.154 s, $p = 0.01$).

A novel approach to assessing agility was presented in this thesis through technical feature templates, multi-directional unilateral leg power assessments, and an ecologically valid reactive passing task. The prognostic/diagnostic information gained from this assessment battery can be used by netball practitioners to guide individual players' training programmes to better effect. Practitioners should be aware that grouped data masks individual player's strengths and weaknesses and the ability to individualize programmes. Throughout the thesis data have been presented in a number of ways to fulfil both the academic needs associated with research as well as the needs of practitioners.

TERMINOLOGY

Acceleration	Rapid change in velocity
Agility	Rapid whole-body movement involving changes in direction or velocity in response to an external stimulus
Airborne	When a player is no longer in contact with an external surface.
Bilateral	Pertaining to both legs or feet simultaneously.
Contralateral	Opposing body segments (e.g. foot, leg, arm, etc.).
Deceleration	Rapidly slowing the body's movement.
End-Court player	Goal defence, goal shooter and goal keeper playing positions in netball.
Flight phase	Phase of sprinting between takeoff and touch-down of contralateral feet.
Free leg	Leg that is no longer in contact with the ground.
Impulse	Product of force and time (f x t).
Impulse – Momentum relationship	Effect that impulse (force x time) and momentum (mass x velocity) have on each other (f x t = m x v).
Inertia	Resistance to change in motion.
Key technical feature	Descriptive qualities of technique thought to contribute to a superior performance.
Mid-Court/Attacking player	Centre, wing attack, wing defence, and goal attack playing positions in netball.
Plant foot	Last foot strike in the original direction that initiates the directional change.
Rotational inertia	Resistance to rotate (i.e. moment of inertia), equal to the product of distribution of mass about the axis of rotation (mass x radius^2).
Step frequency	Number of steps taken over a specified distance or time.
Step length	Distance from takeoff of one foot to the contralateral foot touchdown.

Support phase	Phase of sprinting when at least one foot is in contact with the ground.
Takeoff distance	Distance from the vertical line through the centre of mass to the takeoff foot as it leaves the ground.
Takeoff foot	Second foot to leave the ground during the support phase.
Unilateral	Pertaining to one leg or foot.

ABBREVIATIONS USED THROUGHOUT THIS THESIS

Abbreviation	Definition
180˚ gbCOD	180˚ ground-based change of direction.
90˚ gbCOD	90˚ ground-based change of direction
AAB	Agility assessment battery
aCOD	Aerial change of direction
ASI	Average symmetry index
COD	Change of direction
CODA	Change of direction acceleration
COM	Centre of mass
CV	Coefficient of variation
DT	Decision time
FMS	Forward-moving sidestep
FSP	False-step pivot
gbCOD	Ground-based change of direction
GCT	Ground contact time
GRF	Ground reaction force
ICC	Intraclass correlation coefficient
KE	Kinetic energy
MT	Movement time
N-SAAB	Netball-specific agility assessment battery
N-SAT	Netball-specific agility task
NZ-U21	New Zealand under 21 (netball squad)
PC	Pivoting crossover
RDM	Reactive decision-making
SA	Straight acceleration
SF	Step frequency
SL	Step length
SLCM	Single-leg countermovement (jump)
SLCM-H	Horizontal single-leg countermovement (jump)

SLCM-L	Lateral single-leg countermovement (jump)
SLCM-V	Vertical single-leg countermovement (jump)
TT	Total time
U &B	Up and back

RESEARCH OUTPUTS RESULTING FROM THIS DOCTORAL THESIS

Peer reviewed journal publications

Hewit, J.K., et al., *Understanding change of direction performance via the 90 degree turn and sprint test.* Strength and Conditioning Journal, 2010. **32**(6): p. 82-88.

Hewit, J.K., et al., *Understanding deceleration in sport.* Strength and Conditioning Journal, 2011. **33**(1): p. 47-52.

Journal manuscripts currently under peer review

Hewit, J.K., Cronin, J.B., & Hume, P.A., *Asymmetry in multi-directional jumping tasks.* Submitted to Strength and Conditioning Journal.

Hewit, J.K., Cronin, J.B., & Hume, P.A., *Kinematic factors affecting fast and slow straight and change of direction acceleration times.* Submitted to Journal of Strength and Conditioning Research.

Hewit, J.K., Cronin, J.B., & Hume, P.A., *Leg power assessment in sport: multi-directional leg asymmetry.* Submitted to Physical Therapy in Sport.

Hewit, J.K., Cronin, J.B., & Hume, P.A., *Understanding change of direction performance: a technical analysis of a 180˚ aerial catch and turn task.* Submitted to International Journal of Sport Sciences and Coaching.

Hewit, J.K., Cronin, J.B., & Hume, P.A., *Understanding change of direction performance: a technical analysis of a 180˚ ground-based turn and sprint task.* Submitted to International Journal of Sport Sciences and Coaching.

Technical reports

Hewit, J.K., Cronin, J.B., Hume, P.A., & Button, C. (2010). *A compilation of regional netball testing feedback for the netball-specific agility assessment battery: A technical report for Netball New Zealand (Technical Report No.7).* Auckland, New Zealand: AUT University and Netball New Zealand.

Hewit, J.K., Cronin, J.B., Hume, P.A., & Button, C. (2010). *An individualized agility profile for netball players: A technical report for Netball New Zealand (Technical Report No.8).* Auckland, New Zealand: AUT University and Netball New Zealand.

Hewit, J.K., Cronin, J.B., Hume, P.A., & Button, C. (2009). *Netball-specific* agility *assessment battery testing protocol and initial results*: *A technical report for Netball New Zealand* (Technical Report No. 2). Auckland, New Zealand: AUT University and Netball New Zealand.

Hewit, J.K., Cronin, J.B., Hume, P.A., & Button, C. (2009). *Assessing leg power capabilities in netball players: A technical report for Netball New Zealand (Technical Report No. 5).* Auckland, New Zealand: AUT University and Netball New Zealand.

Hewit, J.K., Cronin, J.B., Hume, P.A., & Button, C. (2009). *Developing an aerial change of direction test for netball players: A technical report for Netball New Zealand (Technical Report No.4).* Auckland, New Zealand: AUT University and Netball New Zealand.

Hewit, J.K., Button, C., Hume, P.A., & Cronin, J.B., (2010). *Developing a reactive decision-making passing test for netball players: A technical report for Netball New Zealand* (Technical Report No. 6). Auckland, New Zealand: AUT University and Netball New Zealand.

Hewit, J.K., Cronin, J.B., Hume, P.A., & Button, C. (2009). *Needs analysis of agility in New Zealand netball players*: *A technical report for Netball New Zealand* (Technical Report No. 1). Auckland, New Zealand: AUT University and Netball New Zealand.

Hewit, J.K., Cronin, J.B., Hume, P.A., & Button, C. (2008). *Preliminary change of direction assessment and initial findings: A technical report for Netball New Zealand* (Technical Report No. 3). Auckland, New Zealand: AUT University and Netball New Zealand.

Conference publications

Hewit, J.K., Cronin, J.B., Button, C., & Hume, P.A. (2010). Developing a netball specific aerial change of direction assessment task. *Sports Performance Institute of New Zealand (SPRINZ) Conference*. November 2010, Auckland, New Zealand.

Hewit, J.K., Cronin, J.B., Button, C., & Hume, P.A. (2009). Leg asymmetries between various direction-based movement tasks in netball players. *New Zealand Sports Medicine and Science Conference*, November, 2009, Rotorua, New Zealand. p.46.

Hewit, J.K., Cronin, J.B., Button, C., & Hume, P.A. (2008). Assessing Change of direction techniques in netball. *New Zealand Sports Medicine and Science Conference*, November, 2008, Dunedin, New Zealand. p.45.

CHAPTER 1

INTRODUCTION AND RATIONALISATION

Introduction and thesis rationale

Agility is quite complex and often difficult to define as it encompasses an extensive range of movements in sport that may be performed at varying velocities and across multiple directions. Such movements may also focus on the body as a whole (completing a change of direction while sprinting, initiating a vertical jump from a horizontal or lateral sprint, etc.) or on specific limbs and more refined motor skills specific to the sport (dribbling a soccer ball around an opponent, catching and initiating a pass while airborne in netball, etc.). With so many different facets of agility in sport, many definitions have been presented in the literature [1-7]. The definition presented by Sheppard et al. [8] appears to be comprehensive and pertain to a variety of movement patterns associated with agility maneuvers and therefore will be the definition used in this thesis: “a rapid whole-body movement with change of velocity or direction in response to a stimulus”. A deterministic model of agility developed by Young et al. [5] has also been used throughout this thesis as the foundation for understanding the components of agility - perceptual/decision-making and change of direction which incorporates technical and physical components.

While several studies have attempted to integrate two of the three components of agility into a single assessment [1, 2, 6, 9], no researcher has included all three components of agility in a sport-specific assessment battery. It seems reasonable to assume that if one or more of these components is lacking or missing in a given performance, the overall agility performance will likely be compromised. Hence there is a need to identify these deficiencies so that training programmes may be guided to a better effect. The purpose of this thesis therefore was to develop a netball-specific assessment of agility that is both easily administered and cost effective, which provides information regarding strengths and weaknesses of individual players in terms of perceptual decision-making, technical and physical factors.

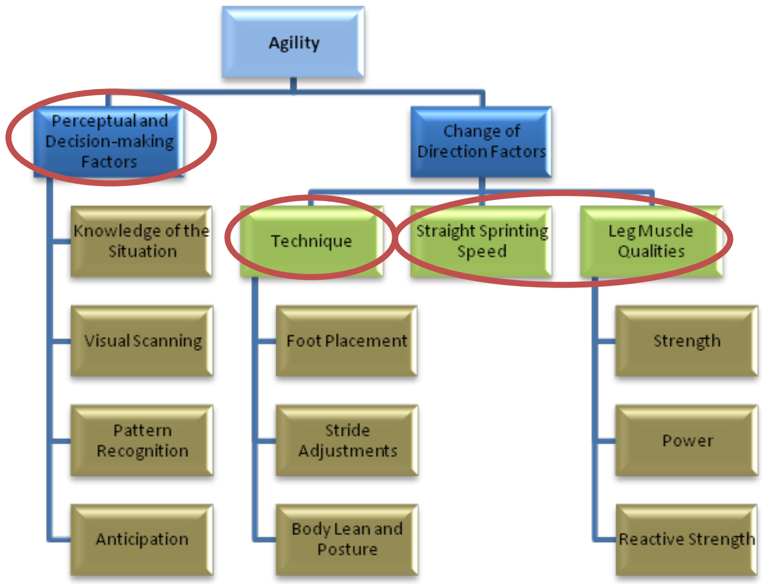


Figure 1: Deterministic model of agility (adapted from Young etal. 2002) with the three main components of agility circled (perceptual, technical and physical).

It should be noted by the reader right from the outset of this thesis that each of these components of agility are thesis studies in and of themselves (i.e. a thesis could have been undertaken on perceptual decision making alone). However, after consultation with the National Sport Organization, Netball New Zealand who funded a PhD scholarship in this area, it was agreed that the assessment needed to be all encompassing and of utility to coaches and strength and conditioning practitioners. With this in mind the thesis has been developed to address all three components so as a holistic picture of a player's agility ability is understood. The reader needs to be cognizant of this fact when reading the thesis. Furthermore the author comes from an applied biomechanical and strength and conditioning background, so much of this thesis is written with this audience in mind.

Originality of Thesis

Central to this thesis is the development of an agility assessment battery specific to netball which is able to identify individual player strengths and weaknesses across the three primary components of agility (technical, physical and perceptual/decision-making), as presented by Young et al. [5]. In terms of the technical component, a paucity of literature addressing this component of agility was found, in particular the identification of specific techniques or strategies employed by individual players to accomplish complex movement tasks [10, 11]. Only two studies [11, 12] investigated the strategies used by players when performing ground based specific change of direction movements as performed in the associated sport. Certainly no research has investigated both ground based and aerial change of direction tasks specific to netball. When change of direction ability has been addressed in research, the focus has been around the speed at which the task is completed (i.e. proficiency based on performance times – see Breughelli [13] for a review). Unfortunately, this provides little insight into *why* the athlete is faster or slower at a particular task or portion of a task. For coaches and strength and conditioning practitioners to improve agility performance, it would seem fundamental to understand what makes better agility performance via a movement analysis and identify the critical features of the movements of interest. The aim of the first section of this thesis was to address this limitation and provide technical (qualitative and quantitative) information on netball specific movement patterns. The information provided from this analysis should focus coaching and conditioning to a better effect. Furthermore, as the technical component of agility appears to be the component that has the least amount of information, this thesis will focus the majority of attention on the analysis of various change of direction techniques that are commonly performed by netball players throughout a game. This includes both ground-based and aerial-based change of direction maneuvers.

The physical component can be divided into leg strength qualities and straight sprint ability. With regards to the leg strength qualities, each sport requires specific movement patterns and physical capabilities from an athlete with many of these maneuvers being unilateral (single-legged) and multi-directional in nature. Until recently, the majority of literature has focused on leg strength and power when performing bilateral assessments in primarily one direction (e.g. vertically) [14, 15]. While this information may be useful, it does not give insight into the leg strength and power capabilities as they are required in sport (i.e. limited transference). Recent research conducted by Meylan et al. [16] and Maulder et al. [17] however, has investigated the reliability and importance of unilateral assessments across multiple directions. As agility performance can occur in a multitude of directions it would seem intuitive to develop leg strength/power profiles in a multitude of directions. Furthermore, given that much of agility performance is unilateral in nature it would also seem sagacious to identify whether unilateral imbalances exist between legs. This form of assessment is able to provide valuable prognostic and diagnostic information concerning symmetry between legs, directional-specific strengths and weaknesses, as well as a possible baseline data for readiness to return to play following an injury. Given this information, the aim of this section of the thesis was to develop and discuss leg power and asymmetry profiling and the influence of assessments on programming.

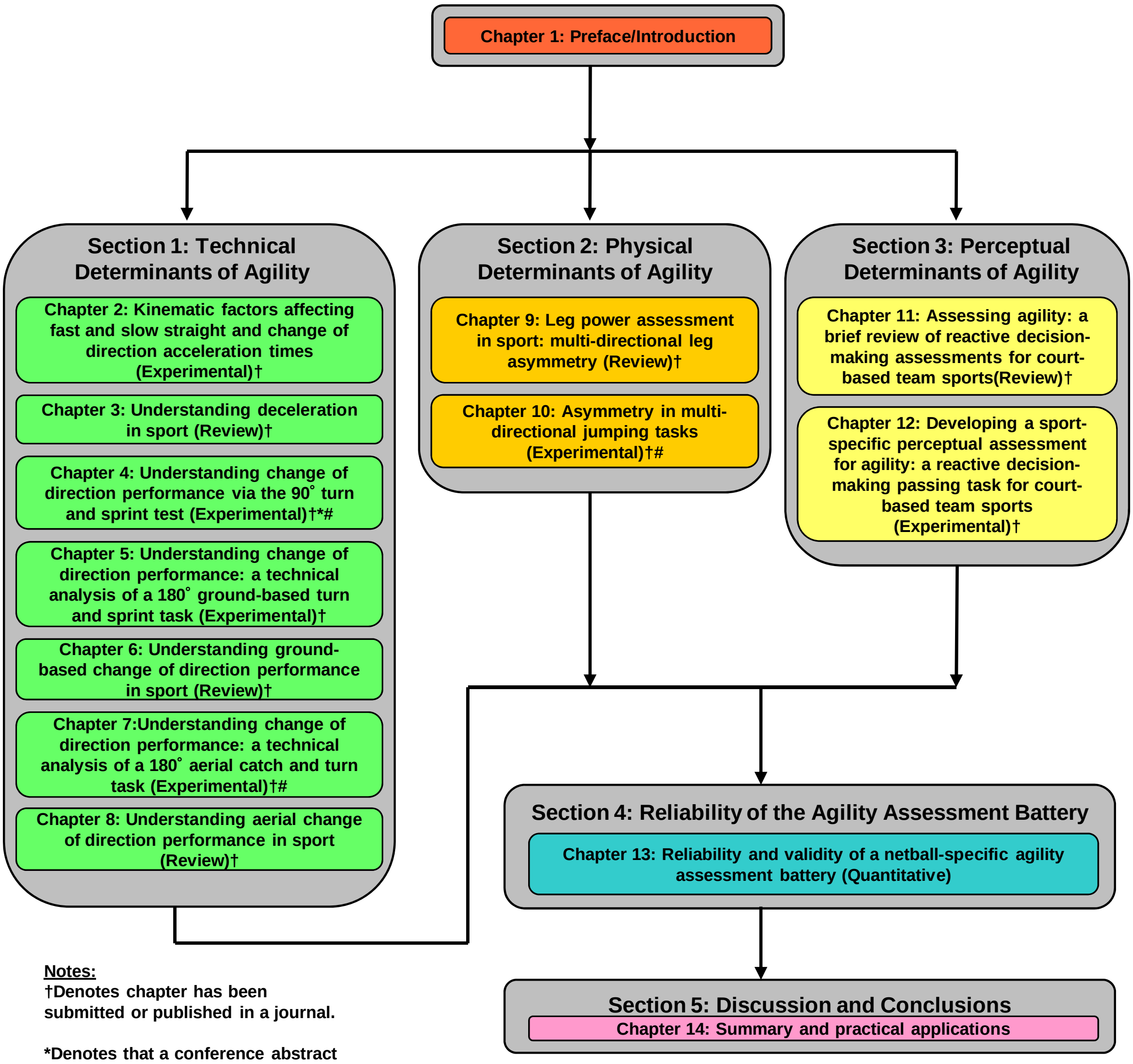
There is an abundance of research that has investigated straight sprint ability [18-21]. However, most of this research measures sprint performance over long distances (10 - 100 m), the mechanics of which is unlike sprinting over shorter distances. For sports like netball the first few steps are pivotal in driving onto the ball and/or freeing oneself from an opponent. Sprinting in netball is further constrained by the dimensions of the court and that most players are only allowed in one (10 m) to two thirds (20 m) of the netball court dependent on their position. Given this information it would seem evident that understanding the kinematics of the first few steps (2.5 m) of a straight sprint and comparing it to other movement tasks may offer more sport specific assessment and training information. Certainly no research has taken this approach in any great detail for court based sports like netball, addressing this limitation another aim of this thesis

The third component of agility (perceptual/decision-making) is a difficult quality to accurately assess in a lab and field setting while maintaining both validity and reliability. As a result, many studies have focused on maintaining high reliability at the expense of decreased validity/specificity to the sport. For example, a large portion of the literature addressing this component limited the reactive element by reacting to two-dimensional stimuli such as pre-recorded video clips of a specific movement sequence or LED lights indicating a specific event [22, 23] and verbal and/or physical responses that would not be performed by the player in competition (e.g. pointing, pushing a button, moving to a general location, etc.) [24, 25]. While this approach offers high reliability as the same video clip is presented to all participants, it is unlikely that a player will react the same when responding to a two-dimensional image out of context as they would to game-based contexts involving players which are inclusive of the many additional environmental cues that would be lacking in the more controlled lab-based setting [26]. Therefore the information gained from such assessments and transference to sport can be questioned. Of interest therefore, is whether a netball-specific reactive decision-making assessment could be developed that has high ecological validity as well as high reliability. While using a pre-recorded video of player movement sequences will increase the reliability in decision-making across players, the main objective of the agility assessment battery is to create a cost-effective netball-specific test of agility performance that maintains high validity and transference to the sport across all tasks. Once more to the knowledge of the authors no research has taken such an approach, addressing this limitation another aim of this thesis.

Organization of the thesis

The thesis has been divided into five sections (see Figure), each containing a series of related papers and literature reviews that have contributed to the development of the agility assessment battery (see Appendix 3). Each individual chapter has also been submitted to or will be submitted to a per-reviewed journal for publication, therefore some repetition of foundational terms (e.g. agility) and themes (e.g. key technical feature template) may be observed. As this research was designed to provide netball coaches and strength and conditioning professionals with an assessment battery that identified strength and weaknesses in players' agility performance, a survey (see Appendix 1) was first developed and administered to 52 Netball New Zealand coaches, strength trainers and administrators to gain a better understanding of the areas of agility performance that were of greatest importance to the development of players. The results of this survey were presented as "Technical Report No. 1 for Netball New Zealand" (see Appendix 2). The agility assessment battery testing protocol was developed based on these results and was presented as "Technical Report No. 2" (see Appendix 3).

Assessing and Developing Agility in Netball players



Notes:
†Denotes chapter has been submitted or published in a journal.

*Denotes that a conference abstract and poster/presentation resulted from this chapter.

Appendices

Appendix 1: Agility survey
Appendix 2: Technical Report 1 - Needs analysis of agility in New Zealand netball players
Appendix 3: Technical Report 2 - Netball-specific agility assessment battery testing protocol and initial results
Appendix 4: Fact Sheet 1 – Accelerating from a static start and following a change of direction
Appendix 5: Technical Report 3 - Preliminary change of direction assessment and initial findings
Appendix 6: SESNZ Conference Abstract (2008) – Assessing change of direction techniques in netball players
Appendix 7: Fact Sheet 2 – 90˚ ground-based change of direction
Appendix 8: Fact Sheet 3 – 180˚ ground-based change of direction
Appendix 9: Technical Report 4 - Developing an aerial change of direction test for netball players
Appendix 10: SPRINZ Conference Abstract (2010) – Developing a netball-specific aerial change of direction assessment task
Appendix 11: Fact Sheet 4 – 180˚ aerial change of direction
Appendix 12: Technical Report 5 - Assessing leg power capabilities in netball players
Appendix 13: SESNZ Conference Abstract (2009) – Leg asymmetries between various direction-based movement tasks in netball players
Appendix 14: Fact Sheet 5 – Leg power asymmetry
Appendix 15: Technical Report 6 - Developing a reactive decision-making passing test for netball players
Appendix 16: Fact Sheet 6 – Reactive decision-making
Appendix 17: Technical Report 7 – A compilation of regional netball testing feedback for the netball-specific agility assessment battery
Appendix 18: Technical Report 8 - An individualised agility profile for netball players

Figure 2: PhD flow diagram.

Section 1 addressed the technical component of agility focusing on both ground-based and aerial-based change of direction movements. As there was a paucity of research focusing on the technical strategies employed by players when performing sport-specific movement tasks, experimental studies were conducted first for this section, wherein the associated literature review was reflective of the findings presented in the experimental studies. As rapid increases and decreases in velocity are performed in conjunction with directional changes (ground-based or aerial), the first two chapters (Chapters 2 and 3) in this section along with the Fact Sheet 1 (Appendix 4) investigated the underlying kinematics that were associated with safe and effective acceleration and deceleration performances. A preliminary study was conducted to investigate the 'natural' ground-based change of direction strategies of netball players when performing various movement tasks (90˚ turn and sprint, 180˚ turn and sprint and a 5 m up and back sprint) commonly performed throughout a netball game [27]. The initial results from this study were presented as Technical Report No. 3 for Netball New Zealand in Appendix 5. Due to the paucity of literature investigating the technical qualities in various ground-based change of direction movements, Chapters 4 and 5 report on the technical performances of 90˚ and 180˚ ground-based change of direction tasks. Within these two studies, five key technical features have been identified that were consistently present in superior performances (i.e. faster, balanced, first ground contact parallel to the new direction) but absent in the lesser skilled. These two chapters combined with the associated Appendices (6 -8) contributed to the ground-based change of direction review article (Chapter 6), which was written to improve the understanding of the technical characteristics required when performing rapid and effective ground-based change of direction movements in sport.

While many agility movements in sport are ground-based in nature (e.g. cutting, turning, accelerating, decelerating, etc.), aerial maneuvers also play a large role in sport yet are often overlooked in research. Similar to ground-based change of direction movements, a paucity of literature has been published where the focus has been the technical characteristics associated with aerial changes of direction in sport. Therefore, a preliminary experimental study was conducted to assist in the development of an aerial change of direction assessment specific to netball. The technical results of a novel aerial catch and turn task wherein players grabbed an elevated netball (attached to a quick-release bungee) and completed a pass to a designated target player are presented in Chapter 7 (and Appendices 9 – 11). The technical strategies employed by superior aerial change of direction performances (full 180˚ rotation prior to a bilateral, parallel landing) were highlighted in this chapter. The aerial change of direction review article (Chapter 8) detailed the underlying biomechanical principles that support the key technical features identified in the two previous chapters. From the information provided in this section, coaches and strength trainers can identify those technical characteristics (e.g. ground contact, step length, body segments alignments, etc.) that are lacking in their own players' performances and adjust training programmes accordingly to better target the weaknesses.

Section 2 addresses the physical component of agility. There are many different facets and approaches to assessing physical performance in players (i.e. performance times, maximal strength tests, isokinetic testing, sprinting, vertical jump assessments, etc.). The no-stepping rule in netball is often a concern to coaches and strength trainers as the intense torques and forces associated with landing place the player's lower limbs in a compromising position. As a result, limiting the potential for injury when performing powerful and explosive unilateral movements was of particular interest to this author. There is an abundance of literature that has examined leg power and strength qualities, so this section took a slightly different focus and reviewed literature that examined multi-directional leg power assessments as a means of determining the magnitude of imbalances between legs (Chapter 9). The limited assessment of multi-directional leg asymmetries in previous literature, and the effect that larger asymmetry magnitudes (>15%) are likely to have on the injury potential in players led to the development of the experimental study on multi-directional leg power and asymmetry profiling when performing explosive unilateral jumping tasks (Chapter 10 and Appendices 12 - 14).

Section 3 addresses the perceptual component of agility. Assessing perceptual/decision-making ability in players is a difficult task as each decision is made dependent upon the current sporting situation. As a result, replicating these ever-changing situations in a laboratory setting becomes somewhat of a challenge. The more standardized a task becomes, the greater the reliability of that task. However, the further each task deviates from the original sporting context, the less validity and transference the task will have to the sport. Chapter 11 reviews different approaches to assessing reactive decision-making ability in court-based team sports. As validity to the sport was a high priority when developing this assessment battery, a relatively simplistic yet sport-specific reactive passing task was developed for this thesis. Testing protocol and initial results of the reactive decision-making task are presented in Appendices 15 and 16, while Chapter 12 provides a more thorough analysis and interpretation of this assessment task.

When developing the agility assessment battery, several testing sessions were conducted as the battery became more refined. A series of technical reports outlining testing results and feedback pertaining to each of the three components is provided in Appendices 17 and 18. The first report (Appendix 17) consisted primarily of feedback regarding the three components within each task in the assessment. The results and feedback regarding individual player performances of the comprehensive assessment battery are presented in Appendix 18. Suggested areas that training should be focused are also included in these two technical reports.

The reliability of the individual assessment tasks within the battery is provided in section 4 of this thesis (Chapter 13). Qualitative templates were created for both the ground-based and aerial change of direction tasks, to enable consistency in rating technical criteria thought important to completing the movements of interest efficiently. Additionally, when performing the single-leg countermovement jumps, proper jumping technique should be enforced across all players, e.g. players should avoid hip and knee flexion while airborne (tucking the knees to the chest), particularly in the vertical jumps, as this will alter the time in the air and the resulting jump distance. The reactive decision-making passing task had the greatest variability. While this task focused on the decision and movement times of players, perhaps the appropriateness of pass selection and the timing of the pass release in relation to the opponents and teammates would be of greater importance to coaches and trainers. Additional practical applications are presented in Section 5 (Chapter 14).

Significance of the thesis

For sports like netball that are played in a confined space and involve many multi-directional movements, the ability to react and change direction quickly is thought desirable. Given the importance of agility in netball the National Sporting Organisation Netball New Zealand has investigated resources in developing understanding in this area. The issues relating to the assessment and development of agility performance are seminal not only to netball but to many other sporting and athletic tasks, and hence central to sport science research. To aid development in this area, research into agility needs to be systematic and disseminate findings in relation to: 1) the development of a technical/mechanical understanding of the movements of interest; 2) understanding the leg power requirements and addressing asymmetries of different sports/positions; and, 3) the development reactive decision-making tasks that provide sport and context specific information about player ability. The aim of the series of studies presented in this thesis is to contribute to each of these three areas.

Limitations

The primary limitation of the research was access to elite (National Senior) and sub-elite (National age group and Franchise) netball players. As the research was aimed at identifying "ideal" performance in many facets, high quality players were needed. Due to the demanding schedules of elite and sub-elite level netball players, regular access to large number of players at any time throughout the three plus years of this research (regardless of training season) was problematic.

Delimitations

In the process of designing the completed research projects, the following delimitations were imposed:

1. All participants were current members of intermediate, sub-elite or elite level netball training squads.

2. All participants were required to complete an informed consent prior to participation in the testing session.

SECTION ONE: TECHNICAL DETERMINANTS OF AGILITY

Chapter 1 outlined how knowledge of the technical, physical and perceptual decision making components of agility are important. In this section the five studies aim to improve knowledge of the technical requirements associated with netball specific movements.

CHAPTER 2

KINEMATIC COMPARISON OF STRAIGHT AND CHANGE OF DIRECTION ACCELERATION TASKS

This chapter comprises the following paper:

Hewit, J., Cronin, J.B., & Hume, P.A. *Kinematic comparison of straight and change of direction acceleration tasks*. Submitted to *Journal of Strength and Conditioning Research.*

Author contributions - JH: 85%, JC: 10%, PH: 5%.

Prelude

This article focuses on acceleration over distances specific to netball. Previous acceleration research has focused on straight acceleration (SA) ability over distances in excess of 10 m. However, accelerations in netball often require players to accelerate and decelerate over minimal distances (2.5 to 5 m) and between consecutive directional changes. Technical cueing regarding straight and change of direction accelerations (CODA) are likely to differ greatly between tasks and as compared to longer distance accelerations. The aim of this study was to determine what kinematic factors affected fast and slow SA and CODA times as well as those factors that were different between tasks.

Introduction

The ability to travel from one point to another as quickly as possible is a desirable quality and prerequisite to success in many activities and sports. As illustrated in Young et al.'s [5] deterministic model of agility (see Figure 3), straight sprinting speed is one of the main qualities that contribute to the effectiveness of a change of direction performance. Team sports that are performed on a court or field often require numerous bouts of rapid increases and decreases in velocity (i.e. acceleration and deceleration) [28, 29] due to the defined area of play as well as to pursue or evade other players or objects. Players will be required to accelerate from a static start (i.e. straight acceleration) as well as immediately following a rapid directional change (i.e. change of direction acceleration). Furthermore the sprints in many sports will take place over very short distances i.e. less than 10 m.

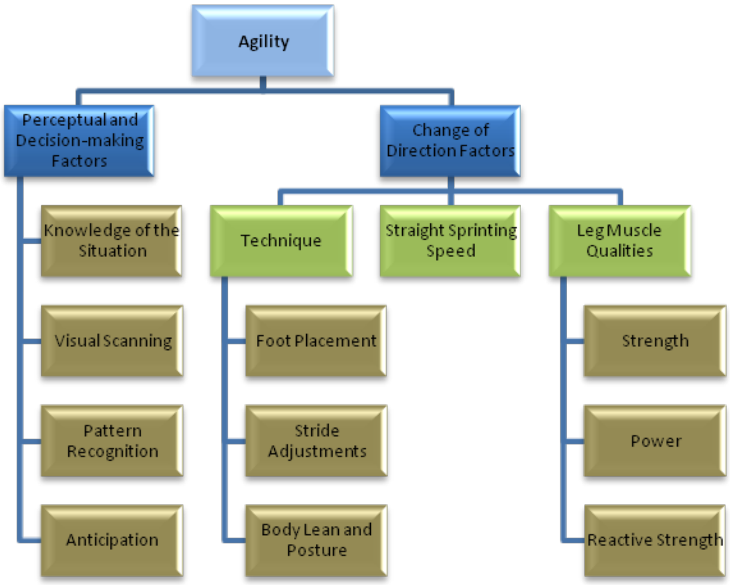


Figure 3: Deterministic model of agility (adapted from Young etal. 2002).

While there is literature that investigates the kinematics and kinetics of acceleration [18, 30, 31], these analyses are performed using straight-line movements over distances (50-200 m) that are for the most part unrelated to many sports, particularly court based sports [32-39]. That is, in many sports players are often required to accelerate between consecutive changes of direction and as a result, the kinematics of importance are over the first few steps. Therefore, a court-based player will most likely not attain anywhere near their maximum velocity before having to decelerate and change direction again. As a result, a player who is able to excel in straight-line sprints may not have the same success accelerating out of a rapid change of direction (COD) and vice versa. This may be especially the case for larger players who have greater inertia (resistance to motion) to overcome and once moving, have momentum (mass x velocity) to control.

Research investigating the relationship between straight line acceleration ability and COD ability (i.e. performance times) has shown little correlation between the two [5, 16, 40, 41]. This is to be expected as the technical characteristics required for each movement task (e.g. step length, step frequency, body positioning, etc.) are likely to differ greatly. To the knowledge of these authors, no research has been published comparing the individual technical characteristics or kinematics between sports or tasks. For example, body positioning when accelerating is likely to vary markedly between a field hockey player with the ball on the ground (e.g. increased torso lean and hip and knee flexion) to a netball or basketball player where the ball is elevated off the ground (e.g. more erect torso with decreased hip and knee extension). When training COD acceleration (CODA) in athletes appropriate "cueing" (e.g. decrease the length of steps, keep the torso up, etc.) from coaches is thought necessary in order to optimise performance, and therefore research in this area is needed.

While COD movements are often performed in succession to one another in court-based sports, it is hypothesized that body positioning and stride characteristics when accelerating between COD movements differ greatly when compared to straight acceleration (SA) with no additional alterations to direction or velocity. In their research investigating top running speeds of males and females, Weyand et al. [42] found that faster performances were a result of increased ground reaction forces and more rapid repositioning of limbs. The longer the free leg is in the air, the longer the duration before a ground reaction force is applied to change direction. Therefore an increased hip angle at contralateral takeoff combined with an abbreviated step length is hypothesized to be associated with better CODA performance. An increased forward lean typically associated with SA performances would result in an increased takeoff distance as the centre of mass is brought forward of the takeoff leg, and would contribute to a longer step length and result in a longer interval between propulsive foot strikes [18, 43-45]. Additionally, a decreased forward lean (smaller torso angle) would position the COM closer to the base of support, increasing stability when completing rapid changes of direction. Therefore, it was hypothesized that a decreased forward lean would be present in the better CODA task performances. Given these hypotheses the primary purpose of this article was to compare the stride characteristics and body positioning adopted by faster and slower court-based team players during the first three strides when accelerating in a straight line (i.e. SA) with that of the acceleration following a rapid 180˚ ground-based COD movement. The secondary purpose was to identify key technical features associated with CODA to assist coaches and strength and conditioning coaches in their understanding of how to condition and "cue" for more effective CODA ability.

Methods

Experimental approach to the problem

This study analyzed the technical differences in two acceleration tasks: 1) straight acceleration (SA) – a 5 m straight sprint from a static start with a 2.5 m split time; and, 2) change of direction acceleration (CODA) - a rapid 180° ground-based change of direction from a static start followed immediately by a 2.5 m straight sprint (commonly performed throughout various court-based sports such as netball and basketball). In order to elicit a 'natural' acceleration performance from each player, specific instructions about the tasks were kept to a minimum and each subject was instructed to "perform the tasks as fast as you can, as if you were in a game". High speed video was used to quantify torso and hip angles, and step length through the first three steps of the acceleration phase for each task. Players were divided into two groups based on performance times and the kinematic variables of interest statistically compared for inter-group differences.

Subjects

A total of 22 players from the National under-21 training squad participated in this study. Testing took place in the morning during a pre-season training camp. At the time of testing, all participants were free of injury. Prior to completing the warm-up, the age (19.3 ±1.1 years), height (1.79 ±0.06 m), and body mass (77.1 ±1 kg) were recorded for each player. The human research ethics committee of AUT University approved all procedures before commencing the study. Prior to participation, an informed written consent was obtained from each athlete.

Equipment

Three sets of dual beam timing lights (Swift Technologies, NSW, Australia) (60 m high) and a 300 Hz high speed video camera (Casio EX-F1, Casio Computer Co., LTD, Tokyo, Japan) were used for data collection (see Figure 4). The players' start mark was designated by a 1 m long piece of floor tape. The timing lights were placed 2 m apart at 0.3 m from the start mark, 2.5 m beyond the start mark and 5.0 m beyond the start mark. The high speed camera was placed 5.5 m away from the start mark, perpendicular to the sprinting direction and calibrated using a calibration board of known measurements facing the camera at the start-mark. Video was analyzed using a combination of Quick Time 7 Pro (Apple Inc.) and SiliconCoach Pro software (Dunedin, New Zealand). Sprint and split times were recorded from the timing gates following each trial.

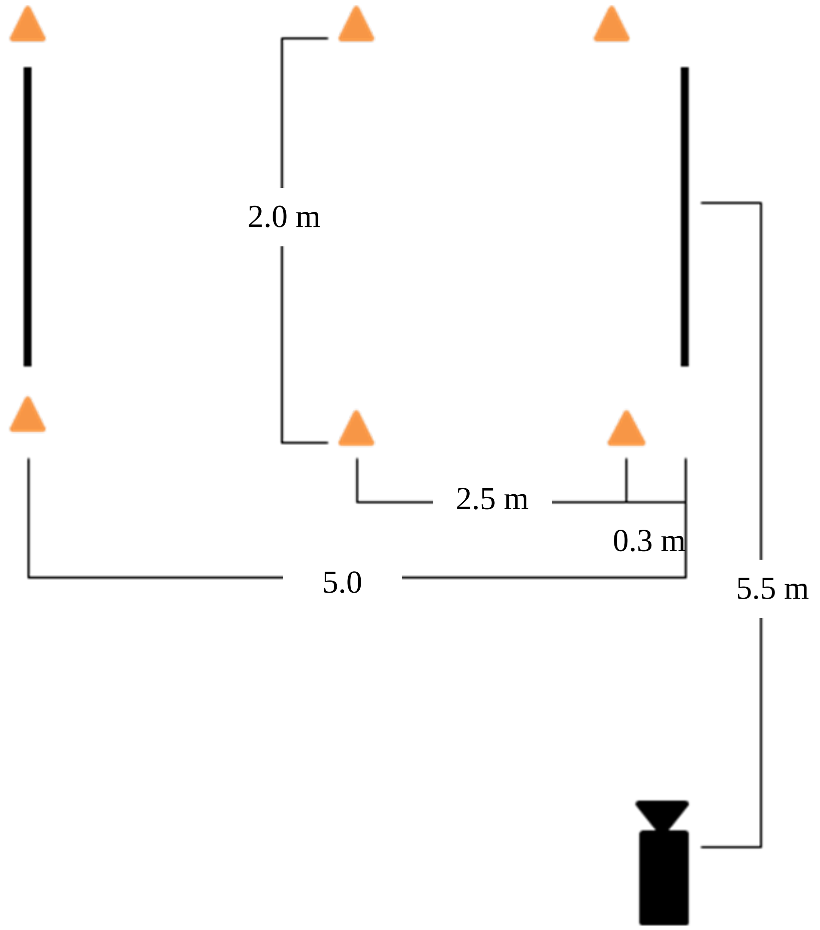


Figure 4: Diagram of the testing set-up for the straight acceleration and change of direction acceleration tasks.

Testing procedures

Testing was performed within one session on an indoor sprung wooden netball court. Following a standardized warm-up, markers were placed at the following locations for analysis: acromion process, greater trochanter, lateral epicondyle and lateral malleolus. Players were allowed up to three practice trials of each of the two movement tasks prior to data collection. For the SA task, players began in a parallel stance with both toes at the start mark. When ready, the player sprinted with maximal effort through all three timing lights.

Once all players had performed three trials of the SA, three trials of the CODA task were performed. For the CODA task, players began with their heels placed at the start mark. When ready, the players performed a 180˚ turn followed immediately by a 2.5 m straight sprint through the second timing light. A 30 s recovery was taken by each player between trials for both tasks. All players were instructed to perform the task as quickly as possible, however verbal instruction regarding technique was not provided so as to elicit 'natural' acceleration performances from each player.

Data analyses

Players were ranked based on 2.5 m times (averaged across three trials) and grouped into two categories; faster (n = 11) and slower (n = 11). Video was advanced frame by frame to code the events of interest. Performance times (for the three trials) were averaged together for both tasks. Torso angle (TOR) (from the torso to the vertical) (see Figure 5), hip angle (HIP) (from the thigh up to the horizontal) of the free leg at contralateral foot takeoff (see Figure 6), and step length (SL) were measured for the first three steps of both tasks. Average step frequency (SF) was calculated by the time from when the takeoff foot (second foot) left the ground at the start of the sprint to the ground contact of the third step. These four variables were of particular interest as they were thought to vary considerably between the two tasks, yet be observed by the naked eye for immediate feedback by coaches when analyzing player performances during training sessions. As data consisted solely of performance times and video analysis, any reference to forces or body weight distribution is purely observational and not the result of force plate data.

Figure 5: Description of torso angle as measured from the vertical.

Figure 6: Description of hip angle as measured from the horizontal.

Statistical analyses

Average performance times, SL, SF and joint angles were calculated across the three trials for SA and CODA. Performance times are presented as means and standard deviations (SD). Coefficient of determination (r^2), paired t –tests, and independent t-tests were used to compare the faster and slower groups on the variables of interest. Statistical significance was set at $p \leq 0.05$.

Results

The squad rankings for SA and CODA tasks based on 2.5 m times can be observed in Table 1. Those players with faster 2.5 m times in the SA task, didn't necessarily perform equally fast in the CODA task ($r^2 = 0.15$). Five out of the 22 players dropped from the faster group in the SA task to the slower group in the CODA task. Five players also improved from slower in the SA task to faster in the CODA task.

Table 1: Squad rankings for mean ±SD of straight acceleration (SA) and change of direction acceleration (CODA) 2.5 m times for faster and slower groups.

	Player	SA 2.5 m	Player	CODA 2.5 m
Faster	**1**	0.72 ±0.02	**2**	0.59 ±0.06
	2	0.74 ±0.02	**1**	0.61 ±0.02
	17	0.76 ±0.02	**18**	0.61 ±0.04
	11	0.76 ±0.03	**11**	0.61 ±0.05
	12	0.77 ±0.06	**16**	0.61 ±0.04
	4	0.78 ±0.01	**4**	0.62 ±0.04
	3	0.78 ±0.01	**12**	0.62 ±0.04
	6	0.78 ±0.03	**19**	0.62 ±0.02
	7	0.78 ±0.01	**9**	0.64 ±0.02
	22	0.78 ±0.01	**3**	0.64 ±0.02
	10	0.79 ±0.04	**5**	0.64 ±0.04
	Group mean ±SD	***0.77 ±0.02***	***Group mean ±SD***	***0.62 ±0.01***
Slower	**16**	0.79 ±0.02	**10**	0.64 ±0.04
	19	0.79 ±0.02	**8**	0.65 ±0.01
	9	0.81 ±0.03	**13**	0.65 ±0.01
	14	0.81 ±0.02	**7**	0.66 ±0.01
	20	0.82 ±0.01	**6**	0.67 ±0.04
	13	0.83 ±0.01	**21**	0.67 ±0.04
	5	0.84 ±0.07	**15**	0.67 ±0.04
	8	0.85 ±0.01	**17**	0.67 ±0.01
	18	0.86 ±0.02	**14**	0.68 ±0.02
	21	0.86 ±0.02	**22**	0.69 ±0.05
	15	0.89 ±0.01	**20**	0.71 ±0.04
	Group mean ±SD	***0.83 ±0.03***	***Group mean ±SD***	***0.67 ±0.02***

In terms of the group comparisons, only one variable differed significantly between groups for the CODA task. There was a significantly higher average step frequency (4%, $p = 0.03$) for the faster group when compared to the slower group (see Table 2).

For the SA task, faster times were associated with significantly smaller average step lengths (7%, $p = 0.03$), greater torso angles (i.e. greater forward lean; 30 - 37%, $p < 0.001$) and smaller hip angle (higher knee lift) in the first step (21-22%, $p = 0.00$). On average, the faster group had smaller step lengths, higher average step frequency and a higher knee lift than the slower group.

Table 2: Kinematic values averaged across groups and tasks presented as the mean ±SD.

		SA	CODA
Faster Group	SL (m)	1.12 ±0.10[1,3]	0.89 ±0.07[3]
	SF (Hz)	5.45 ±0.42	5.55 ±0.21[2]
	2.5 m time (s)	*0.77 ±0.02*	*0.62 ±0.01*
Slower Group	SL (m)	1.20 ±0.06[1,3]	0.93 ±0.05[3]
	SF (Hz)	5.22 ±0.26	5.31 ±0.22[2]
	2.5 m time (s)	*0.83 ±0.03*	*0.67 ±0.02*

SA = straight acceleration, CODA = Change of direction acceleration, SL = step length, SF = step frequency. Significant difference: [1]fast and slow average SL for the SA task, [2]fast and slow average SF for the CODA task, [3]average SL between SA and CODA tasks.

With regards to the task comparison, the SA task was associated with significantly longer average step lengths (21-23%, p = 0.00) (see Table 2) as well as significantly longer SL across all three steps than the CODA task (17 – 27%, p < 0.001) (see Table 3). Additionally, a significantly larger torso angle was associated with the first step of the SA task (34%, p < 0.001) as well as significantly smaller hip angles (higher knee lift) for the first and second step of the SA task (11-22%, p = 0.00 and 0.04, respectively).

Discussion

Acceleration in court-based team sports such as netball and basketball are typically confined to a relatively small area which is defined by boundary lines and/or opponents. Players are often not able to accelerate for more than 2.5 – 5 m before an evasive COD is required. However, the majority of research addressing acceleration technique is from a static start over more than 5 m (i.e. more reflective of track sprinting ability as opposed to game speed ability) [18, 32, 33, 35-39]. As the objectives of acceleration movements performed across sports vary considerably, it is likely that SA technique also differs considerably to that of the more sport-specific CODA technique. Consequently, the primary purpose of this article was to compare the stride characteristics and body positioning adopted by faster and slower court-based team players during the first three strides when accelerating in a straight line (i.e. SA) with that of the acceleration following a rapid 180˚ ground-based COD movement (i.e. CODA).

Table 3: Average kinematic values of each step for the straight acceleration (SA) and change of direction acceleration (CODA) tasks presented as the mean ±SD.

		SA			*CODA*		
		SL (m)[4]	**TOR (°)**	**HIP (°)**	**SL (m)[4]**	**TOR (°)**	**HIP (°)**
Faster Group	1st step	0.95 ±0.03[1]	39.3 ±6.6[2, 5]	28.0 ±8.4[3,6]	0.74 ±0.08	27.5 ±6.0[5]	35.4 ±10.1[6]
	2nd step	1.10 ±0.11[1]	37.0 ±6.2	29.3 ±5.2[7]	0.92 ±0.08	34.6 ±4.6	33.7 ±6.0[7]
	3rd step	1.31 ±0.11[1]	32.3 ±4.8	25.5 ±4.0	1.00 ±0.11	34.8 ±3.4	29.1 ±3.4
Slower Group	1st step	1.00 ±0.09[1]	38.0 ±7.3[2]	32.4 ±5.7[3,6]	0.81 ±0.06	23.9 ±7.0	41.5 ±9.4[6]
	2nd step	1.21 ±0.08[1]	37.3 ±7.7	34.7 ±5.3[7]	0.99 ±0.08	34.6 ±7.3	37.9 ±5.3[7]
	3rd step	1.40 ±0.09[1]	33.1 ±7.3	29.9 ±5.7	1.03 ±0.10	31.7 ±5.1	31.2 ±7.9

SA = straight acceleration, CODA = change of direction acceleration, SL = step length, TOR = torso angle, HIP = hip angle. Significant differences: [1]SL of SA between groups, [2]first torso angle of SA between groups, [3]first hip angle of SA between groups, [4]SL between tasks, [5]first torso angle between tasks, [6]first hip angles between tasks, [7]second hip angle between tasks.

When the kinematics (i.e. step length, hip and torso angles) of each group were compared, several differences were observed between the SA and CODA tasks. Unlike Mann and Herman [18] who reported 3% longer step lengths in faster straight sprinting performances, abbreviated average SL as well as individual SL's (7-8%) were observed in the faster SA performances in the present study. While average SF was not significantly different between groups for the SA task ($p = 0.13$), it may be speculated that the higher SF of the faster group was that which differentiated the two groups (i.e. since velocity = SL x SF). In terms of increasing player first step quickness, it would seem that cueing faster SF or conversely teaching players not to over stride may optimize 2.5 m sprint performance.

While average SFs in the present study were greater than that reported in previous research (4.01 to 4.45 Hz - [18, 37]), the sample of participants and data collection varied greatly to that of the present study. The participants of the current study were female court-based sport players while previous research was conducted using Olympic level male sprinters [18] and male athletes from various field sports[37]. Track speed is different to sport speed [3, 46-48]; most players achieving maximum velocity in a shorter distance compared to track athletes. It is likely that those athletes that need to accelerate quicker over shorter distances would have different step kinematics i.e. SF. Additionally, in both of these previous studies, the SFs were calculated during a mid-section of a sprint greater than 10 m from the start of the task (a paucity of research has investigated acceleration kinematics over 2.5 – 5 m), whereas the present study reported SFs over the first three steps from a static start. These two factors, likely contributed to the difference in reported SFs.

The faster players also had a higher knee lift (decreased hip angle) and increased torso angle (increased forward lean) in the SA task. A higher knee lift at takeoff would increase the time the free leg is spent in the air, thereby allowing for a larger SL to be attained through each step. However, this was not the case for the faster athletes and in fact their SL was significantly less than the slower players. It can only be speculated that even though there was higher knee lift, the velocity of limb movement was quicker in the fast group (e.g. SF), the product being a leg that drives down into the ground further, faster and more rearward. It is likely that greater propulsive ground reaction forces are the resultant, however further analysis (e.g. force plate) would be needed to investigate this contention.

During the acceleration phase of straight-line sprinting, a forward lean of the torso up to 45˚ has been reported as being 'optimal' [31, 32, 34] in elite-level sprinters. The SA torso angle in the current study (32.3 – 39.3˚) was similar to that reported in previous research by Atwater et al. [31] (15 - 45˚) over the first three steps of a SA performance in elite sprinters. An increased forward lean (increased torso angle) at takeoff in the SA task assists in the ability to accelerate as the body's centre of mass is brought ahead of the base of support. This allows for increased horizontal propulsive forces to be applied into the ground [39] at takeoff.

In terms of the task comparisons, when performing the SA task all players had longer SLs, increased torso angle for the first step, and decreased hip angles for the first two steps than observed for the CODA task. When a player is accelerating following a rapid COD, the free leg must first rotate around into the new direction prior to driving upwards. In contrast, during the SA task the knee can be driven upwards immediately following takeoff. As a result, a higher knee lift (as observed in the SA task) allows more time for the lower leg to extend into a longer SL. The longer the free leg is airborne through the swing phase, the longer it will take before a horizontal or lateral force can be applied into the ground for a COD movement. The increased forward lean associated with the SA task allows for increased stability as well as horizontal propulsive forces into the ground at takeoff [39]. Therefore, the more erect posture associated with the CODA task (i.e. an abbreviated step length, decreased forward lean and decreased knee lift) will be more advantageous when performing consecutive COD movements, as the free leg is able to be repositioned earlier for the next ground contact.

Interestingly, players that performed well in one task, didn't necessarily perform equally well in the other task (as observed by the low shared variance of performance times and task). This finding is reinforced by the data in Table 1 where quite substantial differences in rankings between the SA and CODA tasks can be observed for some players. The value of such an analysis is in the ability to diagnose athletes that have straight acceleration or change of direction limitations. Identifying either as a problem will thereafter involve very different strategies by the coach and/or strength and conditioning coach to remediate the limitations. That is, an athlete that has a faster sprint time but a slower CODA time would most likely benefit from technique training around changing directions. Conversely and athlete with a slower sprint time would most likely benefit from explosive strength and power type training. With regards to the first scenario, where the CODA time is slower, identifying those technical cues that are predictors of faster performance would seem of practical value. For this to occur, a sport-specific approach using a relevant CODA task would seem pre-requisite to identifying those factors that optimize sport specific COD performance. An assessment tool that more closely resembles the movement characteristics required in competition increases both the validity of the assessment itself as well as the diagnostic value to the strength and conditioning coach.

This study has not exhaustively investigated the technical characteristics specific to SA and CODA tasks. Insight into the differences in the technical characteristics when performing two forms of acceleration tasks for faster and slower players have been identified based on kinematic data. Those qualities consistently present in faster performances (e.g. more erect posture at takeoff and decreased step length and knee drive for CODA when compared to SA performances) would seem desirable qualities to emphasize in training sessions for all levels of players. Research is needed to further examine the technical qualities that contribute to faster sport-specific acceleration performances.

Practical applications

The faster players in this study had several kinematic differences between SA and CODA tasks when compared to slower players. As these characteristics are associated with more optimal force productions and resulting velocities through the acceleration phase of sprinting, emphasizing those technical characteristics that were associated with the faster players' SA (decreased SL, increased forward lean and knee lift in the initial step) and CODA (increased SF) performances in the training programmes of all players would likely improve SA and CODA performances, respectively.

The results from this study also indicated that the technical characteristics of SA are not the same for CODA. The goal of SA is to attain maximum velocity as quickly as possible. In contrast, CODA requires players to accelerate as quickly as possible following a rapid directional change and may also occur prior to a subsequent COD movement. As a result, the body positioning and posture differs between the two acceleration tasks (i.e. a more erect posture at takeoff and decreased step length and knee drive for CODA when compared to SA performances). Task-specific training programs that target these features may lead to improved performance times in each respective task as well as increased transference into the sport.

When group means are compared, information regarding individual player strengths and weaknesses is lost. Investigating the inter-squad player rankings in various tasks (i.e. SA vs. CODA) can give insight into the task-specific capabilities of players as well as areas in need of improvement within the movement sequence. Likewise, when raw kinematic values of players are compared, individual technical weaknesses may be identified. As a result programming can be guided to a better effect. While this study investigated only four kinematic features of SA and CODA performances, more research is needed that further examines these characteristics as well as additional kinematic variables (e.g. knee angle at touchdown) over a variety of movement tasks that are commonly performed in sport.

CHAPTER 3

UNDERSTANDING DECELERATION IN SPORT

This chapter comprises the following paper:

Hewit, J., Cronin, J.B., Button, C., & Hume, P.A. (2011). *Understanding deceleration in sport.* Strength and Conditioning Journal. 33(1): 47-52.

Author contributions - JH: 83%, JC: 10%, PH: 5%; CB: 2%.

Prelude

Netball is typified by accelerative and decelerative movement patterns as outlined in Chapter 2. Rapid decelerations can be observed in a wide variety of sports when stopping or as a precursor to a change in direction. Similar to the accelerative phase in netball, these rapid changes in velocity often occur over minimal distance or time and are often in response to external stimuli such as an opponent's movement or boundary lines. Little attention has been given in the literature to the kinematics and kinetics of running deceleration. Given the theme of the thesis around improving the technical understanding associated with various movement patterns, this article aims to enhance the understanding of the mechanical characteristics associated with deceleration performance in sport.

Introduction

There is literature that investigates the kinematics and kinetics of human acceleration while running [18, 30, 31]. However, in many sports, the act of rapidly slowing the body (deceleration) is critical to the success of the movement [34]. Deceleration is often employed in sports that require an immediate or gradual stop or to decrease the body's velocity before a change in direction (horizontal, lateral, or vertical). The forces applied to the body when decelerating can be exceptionally large in magnitude, especially when the time over which these forces must be absorbed is small. Therefore, appropriate technique is essential for not only decreasing the risk of injury but also controlling balance and effectively transferring accumulated elastic energy into the subsequent movements [34, 49]. This article describes some of the key technical features (kinematics and kinetics) associated with deceleration to assist strength and conditioning coaches in their understanding of how to condition and ‘‘cue’’ for better change of direction ability. It should be noted that the information presented in this article is a blending of the available empirical information and the qualitative analysis of elite and sub-elite female netball players.

Deceleration in sport

Deceleration is required after any sprint performance regardless of the relative velocity of the sprint, to slow the body’s center of mass (COM). The amount of time/distance allocated to slow the COM is dependent upon a wide variety of factors determined by the individual requirements of the sport. Team sports (e.g. touch rugby, netball, basketball, soccer, etc) have distinct boundary lines that confine numerous players to a specific area. Deceleration in these sports may occur in response to other players’ movements (marking, evading, or collision avoidance) or to stay within the playing area. Under these circumstances, players will be required to decelerate from varying velocities over a variety of distances and times.

In contrast, individual sports (e.g. tennis, squash, badminton, etc.) require players to accelerate and decelerate very rapidly over short distances primarily in response to the opposition’s shot selection. Irrespective of the sport, it is clear that deceleration plays an important role in both team and individual player performance. This article highlights the differences between acceleration and deceleration in sport, presents qualities of deceleration technique that are important for the safe and effective execution of such rapid changes in velocity, and briefly provides criteria that should assist in exercise selection that enhances the quality of deceleration performances.

Biomechanical differences between acceleration and deceleration in sport body positioning and joint angles

The kinematic characteristics apparent when accelerating and decelerating are similar, with the placement of the limbs in relation to the body’s COM being the primary difference between the two acts (see Tables 4 and 5). The objective of decelerating when moving over ground is to decrease the body’s momentum (mass x velocity) by applying as much force as possible over minimal time to allow a complete stop or movement in a new direction to occur (force x time = mass x velocity) [50].

Table 4: Kinematic differences between the ground contacts of the acceleration and deceleration phases of sprinting (information compiled from Hay, 1993; Dintiman and Ward, 2003; Andrews et al., 1977; Mackala, 2007; Atwater, 1982; and Luhtanen and Komi, 1977).

Kinematic characteristic	**Acceleration phase (0-10 m)**	**Deceleration phase (0-5 m)**
COM in relation to point of contact	Anterior	Posterior
Step length	Short	Short
Step width	Wide	Wide
Step frequency	High	High
Braking phase	Minimized/eliminated	Maximized
Propulsive phase	Maximized	Minimized/eliminated
Joint stiffness	Increased	Decreased
Support phase	Lengthened	Lengthened
Ground contact time	Long	Long
Predominant muscle action through support phase	Concentric	Eccentric
Flight phase	Minimized	Minimized/eliminated

Table 5: Body positioning differences during ground support between the acceleration and deceleration phases of sprinting (information compiled from Andrews et al., 1977; Dintiman and Ward, 2003; and Kreighbaum and Barthels, 1996).

Joint/Body Segment	Acceleration phase (0-10 m)	Deceleration phase (0-5 m)
GROUND CONTACT		
Foot	Ball of foot	Heel strike
Ankle	Primarily plantarflexion	Dorsiflexion
Tibia	Anterior to vertical axis	Posterior to vertical axis
Knee	Flexed to 30-35°	Extended
Hip/pelvis	Flexed to 20-30°	Posterior tilt, slight hip flexion
Torso	45° anterior lean	Erect or posterior lean
Arms	In line with body, elbows flexed	Abduction, elbow flexion (wide)
SUPPORT PHASE		
Foot	Ball of foot	Full foot contact
Ankle	Plantarflexion	Immediate dorsiflexion until tibia passes the vertical axis
Tibia	Anterior to vertical axis	Moves anterior to vertical axis
Knee	Extended	Immediate increased flexion to 90°
Hip/pelvis	Extended	Immediate increased flexion
Torso	45° anterior lean	Erect or posterior lean
Arms	Aggressive contralateral shoulder flexion and extension	Abduction, elbow extension (wide)

Proper joint angles and muscle tension before ground contact are essential to resist the forward momentum. Leg kinematics are crucial to deceleration because of their role as the initial force absorption mechanism. Although a rapid deceleration ideally occurs over a limited number of strides, several shortened gait cycles are used to safely decelerate the body by absorbing the high eccentric forces with as little stress to the joints as possible [10]. Therefore, greater braking forces and ground contact times are typically observed when rapidly decelerating.

Because force can only be applied or generated while the foot is in contact with the ground, the time in air of the non-stance leg during deceleration is limited to allow for extended time on the ground. In contrast to the acceleration phase (see Figure 7a), ground contact of the landing leg during the deceleration phase occurs ahead of the COM (large landing distance—

horizontal distance that the lead leg is ahead of the COM when the foot strikes the ground [28], resisting the forward momentum of the body (see Figure 7b). This is accomplished through hip flexion (to an angle similar to that during the maximum velocity phase) while the knee extends and the ankle plantar flexes [10, 49].

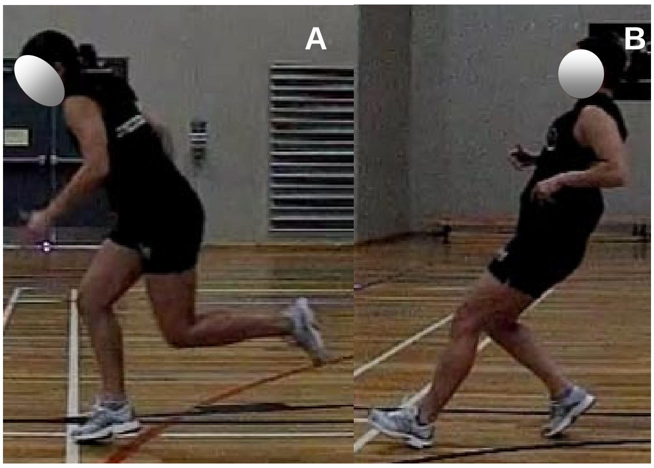


Figure 7: Body positions at ground contact of the acceleration (a) and deceleration (b) phases when sprinting.

To maintain ground contact for as long as possible, the foot initially strikes the ground with the heel (see Figure 7b), creating a horizontal braking force, then rapidly rolls to the forefoot, creating a full foot-ground contact (see Figure 8b) [10]. This is in contrast to the acceleration phase where the forefoot contacts the ground first (see Figure 7a), maintaining an elevated heel throughout the support phase (i.e. minimizing braking forces and maximizing propulsive forces) (see Figure 8a). The support foot during the acceleration phase remains in contact with the ground until the tibia passes ahead of the ankle's vertical axis [10], allowing for a greater amount of negative work (force x displacement) to be absorbed by the legs.

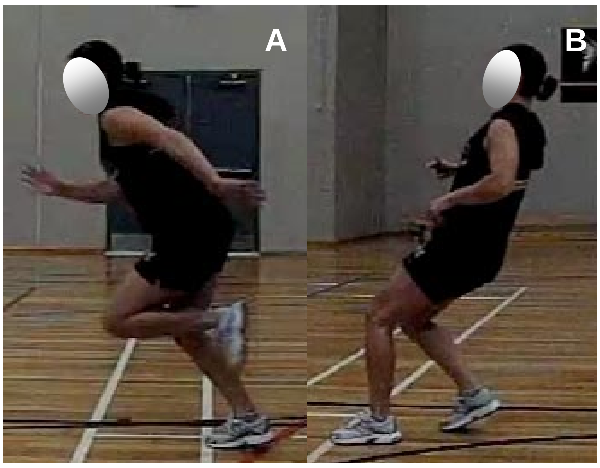


Figure 8: Body positions during the support phase of the acceleration (a) and deceleration (b) phases when sprinting.

Body positioning in the deceleration phase is adjusted to allow for the substantial eccentric forces to be absorbed and dispersed throughout the body [34] (see Table 6). To slow the forward moving COM, several body segments are adjusted when compared with the acceleration phase. The forward lean present in the acceleration phase that allows body positioning for greater horizontal propulsive forces is not evident in deceleration, as the body's momentum must be decreased. The torso assumes a more erect posture (in relation to the lower body) and posterior lean during deceleration, moving the COM posterior to the base of support [10, 50], which results in additional horizontal braking forces. On landing, immediate hip and knee flexion and ankle dorsiflexion occur, dissipating the impact forces over as many joints as possible [34, 49]. This decreases the magnitude of the stress by allowing the muscles to do greater negative work; that is, applying forces over a greater eccentric range of motion.

Although arm action during the acceleration phase is rapid and of large amplitude in the sagittal plane (see Figures 7a, 8a) to counteract the powerful driving action of the legs, during the deceleration phase, arm action velocity decreases to coincide with the lengthened support phase (see Figures 7b, 8b). A relaxed shoulder position and 90˚ flexion at the elbows, observed with both the acceleration and maximum velocity phases, are different to the deceleration phase where increased shoulder abduction may be seen [10, 34].

Primary muscle groups

The primary muscles used for deceleration are the quadriceps and gastrocnemius [10]. However, unlike the concentric contraction of the acceleration phase, these muscle groups work through an eccentric contraction as the impact force is absorbed and dispersed. The relatively extended leg at impact combined with the purely anterior–posterior forces acting on the body place the leg in a potentially compromising position [10, 49]. However, the pre-activation of these two muscle groups before ground contact contributes to the absorption of the substantial eccentric forces (negative work = eccentric force x downward displacement of the COM) that occur during ground contact. The kinetic energy (KE = ½ x mv2) of the body decreases during this phase as the downward (negative) velocity decreases to zero before the propulsive concentric phase. The KE is not lost but rather transferred to elastic energy [34], which is immediately available for a subsequent movement (e.g. change of direction or jump) or dissipated as heat [51] and sound in the case of a complete stop.

Stance phase

As shown in Table 4, the lengths of the support and flight phases are similar between acceleration and deceleration; however, the purpose for each differs markedly between the two movement strategies. When accelerating, the support phase is maximized to generate greater propulsive forces at push-off [46]. However, when decelerating, contact time is maximized, thereby allowing the COM to remain posterior to the base of support longer (i.e. greater and longer landing distances) and to increase the amount and time that energy is absorbed through the legs [10, 34]. The more time that the body is in contact with the ground, the greater the ability of the leg muscles to decrease the momentum and KE of the body by producing greater negative impulse and work [10, 34, 49].

Flight phase

In both acceleration and deceleration, a small flight phase is desired; however, the reasoning behind this abbreviated flight differs again between movement strategies. During the acceleration phase, the greater amount of time spent in the air decreases velocity, as force can only be produced when in contact with the ground. Therefore, the flight phase is kept short as velocity is rapidly increased [31, 52]. In contrast, when decelerating, the absorption of previously accumulated energy and momentum can only take place when in contact with the ground [34, 49]. Additionally, the heel to toe contact observable in the deceleration phase often results in the subsequent foot strike occurring before takeoff, thereby completely eliminating the flight phase.

Ground reaction forces

Similar to the kinematics of deceleration, there has been a lack of research that has investigated the kinetics of deceleration; therefore, the information presented in the following section is primarily anecdotal. The four properties that determine the nature of motion in response to a force (magnitude of force, angle of force application, location of force application, and line of action) remain crucial to the deceleration of a body (see Table 6).

Table 6: Force properties that determine acceleration and deceleration (information compiled from Kreighbaum and Barthels, 1996; and Weaver, 2005).

Property	**Acceleration (0-10 m)**	**Deceleration (0-5 m)**
Magnitude of the force	Large propulsive	Large braking
Angle the force is applied	Approximately 45°	Approximately 135°
Location to the COM the force is applied	Posterior	Anterior
Line of action (GRF) dominant component	Horizontal	Horizontal
Resultant effect on forward momentum	**Increased**	**Decreased**

When accelerating, the large force produced from the ground at takeoff, combined with the posterior force application and decreased angle of application (i.e. the absolute angle created by the horizontal (ground) and the hip at ground contact) (see Figure 9), create a large horizontal force component (propulsive ground reaction force), resulting in an increasing forward velocity [50]. For deceleration, the anterior foot strike to the COM resulting in large forces applied to the ground at greater angles, that is, increased horizontal force into the ground (braking ground reaction force) (see Figure 7b) [50]. The ground reaction force created as a result of the braking force is dissipated through the immediate dorsiflexion of the ankle and flexion of the knee and hip joints, thereby decreasing the magnitude of stress. The combination of these features will result in decreased forward momentum and if repeated, will ultimately result in a full cessation of momentum in that direction.

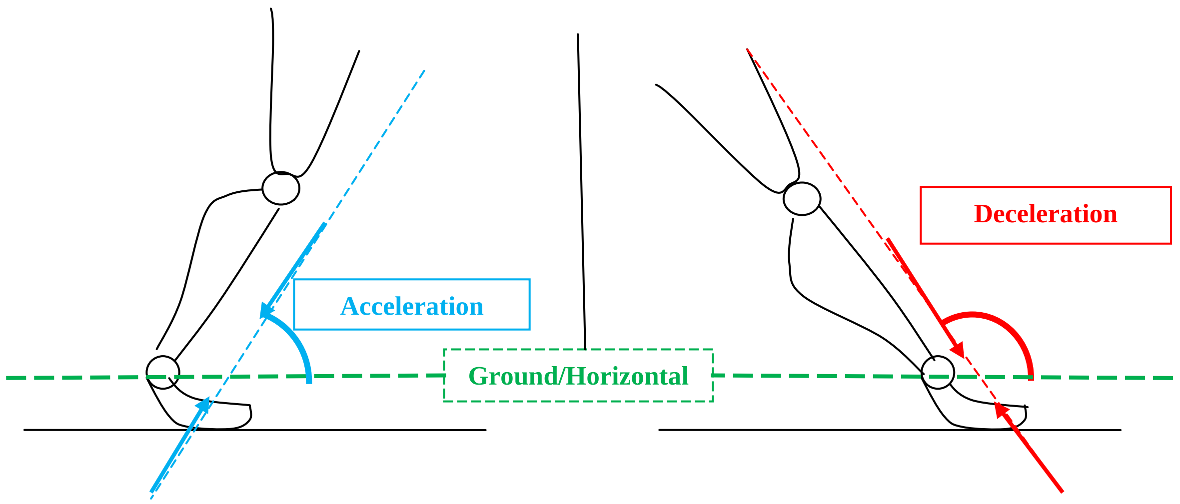


Figure 9: Comparison of the acceleration and deceleration force properties that determine the nature of motion.

Training considerations

The amount of force applied and the time that the foot is in contact with the ground will directly affect the change in momentum, and therefore, velocity is increased or decreased [50]. When accelerating, the impulse developed must be greater than the body's stationary and mobile inertia (resistance to change) in order for an increase in velocity/momentum to occur [50]. The opposite is true when decelerating. In order for a body to decrease its velocity/momentum, the impulse must be greater than the momentum. Therefore, increasing the body's ability to produce greater braking forces is desirable. This can be achieved by 1) increasing the eccentric force capability of muscle via strength training using exercises that accentuate eccentric loading and control (e.g. drop jumps, resisting towing, vest decelerations, etc) and 2) extending the time over which the braking force is applied on landing (i.e. technical cues), resulting in a greater impulse to reduce the velocity/ momentum of the athlete [34]. Additionally, it is important that training stimuli remain as representative of the sporting context as possible. Similar distances (sprinting and deceleration distances or body segment range of motions when strength training), velocities (sprinting velocities or rate of force development when strength training), and directional components should also be incorporated into the eccentric strength training program.

Summary and conclusions

Deceleration in sport is commonly performed throughout the entirety of the event, commonly preceding a rapid change of direction. Unfortunately, there has been a paucity of research investigating the kinematics and kinetics of such critical movements. Although many of the individual step length and step frequency characteristics of acceleration are similar to that of deceleration, it is important to differentiate these two phases of sprinting in both research and coaching as the force, contraction type, and technique demands are dissimilar.

The braking forces incurred during each ground contact when decelerating must be rapidly absorbed throughout the lower limbs. When completing these rapid changes in velocity, athletes need to be given appropriate “cueing” (i.e. “contact ground with heel, mid foot, foot”, “increased knee flexion on landing”, “plant stance leg ahead of body—increase landing distance”, etc.) from their coaches to avoid injury and optimize performance.

Increasing the time that the foot is in contact with the ground allows for the force to be absorbed over a greater amount of time, which should result in decreased stress to the musculoskeletal structure of the lower limbs. However, in many sports, the time taken to decelerate may be the critical determinant of success, so longer deceleration times or decelerating too much before a change of direction is often disadvantageous. High levels of eccentric strength are required in tandem with appropriate training of deceleration technique specific to sporting performance, while the demands of the sport situation determine the critical distance, direction, and time that the deceleration must occur.

CHAPTER 4

UNDERSTANDING CHANGE OF DIRECTION PERFORMANCE VIA THE 90˚ TURN AND SPRINT TEST

This chapter comprises the following paper:

Hewit, J., Cronin, J.B., Hume, P.A., & Button, C. (2010). *Understanding change of direction performance via the 90˚ turn and sprint test*. Strength and Conditioning Journal. 32(6): 82-88.

Author contributions - JH: 83%, JC: 10%, PH: 5%, CB: 2%.

Prelude

Chapters 2 and 3 in this thesis addressed the kinematics and kinetics associated with acceleration and deceleration in sport. Such movements are often performed in combination with rapid directional changes. While research has analyzed the performance times of a variety of movement tasks, the technical analysis of strategies that result in faster change of direction (COD) movement times has yet to be investigated. The aim of this study was to compare three 90˚ ground-based COD strategies to determine if one strategy was superior to the other two. Various fundamental principles of biomechanics were used to analyze the strategies and develop key technical features thought to contribute to superior (i.e. faster, balanced, etc.) 90˚ COD performances. A technical analysis of this nature provides coaches and strength trainers with valuable insight into which strategies appear to result in more effective COD performances in sport.

Introduction

Movement agility has been defined in many different ways (e.g. a rapid whole body movement with a change of velocity or direction in response to a stimulus [1], the ability to change direction or start and stop quickly [4], and any movement involving a rapid change of direction [COD] in response to a sport-specific stimulus [6]. What is clear from these definitions is that agility is multi-factorial in nature and comprised of three main components:

technical, physical, and perceptual [5, 8, 53]. Based on a deterministic model of agility (see Figure 10), it can be deduced that if one of these primary components is missing or lacking, the overall agility performance may be compromised. As indicated in the model, important aspects of agility are the COD factors, which include both leg strength qualities and technique factors. Although there is an abundance of literature on leg strength and power, relatively little is known about optimal techniques for changing direction tasks. Hence, the aim of this article was to explore some of the technical considerations for superior (i.e. faster) COD performance.

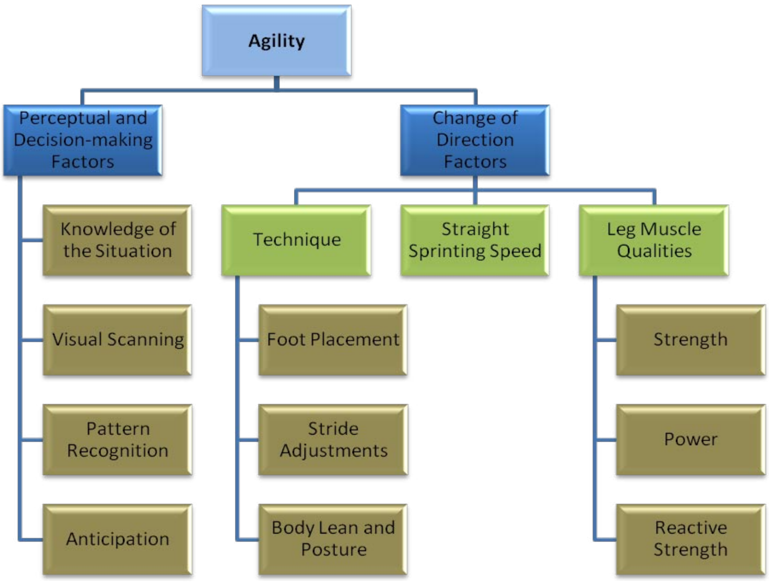


Figure 10: Deterministic model of agility (adapted from Young, 2002).

Strategy 1: False-start pivot

In the false-start pivot (FSP) strategy, the movement is first initiated by taking a small step with the trail leg (right leg) in the opposite direction of the straight sprint (see Figure 11a and 11b). As the player sinks into a wide squat, the left leg (lead leg) externally rotates in the direction of the intended travel (see Figure 11c). The right arm is driven forward and upward across the body, whereas the left arm is driven backward, causing the torso to rotate into the new direction (see Figure 11d). Body weight is then transferred from a relatively equal distribution between the legs to the lead leg. As the trail leg pushes off (see Figure 11e) the body is completely rotated into the new direction, and a straight sprint takes place.

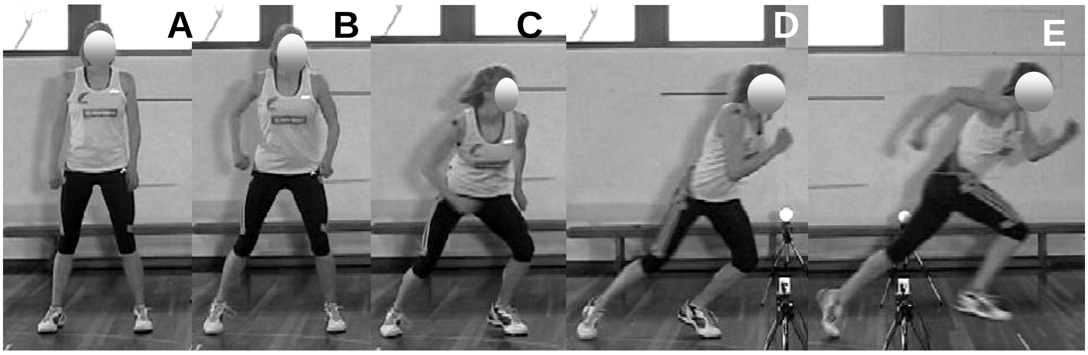


Figure 11: False start pivot (a-e) .

Strategy 2: Forward-moving sidestep

The forward-moving sidestep (FMS) strategy begins with the player first lowering into a small squat (see Figure 12a and 12b). The player then begins transferring their weight from an equal distribution between the legs onto the lead leg (left leg) (see Figure 12c). The arms remain extended at the sides as the athlete begins to lower into a slightly deeper squat. As the player sinks, increasing the forward lean of the torso, they simultaneously abduct their right arm away from their body while both flexing and externally rotating their lead leg (left leg) (see Figure 12d). The player then increases the external rotation at the hip of the lead leg, as the right arm swings low across the body causing the torso to rotate to the left. The trail leg (right leg) fully extends at the ankle, knee, and hip, driving the body forward into the straight sprint (see Figure 12e). As the trail leg pushes off, the lead leg touches down while the right arm is driven upward and forward in line with the body.

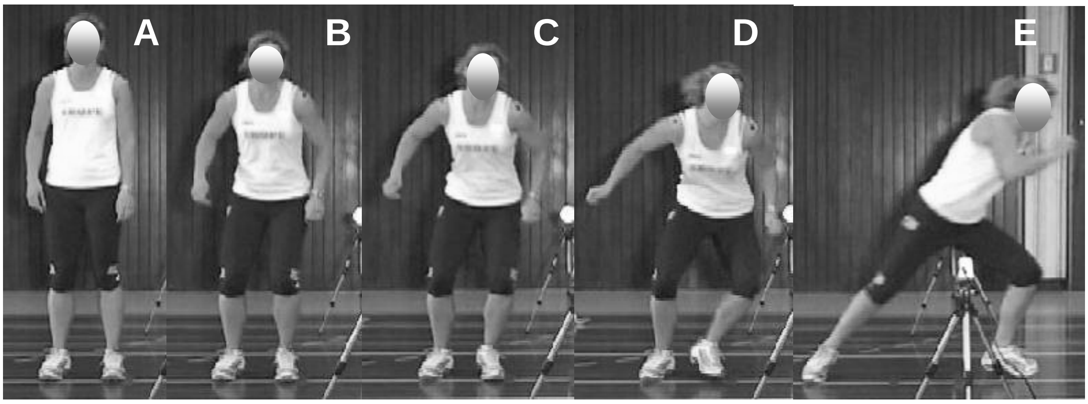


Figure 12: Forward-moving sidestep (a-e).

Strategy 3: Pivoting crossover

The pivoting crossover (PC) movement is initiated by an almost immediate abduction of both arms away from the body. Similar to the FMS, the weight is transferred from both legs to the lead leg (left leg) (see Figures 13a and 13b). However, in this strategy, the torso remains relatively vertical throughout, as opposed to leaning forward into a deep squat. As the right arm crosses in front of the body, the left arm is pulled behind, rotating the torso (see Figure 13c). As shown through Figures 13c and 13d, the whole body rotates, whereas strategies 1 and 2 indicate rotation only in the lower body initially. As the body turns, the lead leg pivots into external rotation, increasing knee flexion as the weight is further transferred (see Figure 13d). In contrast to the two previous strategies, the trail leg (right leg) is also pivoted slightly (internally) before takeoff. While the lead leg remains in contact with the ground, the right leg crosses in front of the left as the right arm drives backward and the left drives forward (see Figure 13e). The left leg now becomes the trail leg, pushing off in the same plane as the sprint.

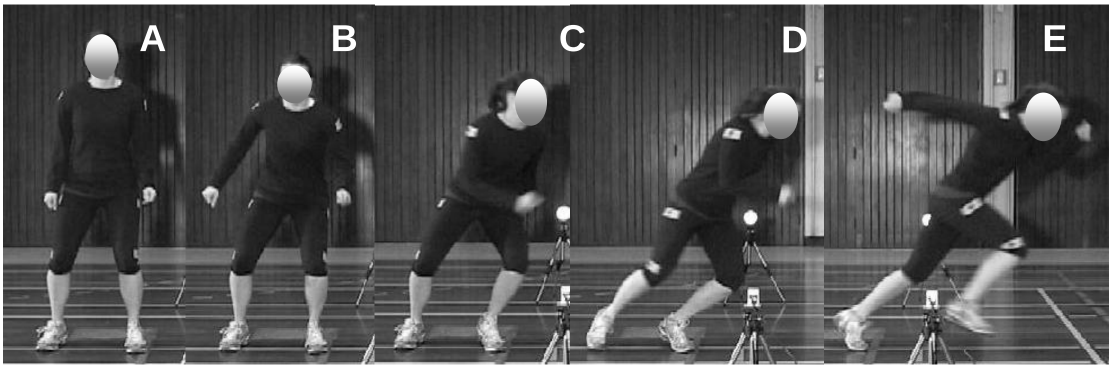
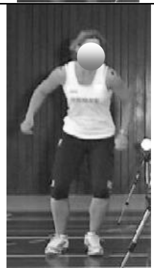
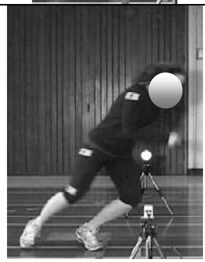


Figure 13: Pivoting crossover (a-e).

Movement analysis

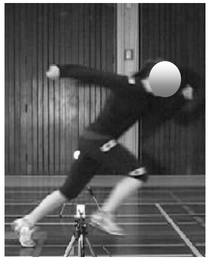
Based on principles of biomechanics, there appears to be various features of the 90˚ COD that produce superior performances. These key technical features, along with the rationale as to why this feature would improve the performance, are listed in Table 7.

Table 7: Key technical features of the 90˚ ground-based change of direction task.

	COD strategy				
Phase	*False-start pivot*	*Forward-moving sidestep*	*Pivoting crossover*	***Key technical feature***	***Biomechanical rationale***
2-3 frames after rest (B)				1. Lowering the centre of mass (COM) prior to the turn	Rapid squatting motion increases stability as well as enables explosive force and power application through the stretch-shortening cycle when used immediately
				2. Moving the COM into the sprinting direction	Helps contribute to increased momentum in the direction of travel
Turn (C)				Arms and legs close to the body when turning	Decreased rotational inertia (resistance to turn) when the body's mass is distributed close to the axis of rotation (i.e. the takeoff foot) ($I = mr^2$)
First Foot Takeoff (D)				COM ahead of the takeoff (T.O.) foot (takeoff distance)	Large takeoff distance equals a large step length (SL) which results in increased velocity ($v = SL \times SF$). Decreased stability in the direction of travel helps promote momentum of the COM in that direction.

(Table 7 continued)

(Table 7 continued)

	COD strategy				
Phase	*False-start pivot*	*Forward-moving sidestep*	*Pivoting crossover*	***Key technical features(CF)***	***Biomechanical rationale***
Second foot takeoff (E)				5.Full lateral extension of the takeoff leg	Applying force over a longer time (impulse) will result in increased velocity as long as the force is at least maintained (f x t = m x v)
				Intense driving action of the arms	Extension of the arms (increased rotational inertia) stops trunk and pelvic rotation both through the turn as well as counteracting the turning effect of the lower extremities when sprinting, allowing the body to continue in a straight line in the new direction

Key technical feature 1 (lowering the centre of mass before the turn)

The relatively erect torso and minimal squat of the participant employing the FMS in particular do not allow for much force generation against the ground compared with a deeper squat. By lowering down into a deep squat, the leg muscles are preloaded and as a result are able to produce greater vertical and horizontal force into the ground, creating a larger ground reaction force in the intended direction of travel at takeoff.

Although the initial step backward of the FSP may appear to be ineffective, it does allow for effective use of the stretch-shortening cycle. By preloading the muscles of the trail leg with potential elastic energy, a greater amount of force may potentially be produced over a greater amount of time (greater impulse). Given the relationship between impulse (force [f] x time [t]) and momentum (mass [m] x velocity [v]) this strategy could result in greater movement velocity, which could arguably make up for the increased time taken by the initial step backward [54].

Key technical feature 2 (moving the center of mass into the sprinting direction)

As soon as the downward motion is initiated, the body begins to transfer weight into the new direction (to the left). Force is applied horizontally, and body parts are aligned in the desired movement direction.

Key technical feature 3 (arms and legs close to the body when turning)

The body's rotational inertia (I) (resistance to turn) is primarily dependent upon the distribution of the body's mass around the axis of rotation ($I = mr^2$). Increased rotational inertia (arms wide) increases the stability of the rotating body but results in a decreased turning effect. By bringing the arms (mass, m) closer to the body (axis of rotation, r) during the turn, a faster rotation will occur while still maintaining stability through the squat and postural adjustments already being employed [43, 50].

Key technical feature 4 (center of mass ahead of the takeoff foot)

The distance of the center of mass in relation to the takeoff foot when it leaves the ground is known as the takeoff distance. The larger this distance is, the greater the step length will be, resulting in increased takeoff velocity and a faster sprint (assuming that the frequency of each step is maintained) [18]. The takeoff distance of the first foot take off is clearly larger for the participants using the FSP and PC strategies than the FMS. In both the pivoting strategies, the participants begin with a wider stance, which allows for a greater takeoff distance once the pivot has been completed. In contrast, the FMS participant begins with a narrower stance and the takeoff is completed before any foot adjustments (pivot, false start, etc). If a wider base of support was employed by this participant, then the takeoff distance would not be increased as the takeoff foot will always be the foot closest to the new direction, as opposed to the rear foot in the pivoting strategies. Additionally, by creating a simultaneous or near simultaneous takeoff and touchdown of contralateral legs, the flight phase is minimized or possibly eliminated, thereby increasing the ground contact time (GCT). Because propulsive force can only be produced when in contact with the ground, the increased GCT may allow for greater impulse to be generated than might occur if the flight phase was increased. An increase in generated impulse would likely result in a faster sprint time (f x t = m x v) [50].

Once the player has rotated into the new direction (second foot takeoff), the takeoff distance is similar across all the three strategies. However, at this point, the participant employing a FMS strategy uses a lateral takeoff, whereas the pivoting participants are able to potentially generate more force in the direction of travel at takeoff through a foot placement parallel to the direction of travel [50].

Key technical feature 5 (full lateral extension of the takeoff leg)

There are conflicting reports as to whether superior sprinting performances use a full triple joint extension (ankle, knee, and hip). By applying force into the ground over a longer time as the leg extends fully, a greater velocity can be attained (f x t = m x v) (5,9). However, it may be an abbreviated range of motion at these joints that is more beneficial for tasks that require quick adjustments to their direction and speed [18, 29, 32]. Because minimizing the amount of time taken to complete a directional change is the goal of this movement, a full extension at the ankle, knee, and hip may not be essential.

The perpendicular position of the trail leg at takeoff in relation to the rest of the body, as well as the movement direction, may not be as effective at producing the large propulsive forces as a foot positioned in the intended direction of motion. When placed parallel to the intended direction, the foot is able to produce potentially greater amounts of force into the ground through plantarflexion as opposed to eversion with a perpendicular (lateral) foot placement [34].

Key technical feature 6 (intense driving action of the arms)

As the athlete reaches the final portion of the turn, a rapid elbow extension occurs. This movement increases the rotational inertia, causing the body to slow (or stop) the turning effect [50]. This movement may be more noticeable in the PC strategy but is present to some extent in all three strategies. The more rapid this movement is performed, the faster the rotation will cease and the sooner the player can continue on in the sprinting direction. The intense driving action of the arms once the body has completed the turn can assist in the takeoff velocity when accelerating [18, 30, 36], although it is important to note that this driving action must be performed in line with the body, as opposed to lifting the arms away from the sides, which would create a tendency to rotate.

Summary and conclusions

The COD movement strategies that athletes commonly employ and the technical cues to improve activity and/or sport-specific COD have received little attention and provide an exciting area for research. Of the three COD movement strategies discussed, the fastest COD time through both the first and the second steps in the new direction likely occurs with the PC. The slowest of the three strategies is likely the FMS (see Table 8). It appears that two technical characteristics may be key technical features to a superior 90˚ COD movement performance when using the PC: aggressive driving arm action through the turn and a limited forward lean (both of which are key technical features of effective sprinting). Differences using a static start compared with a dynamic situation need further investigation.

Table 8: Extent of key technical feature employment for the 90˚ ground-based COD task.

Strategy	***Lowering COM prior to the turn***	***Moving COM into new direction***	***Small rotational inertia***	***Large T.O. distance at 1st T.O.***	***Full lateral extension at 2nd T.O.***	***Intense driving arms***	***Average CODstep (s)***	***Average CODstride (s)***
False-start pivot	OK	-	OK	OK	+	+	0.51	0.97
Forward-moving sidestep	OK	-	-	-	+	OK	0.69	1.07
Pivoting crossover	+	+	+	+	OK	+	0.46	0.84

COM = Centre of mass, COD = Change of direction, T.O. = Takeoff, + = fully present, OK = observed but not to the extent described, - = not present.

Several factors (i.e. individual anthropometric measures, physical coordination, situation-dependent requirements, etc) may contribute to the ability to execute these strategies with a superior performance. A greater distribution of body mass from the axis of rotation will increase the rotational inertia that the player must overcome when turning. Therefore, certain adaptations or adjustments to the COD movement strategy may be needed to overcome this factor. Likewise, an athlete who is less proficient at completing rapid movements, those involving proprioceptive awareness or gross/fine motor skills, may not be as successful at the same COD movement strategy as a more proficient athlete. However, this aspect has the potential to be improved with practice.

Finally, the sporting task or situation that the player is responding to may have specific postural characteristics. For example, a netball player must remain relatively erect to read player movements and catch or intercept a pass. In contrast, an ice hockey player adopts a lower center of mass as a result of where the puck is played (on the ice as opposed to in the air) as well as to increase the length of reach and protect the puck when in possession. Although both players may have similar body types and coordination the demands of the sport may determine which COD movement strategy is most likely to result in a superior COD movement performance.

CHAPTER 5

UNDERSTANDING CHANGE OF DIRECTION PERFORMANCE: A TECHNICAL ANALYSIS OF A 180˚ GROUND-BASED TURN AND SPRINT TASK

This chapter comprises the following paper:

Hewit, J., Cronin, J.B., & Hume, P.A. *Understanding change of direction performance: A technical analysis of a 180˚ ground-based turn and sprint task.* Submitted to *International Journal of Sports Science and Coaching.*

Author contributions - JH: 85%, JC: 10%, PH: 5%.

Prelude

The study outlined in Chapter 4 identified six key technical features thought to contribute to superior 90˚ ground-based change of direction (COD) performances. However, another movement pattern that is common in netball is a 180^{o} ground-based turn and sprint task. To the knowledge of these authors no study has investigated the technical characteristics and underlying principles of this change of direction sprint task. This type of movement is common in many sports and therefore the findings may benefit many sporting codes. The aim of this study was to analyze the movement patterns of sub-elite level netball players in an attempt to determine the key technical features consistently present in superior 180˚ ground-based turn and sprint performances, but lacking in less skilled performances. The development of a ground-based change of direction performance template based on this analysis can be used as a valuable coaching tool.

Introduction

Within the context of sports performance, agility has been identified to be inclusive of rapid, movements involving the whole body in which changes in direction and/or velocity occur in response to a stimulus [1, 4, 6]. This definition presents three main components (technical, physical and perceptual) that appear essential to the effectiveness of agility movements.

While each component should be addressed and promoted in training, change of direction (COD) ability relies directly on the technical and physical components [5] (see Figure 14). These two qualities are of particular interest to the researchers. Prior to program design, an understanding of the mechanics and musculature involved in the movement of interest is needed. A qualitative analysis of players' performances provides strength and conditioning coaches with better insight into those muscles and mechanics that are required to perform the explosive movements for the effective completion of a movement task. Coaches and strength and conditioning professionals can then use this information as a guide for technical cueing and to develop appropriate training programs.

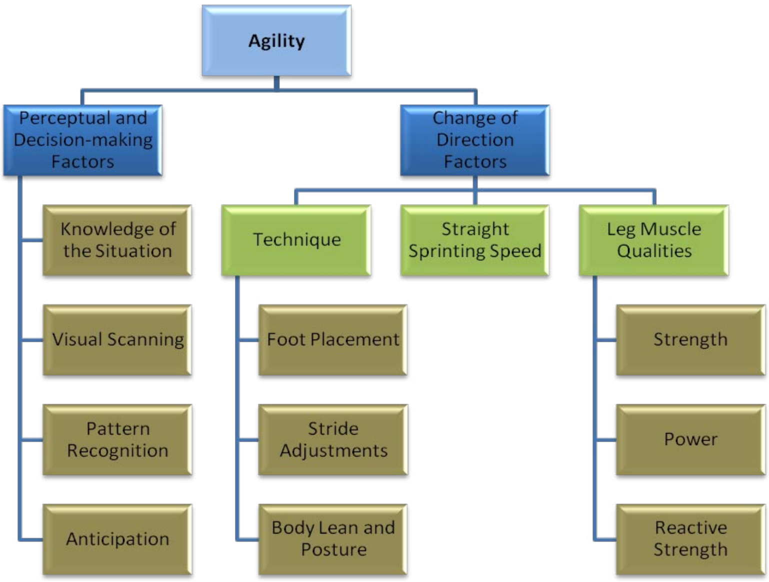


Figure 14: Deterministic model of agility (adapted from Young et al., 2002).

Ground-based change of direction movements ranging between 90˚ and 180˚ are commonly performed in many sports. Previous research [55] has investigated the technical aspects of a 90° COD performance from a static start, and has found that several key technical features (e.g. aggressive driving action of the arms through the turn and leaning into the intended direction) contribute to a faster and more effective COD performance. However, the authors are unaware of any research that have investigated the technical characteristics of a 180° turn and sprint. This type of movement is common in many sports (e.g. netball, rugby league, basketball, football, etc.) and therefore the findings may benefit many sporting codes.

An understanding of biomechanical principles aids in developing a mechanical understanding of gbCOD movements. For example, the impulse-momentum relationship, rotational inertia, Newton's law of action reaction, etc., are all guiding principles that will assist in understanding the underlying determinants of certain technical characteristics. However, the application of biomechanics principles to gbCOD tasks (such as those of interest in this study) is once more for the most part unexplored. The first aim of this study was to analyze the movement patterns of elite and sub-elite netball players to determine key technical features that were consistently present in superior 180˚ ground-based COD performances (180˚ gbCOD), but lacking in less skilled performances. using these key technical features, the second aim was to develop a qualitative rating method for 180˚ gbCOD movement analysis.

Methods

Participants

Twenty-two under-21 national netball players (age 19.3 ±1.1 years, height 179.0 ±5.8 cm, mass 77.1 ±11.6 kg) participated in this study. All players were free of injury that might have affected their performance at the time of testing. The human research ethics committee of AUT University approved all procedures before commencing the study. Prior to participation, an informed written consent was obtained from each player.

Equipment

Testing equipment consisted of one 300 Hz video camera (Casio EX-F1, Casio Computer Co., LTD, Tokyo, Japan), the placement of which and dimensions of the field of capture can be observed in Figure 15. Video was analyzed using a combination of Quick Time 7 Pro (Apple Inc.) and SiliconCoach Pro software (Dunedin, New Zealand).

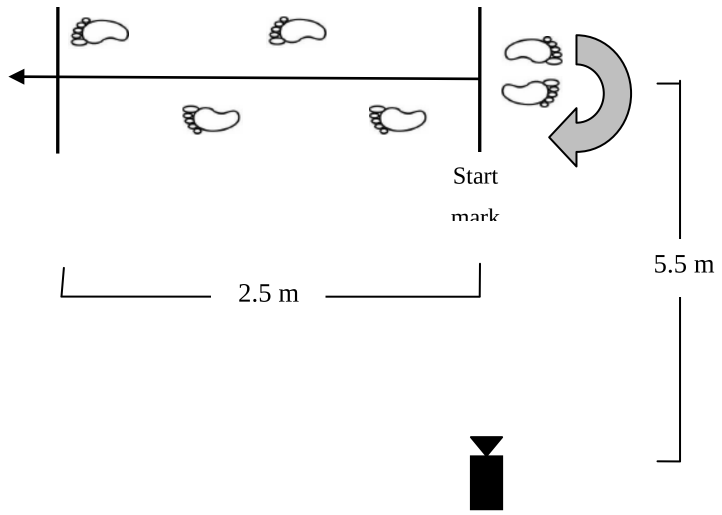


Figure 15: Testing set-up for the 180˚ gbCOD task.

Procedures

Testing took place during a single testing session on a regulation indoor netball court. Age, height and body mass of each player were recorded then each player completed a 10 minute dynamic, netball-specific warm-up. Players then practiced the 180˚ gbCOD task until they felt comfortable. No players required more than three practice trials.

Players began the 180˚ gbCOD task with their heels placed at a designated start mark. When ready, the player performed a 180˚ change of direction, followed immediately by a 2.5 m straight sprint (see Figure 15). Three trials were recorded for a 180˚ turn and sprint to the right. Players were instructed to perform the task as quickly as possible. Verbal instruction regarding technique was not provided so as to elicit a 'natural' 180˚ gbCOD performance from each player. The two best trials (i.e. first ground contact foot placement nearest parallel to the new direction) were used for analysis.

Data analyses

Key technical features of 180˚ gbCOD performance were identified through movement analysis - a form of qualitative analysis (subjective description of the quality of movement based on observations [50]). For this study, the objective of the movement was first identified (i.e. first ground contact parallel to the intended direction of travel), the movement was broken into four phases, and then the key technical features were identified for each phase. The four phases were: A) initial movement – the start of the player's movement until the shoulders or hips began to rotate; B) turn – the start of rotation at the shoulders or hips until both had rotated beyond parallel to the camera; C) takeoff – the point when the plant foot (trail leg) left the ground until the contralateral foot (free leg) touched down; and, D) first foot ground contact – the point when the foot of the free leg touched the ground in the new direction through the next takeoff of that same foot.

Based on the foot placement of the initial ground contact following the turn (phase D), players were initially grouped into three categories: 'Superior' where the first ground contact was approximately parallel to the new direction; 'Average' where the first ground contact was approximately 15 - 30˚ short of parallel to the new direction; and 'Below Average' where the first ground contact was more than 30˚ short of parallel to the new direction. Key technical features were identified from video footage by manually advancing and observing key movement patterns of each player for each phase.

After this analysis, the key technical features were used in a template to cross-check the categorization of players and to finalize those key technical features thought fundamental to superior performance. A player was awarded a '+' for each key technical feature that was observed to be employed to the full extent, an 'OK' for each key technical feature that was observed but not fully employed, and a '-' for each key technical feature that was absent from the gbCOD performance. Finally, the underlying mechanical determinants of each feature were discussed. Data consisted of video analysis, therefore any reference to forces or body weight distribution was purely observational and not the result of force plate data.

Table 9: Key technical features of the 180˚ gbCOD.

Phase	Player Performance		Key technical feature	Biomechanical rationale
	Superior	*Below Average*		
Initial Movement			1.Initiating movement in the intended sprint direction.	Increased momentum in the sprinting direction. Increased horizontal and vertical ground reaction forces at takeoff. Rapid shallow squat may utilize the stretch-shortening cycle increasing velocity.
Turn			2.Head leading body through the turn.	Earlier visual scanning and knowledge of the situation (perceptual component of agility) when head is rotated towards the new direction first.
			3.Arms and legs close to the body axis of rotation.	Decreased resistance of the body to turn (rotational inertia) when the arms and legs are brought closer to the axis of rotation (i.e. the takeoff foot) ($I = mr^2$). [I = inertia; m = mass; r = radius]
Takeoff			4.Full lateral extension of the takeoff leg.	Increased velocity from applying force over a longer time (increased impulse) ($F \times t = m \times v$). [F = force; t = time; m = mass; v = velocity]
			5.Large takeoff distance.	Increased velocity from a large takeoff distance (large step length) ($v = SL \times SF$). [v = velocity; SL = step length; SF = step frequency]

1st Foot Ground Contact			Optimal Performance Outcome: First ground contact parallel to new direction.	Acceleration in a straight line when the first ground contact is parallel to the sprinting direction.

Statistical analyses

As a subjective qualitative analytic approach was used in this study, specific quantitative statistics were not utilized. Therefore, the methods used are principally descriptive in nature.

Results

Five key technical features were identified from the initial analysis based on the ground contact of the player in the new direction. The five features were: 1) initiating movement in the intended sprint direction (e.g. squatting with the weight on the heels of the feet, leaning slightly backwards); 2) head leading the body through the turn; 3) arms and legs close to the body's axis of rotation (i.e. small rotational inertia); 4) full lateral extension of the takeoff leg; and, 5) large takeoff distance (see Table 9).

Based on the inclusion of the five key technical features, players were cross-checked and re-grouped where necessary into three categories: 'Superior' (4 - 5 '+' awarded) (n = 8); 'Average' (3 '+' awarded) (n = 5); and 'Below Average' (0 - 2 '+' awarded) (n = 8) (see Table 10).

Table 10: Exemplar for the key technical features template for the 180˚ gbCOD task.

		Initial movement	**Turn**		**Takeoff**		**1st ground contact**
	Player	***Lowering COM***	***Head leads body***	***Small rotational inertia***	***Full lateral extension at takeoff***	***Large takeoff distance***	***1st GC parallel to intended direction***
Superior	1	+	+	+	+	+	+
	16	+	OK	+	+	+	+
Average	19	-	+	OK	+	+	-
	20	-	+	+	+	OK	OK
Below Average	11	-	+	-	-	-	+
	22	-	+	-	OK	OK	-

COM = Centre of mass, GC = Ground contact, + = fully present, OK = observed but not to the extent described, - = not present.

Discussion

This study has provided a method for qualitatively rating gbCOD performance based on technical characteristics. As technical and physical components are thought to be the main contributors to the success of a COD performance [5], a more effective technical performance is likely to contribute to a more effective COD performance. When such an analysis is conducted prior to the development of strength and conditioning programs, a more thorough understanding of the specific technical and physical qualities required for more efficient movement performances can be developed likely resulting in improved programming and COD abilities in players. These key technical features, along with the biomechanical rationale as to why each feature would improve gbCOD performance provide the basis for the subsequent discussion. Diagrammatic representation of these features can be observed in Table 1.

Key technical feature ***1 (initiating movement in the intended sprint direction)***

As soon as downward body motion is initiated via a rapid, shallow, backward squat with hip and knee flexion, the body begins to transfer momentum into the new direction (backwards). This allows vertical and horizontal force to be applied into the ground at push-off. If there is limited delay between a rapid and shallow pivot, this sinking of the centre of mass (COM) will enable the utilization of any elastic energy stored in the leg musculature (i.e. the stretch-shortening cycle), which in turn will increase the 180˚ gbCOD velocity.

The use of a small amplitude jump into a COD may also assist with the explosive power out of the turn. The storage and immediate use of elastic energy that such a jump would allow for increases the force into the ground at takeoff and therefore, velocity out of the COD.

Key technical feature ***2 (head leads the body through the turn)***

When the head initiates a turn, several advantages result. The first advantage lies with the perceptual/decision-making component of agility. By initiating the turn with the head, the player is able to scan the new direction, opponent and teammate positioning, playing options etc. much sooner than would otherwise have been achieved [5]. Furthermore, anatomically, the head is only able to rotate to a certain point before the rest of the body must follow. Therefore, the turning head will soon be followed by the shoulders, torso, hips and legs; meanwhile perceptual information is being processed.

Key technical feature 3 (small rotational inertia)

The body's resistance to rotate (rotational inertia = I) is dependent upon the body's distribution of the mass around the axis of rotation ($I = mr^2$). The further away the arms and legs are from the longitudinal axis of rotation (the pivoting foot) the greater the rotational inertia. Keeping the arms and legs close to the body's longitudinal midline or axis of rotation when turning decreases the rotational inertia, allowing the player to rotate and complete the turn faster [43, 50].

Key technical feature 4 ***(full extension of the takeoff leg in the direction of travel)***

As the leg extends at takeoff, force is being applied into the ground. A longer time over which the force is applied will result in a greater impulse (f x t) and consequently greater velocity at takeoff (f x t = m x v) [50, 56]. When traveling in a relatively straight line following the 180˚ gbCOD an increased takeoff distance (see technical feature 5) is desirable as the body's COM is brought in front of the base of support, increasing momentum into the new direction. However, when an additional COD is required a full extension of the takeoff leg results in a longer time before the takeoff leg can be repositioned for the next ground contact. This extended time increases the COD time and effectiveness of the movement, which ultimately may compromise performance if a subsequent COD is required. That is, it is probable that an abbreviated range of motion of the takeoff leg when sprinting may be desirable when subsequent directional changes are included. First, a full extension of the takeoff leg would disadvantage the player under these circumstances as the front leg is in the air for a longer period of time. This inhibits the ability to contact the ground rapidly, thereby producing a force into the ground that will result in a directional change (force can only be applied when in contact with an external surface). Therefore, a small takeoff distance and step length will enable rapid COD tasks to be performed.

The ability to produce braking forces is also needed when performing consecutive COD movements. By fully extending at takeoff (large takeoff distance and step length), the braking force for the next foot strike upon ground contact is minimal. While this may be desirable for straight line acceleration, some COD tasks will require braking forces to be applied in the current direction of travel to enable a change of direction. Therefore, a large landing distance (the distance from the contact point back towards the vertical line through the COM) may be of greater importance for consecutive COD movement tasks.

Key technical feature 5 (large takeoff distance)

Velocity is dependent upon an optimal relationship between step length (SL) and step frequency (SF) (SL x SF = velocity) [28]. The distance from the vertical line through the COM to the takeoff foot as it leaves the ground is known as the takeoff distance. A large takeoff distance results in a large SL, resulting in increased velocity as long as SF is at least maintained [18].

When performing a single COD movement followed by a straight sprint into the new direction, a large takeoff distance and step length are beneficial for increased acceleration. However, an abbreviated takeoff distance and step length will enable several rapid COD tasks to be performed in succession to each other.

Optimal performance outcome: First ground contact parallel to the new direction

The goal of the 180˚ gbCOD is to accelerate into the new direction as quickly as possible. When a player's initial ground contact following a rapid COD is parallel to the new direction, the player is able to apply force into the ground in the direction of travel. Therefore, a more rapid acceleration should result from positioning the foot parallel to the intended direction of travel.

Practical applications

The use of a technical feature template, similar to the template presented in this study provides a means for coaches to both identify and prioritize those key technical features that are found to be lacking in individual players' ground-based COD performances. From this information, more appropriate training can be integrated to individualize players' current training programs to better target those features identified as needing further development. As both technical and physical qualities contribute to COD ability, the identification of technical weaknesses should be immediately followed up with training exercises that directly address the physical characteristics that enable the player to perform such features to the extent required (i.e. increased strength, power, etc. of muscle groups involved in specific movement patterns). While more research is needed, the key technical features presented in this study provide coaches and strength and conditioning professionals insight into the fundamental movements that appear to be consistently associated with superior 180˚ gbCOD performance.

CHAPTER 6

UNDERSTANDING GROUND-BASED CHANGE OF DIRECTION IN SPORT

This chapter comprises the following paper:

Hewit, J., Cronin, J.B., & Hume, P.A. *Understanding ground-based change of direction in sport.* To be submitted to *Strength and Conditioning Journal*.

Author contributions - JH: 85%, JC: 10%, & PH: 5%.

Prelude

A paucity of research has investigated the technical characteristics that contribute to superior change of direction performances. As a result of this research gap, several experimental studies were conducted as part of this thesis to address this issue. This brief review of ground-based change of direction ability in sport is a culmination of the information gained from these previous thesis chapters as well as the limited published research in this area. Prior to program design, an understanding of the mechanics required to perform the movement task was needed. Movement analysis provides coaches and strength and conditioners with insight into the segmental movement patterns, muscle activation and technical strategies associated with the movement of interest. Such information assists with appropriate program design for increased effectiveness and decreased injury potential. Given the theme of the thesis around improving the technical understanding associated with various movement patterns, the aim of this brief review article was to provide a better understanding of the underlying mechanics thought fundamental to a ground-based COD task. Exercises were suggested which when used jointly with the mechanical analysis of player movement strategies, may enhance player COD performance.

Introduction

Rapid changes of direction are commonly performed by all players in court-based sports throughout the entirety of a competition. Such movement tasks are often complex in nature and rely on both technical and physical qualities (see Figure 16) [5]. Ground-based changes of direction (gbCOD) are typically used when attempting to evade an opponent, create an open space for a teammate or move to an open space. When movements of this nature are performed at rapid velocities, the forces and torques placed on the body are increased dramatically. If a player does not possess adequate strength and technical skills to effectively perform such complex movements at high velocities, the risk of injury increases and it is likely the overall performance will suffer.

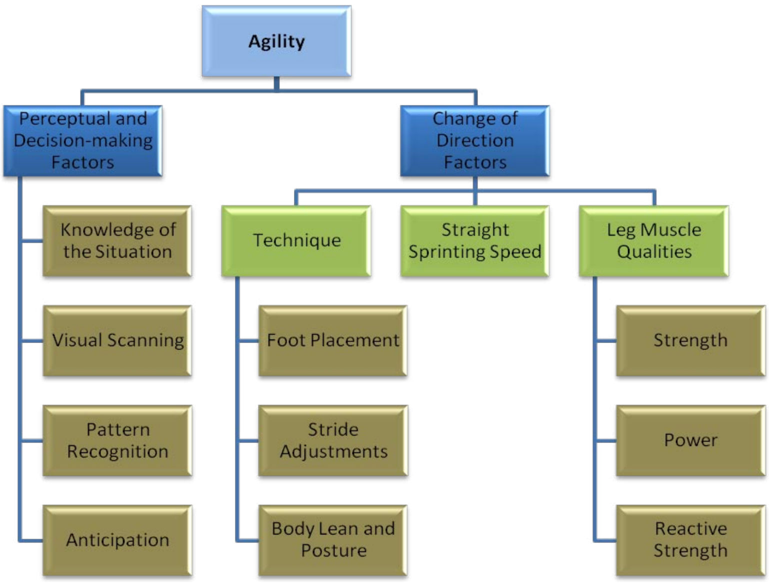


Figure 16: Deterministic model of agility (adapted from Young et al., 2002).

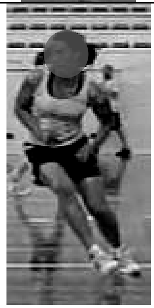
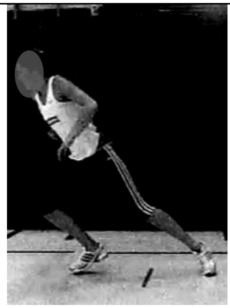
Given this information it would seem important to precondition athletes for multi-directional COD movements specific to their sport or activity as well as coach the key technical features thought fundamental to the particular COD task. While there is literature that has reported ground-based COD performances [5-7, 10, 11, 57], this research typically has been concerned with recording performance times of various COD tasks rather than focusing on the technical characteristics of the movement task. A recent study conducted by the authors of this thesis identified five key technical features thought to contribute to the overall success of a 180˚ ground-based COD task (180˚ turn from a static start followed immediately by 2.5 m straight sprint). There is a paucity of literature that takes such a qualitative approach to understanding technical performance of players. An understanding of the technical and physical aspects of the movement task provides insight into the movement patterns, muscle activation and technical strategies fundamental to the movement and program design. Therefore, the aim of this brief review is to provide coaches and strength training professionals with a better understanding of the rationale behind key technical features of the movement for more appropriate training and cueing of players' performance in sport.

The 90˚ and 180˚ change of direction tasks from both static and dynamic starts are of particular interest as these movements are commonly performed throughout many sports [27]. Therefore, for the purposes of this article, a gbCOD task will represent a rapid 90˚ to 180˚ turn followed immediately by a straight sprint into the new direction.

The primary researcher independently searched the electronic databases of AUSPORT, Expanded Academic ASAP, ProQuest 5000, PubMed, and SPORTDiscus. The following keywords were used in different combinations to narrow the search; agility, change of direction, cutting, biomechanics, and technique. Studies were chosen for inclusion in this review if biomechanics principles were used to describe or analyze the performance, or if the study focused on a ground-based change of direction movement (turn, cut, etc.). Additionally, only studies published in the English language in a peer-reviewed journal or conference proceedings were included. Unfortunately, the paucity of research in this area (less than 5 articles that met the criteria) required additional resources to be included in the review. As a result, biomechanical commentary from various experts and their texts has been included in the discussion.

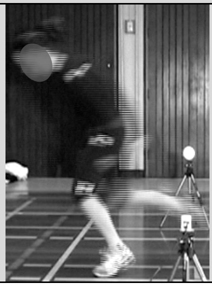
The six key technical features of interest [55] are shown in Table 11. These features are thought to contribute to an overall superior change of direction ability as they were consistently observed during player performances where the first ground contact following the turn was approximately parallel to the new direction of travel, thereby allowing the player to accelerate into the new direction without the inclusion of additional steps for alignment. Each of the five features is accompanied by three photos of the characteristic being performed in each movement task (90˚ turn from a static start, 180˚ turn from a static start, and 180˚ turn from a dynamic start) as well as the biomechanical rationale in support of importance of each feature to the success of the movement task.

Table 11: Key technical features that determine the nature of ground-based change of direction motion.

Phase	Movement task			Key technical feature	Biomechanical rationale
	90˚ Static Start	***180˚ Static Start***	***180˚ Dynamic Start***		
Initial Movement				1. Initiating movement in the intended sprint direction.	Increased momentum in the sprinting direction. Increased horizontal and vertical ground reaction forces at takeoff. Rapid shallow squat to utilize the stretch-shortening cycle for improved turning velocity.
Turn				2. Head leading body through the turn.	Earlier visual scanning and knowledge of the situation (perceptual component of agility) when head is rotated towards the new direction first.
				3. Arms and legs close to the longitudinal axis of rotation.	Decreased resistance of the body to turn (rotational inertia) when the arms and legs are brought closer to the axis of rotation (i.e. the takeoff foot) ($I = mr^2$). [I = inertia; m = mass; r = radius]
Takeoff				4. Near full extension of the takeoff leg.	Increased velocity from applying force over a longer time (increased impulse) (F x t = m x v). [F = force; t = time; m = mass; v = velocity]
				5. Large takeoff distance.	Increased velocity from a large takeoff distance (large step length) (v = SL x SF). [v = velocity; SL = step length; SF = step frequency]

(Table 11 continued)

(Table 11 continued)

Phase	**Movement task**			**Key technical feature**	**Biomechanical rationale**
	90˚ static start	***180˚ static start***	***180˚ dynamic start***		
1st foot ground contact				Optimal performance outcome: First ground contact parallel to new direction.	Acceleration in a straight line when the first ground contact is parallel to the sprinting direction.

As movements in sport are often performed rapidly, it is important to recognize the potential for injury. While technical skills are of great importance to the success of the performance, without adequate physical strength and power the ability to execute such rapid movements will be less than optimal. Therefore, a combination of the knowledge and understanding of each of the key technical features as well as the ability to integrate these movements into sport-specific training sessions that target the physical qualities essential for an explosive performance in sport are paramount. The remainder of this article will address the underlying biomechanics of the key technical features within each movement phase of a 90-180˚ gbCOD task as well as exercise suggestions for integration into training programs.

Initial movement phase

Static

Performing a 90˚ or 180˚ gbCOD from a static start includes several key technical features that can be cued by coaches to optimise gbCOD performance. First, the player sinks down into a rapid and shallow squat (see Figure 17A). This movement temporarily stores elastic energy in the leg muscles, preloading them for a more explosive takeoff through the use of the stretch shortening cycle [56]. A delay between lowering into the squat and extending into the turn dissipates the elastic energy as heat, requiring the player to generate more force at takeoff. The lowered body position that results from the shallow squat also helps moves the centre of mass (COM) into the intended direction, allowing the player to apply a greater amount of horizontal force into the ground [43]. Greater horizontal force will result in increased acceleration horizontally into the new direction (acceleration = force/mass). When a player doesn't include a shallow squat in the approach, greater vertical force is applied into the ground resulting in a more upright takeoff and shorter first step.

Figure 17: Completing a 180˚ gbCOD task from a static start.

Dynamic

A player already in motion prior to the gbCOD will often need to first slow their velocity before attempting the turn. To do this, a force must be applied into the ground ahead of the body [55] (see Figure 18A). In order to effect the player's motion, this force must be greater than the player's mass [44]. Therefore, a larger player may be less successful at completing rapid gbCOD movements as compared to their smaller counterparts due to the greater momentum (mass x velocity) and therefore forces that must be generated to overcome their mobile inertia. A player's leg strength qualities and their anthropometry are factors that influence their turning ability [8], i.e., the larger the player's relative leg strength (force) the more advantaged they are in quickly overcoming their inertia.

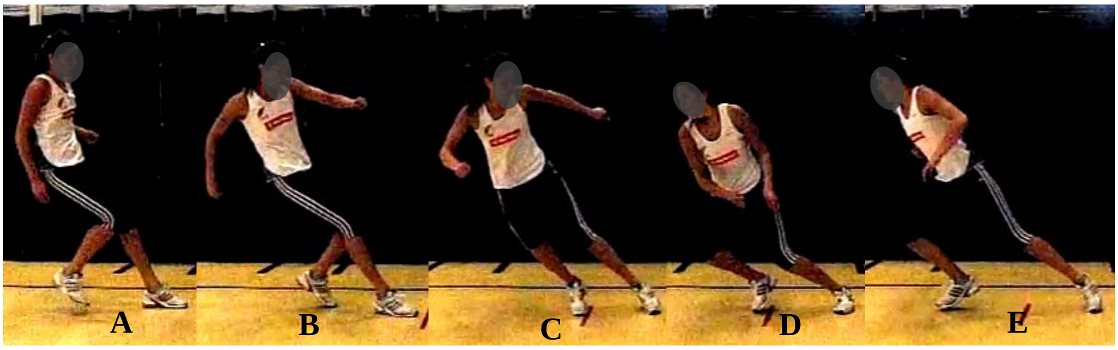


Figure 18: Completing a 180˚ gbCOD task from a dynamic start.

Several adjustments are also made to the player's body positioning to assist in slowing the body's momentum prior to the turn. An erect posture with a slight posterior (backward) lean allows the free leg to contact the ground in front of the COM with the heel first [55], rolling to the forefoot. This increases the time the foot is in contact with the ground. The lengthened ground contact phase combined with immediate flexion at the hip and knee upon contact allow the impact force to be rapidly absorbed over the lower limbs, decreasing momentum. Additionally, similar to the static start, lowering the COM (through the hip and knee flexion) allows the force applied into the ground at ground contact to be more horizontal in nature, resulting in a greater horizontal braking force through the contact phase.

Early initiation of the turn is also beneficial to the successful completion of a rapid gbCOD [58]. Rotation of the hips and legs into the new direction begins during the final steps of the approach (see Figure 18). These advantage the player as a smaller degree of rotation is required during the plant phase. Completing the full turn during the plant will take additional time and may even result in multiple steps taken prior to accelerating in the new direction.

Friction plays an important role when changing directions from both static and dynamic starts. Greater amounts of friction are present when two rough surfaces slide together as opposed to two smooth surfaces [44, 50]. Rapid and forceful gbCOD movements require large amounts of friction between the plant foot (the foot contacting the ground and initiating the gbCOD) and the ground. If either of these two surfaces is too smooth (e.g. slippery floor or worn-down shoes) the foot will slide and the gbCOD will be less effective.

Turning phase

Static

When turning from a static start, rotational inertia (resistance to rotate) must be overcome. Rotational inertia refers to the distribution of mass about the axis of rotation (from the plant foot up through the midline of the body) (rotational inertia = mass x radius^2) [44, 50]. Extending the arms and legs away from the body's midline (increased radius) increases the rotational inertia (see Figure 19A), making it more difficult to rotate resulting in a slower turn. Therefore, when completing rapid changes of direction the arms and legs are brought close to the body, decreasing the radius and rotational inertia (see Figure 19B).

Dynamic

During the deceleration phase, the plant foot is positioned away from the contralateral foot (axis of rotation) for the final ground contact prior to the COD producing a torque (turning force) in opposition to the intended direction of travel [43]. For example, if the player is attempting to complete a 180˚ turn to the right, the left leg will apply a GRF in front of the COM (see Figure 18C - D). A larger GRF will result in a faster acceleration (acceleration = force/mass) into the new direction. Additionally, a rapid transition from the initial direction through the turn and into the new direction will immediately utilize the stored elastic energy (i.e. stretch-shortening cycle), thereby requiring less force to be produced at takeoff (as discussed previously).

A

B

Figure 19: Completing a 180˚ gbCOD task from a static start with large (A) and small (B) rotational inertias.

A second technical characteristic that assists in a rapid transition through the turn is an early rotation of the head into the new direction. As the head rotates, the shoulders will begin to rotate, followed by the hips. More importantly, rotating the head into the new direction early on through the turn will allow the player to view the options available in the new direction earlier. This will allow the player additional time to prepare and react to any opponents or other obstructions in the new direction. Early rotation of the head is beneficial to gbCOD from both static and dynamic starts.

Takeoff phase

Once the player has successfully completed the turn, subsequent movements are dependent upon the objectives of individual sporting scenarios. A player may be required to; a) accelerate into this new direction in a straight line, b) perform additional gbCOD movements, or c) rapidly decelerate to backpedal, to avoid a collision, boundary line or to adhere to the requirements of the game (e.g. stepping rule in netball or travelling rule in basketball). A large takeoff distance (the distance from the COM to the takeoff foot) combined with an increased forward lean and near full extension of the takeoff leg are desirable when accelerating in a straight line into the new direction. This ensures that maximal propulsive forces are applied into the ground at a more horizontal angle. In contrast, a decreased takeoff distance and slightly more erect posture would be more advantageous when completing additional gbCOD movements as the free leg can be repositioned in the appropriate direction (e.g. to the side of the COM for a lateral turn, directly under the COM for a vertical jump, etc.) for the next ground contact sooner [46]. Finally a rapid deceleration following a gbCOD would require the free leg to contact the ground in front of the COM [55] to apply a braking force into the ground. Therefore, an erect posture with a slight posterior (backwards) lean combined with a heel strike at ground contact, as stated previously, would be beneficial.

Training approach

While the technical strategies used by players greatly affect the success of a change of direction movement, it is not the only contributor to the COD performance. A player must possess adequate muscle strength, power and reactive strength to be able to perform the required movements explosively as is required in sport. A player that employs less than optimal technical features in the performance may be doing so as a result of a lack in physical strength. Therefore, it is important to address all weaknesses identified throughout the movement task assessment in training sessions through sport-specific exercises. Table 12 shows some exercise suggestions for each movement phase of the gbCOD task that target the primary muscle groups used when employing the key technical features. There are a multitude of exercises that can be used to train the leg strength qualities associated with the movements of interest in this article. For example, exercise and load selection would depend on the specific needs of athletes (e.g. strength vs. power) and time of season (e.g. off-season vs. in-season).

During the initial movement phase, several actions occur in preparation for the turn. First, lowering and moving the COM into the intended direction of travel allows the leg muscles to become pre-loaded for a more explosive takeoff while transitioning the body's COM into the new direction. Rotation of the lower body into the new direction requires a pivoting action at the feet. Following the pivot, the first foot ground contact should aim to be parallel to the new direction and result from a relatively large takeoff distance. While resisted sprinting drills are commonly used to increase the leg extensor strength in the vertical and horizontal directions, integrating these features into an exercise that also targets the initial movement phase would be desirable as sport-specificity would be increased. A traditional concentric squatting exercise (squat jump) will target the muscles needed to extend from a lowered COM position. Combining this movement with an explosive horizontal propulsion (i.e. forward-driving sled lunge out of a static squat, see Table 12) places greater emphasis on both the transitional movement into the new direction as well as rapidly and forcefully driving off the trail leg at takeoff. This exercise should be performed slowly until the key technical features of these phases are successfully employed throughout the movement task; wherein the pace or explosiveness of the task can then be increased. Additionally, greater resistance can be used to encourage player improvement once the features are consistently being performed throughout the exercises.

Table 12: Exercise suggestion for targeting the primary muscle groups involved when performing a 180˚ gbCOD movement.

Primary muscle group(s)	**Exercise**		
	Forward-driving sled lunge out of a static squat		
• Quadriceps •Hamstrings/gluteals, and gastrocnemius			
	Start: Begin standing wearing a harness attached to a weighted sled extending behind (tension should be placed on the harness strap).	Action: Rapidly sink into a shallow squat then explosively drive forward into a lunging position, rapidly extending the trail leg at takeoff.	End: Return to the starting position by bringing the trail leg forward, keeping tension on the sled harness strap.

Summary

There are several technical characteristics that are required to safely perform effective gbCOD movements in sport. While the rules of each sport and sporting context may vary greatly, the fundamental characteristics outlined in this article should be fundamental to most movement contexts. The potential for injury increases when a player performs complex movement tasks at rapid velocities with large force magnitudes. Therefore, to decrease the potential for injury, it is important for players of all skill levels to be taught proper technique and be appropriately conditioned to ensure that the forces being applied and absorbed by the body at any time during play are manageable and the body is positioned for optimal movement effectiveness.

Players must first be assessed on their technical ability through a standardized task, specific to the sport such as a 90 - 180˚ gbCOD tasks. Individual player technical and physical weaknesses identified from the COD performance can then be addressed through specific exercises integrated into the existing training program. As the player's technical and physical ability improves, the overall gbCOD performance should be enhanced while simultaneously decreasing the potential for injury.

CHAPTER 7

UNDERSTANDING CHANGE OF DIRECTION PERFORMANCE: A TECHNICAL ANALYSIS OF A 180˚ AERIAL CATCH AND TURN TASK

This chapter comprises the following paper:

Hewit, J., Cronin, J.B., Hume, & P.A. *Understanding change of direction performance: A technical analysis of a 180˚ aerial catch and turn task.* Submitted to the *International Journal of Sports Science and Coaching*.

Author contributions - JH: 86%, JC: 8%, & PH: 6%.

Prelude

Previous studies in this thesis reported the investigations of the key technical features associated with ground-based COD movements. However, as COD movements in sport are often performed while airborne, it is necessary for a technical template (similar to the ground-based template) to be developed for aerial COD movements. Since one of the aims of this thesis was to improve the technical understanding associated with various movement patterns, the aim of this study was to determine the key technical features (supported by principles of biomechanics) associated with four phases of a 180˚ aerial change of direction (aCOD) task. Of particular interest was investigating those key technical features that resulted in players completing the full 180˚ aerial COD prior to a bilateral landing, as decreased force and torque magnitudes at ground contact are thought to be associated with such a landing.

Introduction

Agility can be defined in many different ways as there are many different facets it, especially within a sport-specific context. It is important to note that agility involves rapid, whole body movements requiring changes of velocity or direction in response to a sport-specific stimulus [1, 4, 6]. From this working definition, three distinct components of agility (technical, physical and perceptual) appear to be critical to the success of such complex movement tasks (see Figure 20) [5]. Since developing the perceptual decision making capability of players is usually outside the skill set of most strength and conditioning coaches, of interest to these researchers is the technical and physical components associated with agility performance i.e. change of direction (COD) performance (see Figure 20). It is the premise of these authors that prior to improving the strength/power qualities associated with a movement, strength and conditioning coaches need to first understand the mechanics and musculature involved in the movement of interest via some sort of movement analysis. Such analysis provides information as to what movement patterns and therefore musculature are of fundamental importance, which in turn provides the focus of movement specific programming. Furthermore such analysis provides coaches with technical cues for the coaching of the movement.

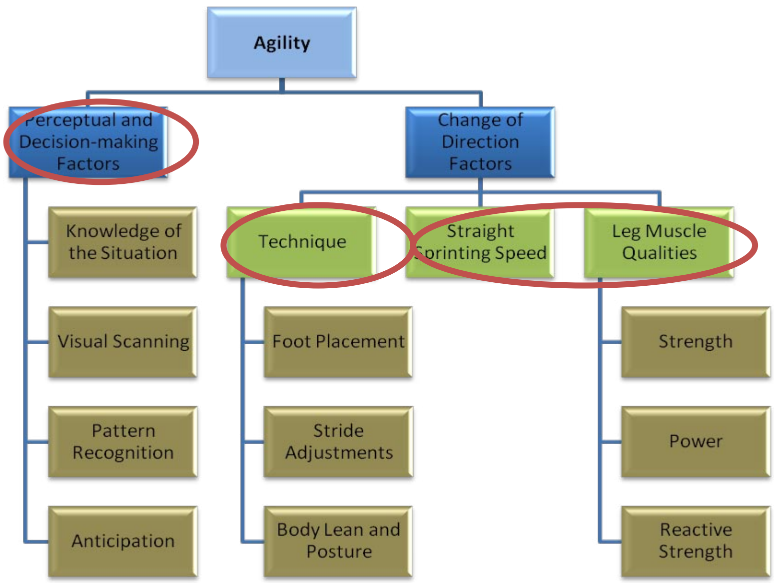


Figure 20: Deterministic model of agility (adapted from Young et al., 2002) with the three main components of agility circled (perceptual, technical and physical).

Change of direction ability has been identified as one of the main contributors to agility performance [5]. Changes of direction can encompass an extensive and complex variety of ground-based and aerial-based change of direction movements. A limited amount of research has investigated ground-based COD performances [5-7]. However, the majority of this research has focused on performance times of various COD tasks rather than focusing on an analysis of the movement task of interest. In terms of aerial changes of direction (aCOD), no research to the knowledge of the authors has investigated the performance or technical characteristics associated with such movement tasks. Therefore, the focus of this paper is with the movement stratiegies employed when completing a 180˚ aerial change of direction (180˚ aCOD) task.

Situations requiring players to perform 180˚ aCOD movements are common in sport. For example in netball, players that can catch a ball and change direction before landing are then well positioned to complete a more effective pass to a teammate. However, the occurrence of such 180˚ aCOD maneuvers is less common or performed to a lesser degree (e.g. 90˚ as opposed to 180˚) than one might expect [27]. The surprising lack of 180˚ aCOD movements in netball is likely due to the inability of players to complete the full 180˚ turn prior to ground contact. There are two likely causes of this lack of ability. The first is directly related to the leg muscle qualities possessed by players. Adequate leg strength and power are required to generate the necessary take-off velocity and subsequent flight time to complete the turns [28]. Therefore when a player's physical capabilities are less than optimal, the ability to complete such a movement task is decreased. Conversely or in addition to, it may be that there is a lack of knowledge as to what key technical factors are determinants of safe and skilled aCOD movements. Without this knowledge, coaches are unable to effectively promote and emphasize the appropriate movement patterns required for the successful completion of the task. This contention is certainly supported by the paucity of literature in this area.

No doubt there are principles of biomechanics that will be relevant and applicable to aCOD tasks. For example, angular momentum, angular velocity, rotational inertia, and nutation are all principles that are used for understanding the aerial motion of gymnasts and divers. However, the application of these principles to court/ball related sports and the associated aCOD tasks is unexplored. Therefore, the aim of this study is to analyze the movement strategies of elite and sub-elite netball players in an attempt to determine the key technical features that are consistently present in superior 180˚aCOD performances (a full 180˚ turn in the air to land with the body weight evenly distributed on two feet simultaneously).

Methods

Participants

Five elite level netball players from New Zealand's 2010 ANZ Championship league (age 25.8 ±6.1 years, height 1.81 ±0.09 m, and body mass 79.7 ±9.8 kg) and 32 sub-elite level players from New Zealand's 2009 national under-21 training squad (n = 22, age 19.3 ±1.1 years, height 1.79 ±0.06 m, and body mass 77.1 ±11.6 kg), and 2010 regional netball team (n = 10, age 24.7 ±4.9 years, height 1.73 ±0.13 m, and body mass 79.7 ±9.8 kg) participated in this study. All players were free of injury that might have affected their performance at the time of testing. The human research ethics committee of AUT University approved all procedures prior to commencing the study. Written informed consent was obtained from each subject prior to participation.

Equipment

Testing equipment consisted of two 300 Hz video cameras (Casio EX-F1, Casio Computer Co., LTD, Tokyo, Japan) placed perpendicular to each other and 7 m away from the players' designated takeoff mark (see Figure 21). A detachable regulation-size netball was elevated at fingertip height for each player and hung over the rim of the netball hoop via bungee cord. Video was analyzed using Quick Time 7 Pro (Apple Inc.) software.

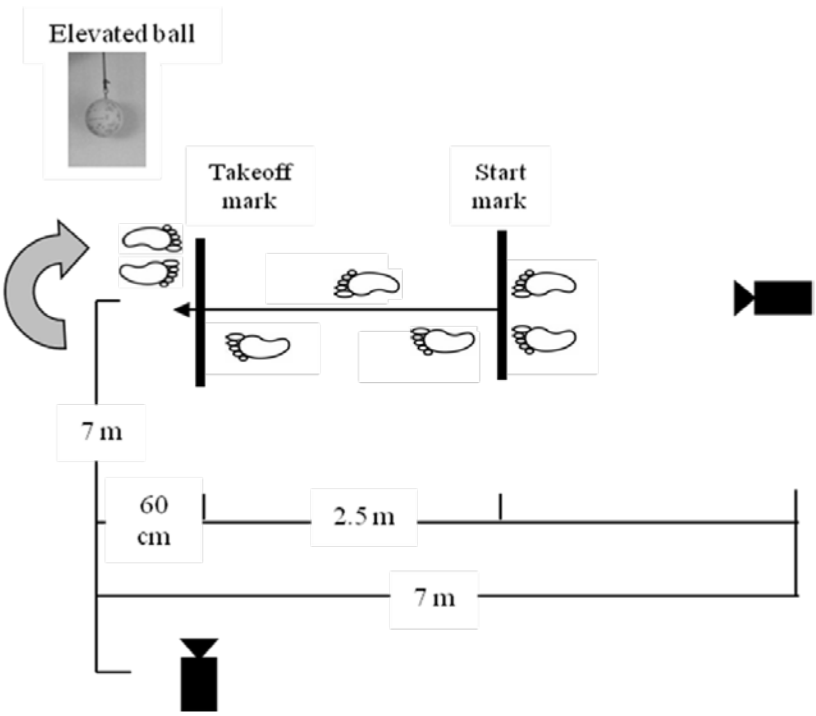


Figure 21: Diagram of the 180˚ aCOD task and set-up.

Procedures

Testing took place during a single testing session for each netball squad on a regulation indoor netball court. Upon arrival, the age, height and body mass for each player was recorded followed by a 10 minute dynamic, netball-specific warm-up. Players were allowed to practice the aCOD task until they felt comfortable. However, no more than three practice trials were taken by any of the players.

Players began their approach 2.5 m away from a designated takeoff mark which was 60 cm from the elevated netball (see Figure 21). Players then performed a 180˚ turn in the air while grabbing the detachable netball and landing bilaterally (two-feet simultaneously) facing down-court. Three successful trials were recorded for each player thereafter the two best (i.e. bilateral landing, closest to 180˚ of rotation) were used for analysis. A trial was considered successful if the player maintained control of the ball and was balanced through the landing (i.e. an additional step was not needed upon landing and a pass was able to be executed immediately). All players were required to perform the task as quickly as possible. Verbal instruction regarding technique was kept to a minimum in order to elicit a 'natural' aCOD performance from each player. However, each player was instructed to "jump, grab the ball and turn 180˚ in the air to face the direction from which you came, landing with both feet at the same time."

Data analyses

A form of qualitative analysis was used to identify the key technical features of an aCOD performance. Conventionally, qualitative analysis refers to a subjective description of the quality of movement based on observations [50]. For this study, a movement analysis was performed, first identifying the objective of the movement (i.e. full 180˚ rotation prior to a bilateral landing), second breaking the movement into phases, and third identifying key technical features for each phase. The four phases were: A) approach - the two steps taken prior to leaving the ground; B) takeoff - the point at which the weight-bearing leg leaves the ground (toe-off) and the athlete becomes airborne; C) airborne - from toe-off until the player first contacts the ground (touchdown); and, D) landing - from touchdown until both feet were completely in contact with the ground.

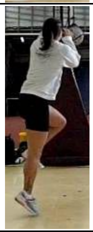
Based on the landing characteristics (i.e. 180˚ turn completed, and a bilateral, parallel landing) players were grouped into three categories: 'Superior' where there was a full 180˚ turn and a bilateral balanced landing; 'Average' where there was either a 90˚ to 180˚ turn or a unilateral; and 'Below Average' where the turn was less than 90˚ and the landing was unilateral. Key technical features for each phase were identified from video footage by manually advancing and observing key movement patterns of each group for each phase (see Table 13).

After this analysis, the key technical features were used in a template to cross-check the categorization of players (see Table 14). A player was awarded a '+' for each key technical feature that was observed to be employed to the full extent, an 'OK' for each key technical feature that was observed but not fully employed, and a '-' for each key technical feature that was absent from the aCOD performance. Finally, the underlying mechanical determinants of each feature were identified. Data consisted solely of video analysis, therefore any reference to forces or body weight distributions were purely observational and not the result of force plate data.

Statistical analyses

The qualitative analytic approach, which by design is more subjective in nature, typically does not utilize a quantitative statistical approach. The methods used are principally descriptive in nature.

Table 13: Movement features determined to be critical to a superior and more effective 180˚ aCOD task.

Phase	Player performance		Key technical feature	Biomechanical rationale
	Superior	***Below average***		
Approach			1. Deep hip and knee flexion	Greater hip and knee flexion through the approach allows for an increased vertical GRF component over a longer time (impulse) at takeoff, as well as utilization of the stretch-shortening cycle which increases takeoff velocity and vertical height jumped allowing more time in the air for the body to rotate.
			2. Rotation prior to takeoff	Early initiation of rotation allows the body to begin the 180˚ turn prior to becoming airborne, allowing for a more advantageous body positioning through flight and upon landing.
Takeoff			3. High arm drive	High arm drive through the takeoff assists in moving the centre of mass vertically, increasing vertical height of the jump.
			4. Free leg drive	Driving the free leg upwards as the weight-bearing leg (takeoff leg) extends rapidly assists in moving the centre of mass vertically at takeoff.
Airborne			5. Rapid head turn	Turning the head rapidly into the new direction immediately following ball possession allows for early visual scanning and identification of possible passing options.
			6. Ball at chest	The ball is positioned close to the body for decreased rotational inertia, and at chest height in preparation for a rapid pass release.
			7. Aggressive lower body rotation	The lower body is rotated around into the new direction in preparation for landing (nutation).

(Table 13 continued)

(Table 13 continued)

Phase	Player performance		Key technical feature	Biomechanical rationale
	Superior	*Below average*		
Landing			8. Bilateral, parallel landing 9. Full 180˚ turn completed	When a full 180˚ turn is not completed prior to landing, or a single leg contacts the ground first a greater turning force (torque) must be absorbed upon landing, increasing the potential for injury.

Table 14: Exemplar of the key technical features template for the 180˚ aCOD task.

		Approach		Takeoff		Airborne			Landing	
	Player	***Deep hip/knee flexion***	***Rotation prior to takeoff***	***High, narrow arm drive***	***Free leg drive***	***Rapid head turn***	***Ball at chest***	***Aggressive lower body rotation***	***Bilateral, parallel***	***Full 180˚ turn completed***
Superior	1	+	+	+	+	+	+	+	+	+
	16	+	+	OK	+	+	+	+	+	+
Average	17	+	+	+	OK	+	OK	-	+	-
	3	+	-	OK	-	OK	+	-	-	+
Below average	8	OK	+	OK	-	OK	OK	-	-	-
	10	-	+	+	OK	-	OK	-	-	-

Results

There were five players allocated to the Superior group, ten to the Average group and twenty-two to the Below Average group based on the criteria outlined previously for the landing phase and cross-checking template. Seven key technical features were identified as contributing to the ability of a player to complete the full 180˚ rotation prior to a bilateral landing. The seven key technical features included: 1) sinking into a deep hip and knee flexion (~135˚) through the final ground contact in the approach; 2) rotating about the takeoff leg prior to leaving the ground; 3) driving both arms up towards the ball, no more than shoulder width apart; 4) driving the free leg up towards the ball at takeoff; 5) following possession of the ball, rapidly rotating the head into the new direction; 6) holding the ball close to the body at chest height once possession had been made in preparation for a quick release pass; and 7) rapid rotation of the lower body throughout the airborne phase to elicit a full 180˚ turn (see Table 13).

An exemplar of the technical features checklist can be observed in Table 14. The Superior group had on average 5-7 key technical features with '+' while the Average group had 5-7 key technical features with 'OK' or an equal number of '+', 'OK', and '-', while the Below Average group had 5-7 key technical features with '-' ratings.

Discussion

This study has provided a method for qualitatively rating aCOD performance based on technical characteristics. As a paucity of research has addressed aCOD technique, this article is intended to provide insight for coaches and strength and conditioning professionals into the technical features associated with a 180˚ aCOD performance. As argued previously this type of analysis should occur prior to the strength and conditioning coach writing programmes to improve COD performance. By integrating this knowledge (technical and physical – straight sprinting speed and leg strength qualities, see Figure 20) the strength and conditioning coach is more likely to improve COD abilities in their athletes. These key technical features, along with the rationale as to why each feature would improve aCOD performance (see Table 13) provide the basis for subsequent discussion.

Key technical feature 1 (deep hip and knee flexion through the approach)

The final step prior to takeoff utilizes a greater amount of hip and knee flexion in the weight-bearing leg through the swing phase (i.e. as the free-leg is brought forward) of the ground contact. This allows ground reaction forces (GRF) to be applied over a greater time (impulse), which in turn results in greater subsequent take-off velocity and jump height [56]. Additionally, as the knee is flexed through the ground contact phase, the leg muscles undergo a rapid stretch followed immediately by a rapid shortening (i.e. stretch-shorten cycle) as the leg is extended through takeoff. As long as the subsequent shortening phase is performed immediately following the stretch, it is likely that the ensuing explosive extension will be potentiated via reflex potentiation and the utilization of stored elastic energy, assisting in the vertical propulsion at takeoff and the height attained when airborne [59]. A minimal hip and knee flexion through the approach will limit the amount of GRF and utilization of the stretch-shorten cycle, resulting in decreased time in the air to complete the necessary amount of rotation prior to touchdown.

Key technical feature 2 (initiating rotation prior to takeoff)

When completing aerial twists and turns, several benefits may result from initiating the rotational component prior to takeoff. By swinging the free leg medially (i.e. towards the body's midline) the body is able to begin rotation earlier [58]. As forces can only be applied while the player is in contact with the ground [50], the portion of the turn completed prior to takeoff will allow for greater amounts of turning force (torque) to be used (through the use of the powerful leg muscles) which is required for rotation. Additionally, when the turn is initiated earlier the body positioning while airborne will be more advantageous for subsequent movements upon landing (e.g. head rotation, full body rotation prior to landing), thereby decreasing the potential for injury upon landing as the rotation will be completed before impact. Limited rotation prior to takeoff combined with limited hip and knee flexion through the approach will require a greater amount of rotation to be completed over a decreased amount of time in the air. Under these circumstances a full 180˚ rotation prior to touchdown is typically not achieved.

Key technical feature 3 (high, narrow arm drive through takeoff)

When extending through the takeoff, the arms are driven upwards towards the elevated ball. A high arm drive assists in raising the body's center of mass (COM) [28], thereby increasing the height reached when jumping and also positioning the hands in a better position to grab the ball. A higher jump height affords the player more time in the air to complete the full 180˚ rotation and align the body for a bilateral, parallel landing.

Key technical feature 4 (free-leg drive upwards through takeoff)

As the weight-bearing leg is rapidly extended through the takeoff, the free-leg is aggressively driven upwards as well. This movement (similar to the high arm drive) assists in the vertical displacement of the COM while airborne [28]. As the leg is driven upwards, the height attained by the jump is increased, allowing for extended time for the rotation to be completed prior to landing.

Key technical feature 5 (rapid head turn following ball possession)

Once the ball has been grabbed, a rapid rotation of the head into the new direction allows for early perceptual identification of the situation upon landing (e.g. opposition location, teammate location, passing options, etc.). The sooner this information can be perceived, the earlier the player can prepare for the subsequent movements (e.g. taking a step, passing, etc.) Early pattern recognition and anticipation in sport has been identified as a defining characteristic of elite performers [23].

Key technical feature 6 (ball close to the body, at chest height)

Several advantages can arise from positioning the ball close to the body following possession. In addition to protecting the ball from possible opposition interference, positioning the ball close to the body allows for decreased rotational inertia (resistance to rotate) [56]. That is, a player with mass arranged closer to the axis of rotation, which is the longitudinal axis in this case, will rotate quicker while airborne. Furthermore by keeping the ball at (or near) lower chest height, the player is prepared to complete a pass prior to or immediately following landing as the muscles are already preloaded and only extension of the arms is needed to complete the pass.

Key technical feature 7 (rapid lower body rotation while airborne)

During the airborne phase an aggressive rotation of the lower body is required. As the body is typically rotated segmentally through the air (‘cat-twist technique’, principle of nutation [43] allowing for early ball possession and perceptual identification of the new direction through upper body rotation, the lower body must also be rapidly rotated around prior to landing. As the body nears the ground, an early ground contact (i.e. decreased jump height) or lack of rotation will incur large amounts of torsion (turning force) upon landing, increasing the potential for injury. Therefore, the lower body must be rapidly rotated to ensure that the full rotation is completed prior to ground contact and that the impact force is limited to the anterior-posterior (front/back) direction. As the player leaves the ground, the lower body has already begun to rotate (technical feature 2). This rotation is continued through the airborne phase as the legs remain relatively close to the body's midline, decreasing rotational inertia (resistance to rotate) and allowing for a faster rotation. Once the lower body has completed approximately 90˚ of rotation, the legs are extended away from the body's midline (i.e. hip abduction) to create a wider base of support for a more balanced landing as well as to slow the speed of rotation to avoid over-rotating. At this point, the upper body begins to rotate rapidly around by bringing the arms (with the ball) close to the body (technical feature 6), decreasing rotational inertia.

Optimal performance outcome: Full 180˚ turn completed prior to a bilateral, parallel landing

If all features have been fully employed, the full 180˚ rotation should be easily completed prior to ground contact. Single-leg or staggered landings are signs that the full rotation was not completed while airborne and that additional torques have been placed on the less stable lower limbs which could increase the potential for injury [60]. As females have been shown to be at greater risk for lower limb injuries due to anatomical and biomechanical differences in force absorption upon landing [60-62], it is important for females in sports involving repetitive high impact forces (e.g. netball, basketball, etc.) to ensure they have biomechanically effective and safe landing techniques. In addition, netball requires aerial full rotation movements completed prior to ground contact which can result in increased torque and stress on the lower limb joints on landing. Control of the body during these types of landings after rotation is particularly important. A parallel foot placement (i.e. square to the hips and shoulders) ensures that the body weight is more evenly distributed between the feet upon impact, thereby decreasing the potential for injury.

Several benefits are associated with a bilateral (two-footed) landing when compared to its unilateral (single-footed) counterpart. Increased leg stiffness (decreased hip and knee flexion at impact) has been observed with unilateral landings [60, 63, 64], predisposing players to knee and ankle injuries. A bilateral strategy allows the landing to be absorbed using greater muscle mass (decreased impact forces) and over a larger base of support (increased stability) compared to a unilateral landing. The rules of the specific sport may also support a bilateral landing, as is the case with netball. When a bilateral landing is employed, the player is able to take the first step off either foot as opposed to being limited to the ground contact foot when a unilateral landing is used. This affords the player with more options that are likely to contribute greatly to the success of the game as well as absorbing landing forces over time (i.e. impulse).

Practical applications

Movement analysis can help in designing of programmes to improve COD performance. The authors have used a simplistic qualitative analytic approach, which can be easily used by practitioners to gain useful information about COD performance. This type of information would seem much needed as evidenced by the paucity of information in this area.

Seven technical features were identified that were thought critical to superior aCOD performance. By using a template similar to that shown in Table 14 and prioritizing those key technical features that are found to be lacking in an aCOD performance, training is more likely to meet the specific technical needs of individual players. While more research is needed in this area, these key technical features are able to provide coaches and strength and conditioning professionals some insight into the fundamental characteristics that appear to be consistently associated with a 180˚ aCOD involving an elevated ball. Furthermore this approach provides a template for analysis of other movements.

It should be noted however, that an integrated approach is needed for the athlete to optimise their aCOD performance as technical factors are sometimes limited by an athlete's leg strength qualities (i.e. not enough flight time to complete the full rotation) rather than their biomechanical technique. The coach and strength and conditioning coach need to design and conduct assessments and develop individual training programmes with both the player's physical and technical requirements in mind.

Acknowledgements

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CHAPTER 8

UNDERSTANDING AERIAL CHANGE OF DIRECTION PERFORMANCE IN SPORT

This chapter comprises the following paper:

Hewit, J., Cronin, J.B., & Hume, P.A. *Understanding aerial change of direction performance in sport.* To be submitted to *Strength and Conditioning Journal*.

Author contributions - JH: 86%, JC: 8%, & PH: 6%.

Prelude

Similar to the review on ground-based change of direction, there has been a lack of research addressing aerial COD (aCOD) ability in players. This brief review combines information gathered from the previous thesis experimental studies investigating aerial COD and the limited available published research in this area. Given the need to understand the technical demands of netball specific movements, the aim of this brief review article was to enhance the understanding and mechanical awareness of key technical features thought fundamental to a 180^{o} aCOD task. Some suggestions as to exercises that can be used in tandem with the mechanical analysis were provided.

Introduction

Changes of direction (COD) occur frequently in many sports and may be performed while in contact with the ground or while airborne. Rapid COD movements rely on both technical and physical qualities of a player [5]. As a result, when either the technical skills or physical strength are under-developed in a player the potential for injury and sub-optimal movement patterning is increased.

While many change of direction movements in sport occur while maintaining full contact with the ground (e.g. horizontal and lateral transitions), there are also many situations throughout a game or match that require a player to transition vertically. These aerial movements may include a rotation about one or more axes. Some sports (e.g. netball, basketball, rugby, etc.) require the athlete to rotate about the longitudinal axis (see Figure 22) while in the air primarily to gain a competitive advantage upon landing (e.g. facing down-court following an interception).

Figure 22: Diagram showing the longitudinal axis of rotation.

When aerial-based movements are performed at rapid velocities, the forces and torques (turning force) placed on the body upon impact are increased dramatically. It is therefore imperative that coaches emphasize and promote key aerial change of direction (aCOD) techniques in conjunction with appropriate strengthening of the active musculature to minimise the potential for injury and increase the effectiveness of the performance. However, there is a paucity of research that has investigated the physical and technical demands of COD movement particularly of aCOD tasks. Intuitively a technical understanding of the movement precedes programming as such analysis provides information as to the segmental movement patterns, active musculature and the technical features associated with the movement. This information in turn can guide programming and coaching.

Two recent studies conducted in our own lab presented key technical features that were thought to contribute to a successful 90 - 180˚ ground-based change of direction movement. While many of the key technical features concerning ground-based principles of motion are applicable during the preparatory (takeoff) and follow-through (landing) phases of aerial manoeuvres, we have also found several additional key technical features associated with airborne motion that should be addressed to further enhance our understanding of the mechanics involved in such complex movement tasks and improve efficiency of such tasks. The aim of this brief review is to share this information with coaches and strength and conditioning practitioners, cognizant that this knowledge coupled with appropriate conditioning around the technical requirements of the movement, should result in safer and more effective aCOD performance. Table 15 provides an overview of the key technical features that are proposed to elicit a safer and more effective aCOD performance. Each of the seven features is accompanied by a photo of that feature being performed (superior player performance) as well as a photo of a performance lacking that feature (less effective player performance). A biomechanical rationale has been provided as explanation why each feature is beneficial to the overall aCOD movement performance. Finally suggestions as to exercises that can be used in tandem with the mechanical analysis have also been detailed.

Approach phase

The initial ground-based phase of an aerial task refers to the preparation portion (approach) of the movement where the player is fully in contact with the ground. The movements that occur during this phase greatly affect the nature and outcome of the airborne phase. The primary purpose of the approach is to generate the appropriate ground-reaction forces needed to propel the player high enough into the air to complete the necessary airborne task (i.e. 180˚ rotation).

The magnitude of force/torque and the point of application at takeoff are critical for aerial movements, as the amount of time in the air and trajectory of the flight (e.g. angle and distance travelled) are a direct result of it [28] (see Table 15). The direction of the jump (e.g. vertical, horizontal, lateral, etc.) is dependent upon the point of application of the force/torque in relation to the body’s base of support [50]. When the force is applied directly through the base of support, the body will continue in the direction the force is being applied. However, when a force is applied outside the base of support (torque), a change in the current direction will result [43]. As a force can only be applied while in contact with an external surface, the location of the final approach step in relation to the body’s base of support will also have an effect on whether a rotation is included.

As a player initiates takeoff when jumping a force/torque must be applied into the ground primarily through increased hip and knee flexion. A minimal flexion through the final approach step prior to takeoff will result in limited elevation while airborne (i.e. reduced GRF), as height jumped will be proportional to the velocity produced as the leg is rapidly extended at takeoff [56]. In order to gain enough height when jumping to complete a turn in the air, a deeper more forceful flexion at the hip and knee combined with optimal sequencing of the joints is required.

Table 15: Key technical features that determine the nature of aerial motion (e.g. vertical, horizontal, lateral, rotation, etc.).

Phase	Player performance		Key technical feature	Biomechanical rationale
	Superior	**Less effective**		
Approach			1.Deep hip and knee flexion	Greater knee flexion through the approach allows for an increased vertical GRF component at takeoff, as well as utilization of the stretch-shortening cycle which increases takeoff velocity and vertical height jumped allowing more time in the air for the body to rotate.
			2. Rotation prior to takeoff	Early initiation of rotation allows the body to begin the 180˚ turn prior to becoming airborne.
Takeoff			3. High arm drive	A high arm drive through the takeoff assists in moving the centre of mass vertically, increasing vertical height of the jump.
			4. Free leg drive	Driving the free leg upwards as the weight-bearing leg (takeoff leg) extends rapidly assists in moving the centre of mass vertically at takeoff.
Airborne			5. Rapid head turn	Turning the head rapidly into the new direction immediately following ball possession allows for early visual scanning and identification of possible passing options.
			6. Ball at chest	The ball is positioned close to the body for decreased rotational inertia, and at chest height in preparation for a rapid pass release.
			7. Lower body rotation	The lower body is aggressively rotated around into the new direction in preparation for landing.

(Table 15 continued)

(Table 15 continued)

Phase	Player performance		Key technical feature	Biomechanical rationale
	Superior	Less effective		
Landing			<u>Optimal Performance Outcome</u> ateral, parallel landing ll 180˚ turn completed	When a full 180˚ turn is not completed prior to landing, or a single leg contacts the ground first a greater turning force (torque) must be absorbed upon landing, increasing the potential for injury.

Takeoff phase

As the player rapidly extends through the takeoff leg, a pivoting motion is performed with the plant foot [58, 65]. Initiating the turn prior to leaving the ground creates an advantage to the player as a smaller portion of the rotation will be required while airborne. This increases the likelihood of the player successfully completing the full turn and potentially decreases the amount of rotation at landing, thereby minimizing the potentially harmful torques incurred at impact.

Driving both arms upwards toward the ball during takeoff will assist in the height attained during the jump [28] (and therefore having a positive effect on the time in the air for completing the rotation). An aggressive arm drive will also benefit the sport-specific task. By driving both arms upwards over the head through the takeoff the player will have an opportunity to secure possession of the ball earlier during the movement task. When the arms are elevated following takeoff, the ball will be grabbed later into the flight phase and decrease the amount of decision time allocated prior to landing [9].

Additional jump height can also be gained when taking off of a single leg by driving the free leg upwards. This movement increases the takeoff velocity as well as increases the height of the centre of mass (COM), resulting in increased jump height [28]. A common technique used by players employs a double-leg takeoff [15, 66] when jumping towards an elevated target (i.e. basketball, volleyball etc.). A double-leg takeoff, however limits the amount of rotation that can be initiated as the player leaves the ground and therefore requires a greater degree of rotation to be completed while airborne.

Airborne phase

The airborne phase of an aerial task refers to the portion of the movement when the player is no longer in contact with any external surface (e.g. the ground). If the movements (i.e. rotation) performed during this phase are not completed prior to ground contact, the body positioning upon landing will be less than optimal and increase the potential for injury. The main objective of this phase is to complete the full rotation prior to landing. The underlying biomechanics of the rotation component will be addressed more extensively than the other two features which are more directly related to the sport-specific task (i.e. catching an elevated ball in preparation for a rapid pass release).

One objective of the airborne phase is to prepare the body for landing and any subsequent movements performed immediately following landing (e.g. pass). Therefore, as soon as ball possession has been obtained visual, identification of the new direction is made through a rapid head rotation. This allows the player to identify the various options (e.g. passing location, opponent positioning, pressure of pass release) upon landing and select the most appropriate while still airborne [67].

The positioning of the ball following possession is important for both the success of the aCOD performance as well as the sport-specific context of the task. Following possession, the ball is immediately brought close to the body to decrease the rotational inertia [43], thereby allowing the player to rotate more rapidly while airborne (see key technical feature 7). This positioning also assists in protecting the ball from the opposition. The ball is held at lower chest height as the rotation is completed in preparation for an early pass release (i.e. preloaded muscles of the upper body) upon landing. When the ball is held away from the body, the arms must first be flexed at the elbow prior to extension as the pass is executed.

An aCOD can be initiated by applying a torque (pivot) while in contact with the ground (as discussed previously), as well as by repositioning body segments in relation to the axis of rotation while airborne. In the early flight phase it is desirable to have all segments as close to the longitudinal axis of rotation (body's midline) as possible so that rotation in the air is faster. However, during the late flight phase the limbs are extended away from the axis so that rotation slows. To understand this principle, we need to understand how angular momentum is conserved and how the body's rotational inertia (resistance to rotation) and angular velocity (rate of rotation) [56] interact to affect the characteristics of motion while airborne.

Once the body begins to spin or twist, rotational inertia must be overcome to slow the rotation and minimize torque incurred upon landing. Two components determine the amount of rotational inertia the body possesses. The first is directly related to the body's mass. Greater mass requires increased force or torque to move it. Therefore, a heavier body will be more difficult to rotate or alter the magnitude of rotation once it is moving [43]. This quality is often not easily adjusted in sport unless additional weight is added or subtracted from the body (e.g. weighted vest, medicine ball, etc.). As a result, the second determinant of rotational inertia becomes more easily adjusted; the distribution of mass relative to the axis of rotation [43]. For example, when a larger portion of the body's mass is positioned closer to the point of rotation (axis) the radius decreases and it is easier for the body to rotate. Decreased rotational inertia can be observed in Figure 23A as the player's arms and legs are positioned close to the axis of rotation (longitudinal axis, running vertically through the body). In contrast, the player in Figure 23B has one leg flexed at the hip and knee (a result of the free leg drive at takeoff), thereby distributing the body mass further away from the longitudinal axis and reducing the ability to turn in the air. While hip and knee flexion during the takeoff was advantageous for increasing the height of the jump, once the body becomes airborne and begins rotating the free leg should be extended to decrease the rotational inertia through the turn.

Figure 23: Players displaying decreased (A) and increased (B) rotational inertia.

The angular velocity of a body refers to the rate at which the body is rotating about an axis (i.e. the number of revolutions or degrees completed in a given direction and time), or how fast a player can turn. Optimal angular velocity varies throughout movement tasks and is dependent upon the objective of the movement. Increased angular velocity is of interest during the initial portion of aerial rotations as a faster angular velocity will benefit the success of the movement (e.g. a player attempting a 180° aerial turn before landing). In contrast, decreased angular velocity is of interest in the latter portion of aerial rotations as the body must slow the rotation in preparation for a landing with minimal torque at touchdown (see Figure 24D).

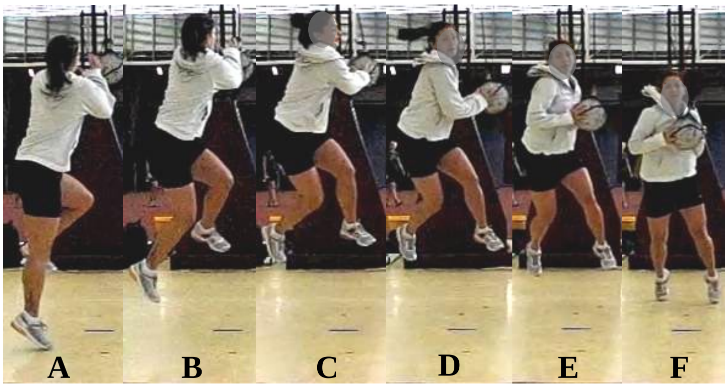


Figure 24: Successful completion of a 180˚ aerial change of direction, using the proposed key technical features.

The amount of motion that a rotating airborne body possesses is known as its angular momentum. Angular momentum (H) is the product of rotational inertia (I) and angular velocity (ω) (H = Iω). In sport, both linear and angular momentum are often needed simultaneously to complete various dynamic movement tasks. Linear momentum (amount of motion in a straight line) is necessary during takeoff to propel the athlete off of the ground. As forces can only be applied to a body when it is in contact with a surface, the only force acting on an airborne body is that of gravity (acting vertically down through the COM) and air resistance (typically negligible). Therefore, when a body is airborne, its angular momentum remains constant until an external force or torque can again be applied upon landing. Under these circumstances, angular momentum is said to be 'conserved' (i.e. maintained or unchanged).

Although angular momentum remains the same when airborne, a player is able to manipulate their own angular velocity and rotational inertia by altering the position of body segments while in flight. When body segments are positioned close to the axis (decreased rotational inertia), the body spins faster (increased angular velocity). As a player completes the desired rotation and nears the ground, extending the arms and legs away from the axis of rotation increases the rotational inertia and decreases the angular velocity, thereby slowing and ultimately stopping the rotation (see Figure 24D).

Landing phase

Aligned limbs and balanced weight distribution are critical for a successful landing following an aerial manoeuvre. When all movements during the preparatory (approach and takeoff) and execution (airborne) phases have been performed optimally, a successful landing phase should result.

As rotation was first initiated prior to leaving the ground and fully completed through the airborne phase, the torques absorbed upon impact should be relatively minimal. However, when the rotation is not completed prior to landing (see Figure 25) a pivoting action is required following ground contact in order to complete the full rotation. This places increased strain (torques) on a number of joints - in particular the knee. This added torque will cause the lower body to become less effective at absorbing and dissipating the large ground reaction force upon impact [43]. The combination of the over-rotation and the ground-reaction impact forces may result in the player landing off-balance and needing an additional step to recover, or may have a more serious consequence such as an injury to the ligaments of the knee.

Figure 25: Aerial COD where the full 180˚ rotation is not completed prior to ground contact.

The less rotation the player is able to complete prior to ground contact, the more likely a unilateral (one legged) landing will be. When the full rotation is completed prior to ground contact (see Figure 24), the player is able to land simultaneously with both feet (i.e. bilaterally) allowing the impact forces to be dissipated over both legs and a wider BOS [43]. Subsequent movements can then be performed more powerfully (from the balanced, wider stance) and immediately following ground contact. In some players, subsequent movements (e.g. passes) may even be performed prior to landing when the rotation has been completed early enough in the movement.

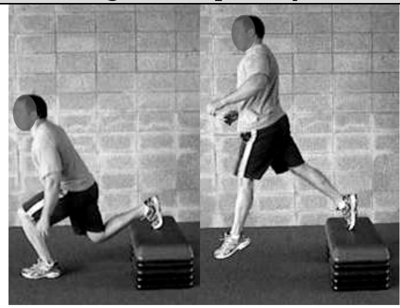
Training approach

As change of direction ability is dependent upon both technical and physical characteristics, each movement phase of the aCOD task requires adequate muscle strength and coordination. It is important that individual player weaknesses associated with each phase are addressed in training sessions. Examples of exercises that target the primary muscle groups of interest for key technical features within each phase are presented in Table 16 and discussed below. The exercises recommended in this paper can be easily modified or adjusted to suit the needs of the player, sport and phase (i.e. strength vs. power) as there are a plethora of exercises available to the strength and conditioning coach.

Increased hip and knee flexion of the weight-bearing leg through the approach has been identified as a key technical feature in the 180˚ aCOD task. This movement requires both strength and flexibility in the hip flexors, quadriceps and hamstring muscle groups. By placing the free leg on an elevated surface (e.g. bench, exercise ball, etc.) behind the player, the 'Bulgarian Split Squat' (see Table 16) stretches the hips flexors and quadriceps of the free leg while simultaneously strengthening the quadriceps and hamstrings of the weight-bearing leg. The lower the player is able to sink during the downward phase of the lunge will result in increased flexibility and range of motion in addition to increased strength throughout the range of motion.

As the player transitions from the approach into the takeoff phase, the arms and free leg are driven upwards as the takeoff leg extends. Both shoulder and hip flexion are the primary actions required for driving the body upwards. The explosive arm drive is strengthened through a 'Medicine Ball Vertical Throw' (see Table 16) where the player lowers down into a three-quarter squat and rapidly extends as the ball is thrust overhead. Rapid hip flexion can be targeted through a resisted leg drive using elastic bands tethered to the ankle. Powerful hip extension is also required for the explosive single-leg takeoff. Single-leg countermovement jumps (vertical, horizontal and lateral) are used to increase unilateral leg strength, stability and power through explosive extension of the takeoff leg.

Table 16: Exercise suggestions for targeting the primary muscle groups involved when performing a 180˚ aCOD movement.

Phase	Movement	Primary muscle group(s)	Exercise		
			Bulgarian Split Squat		
Approach	Hip and knee flexion	• Hip flexors/Quadriceps • Hamstrings	 Start: Elevate one leg on a solid surface behind the body	 Action: Lower down into a lunge with the weight on the front leg. The knee of the front leg should remain behind the toes of that foot	 End: Push up through the heel of the front foot, returning to the start position
			Medicine Ball Squat Throw		
Takeoff	Upward driving of the arms and free leg	• Deltoids • Hip flexors • Gluteals and Hamstrings	 Start: Holding a medicine ball, stand with feet approximately shoulder width apart	 Action: Lower down into a squatting position, keeping the chest out and abdominals engaged	 End: Rapidly extend the hips, knees and ankles while throwing the ball overhead

Once airborne, the player relies on the ability of the obliques to rapidly rotate the lower body around to complete the full rotation and align the body prior to landing. Prone rotations on an exercise ball (see Table 16) allow the player to initiate an explosive rotation of the lower body with the obliques. While many exercises that target the obliques are performed either in a sitting position (i.e. hip flexion) or through isolated upper body rotation, this exercise maintains the extended hip positioning and lower body rotation that is required during the aCOD task.

Finally, upon landing the intense impact force incurred at ground contact must be dissipated over as many joints as possible to decrease the negative effect it has on the body. A bilateral landing allows this force to be absorbed over both legs, thereby doubling the number of joints involved when compared to a unilateral landing. Drop jumps (see Table 16) can be used to teach players how to effectively absorb and transfer impact forces through joint sequencing. A variety of sport specific movements (e.g. explosive reactive jump, sprint, ground-based COD, ball catch, etc.) can also be easily added to such a task. The height of the drop should progress with the experience of the player and ability to dissipate impact forces.

Summary

There are several key technical features that are required to safely perform effective (e.g. balanced, rapid, etc.) aCOD movements in sport. While the rules of each sport and sporting context may vary greatly, these fundamental movements should be fundamental regardless of the individual sport requirements. The potential for injury is increased when a player completes complex movements that require large forces/torques to be performed at rapid velocities. Therefore, to decrease the potential for injury, it is important for players of all skill levels to be taught proper technique and be appropriately conditioned to ensure that the forces being applied and absorbed by the body at any time during play are manageable and optimal.

An effective aCOD performance begins with the approach phase. It is crucial during this phase to generate an adequate amount of ground reaction force through deep knee flexion of the weight-bearing leg in order to propel the player high enough into the air. Additionally, the free leg and arms should be aggressively driven upwards as the weight-bearing leg is rapidly extended. This assists in raising the body's COM and increases the takeoff velocity, resulting in an increased jump height. The amount of time spent airborne will affect how much rotation will be completed by the player prior to landing, all other things being equal.

The second phase of the movement task concerns the body positioning and adjustments while airborne. The only force acting on the body while airborne is gravity (pulling the body downwards). However, moving the arms and legs closer or further away from the axis of rotation, will allow the player to rotate faster or slower through the air. A faster rotation (arms and legs close the body) is typically desirably during the initial portion of the airborne phase allowing the player to become aligned with the new direction as quickly as possible. Once the rotation has been completed, the arms and/or legs may be extended away from the body (axis of rotation) increasing the rotational inertia and slowing the rotation prior to landing.

As the player nears the ground, a balanced bilateral landing with a large base of support decreases the potential for injury as the rotational component is decreased and the impact force can be dissipated across two legs as opposed to one. Additionally, the player is now in an advantageous body position where more options for subsequent movements are available (e.g. moving off of either leg, passing, pivoting off of either leg, etc.) An unbalanced unilateral landing increases the potential for injury as well as limits the options available to the player upon landing.

It is hoped that the inclusion of these key technical features in training sessions targeting aCOD maneuvers will assist in the development of safe and effective aCOD performances. Once these principles have been integrated, it is likely that a competitive advantage will result allowing the player(s) to reach their full aerial performance potential. It should be remembered that some technical factors may be limited by the strength and length of muscles. Therefore training that simultaneously addresses physical and technical capabilities of players is thought beneficial for the performance and recommended as supplement to the technical component. For example, it may be that the aCOD is limited by the amount of time in the air the athlete achieves and therefore the power of the leg extensors becomes the foci.

SECTION TWO: PHYSICAL DETERMINANTS OF AGILITY

Chapter 1 outlined how knowledge of the technical, physical and perceptual decision making components of agility are important. Section one in this thesis addressed the technical component of agility as it pertains to change of direction ability. However, adequate physical strength and power are also required for the successful execution of such movements. In this section the two studies aim to improve knowledge of the physical requirements associated with netball specific movements.

CHAPTER 9

MULTI-DIRECTIONAL LEG ASYMMETRY IN SPORT

This chapter comprises the following paper:

Hewit, J., Cronin, J.B., & Hume, P.A. *Multi-directional leg asymmetry in sport.* Submitted to *Physical Therapy in Sport.*

Author contributions - JH: 85%, JC: 10%, & PH: 5%.

Prelude

Leg power assessments provide coaches and strength training professionals with valuable prognostic and diagnostic information about players regarding current training status including the potential for injury and when a player is ready to return to play following an injury. While leg power assessments are traditionally performed in the vertical direction, multi-directional assessments provide a more thorough understanding of player strengths and weaknesses in a movement-specific context. Since most movement in sport is typified by single-leg propulsion it would seem intuitive to develop single-leg multi-directional profiles of athletes. Such profiles can serve many purposes, one of which is to determine the magnitude of asymmetry or imbalance between legs. This average symmetry index (ASI) may be able to identify players that may be at a greater risk of injury due to increased muscle imbalances between legs. Given the theme of the thesis around improving understanding associated with the physical component of agility, the purpose of this brief review was to improve understanding of assessment of asymmetry in athletes. From such information, it is thought that more effective training programmes can be designed to address weaknesses and decrease the potential for injury.

Introduction

Leg power in sport is commonly assessed using a vertical jump assessment task and subsequent derivations. The combination of the simplistic testing procedures and equipment (e.g. contact mat, high speed video, Vertec apparatus, etc.), supposedly high specificity to sport and highly reliable results associated with this task make it a popular test among coaches and strength training professionals. While this task provides coaches and strength trainers with information regarding performance in the vertical direction, leg power in sport is not limited to the vertical direction. Many movements a player is required to perform throughout a competition occur in the vertical, horizontal and/or lateral directions. Using only the vertical jump to create a profile of a player that also performs movement tasks in horizontal and/or lateral directions during competition is flawed. [47]. The assumption that leg muscle qualities are the same across all three directions (vertical, horizontal and lateral) is most likely incorrect [16, 17]. Therefore, an assessment task that targets each of these directions is needed to create an accurate player profile.

Multi-directional leg power assessments provide coaches and strength training professionals with data that can be used for monitoring and assessment, baseline comparative values when athletes are injured, or threshold values for predictors of performance (e.g. minimum standards). Of interest in this paper is the use of single-leg assessments to detect limb asymmetry which may provide information about the potential for injury and hence guide injury prevention or off-season programming. This brief review provides information on outcome measures that describe limb asymmetry and the reliability of single-limb multi-directional assessments. The determinants of these asymmetries can be many (e.g. hereditary, injury, mechanical, physiological, anatomical, etc.) and are outside the focus of this article. Furthermore it should be noted that asymmetry between limbs can be a naturally occurring phenomenon reflecting the demands of the specific sport. For example, the dominant arm of a baseball pitcher or tennis player will likely have greater muscle mass and strength and power outputs when compared to the contralateral arm. As such, substantial asymmetries are expected, however the magnitude of these asymmetries in non-injured players for specific sports should be documented so that normative ranges of asymmetry in players can be identified. This provides another focus of this article.

Outcome measures that describe leg asymmetry

Dynamic directional changes in sport (vertical, horizontal or lateral) are not always performed using a bilateral take-off or landing. When a single-leg is used to propel the body and absorb the intense impact forces and torques incurred upon landing, any muscle imbalances could affect the success of the movement task by placing increased strain on the weaker leg [68]. Therefore, leg power asymmetry is commonly assessed using various forms of single-leg jumping tasks due to the relative ease of administration and cost effectiveness of testing and analysis. When the percent difference between legs is calculated, a measure of limb asymmetry is produced (e.g. average symmetry index (ASI) = [1- dominant leg/non-dominant leg]*100). Researchers have presented absolute values, but these do not clearly indicate the direction of the change, only that there is a difference. Strength and conditioning coaches should provide positive or negative ASI values so that it is clear that a positive percentage change indicates the non-injured limb is better than the injured limb, for example.

Leg asymmetry magnitudes can be calculated from jump distance and/or jump height measurements (e.g. tape measure, Vertec, etc.) or if the technology is available, a force plate (e.g. peak force and peak power). Measures such as jump height and distance may be less sensitive for limb asymmetry than power output. For example, Meylan et al. [69] reported different ASI magnitudes for distance (3.9-6.0%), force (0.4-7.6%) and power (2.1-9.3%) for the same jumps across different directions. Work in our lab for a study of 22 netball players showed greater ASI for power output (8.9-11.9%) across the three directions compared to force or distance (3.2-8.6% - see Table 17). While all three variables provided valuable information regarding player leg asymmetries, those calculated from peak power identified a greater number of players with asymmetry magnitudes above 10% than both peak force and jump distance/height variables. With power being a product of both force and velocity, it may be that this measure can better detect differences between limbs. Velocity may be the limiting factor for an athlete, so velocity of movement would become the focus of training. Using a measure such as power output in conjunction with force output could help with programming. To the knowledge of the authors, no study to date has assessed the sensitivity of force, power and distance as measures to detect limb asymmetry.

Table 17: Acyclic single and double-leg direction-specific jumping task reliability.

Study	Task	ICC	CV (%)
Vertical jumping direction			
Brosky et al. [70]	SL CMJ with arm movement	0.86 – 0.97	--
Hopper et al. [71]	SL CMJ without arm movement	0.92	--
Meylan et al. [16]	SL CMJ without arm movement	0.96	6.7
Maulder et al. [17]	SL SJ without arm movement SL CMJ without arm movement	0.82 – 0.86 0.86 – 0.95	3.3 – 4.4 3.3 – 4.1
Markovic et al. [72]	Stand & reach DL CMJ with arm movement DL SJ without arm movement DL CMJ without arm movement	0.96 0.97 0.98	3.0 3.3 2.8
Chamari et al. [73]	DL SJ without arm movement DL CMJ with arm movement	--	10.5 8.94
Burr et al. [14]	DL CMJ with arm movement DL SJ with arms	0.99 0.97 – 0.99	--
Horizontal jumping direction			
Bolga & Keskula [74]	SL CMJ with arm movement	0.96	--
Brosky et al. [70]	SL CMJ with arm movement	0.86 – 0.97	--
Greenberger & Paterno [75]	SL CMJ without arm movement	0.92 – 0.96	--
Paterno & Greenberger [76]	SL CMJ without arm movement	0.92 – 0.96	--
Meylan et al. [16]	SL CMJ without arm movement	0.97	3.1
Maulder et al. [17]	SL SJ without arm movement SL CMJ without arm movement	0.89 – 0.90 0.80 – 0.95	1.1 – 1.9 1.9 – 2.0
Markovic et al. [72]	DL CMJ with arm movement	0.95	2.4
Lateral jumping direction			
Meylan et al. [16]	SL CMJ without arm movement	0.94	4.4

Note: ICC = intra-class correlation coefficient, CV = coefficient of variation, SL = single-leg, DL = double-leg, CMJ = countermovement jump, and SJ = squat jump. All reliability measures are based on height or distance attained when jumping.

Reliability of single-limb multi-directional leg power assessments

Until recently, there has been limited research addressing the reliability of multi-directional leg power. A straight-forward approach to creating multi-directional assessments is to take the vertical jump task (known to be reliable) and perform it across the horizontal and lateral directions. Individual players' directional strengths and weaknesses can be identified through this approach and can provide direction for programming. Very little research has assessed the reliability of single-leg countermovement jumps performed in the vertical, horizontal and lateral directions [16]. Given the paucity of literature in this area, Table 2 presents some studies that have investigated the reliability of double-leg and single-leg jumps in various directions. Though there are no preset standards as to what is and is not acceptable as a reliable measure, Walmsley and Amell [77] suggested that intraclass correlation coefficient (ICC) values above 0.75 may be considered reliable and this index should be at least 0.90 for most clinical applications [77]. An analytical goal of the coefficient of variation percentage (CV%) being 10% or below has been chosen arbitrarily by some scientists but the merits of this value are the source of conjecture [78]. It would seem that all variables detailed in Table 2 had relative consistency (ICC) greater than the 0.75 threshold. Double-leg jumps appear to have greater consistency while jump performance without arms affixed to the hip seems to be less consistent (i.e., less reliable). With regards to absolute consistency (CV%), no observable trend was apparent. In the only study [16] that compared reliability of three jumps, the jump measures across all three directions were highly reliable (ICC's ranging from 0.82 – 0.98, CV%'s ranging from 1.1 – 7.2%) with the greatest reliability associated with the horizontal direction (see Table 18).

Table 18: Direction-specific leg asymmetry (%) calculated from peak power, peak force and jump height/distance and averaged over 22 sub-elite netball players.

	Asymmetry variable [mean ±SD]		
Jump Direction	***Peak power***	***Peak force***	***Height/Distance***
Vertical	9.9 ±11.7	3.2 ±2.9	8.4 ±6.9
Horizontal	11.9 ±7.8	8.6 ±9.0	5.0 ±3.7
Lateral	8.9 ±9.0	4.4 ±2.9	5.4 ±4.1

Shared variances between single and double-leg vertical, horizontal and lateral countermovement jumps reported in three studies (5, 6, 10) ranged from 13 - 62%. This suggests that testing athletes across three directions measures relatively independent leg power qualities. Therefore, when assessing the leg power capability of players that consistently perform rapid and explosive multi-directional movements in competition, the inclusion of an assessment targeting all three directions is desirable.

Magnitudes of leg power asymmetry in injured and non-injured athletes

Strength and conditioning coaches need to know the expected magnitude of asymmetry in non-injured players. Maulder et al. [17] reported mean asymmetries of 1.1% for the horizontal countermovement jump and no difference for the vertical countermovement jump distance for 18 male sportsmen. Studying the ASI magnitudes of 30 non-injured team sport athletes (soccer, basketball, field hockey and rugby), Meylan et al. [69] cited mean ASI's in height and distance for the vertical, horizontal and lateral jumps ranging from 2.6-6.0%. This study also reported the mean ASI's of a variety of kinetic variables (eccentric and concentric peak force and powers), ranging from 0.4% (horizontal concentric peak force) to 9.3% (lateral concentric peak power). Work in our own lab with 22 non-injured national netball female athletes has found mean asymmetries in height and distance for the vertical, horizontal and lateral jumps ranging from 4.6-7.8%. With regards to kinetic variables across the three jump directions, mean ASI's ranging from 3.0% (vertical concentric peak force) to 11.4% (horizontal concentric peak power) have been observed.

There is no specific magnitude of asymmetry that has been identified in the literature as a definitive threshold separating injured and non-injured players or the potential for injury. However, it would seem magnitudes of 15% or more are often associated with players that have recently sustained an injury, while magnitudes below 10% are typically reported in non-injured populations [17, 69, 79, 80]. Therefore, an asymmetry threshold of 10-15% or more is thought to place additional strain on the weaker leg, compromising the player's performance as well as predisposing the athlete to various injuries [68, 81-83]. As gender and the physical requirements of the sport (e.g. positional demands) are likely to contribute to muscle development and imbalances, such a threshold can be used as a guideline for injury prevention, programming, and readiness to return to play but not as a definitive predictor or indicator of injury.

Paterno et al. [81] compared leg asymmetry of anterior cruciate ligament rehabilitated athletes with that of non-injured collegiate athletes when performing a single-leg drop jump for height. Asymmetry of 15% or more was observed in the rehabilitated subjects up to two years post surgery, which reportedly placed them at a greater risk of injury to either leg in the future. Similar results were found in a study conducted by Shiltz et al. [84] where single-leg drop jump leg asymmetry was compared between junior-level (non-injured), recreational (non-injured) and professional-level basketball players (with and without previous knee injury). While the two non-injured groups had mean asymmetry magnitudes lower than 5% for jump height, the mixed group of professional players had asymmetry magnitudes of 12 ±7.9%. Professional players with previous knee injuries had asymmetry magnitudes averaging 18.4 ±7.8% while players without previous injury had mean asymmetry magnitudes of 8.9 ±6.1%.

Players presenting leg asymmetries greater than 15% in any direction may not necessarily incur an injury, while those players with asymmetries below the threshold are certainly not exempt from injury. Regardless of the threshold used, symmetry between legs is thought desirable by coaches, trainers, clinicians and players, and minimizing imbalances between legs is a goal within many training programs.

Multi-directional leg power asymmetry

It is important for professionals to incorporate assessments that will provide the most accurate, dependable and relevant information (without overlap) regarding player performance for the particular sport of interest. Shared variance between countermovement jumps performed in the vertical, horizontal and lateral planes is moderate at best [17, 82, 83], with assessments being relatively independent of each other. Strength and conditioning coaches working with athletes involved in multi-directional movements may find that a multi-directional leg power profile can help drive subsequent programming. The prognostic/diagnostic value of a test of leg asymmetry seems to be dependent upon not only the specificity (face validity) of the test, but also the reliability. While data in literature is often presented as means and standard deviations for a group of athletes (i.e. Table 18), the presentation of ASI data as an average response (mean and standard deviation) often masks critical individual responses to testing. Individualization of programming is fundamental to an athlete's development and needs to be kept in mind. An excerpt from analysis of a netball squad of 22 players (see Table 19) reinforced the notion of individual responders and how asymmetry in one direction is not indicative of all directions. Validation of limb asymmetry thresholds and research on movements and variables that provide the most valuable information to clinicians and strength and conditioning coaches is needed.

Table 19: Excerpt of four players' ASI squad rankings (n = 22) for each single-leg countermovement (SLCM) jump.

	SLCM jump direction		
Player	**Lateral**	**Horizontal**	**Vertical**

A	1	11	13
B	2	21	17
C	3	6	9
D	4	10	18

SLCM = single-leg countermovement.

Summary

Players' movements in sport involve multiple directions, so jump assessments are conducted in vertical, horizontal and lateral directions. Jump assessments can be used to assess leg asymmetries across multiple directions to gain insight into individual player's strength and weaknesses.

Leg asymmetries are most usually obtained from velocity, force or power measures. Leg power asymmetry is possibly the most reliable and of greatest prognostic value. Given force plates are not readily available to many strength and conditioning coaches, jump distance and height should be used to evaluate leg asymmetry. A threshold of 15% can be used to identify players that may be at risk of incurring a lower limb injury, and therefore requiring additional training focused on correcting the limb asymmetry in the appropriate manner. Once an asymmetry above the considered threshold of 15% has been identified in an athlete, it may be beneficial to include additional assessments (i.e. balance – proprioception, ROM of joints, etc.) to try to determine the mechanism of injury. Additionally, introducing a physical therapist at this stage may be good practice (particularly if the asymmetry is due to injury) as they may have a more refined sense of movement dysfunction and may be more attuned to the key indicators of specific symptoms associated with such dysfunctions.

CHAPTER 10

ASYMMETRY IN MULTI-DIRECTIONAL JUMPING TASKS

This chapter comprises the following paper:

Hewit, J., Cronin, J.B., & Hume, P.A. Asymmetry *in multi-directional jumping tasks.* *S*ubmitted to *Strength and Conditioning Journal*.

Author contributions - JH: 85%, JC: 10%, PH: 5%

Prelude

Leg power capabilities of players have received much attention in research as briefly outlined in Chapter 9; however until recently such assessments have focused on bilateral power production in primarily one direction (vertical). As movements in sport are not limited to one direction and are often performed on a single leg, an assessment of unilateral leg power (single-leg countermovement jumps - SLCM) across multiple directions (vertical, horizontal and lateral) seems appropriate and may provide coaches and practitioners with valuable prognostic/diagnostic information regarding leg asymmetries. While multi-directional SLCM assessments have been investigated in recent research, baseline measures for non-injured female players have yet to be established. Therefore, the aim of this study was to quantify the magnitude of leg asymmetry in non-injured sub-elite level netball players during three different direction-based movement tasks. Of particular interest was investigating whether leg power asymmetry varied across jumping directions or variables.

Introduction

A variety of functional performance assessments are often used by strength and conditioning coaches as well as clinicians to identify player strengths and weaknesses. These diagnostic tests may play an important role in determining a player's potential for injury, appropriate programming for strength and conditioning and injury prevention, and baseline data for readiness to return to play following an injury. The vertical jump is one such functional performance assessment and is often used as a measure of leg power due to the relative ease of testing set-up and administration [2, 5, 47, 68, 81, 85, 86]. However, due to the positional demands of individuals as well as the movement patterns of various sports, a vertical jump performance may not always be the best representation of the functional movement performance of players. As such the use of a single-leg countermovement jump (SLCM) in various directions can provide a highly reliable and more complete leg power profile in athletes across various sports [16, 17, 69, 73, 75, 76, 80].

The utilization of single-limb assessments is intuitively appealing in that most propulsion in sport is unilateral in nature. However, the leg power that an athlete can produce may differ greatly between legs, as well as across directions and variables based on several factors including coordination, leg dominance, previous injury and current muscle imbalances. It is thought by strength and conditioners and clinicians that a greater imbalance (asymmetry) between legs increases the potential for injury, a 10-15% threshold thought problematic and requiring attention [68, 81-83]. However, this threshold is used rather loosely as those players identified with less than 10% magnitude asymmetry may still incur injury while those players with greater than 15% imbalances may not. Furthermore whether this threshold is similar across different jump variations for the outcome measures of interest is unknown.

In terms of asymmetry in players, a number of studies have reported average symmetry indexes (ASI) in previously injured populations [76, 82, 84, 87]. For example, Shiltz et al. [84] reported mean asymmetries for their subjects (15 professional basketball players) with previous knee injuries (n = 5) of 18.4% for a single-leg drop jump, and 20.5% for a 10-s maximum jump frequency single-leg vertical jump test, while those participants without previous knee injuries presented asymmetries of 8.9% and 5.5%, respectively. These studies however, were not prospective and so therefore the magnitude of asymmetry prior to injury were unknown. That is, of interest is the asymmetry expected in non-injured populations.

The testing protocols used by Schiltz et al. [84] and others [82, 83, 87, 88] have not assessed force or power capability in athletes in multiple directions. It is quite likely that force and power capability and subsequent asymmetry magnitudes may vary between the vertical, horizontal and mediolateral directions. Furthermore it is quite likely that some variables may be more sensitive in detecting asymmetry between legs. However, whether such contentions are true need further investigation. Normative data must also be generated to determine what acceptable levels of asymmetry in non-injured athletes might be. Therefore, the purpose of the present study was to first quantify the magnitude of leg asymmetry in non-injured national level netball players during three different direction-based movement tasks; and secondly to determine if leg asymmetry varies across jumping directions in the outcome measures of interest. Such information provides insight into the multi-directional capability of players, as well as the degree of imbalance between limbs. The data can be used as normative data for talent identification purposes, as baseline measures should players injure themselves and provide the basis for improved individualized programme design.

Methods

Participants

Participants (n = 19) for this study were current members of the national under-21 netball training squad and were free of injury at the time of testing. Subject characteristics recorded included (mean ±SD): age (19.5 ±1.1 years), body mass (75.1 ±11.8 kg), height (177.6 ±5.1 cm), and leg dominance (12 right leg, 7 left leg). The human research ethics committee of AUT University approved all procedures before commencing the study. Prior to participation, an informed written consent was obtained from each participant.

Equipment

A Bertec force plate (Bertec Corporation, AM6500, Columbus, OH, USA) sampling at 1000 Hz was used to collect information from the three different jump directions. Jump distances were measured via tape measures fixed to the floor extending in front of and to both sides of the force plate.

Procedures

Data were collected during a single testing session. Prior to testing, each subject's age, height, body mass and leg length were recorded. Leg dominance was determined by questioning of participants as which leg the subject used to regain balance following a slight unexpected perturbation. Participants then completed a 10-minute standardized warm-up conducted by their team strength and conditioning coach which included dynamic drills, sprints and stretching. Following the warm-up, participants were informed of the testing procedures and allowed practice trials for each task prior to data collection. Testing began when the subject reported that they felt comfortable with the task. Testing was completed when three successful trials per leg of each of the SLCM jumps (18 jumps total) were executed.

SLCM Jumps: All trials of the SLCM task were performed on the force plate with each subject standing with the toes of the designated leg positioned just behind a starting line (marked on the force plate with tape), hands on hips and the alternate leg flexed to approximately 90˚ at the knee. When ready, the subject sunk down then rapidly extended the weight-bearing leg, jumping as far as possible in the designated direction (up, forward or to the side), landing on both feet simultaneously. Testing began with three successful trials on each leg in the vertical direction (SLCM-V) (landing back on the force plate), then horizontally (SLCM-H) (jumping forward off of the force plate) and laterally (SLCM-L) (jumping off of the force plate to the opposite side as the weight-bearing limb) (see Figure 26). A trial was considered successful if the hands remained on the hips throughout, and if balance was maintained upon landing. Jump height was calculated for the SLCM-V trials based on time in the air from the force plate data. A tape measure from the starting line to the nearest point of the shoe closest to the force plate upon landing was used to determine the distance jumped for the horizontal and lateral trials. Subjects were allowed 30 seconds recovery between each trial. The between session reliability for the procedures/variables used in this study have been established previously: percent change in the mean 0 to 3.5% and co-efficient of variation of 2.9 to 7.9%.

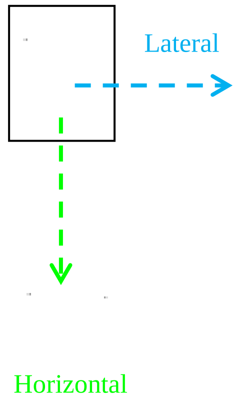


Figure 26: Diagram of the SLCM-H and SLCM-L jump tasks as viewed from above.

Data analyses

Upon landing, jump distance was measured to the nearest 0.01 m as the distance from the toe-mark on the force plate to the heel of the foot closest to the force plate for the horizontal trials and the side of the foot closest to the force plate for the lateral trials. Jump height for the vertical jump test was calculated from the force plate data according to the procedures outlined by Meylan et al. [69] using the following formula:

$$\text{Jump Height} = \text{takeoff velocity}^2/2*\text{gravity}$$

Peak concentric vertical, horizontal and lateral forces and powers were also calculated as described by Meylan et al. [69]. The acceleration produced by the participant was calculated by subtracting acceleration due to gravity from the acceleration of the center mass (vertical ground reaction force divided by body mass). Take-off velocity was calculated from numerically integrated acceleration-time data and multiplied by the original force values to determine the peak concentric powers. An average symmetry index (ASI) between legs was calculated for each of the three jumping directions using the following formula:

$$\text{ASI} = \left| 1 - (\text{right leg} / \text{left leg}) * 100 \right|$$

Statistical analyses

The means and standard deviations (SD) for all three trials for the dominant (D) and non-dominant (ND) leg per task were averaged to represent an individual's performance for each task (mean and SD). ASI magnitude was calculated for each individual for the following dependent variables: peak power, peak force, and jump distance/height. Coefficients of determination (r^2) were used to quantify the shared variance between dependent variables. Paired t-tests were used to determine if significant differences were present between legs for each task while repeated measures ANOVA with Holm-Sidak contrasts were used to determine if there were significant differences between the dependent variables of interest. Statistical significance was set at $p \leq 0.05$.

Results

Squad means and SD's for each task are summarized in Table 20. No significant differences ($p \leq 0.05$) were observed between dominant and non-dominant legs. As can be observed, significantly greater peak forces (71-72%, $p = 0.00$) and peak powers (39 – 49%, $p = 0.00$)

were associated with the vertical direction when compared with the horizontal and lateral directions. The horizontal and lateral directions presented relatively similar measures for all three variables (jump distance: 1.50 - 1.53 m, peak force: 431.8 – 451.1 N, and peak power: 1279.3 – 1445.1 W, respectively). Low to moderate shared variance resulted for the variables of force and distance in the three directions (r^2 = 0.12 to 0.46), while moderate to high shared variance resulted for power (r^2 = 0.53 to 0.79) (see Table 21).

Table 20: Squad means ±SD and p values for each variable and task.

Task	Peak power (W)		*P*	Peak force (N)		*p*	Distance (m)		*p*
	D	*ND*		*D*	*ND*		*D*	*ND*	
SLCM-V	2103 ±795	2179 ±714	0.47	1549 ±335	1526 ±345	0.18	0.19 ±0.07	0.18 ±0.08	0.12
SLCM-H	1445 ±521	1378 ±545	0.09	447 ±76	433 ±79	0.08	1.50 ±0.17	1.53 ±0.19	0.12
SLCM-L	1279 ±427	1280 ±461	0.47	451 ±73	432 ±63	0.06	1.50 ±0.11	1.50 ±0.14	0.49

D = dominant leg, ND = non-dominant leg, SLCM-V = single-leg countermovement jump (vertical), SLCM-H = single-leg countermovement jump (horizontal), SLCM-L = single-leg countermovement jump (lateral).

Table 21: Coefficient of determination (r^2) for the raw data for each task.

	SLCM jump direction		
	Vertical vs. Horizontal	**Vertical vs. Lateral**	**Horizontal vs. Lateral**
Height/Distance	0.12	0.13	0.46
Force	0.39	0.36	0.45
Power	0.53	0.79	0.67

SLCM = Single-leg countermovement.

The individual ASI's ranged from 0.0 to 32.7% (see Table 22). The mean squad ASI for each jump and variable can be observed in Table 3. When all the variables were grouped into three directions, mean direction ASI's ranged from 6.7% to 8.4% and were not significantly different to each other. However, in terms of the individual directional ASI comparisons vertical and lateral force ASI magnitudes were significantly different from each other (34% difference, p = 0.02).

Another comparison of interest was whether the ASI's differ in terms of the variable used. When the data were grouped into variables (e.g. power in all three directions) the mean variable ASI's ranged from 6.2% to 10.2% (see Table 22). Average ASI peak power was found to be significantly different (~40%, $p < 0.001$) to force and jump distance/height. The individual comparisons between variables found significant differences for: power and jump distance/height in the horizontal (60%, $p < 0.00$) and lateral directions (38% difference, $p = 0.05$); and, vertical power and vertical force (66%, $p = 0.02$).

Table 22: Mean asymmetry index ±SD and ranges for each variable and movement task.

Task	Peak power	Peak force	Jump Height/Distance	***Mean direction ASI ±SD*
SLCM-V (%)	9.2 ±11.4[1,5] (0.1 – 32.7)	3.0 ±2.8[1,4] (0.0 – 9.8)	7.8 ±6.8 (0.0 – 19.1)	*6.7 ±4.3*
SLCM-H (%)	11.4 ±9.2[2,3,7] (2.3 – 30.1)	8.0 ±5.7[2] (1.0 – 17.6)	4.6 ±3.2[7] (0.0 – 10.8)	*8.0 ±3.0*
SLCM-L (%)	10.0 ±7.5[3,4,8] (0.9 – 27.8)	8.9 ±7.9[3,4] (0.1 – 26.0)	6.2 ±5.7[8] (0.3 – 20.4)	*8.4 ±1.2*
**Mean variable ASI ±SD*	*10.2 ±1.1* [5,6]	*6.6 ±3.1* [5]	*6.2 ±1.6* [6]	

*ASI's averaged across the sample for each variable (peak power, peak force, and jump height/distance). **ASI's averaged across the sample for each direction (vertical, horizontal and lateral).
D = dominant leg, ND = non-dominant leg, SLCM-V = single-leg countermovement jump (vertical), SLCM-H = single-leg countermovement jump (horizontal), SLCM-L = single-leg countermovement jump (lateral).
Significant differences: [1] peak force and power in the vertical direction, [2]peak force and power in the horizontal direction, [3]peak force and power in the lateral direction, [4]vertical peak force and lateral peak force, [5]average peak power and average peak force, [6]average peak power and average jump height/distance, [7]horizontal peak power and horizontal jump distance, [8]lateral peak power and lateral jump distance.

The coefficient of determination (r^2) for the ASI squad means are shown in Table 23. Low values (ranging from 0.00 to 0.13) were observed across all variables. To illustrate the relative independence of the ASI's and raw data, an excerpt of the distance raw data and ASI squad rankings are shown in Table 24. The top four players ranked in the vertical direction didn't necessarily rank in the top four for the horizontal or lateral directions in ASI magnitudes or raw data.

Table 23: Coefficient of determination (r^2) for squad means ASI's for each task.

	SLCM jump direction		
	Vertical vs. Horizontal	**Vertical vs. Lateral**	**Horizontal vs. Lateral**
Height/Distance	0.00	0.02	0.13
Force	0.08	0.07	0.00
Power	0.02	0.02	0.13

SLCM = Single-leg countermovement.

Table 24: Excerpt of four players' SLCM jump distance (dominant leg) and ASI squad rankings.

	Jump direction			**ASI**		
Player	**Vertical**	**Horizontal**	**Lateral**	**Vertical**	**Horizontal**	**Lateral**
A	1	20	5	15	17	14
B	2	16	14	3	8	18
C	3	12	15	10	13	15
D	4	15	6	13	7	6

SLCM = single-leg countermovement, ASI = average symmetry index.

Discussion

To the knowledge of the authors, the present study was the first to assess the leg power of non-injured female athletes across multiple directions. As the force data presented in the current study were similar to that reported by Newton et al. [80] (1167-1174 N) (in which a sample of female softball players were tested completing SLCM jumps in the vertical direction), the present data appears indicative of trained female athletes. With the exception of vertical and lateral raw power, low to moderate shared variances (r^2 = 0.12 to 0.67) were observed in the outcome measures of interest (see Table 22), indicating that these tests are measuring relatively independent qualities of each other. This finding is not novel and has been reported elsewhere [17, 69]. The implications of these findings are that multidirectional leg strength/power needs to be assessed and developed independently. That is, assessing or developing strength/power in one direction may not transfer to other directions.

In non-injured populations, many researchers have suggested that leg asymmetry magnitudes of 10-15% are typical and acceptable [68, 81-83]. In terms of grouped data, all of the mean squad ASI magnitudes in the present study fell within the suggested 15% threshold.

However, the ASI power values were at or above the lower limit of 10% (see Table 22). As the sample of players that participated in this study were non-injured at the time of testing, a 10% threshold for non-injured players appears to be quite low dependent on the variable used to describe the ASI. As a result, 15% may be a better choice of a threshold prior to making decisions around interventions to address leg imbalances.

It should be noted that for some of the variables and directions, individual asymmetries as high as 48.6% were observed in a non-injured population. While the majority of ASI's fell below the 15% threshold, those that were a great deal larger than 15% are considered to be at a greater risk of injury due to the larger muscle imbalances between legs [68, 81-83]. As this sample of players reported no injuries at the time of testing, the ASI's above 15% should be considered atypical and decisions made as to whether interventions need to be implemented that address the imbalance.

In terms of directional-specific asymmetry, the magnitude of asymmetry was found to be dependent upon whether the applied ground reaction force was primarily vertical, horizontal or lateral in nature. When the average ASI magnitudes of all three variables (vertical = 6.7%, horizontal = 8.0% and lateral = 8.4%) were grouped, no significant differences were detected. However, the vertical force ASI (3.0%) was found to be significantly lower than the lateral force ASI (8.9%) when compared across directions. Interestingly, power and distance ASI magnitudes also differed significantly in the horizontal and lateral directions, indicating that for the same jump, the ASI percent difference can differ markedly dependent on the variable used to quantify the imbalance. The reader needs to be cognizant of this finding and that that these differences are magnified when data is analyzed at an individual level (see Table 24).

With regards to the variable analysis, the magnitude of asymmetry was dependent upon whether power, force or distance measures were used for the ASI. When all three directions were averaged (power = 10.2%, force = 6.6% and distance = 6.2%), significant differences in ASI were detected (see Table 22). The findings of this study are also consistent with Meylan et al. [69] where the largest ASI magnitudes were associated with power output (9.3%). While the sensitivity of each variable was not assessed in this study, power output may be a more sensitive measure of ASI given that it is the product of both force and velocity. Interestingly, the vertical power ASI was significantly different from vertical force.

Significant differences between these two variables in the same direction may be useful in terms of jump diagnostics. That is, given power is the product of force and velocity, if there is no statistical difference in force it would seem that the differences may be attributed to the velocity component. If this is the case then training may take a velocity focus to remedy the ASI. Unfortunately, access to equipment to measure power, velocity and force output (e.g. force plate) in many cases is problematic therefore alternative variables such as jump distance or height will need to suffice.

The greatest individual power ASI magnitudes for the present study were observed in the horizontal direction (11.4%) followed closely by the lateral and vertical directions (10.0% and 9.2%, respectively). Meylan et al. [69] reported that the greatest ASI was associated with the lateral direction (9.3%). It would seem that an ASI magnitude of ~10% in multi-directional power output is common in non-injured players.

Another focus of this study was to determine if players' leg power asymmetry was similar across the three SLCM directions. The low shared variance of ASI magnitudes (r^2 = 0.00 to 0.13) for all three directions indicates that these ASI's are measuring relatively independent qualities (see Table 23). That is, asymmetry in one direction does not necessarily predict asymmetry in another. Therefore, using a single direction assessment (e.g. vertical jump) to assess leg power asymmetries in players that perform explosive movements across multiple directions in competition does not provide a complete profile of the asymmetries for each player.

The standard deviations and the ranges presented in Table 3 indicate that there is variability in the asymmetry data. Of importance to programming is the principle of individualization, a guiding principle that is often lost in research investigating the mean response. ASI directional variability can be seen in the excerpt data for individual ASI and raw data rankings for height and distance jumped (see Table 24). While player A had the highest single-leg vertical jump (rank = 1), the same player ranked 20th and 5th in the squad for horizontal and lateral jumping distance respectively. The ASI for all directions for this player was relatively consistent (ranking 14-17). Different trends occurred for other players, some players performing well in one direction while not performing equally well in the other two directions. Coupling the ASI data with their raw data provided insight into the imbalances between legs, and the ability of individual players to produce power and force in a specific direction. This type of analysis provides information to guide more effective programming.

Practical applications

There appears some variation in the magnitude of the ASI depending on the variable and direction used to quantify the asymmetry. Decisions need to be made by the clinician or strength and conditioning practitioner as to which variables and directions are specific to the requirements of their sport and or positions. If in doubt, it may be best to develop a single-leg multi-directional leg power and ASI profile, which will provide information that can drive the individualization of programming.

In terms of the threshold of asymmetry that is thought predictive of injury, it would seem that on average asymmetries of ~10% are expected in some variables (e.g. power output) for non-injured players. Asymmetries of 15% or greater may warrant closer attention dependent on the variable of interest, as inter-limb differences in distance and force would appear substantial. However, some individual inter-limb differences were as great as ~30% for players classed as non-injured. Given the lack of clarity in this area it may be advised to err on the side of caution and where possible, aim to minimize imbalances as much as practically possible.

SECTION THREE: PERCEPTUAL DETERMINANTS OF AGAILITY AGILITY

Chapter 1 outlined how knowledge of the technical, physical and perceptual decision making components of agility are important. The previous two sections in this thesis have addressed the technical and physical components commonly termed change of direction ability. However, adequate perceptual/decision-making ability is also required for the successful execution of such movements in sport. In this section the two studies aim to improve knowledge of the perceptual requirements (i.e. the reactive decision making component) associated with netball specific movements.

CHAPTER 11

ASSESSING AGILITY: A BRIEF REVIEW OF REACTIVE DECISION-MAKING ASSESSMENTS FOR COURT-BASED TEAM SPORTS

Prelude

Researchers have typically focused on isolated aspects of decision-making to increase reliability of assessments. However, such laboratory-based procedures are not representative of players' performances in the sporting context and therefore have little transference to the sport. Therefore a reactive decision-making assessment task that preserves the fast-paced nature of the game, that has high validity to court-based team sports, and relatively high reliability, was required. Given the theme of the thesis around improving understanding of reactive decision making in agility, this article briefly reviewed information about sport-specific decision-making ability of athletes in an attempt to determine a valid approach to distinguishing between player reactive decision-making skill levels. The strengths and weaknesses of such an approach have been discussed and an example of a reactive decision-making assessment for netball has been provided.

Introduction

Agility is a complex concept that has been defined in many different ways, often depending upon the sporting context of interest. What appears to be consistent among these definitions is that agility involves rapid, whole body movements requiring changes of direction or velocity in response to a sport-specific stimulus [1, 4, 89]. From this definition the success of an agility performance is comprised of three inter-related components (technical, physical, and perceptual/decision-making). This contention is supported by the deterministic model of agility developed by Young and colleagues [5] (see Figure 27) which describes agility as being comprised of both perceptual/decision-making factors as well as change of direction factors (i.e. technical and physical characteristics). Based on the working definition and deterministic model of agility, it is reasonable to conclude that if one or more of these three main components are lacking (or missing) from a performance, the success of the overall agility performance will likely suffer. Therefore, research addressing the enhancement of each component is needed in order to create a complete agility assessment task that is able to effectively analyze player performances and address any limitations identified. This brief review will address the perceptual/decision-making component of agility.

The ability to consistently make appropriate and timely decisions plays an important role in the success of sporting performance, whether it be team or individual-based. In team-based court sports (e.g. netball, basketball, handball, etc.) decision-making ability is particularly important as the decisions become more complex with the inclusion of additional players as well as the spatial and temporal constraints associated with such sports. Therefore, a high standard of decision-making ability is thought to be desirable among players, coaches and referees and are often the focus of many training drills and sessions.

Decision-making in sport has been defined in many ways [26, 90-93]. Common to many definitions is the process of gathering and identifying relevant information from the performance environment and responding rapidly and appropriately. For the purposes of this article, decision-making ability is defined as the ability to effectively gather and identify critical information and select the most appropriate movement response based upon the information available. The appropriateness of each movement response is the means by which coaches attempt to assess player decision-making as they are unable to directly monitor players' internal information gathering and analyzing processes. Therefore, a superior decision-maker is often classified as a player that is able to consistently display effective movement responses to the wide variety of circumstances that occur throughout a competition [91]. The time taken to respond to a stimulus (i.e. response time) is the result of the combination of reaction time (i.e. time from stimulus presentation to movement initiation, or decision time) and movement time (i.e. time from movement initiation to movement execution) [94, 95]. Therefore, an appropriate movement response coupled with a slow response time may have a detrimental effect on the outcome of the situation by allowing additional time for the opposition to react appropriately (when a “fake” or “dodge” is not present).

Decision-making in a team-based sport-specific context has received little attention in the literature. For example, netball is a high velocity court-based sport often requiring players to make split-second decisions based on the information that has been presented to them. Attempting to design an appropriate decision-making assessment with the temporal and spatial constraints that are present in netball is a difficult and challenging task. As a result, some researchers have focused on replicating the movements commonly performed throughout the competition (e.g. lunging, jumping, sidestepping, etc.) in an attempt to potentially increase the validity of the task [9, 96]. However, when this approach is taken, the movement patterns that are linked together or replicated (from motion analysis research) often become pre-planned and in turn, limit the validity as movements in team and court-based sport are rarely pre-planned. Additionally, the replication of decision-making tasks must be simplified in order to increase the reliability of the task. As a result, decision-making assessment approaches often fail to establish one of two fundamental components; 1) high sport-specificity (validity), and/or 2) high reliability. The general aim of this article is to examine assessment approaches that satisfy one or both of these characteristics. This article will first outline the importance of decision-making in sport as well as different approaches that have been used when attempting to assess decision-making ability in agility performance. Finally, a brief overview of the different approaches used in an attempt to differentiate between player skill levels will be included. It is hoped that this brief review will provide coaches with an increased understanding of decision-making ability in sport.

The primary researcher independently searched the electronic databases of AUSPORT, Expanded Academic ASAP, ProQuest 5000, PubMed, and SPORTDiscus between the dates of 1995 - 2010. The following keywords were used to narrow the search; agility, change of direction, decision-making, and reactive agility. Studies were chosen for inclusion in this review if decision-making in agility tasks of team-based sports were the focus. Additionally, only peer-reviewed research published in the English language in a book, journal or conference proceedings were included.

Decision-making ability and sports performance

Making appropriate decisions in sport is undeniably essential to successful performances. However, several factors contribute to the effectiveness of a decision. Decisions are the result of a constant perceptual scanning process [92]. Perceptual scanning (or visual search) allows players to identify critical information that assists them in determining how and when to react. The appropriateness of the player's movements is therefore dependent upon their individual ability to detect specific cues from the scenario and interpret them as critical or unimportant. Under certain circumstances (e.g. increased task complexity, pressure or number of options) players may misinterpret cues and prematurely react to the less crucial information, resulting in a 'poor' or less effective decision [92].

Fast-paced court sports offer little room for error. The rapid and reactive nature of such sports often requires players to make decisions concerning their subsequent movement prior to receiving the ball. A delay in this cognitive process will likely result in an undesirable outcome, including an intercepted or incomplete pass, heightened defensive play by the opposition or a pass made to a less advantaged teammate. When poor decisions such as these are made repeatedly throughout a game or match, the likelihood of a successful outcome for the team is compromised. Therefore, training that emphasizes rapid and appropriate movement patterns must be implemented throughout the season to promote and encourage effective decision-making in competition.

In order to decrease the number of poor decisions made, it is important for players to understand which cues to attend to and act upon. Several approaches to this aspect of decision-making training and assessment have been used in recent literature, most commonly including eye-tracking and film occlusion.

Approaches to decision-making assessments in team-based court sports

Accurately and reliably assessing player decision-making abilities is often difficult due to the specific circumstances of each individual sporting context. Therefore, decision-making assessments are typically performed in a more controlled manner than that of an actual competition [92]. However, when a player is removed from the competition setting and context, certain characteristics contributing to their decision-making process cannot be accurately replicated. As a result, researchers often examine isolated aspects of decision-making separate from the actual sporting context [91, 92].

Most commonly, decision-making ability is assessed through simulated performance environments. One form of simulated assessment requires players to respond verbally or with a modified physical movement (e.g. pointing or pushing a button, etc.) to various slides of competition scenarios on a computer screen [24, 95]. These response options however are not representative of the actual performance environment. Though this approach may be highly reliable for assessing decision-making ability, the sporting context is completely lost resulting in limited transference into the sport.

A second approach to decision-making assessment uses video occlusion with physical reactions to a video image. Farrow et al. [9] and Jackson et al. [22] both used life-sized opposition players projected onto a screen in front of the subject as the decision-making stimulus. In both studies, subjects were required to physically react to the movements of the projected player prior to video occlusion. While this form of reactive stimulus has high reliability coupled with some validity to the respective sports and may provide valuable feedback pertaining to specific cue detection, essential perceptual information (e.g. 3-dimensional visual flow, relative motion cues obtained from the performer's actions, auditory and tactile feedback) is lost or diminished [26]. While these two studies have attempted to address the concern for appropriate decision-making responses by requiring players to react physically (i.e. as they would in competition), a 2-dimensional stimulus is still unable to present players with all of the environmental information they rely on to make their decisions [26]. It is therefore desirable to develop representative decision-making tasks that require players to react physically as they would in competition to a live-play scenario.

Eye-tracking devices have been used in recent years to assess the gaze characteristics of players when performing sport-specific tasks [97]. This approach provides valuable information pertaining to the specific fixation patterns for cue pick-up, however it can be argued that the goggles worn may alter the performance as a player will be aware of the testing equipment and may react differently than they might otherwise. A more important limitation with such equipment is that they indirectly indicate what information the player is attending to as peripheral vision is also used when acquiring pertinent information. Additionally, the resources (financial and time) associated with using the eye-tracking equipment may not fit within the budget of most sports organizations regardless of the level of play.

Differentiating between player skill levels in decision-making for team-based sports

Individual decision-making assessments are conducted either to identify which players possess superior versus less effective decision-making abilities, or which specific characteristics are most commonly present in superior (expert) performances and absent with those that are less effective (novice or intermediate). This information appears to be valuable to coaches as those players with superior decision-making abilities are assumed to be less likely to make poor decisions in competition.

Assessment tasks have been selected based on their ability to distinguish between expert and novice/intermediate decision-making skill levels [26]. A task that is not challenging enough or that is not required in competition will not allow superior performance to be detected. Recent studies have reported that superior decision-makers in sport react faster and more accurately than lesser skilled players [91, 95]. This effect however has also been shown to decrease as the complexity of the scenario decreases. This is important to note as expert skill levels encounter more complex scenarios more regularly than novice or intermediate skill levels [91]. As a result, expert players are able to learn from these complex experiences and become more proficient at determining options and predicting outcomes in future scenarios than their novice counterparts [26, 91].

Additionally, sport-specificity of the task is also of great importance as those qualities that distinguish player skill levels often vary depending on the sport or even playing position [94]. When an expert decision-maker is removed from their playing environment or required to react in a specific manner not associated with their sport or position (e.g. verbally, pointing, pushing a button, etc.), the expert performance will be less distinct when compared to a lesser skilled player performing the same task [98]. The further a player is removed from their sporting context, the less of a gap there will be between player skills levels. The ability to distinguish between player skill levels and their associated characteristics is only apparent when a player is assessed performing sport-specific tasks of adequate complexity.

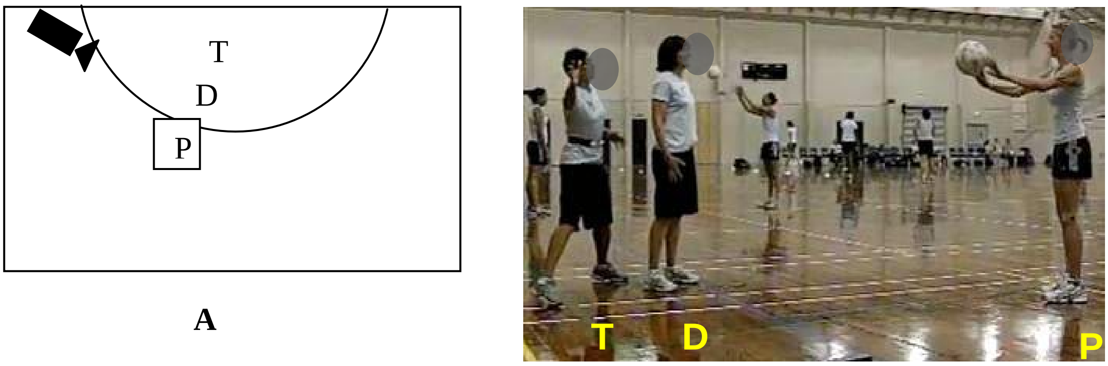
An example assessment task for decision-making in sport

Based on this brief review of current decision-making research literature, an example decision-making assessment task is described in this section. It is important to recognize that not all sports organizations will have the same finances available for assessment resources and equipment. Therefore, this assessment task has been developed based on limited resources in an attempt to create a tool that can be implemented across a variety of skill and financial levels.

Three main points have been carefully considered when developing this reactive decision-making assessment. Maintaining high validity to the sport was the primary concern of the task therefore players are used for all interactions as opposed to video screens or other 2-D objects. Reliability of the test was the second main concern, keeping in mind that higher validity will naturally incur lower reliability as the task more closely replicates the spontaneity of the game. The third concern when developing this test was to attempt to preserve the fast-paced nature of the game as players would need to perform similar movements to the assessment task in an actual competition. As a result, the following task has been developed and proposed for assessing reactive decision-making ability in netball however it serves as a template for other sports.

This task can be performed as a static task, where the player remains relatively stationary for the entirety of the task (aside from passing the ball); or as a portion of a dynamic sport-specific assessment task where the player performs the passing scenario while completing both ground-based and aerial-based change of direction movements. When implementing this task with novice to intermediate skill level players, the static assessment is recommended, progressing to the more advanced dynamic version as skill level and experience increases.

The static version of the task consists of the player (P) positioned outside of the goal circle holding a regulation sized ball (see Figure 28). A target player (T) is positioned facing the player and approximately 4 m away. A passive defender (D) is positioned between the player and the target player, also facing the player. When ready, the target player moves out from behind the defender into one of five directions (left, right, upper left, upper right, or up). As soon as the player is able to determine the direction that the target player is moving to, a pass is completed in that direction. The passive defender is allowed to attempt an interception as long as minimal movement from their starting position is performed.



A

B

Figure 28: Reactive decision-making assessment task (static) testing set-up as viewed from above (A) and from the side with players (B).

A single video camera (preferably high speed, however 60 Hz video can be used) is positioned in the sagittal plane of the player/target player passing lane timing the decision time (target player movement through player pass initiation), movement time (player pass initiation through ball release) and total time (target player movement through ball release) of each pass. It is recommended that a total of at least three trials to each direction (randomly ordered) are performed for increased reliability (i.e. 15 trials). When performing the dynamic version, depending upon the movements being performed by the player a passive defender may not be required.

Conclusions

Decision-making ability in sport is difficult to directly and accurately assess largely because removing a player from their playing environment or context will result in unrepresentative assessments. It is important to replicate the motor skill complexity in decision making tasks while maintaining an environment as similar to the competition as possible. Superior and lesser-skilled performances can often be distinguished in decision-making assessments when the task closely replicates the requirements of the sport. Once player skill levels are distinguished, specific qualities that are present in the superior performances but absent in the lesser skilled (e.g. decreased reaction time with more complex tasks and sport specific tasks) can be determined. From this information, coaches can adjust training drills and sessions to more accurately target the decision-making weaknesses of team and individual players, potentially giving them a competitive advantage.

Additional perceptual information also plays an integral role in the decision-making processes and success of a performance. Inclusive of these contributing concepts are the player's procedural and declarative knowledge, anticipatory skills, pattern recognition, and vulnerability to deception. While these characteristics are not addressed in this article, it is not to say that they are not of great importance to the overall decision-making performance. It is however, important to acknowledge these factors as they do contribute greatly to any perceptual-movement task.

CHAPTER 12

DEVELOPING A SPORT-SPECIFIC PERCEPTUAL ASSESSMENT FOR AGILITY: A REACTIVE DECISION-MAKING PASSING TASK FOR COURT-BASED TEAM SPORTS

This chapter comprises the following paper:

Hewit, J., Button, C., Hume, P.A., & Cronin, J.B. Developing a sport-specific perceptual assessment for agility: A reactive decision-making passing task for court-based team sports. To be submitted to *Journal of Science and Medicine in Sport.*

Author contributions - JH: 85%, CB: 9%, PH: 4, JC: 2%.

Prelude

The assessment and development of agility performance is determined by change of direction factors (involving technical and physical qualities) and perceptual/decision-making factors. In sections one and two of the thesis, the change of direction factors were investigated. This study investigates the perceptual reactive decision making component. Previous literature has attempted to investigate perceptual/decision-making abilities in athletes through various methodologies. However, these approaches often lacked validity/specificity to the sport and as a result offered limited transference to the sporting context. The aim of this study was to analyze performance times and the associated passing location and appropriateness of a netball-specific reactive decision-making passing task.   Of particular interest was the reliability of such measures of performance as the task had high ecological validity and encompassed individual player movement variability as a target player was used as the reactive stimulus.

Introduction

The ability of players to effectively complete agile movements is crucial to the success in competition for both team and individual sports.   Numerous definitions of agility have been used throughout the research literature. A consistent theme among these definitions identifies three main inter-related qualities (technical, physical and perceptual) that enable a player to react rapidly to sport-specific stimuli [1, 4-6]. As each of these three qualities contribute to the overall success of agility performance, it seems reasonable to surmise that if one or more of these components are found to be less than optimal in a player, the success of the agility performance is likely to be compromised. Therefore, research is needed that addresses each of these components in a sport-specific context so that training can be adjusted to more effectively target the weaknesses identified in an individual players' performances.

Recent research by the authors of this study has addressed the technical and physical components of agility in a netball-specific manner, therefore this study focused on the perceptual/decision-making (P/DM) aspect. As netball is a fast-paced sport requiring information to be rapidly identified and processed continually throughout a game, it would seem that coaches and players might benefit from a sport-specific P/DM assessment task. Previous research investigating perceptual abilities in players has used relatively controlled scenarios for player to react to [6, 7, 9, 97]. However, by eliminating a portion of the movement variability in players the validity of the assessment task to the sport is decreased, thereby possibly resulting in decreased transference of the findings to the sport.

Similar to agility, decision-making has been defined in many different ways [26, 90-93]. Much of the existing decision making research suffers from poor external validity by utilizing controlled, simulated scenarios with simplistic response modes (e.g. such as verbal judgments or a button push). The challenge for researchers is to develop naturalistic methodologies to better understand the strategies that experts use to become effective decision-makers when exposed to realistic, time-pressured environments such as those present in competitive sport [99-102]. In sport, the appropriateness of each decision is often as important to a performance as the ability to execute the associated movements. Therefore, desirable decision-making ability is often identified by coaches through the appropriateness and execution (i.e. technical and physical capabilities) of the movement response [26]. For the purposes of this article, decision-making refers to the ability to effectively gather and identify critical information and select the most appropriate movement response based upon the information available.

The total time taken to complete a movement task (e.g. passing a ball) following the onset of a stimulus can provide coaches with valuable insight into the effectiveness of the P/DM performance. Total time is comprised of the time taken to identify and perceive critical information regarding the situation, i.e. decision time (or reaction time) and the time taken to perform the resulting movement response i.e. movement time (or response time) [94, 95]. Decision time is the portion of the performance that begins as soon as the stimulus is presented to the player and ends with the player initiating a movement in response to the stimulus (i.e. pass a ball). The well reported speed-accuracy trade-off (Fitts' law) shows that as the task becomes increasingly more difficult (e.g. more options available), the time taken to identify and process information prior to initiating movement (decision time) will also increase [103]. Movement time begins when the physical response is initiated (i.e. passing movement) and end when the response has been executed (i.e. ball release). As both the perceptual and physical portions of the task contribute to the success of the decision-making performance, an appropriate movement response coupled with rapid temporal characteristics should be emphasized in training sessions. Given the preceding information, the primary purpose of this study was to analyze performance times and the associated passing location and appropriateness for a reactive decision-making assessment as a means of determining possible coaching cues and areas of emphasis for reactive decision-making training programs.

Methods

Subjects

Twenty-two sub-elite level netball players from the national under-21 training squad (age: 19.3 ±1.1 years, height 1.79 ±0.06 m, body mass 77.1 ±11.6 kg, right hand dominant: 15 players) participated in this study. All players were free of injury at the time of testing. All procedures were approved by The Human Research Ethics Committee of AUT University prior to commencing the study. Written informed consent was obtained from each player prior to their participation.

Equipment

Testing equipment consisted of one regulation-size netball, one 300 Hz video camera (Casio Ex-F1, Casio Computer Co., LTD, Tokyo, Japan) placed perpendicular to the passing lane (see Figure 29), and an LED signal connected to a switch belt.

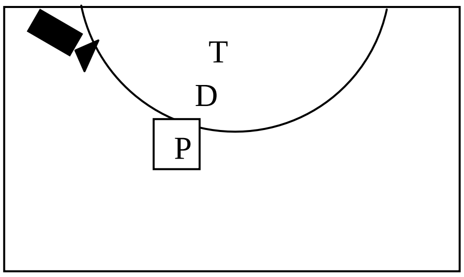


Figure 29: Reactive decision-making task set-up where P = player, T = target player and D = passive defender.

Procedures

Testing was conducted during a single testing session on a regulation indoor sprung wooden netball court. Upon arrival, the age, height and body mass for each player was recorded. Players then performed a 10 minute dynamic, netball-specific warm-up conducted by the team strength and conditioning coach. Players were allowed to practice the reactive decision-making (RDM) task until they felt comfortable; however no more than three practice trials were taken by any of the players.

Reactive Decision-Making Assessment Task: The RDM task required each player (P) to complete a pass as quickly and accurately as possible to a target player (T) that was initially obstructed from view by a passive defender (D). Each player began holding a netball at a designated mark placed just outside the shooting circle. The target player was positioned approximately 5 m from the player inside of the shooting circle with the passive defender positioned just in front. Both the target player and the passive defender were positioned facing the player; therefore the defender had her back to the target player (see Figure 29). The target player wore a switch belt connected to an LED signal which was placed facing the camera (unable to be seen by any of the players). When the switch button was pressed by the target player, the LEDs were illuminated. Upon releasing this button, the LEDs were dimmed identifying the beginning of the trial for the camera.

The target player began by releasing the signal button and immediately moving out from behind the passive defender into one of five randomly selected passing directions respective to the passing player (left, right, upper right, upper left and vertically). The player completed

a pass to the target player as soon as the movement direction was determined. If the passive defender was able to intercept the pass with minimal movement, she was allowed to do so.
A total of 12 consecutive trials were recorded for each player. The same target player and passive defender (head and assistant coaches, respectively) were used for all players to increase reliability across trials. All players were required to perform the task as quickly and accurately as possible.

Analyses

High speed video was used to analyze the performances by manually advancing frames to calculate performance times and rate the appropriateness of each pass. Missed passes were grouped into two categories; incorrect/incomplete (the ball was beyond an estimated 5 cm distance from the target's hand or thrown to the wrong location) and intercepted (the ball was caught or tipped by the defender). A frequency count of the total number of missed passes out of 12 attempts was recorded for each direction. Additionally, the percent of incorrect/incomplete versus intercepted passes from the total missed passes for each player was calculated.

Three performance times [decision time (DT): time from LED dimming until pass initiation, movement time (MT): time from pass initiation through ball release, and total time (TT): time from LED dimming through ball release] were calculated for each of the 12 trials. Trials were grouped according to passing direction (right, left, upper right, upper left and vertical) for analysis.

Statistical analyses

Means and standard deviations for each player were calculated for performance times. Typical reliability statistics [coefficient of variation (CV), and intraclass correlation coefficient (ICC)] were used to quantify the stability of the data. Paired sample t-tests were used to determine if differences between DT and MT time were significant. One-way repeated measures ANOVA with Holm-Sidak comparisons were used to determine if performance times differed significantly with respect to direction of pass i.e. right, left, upper right, upper left and vertical. An alpha level of 0.05 was used where appropriate.

Results

The reliability measures for passing direction and pass appropriateness are shown in Table 25. Relatively high variability was observed for all three performance times (CV = 22.7 to 35.1%, ICC = -0.60 to -0.14).

Table 25: Reliability measures for each performance time with 90% confidence interval in brackets.

Reliability measure	DT	MT	TT
CV (%)	35.1 (25.2 to 59.4)	22.7 (16.6 to 37.4)	28.8 (20.9 to 48.1)
ICC	-0.60 (-0.84 to -0.18)	-0.14 (-0.58 to 0.36)	-0.51 (-0.79 to -0.05)

DT = decision time, MT = movement time, TT = total time, CV = coefficient of variation, ICC = intraclass correlation coefficient.

Average performance times and pass appropriateness for each direction are shown in Table 26 and Table 27, respectively. Relatively large standard deviations were observed for DT (0.06 to 0.08 s) compared to movement times (0.02 to 0.03 s). Right and left DT (0.209 and 0.210 s) were significantly faster than DT to the vertical and upper right locations (0.263 and 0.261, respectively, p = 0.00). Movement times (MT = 0.171 0.176 s) in the vertical, upper right, and upper left directions were significantly different (p = 0.00 to 0.01) when compared to the right and left movement times (0.147 to 0.154 s). Passes to the right were also completed significantly faster than passes to the left (MT = 0.147 and 0.154 s, respectively, p = 0.01) Passes to the right had the highest percentage of interceptions (32%), while passes to the vertical position had the highest percentage of incomplete/incorrect passes (28%).

Table 26: Mean ±SD performance times for each passing direction for n = 22 athletes.

Pass location	DT (s)	MT (s)
Left	0.209 ±0.08[1, 2]	0.147 ±0.02[5, 6, 7, 8]
Right	0.210 ±0.07[3, 4]	0.154 ±0.02[8, 9, 10, 11]
Upper left	0.247 ±0.08	0.175 ±0.03[5, 9]
Upper right	0.261 ±0.07[1, 3]	0.171 ±0.03[6, 10]
Vertical	0.263 ±0.06[2, 4]	0.176 ±0.03[7, 11]
Mean ±SD	*0.243 ±0.03*	*0.158 ±0.01*

DT = decision time, MT = movement time. Significant differences: [1]left and upper right DT, [2]left and vertical DT, [3]right and upper right DT, [4]right and vertical DT, [5]left and upper left MT, [6]left and upper right MT, [7]left and vertical MT, [8]right and left MT, [9]right and upper left MT, [10]right and upper right MT, and [11]right and vertical MT.

Table 27: Mean ±SD pass appropriateness for the reactive decision-making assessment task.

Pass Location	**Complete**	**Incomplete/Incorrect**	**Intercepted**	***Total***
Left	49	2	14	*65*
Right	41	0	19	*60*
Upper left	37	9	5	*51*
Upper right	39	6	6	*51*
Vertical	22	10	4	*36*
Total	*208*	*27*	*38*	

Players were also ranked according to DT (where 1 was the fastest and more appropriate passing, respectively) and compared to MT and appropriateness rankings within the squad (see Table 28). Four players (players A, B, C and E) ranked faster than the squad average for DT (shaded) and below the squad average for MT, while five players (players O, P, S, T, and U) ranked faster than the squad average for MT (outlined) and below average for DT.

Table 28: Player rankings for performance times and appropriateness of the pass.

Player	DT	MT	APP
A	1	21	10
B	2	14	6
C	3	12	1
D	4	3	19
E	5	17	11
F	6	7	18
G	7	11	21
H	8	1	17
I	9	5	7
J	10	4	3
K	11	13	12
L	12	15	22
M	13	16	20
N	14	19	4
O	**15**	**6**	**8**
P	**16**	**10**	**14**
Q	17	20	9
R	18	18	5
S	**19**	**9**	**2**
T	**20**	**8**	**15**
U	**21**	**2**	**13**
V	22	22	16

TT = total time, DT = decision time, MT = movement time, APP = appropriateness of the pass, shaded = players ranking faster than the squad mean for DT and TT and slower than the squad mean for MT, outlined = players ranking faster than the squad mean for MT but slower than the squad mean for DT and TT.

Discussion

The primary focus of this study was to analyze performance times and the associated passing location and appropriateness for a reactive decision-making assessment as a means of determining possible coaching cues and areas of emphasis for reactive decision-making training programs. Considerably lower reliability of performance times throughout the RDM assessment task were observed when compared to previous research [1, 7, 9]. As players are continually reacting to the constantly changing circumstances in sport (i.e. opponent and teammate movements, ball location, etc.) movement variability reflects the ability of players to adapt to the ever changing environment [99]. All three previous studies used an unobstructed view of the stimulus (i.e. tester and opponent movements) whereas the RDM task employed a passive defender to partially obstruct the target players' movements, as would occur in a game. Movement direction options and type of reactive movement also differed between studies. The present study required players to react to the stimulus (target player movement) by passing to the appropriate anticipated direction of target player movement. However in all three previous studies, players were required to move (i.e. sprint, change direction, etc.) into the appropriate direction. Additionally, the RDM assessment had a total of 5 passing options, while Sheppard et al. [1] and Gabbett et al. [7] required players to move off of the appropriate foot to the right or left, and participants in Farrow et al's [9] study were required to sprint at a 45˚ angle to the right or left as if to intercept a pass. Finally, while the RDM task along with the studies conducted by Sheppard et al. [1] and Gabbett et al. [7] used tester movements for the reactive stimulus, Farrow et al. [9] used video projection of players' movements which limits the cues able to be identified by the player due to the 2-dimensional imaging [97].

The use of a target player (as opposed to video projections and static targets) as stimuli throughout the assessment combined with the reactive passing element increase the validity of the RDM task to court-based team sports. While the reliability of the present assessment can be easily increased through the incorporation of additional equipment (e.g. video projection of the target players' movements, eye-tracking goggles, hand sensors to detect the instant of ball release, etc.) the ease of administration (equipment access and assessment set-up) and sport-specificity of the present assessment is thought to be of greater value to coaches and players.

The high CV (22.7 to 35.1%) values associated with the RDM assessment indicate that there was a large amount of variation between performance times. This can be the result of both technological error (error arising from the LED switch belt being released) as well as biological error (participant-related factors). While not directly assessed, it is likely that the target player did not release the LED button at the same time prior to initiating movement for each trial. As the release of the button signalled to the camera the start of the trial (and DT), the potential for error within the calculation of DT is present. In an attempt to minimize this error, the same target player was used for all trials. There will always be increased variability when using players as opposed to equipment (e.g. video projection, beep or flashing light, etc.) to initiate the start of a trial [99-101]. However, video projections of players will eliminate critical cues displayed by the target that the player will use when determining the appropriate passing direction [97]. An auditory stimulus or flashing light used to initiate the trial will require the target player to react to a stimulus prior to initiating movement, also adding variability to the start of the trial.

When assessing performance in a sport-specific context, there will be a trade-off between high validity to the sport and high reliability within the test. As high ecological validity is associated with the RDM task in this study, a great amount of movement variability is present resulting in reduced reliability of the data. Movement variability will always be present in players' performances, regardless of skill level [100] and shouldn't necessarily be eliminated from assessment tasks as they provide valuable insight into the flexibility that individual players possess when adapting to the constantly changing circumstances of sport [101]. As a result, the high sport-specificity of the RDM task is thought to be of greater value to coaches and players than would be achieved through greater standardization of the task. It is important for coaches and strength training professionals to be cognizant of this limitation and make decisions accordingly regarding sport-specific training information versus standardized and less sport-specific information when choosing a RDM assessment.

Performance times in the RDM task varied significantly according to passing direction. It appears that cues associated with movements to the direct left or direct right are able to be identified and perceived faster than movements involving a vertical component (i.e. upper left, upper right or vertical). A player moving to the direct right or left from behind a defender will most likely display a more broad view of the body. In contrast, when a player moves both out and upwards, an angled body position (still obstructed slightly by the defender) is adopted, decreasing the body language able to be perceived by the player. Similarly, a player moving into the vertical direction with no lateral movement will have an even greater amount of the body obstructed by the defender. This direction will typically only allow the arms to be used as cues for the perceptual identification by the player. Therefore, passing opportunities to the direct left or right will typically be completed quicker than the other three passing locations and passes to the vertical location will have a greater incidence of interception and incomplete passes (i.e. are riskier) as was observed in this study.

The value of the RDM task used in this study is in identifying individual player strengths and weakness in performance times (i.e. DT, MT and TT). Once identified, sub-optimal performance times can be addressed through training drills specific to the task and sport i.e. individualization of programmes. For example, this study identified several players with slower than average (i.e. squad average) decision and total times. This indicates that these players require more time to identify and perceive pertinent information regarding the target's movement and correct passing location than the majority of the squad. While the task employed in this study was necessarily very simple in relation to perceptual demand and decision-making in competition, it is likely these players will benefit from additional training targeting early visual scanning and pattern recognition and (i.e. reactive movement drills where multiple options are present – speed/accuracy trade-off [103]). In contrast, several players were also identified as having above average (for the squad) decision time, but have performed below the squad mean when completing the pass (i.e. movement time). This indicates that these players will likely benefit from training which addresses quicker pass execution ability.

Only two of the 22 players completed all 12 passes to the correct location without an interception. Of the players that had intercepted passes or that were completed to the incorrect location, one player's incomplete passes were all released to the incorrect location. Additionally, this player's DT, MT and TT ranks were all below the squad average. This player in particular will most likely benefit greatly from additional training that emphasizes not only executing passes more quickly (i.e. improved MT), but also identifying the correct passing location sooner (i.e. improved DT or reaction time).

A final group of players were identified as having less than optimal passes (i.e. the majority of passes were intercepted) but were ranked in the upper third for movement time. Players in this group are likely to improve reactive decision-making performance as a result of additional training that emphasizes more effective ball placement when passing to avoid interference by the opposition (e.g. passing to the side of the body that is away from the opposition).

Conclusions

The present study relied heavily on reacting to players' movements as a means of increasing validity of the test to the sport. As a result, relatively low reliability was observed. By eliminating the reactive element through increased standardization, validity to the sport is decreased. Greater variability is often associated with increased validity/sport specificity and the reader needs to be cognizant of this limitation and make decisions around test selection and utilization of information accordingly.

The interaction of additional game-specific constraints (e.g. additional teammates and defenders, boundary lines, etc.) will likely have a substantial effect on the decisions a player makes in competition. The passer may need to perform several fakes to delay the opposition and allow the target player enough time to reach the passing location. Therefore, performance times may not provide an accurate profile of the RDM abilities of players as performed in competition. Future research focusing more on selecting the appropriate pass out of several options combined with an assessment of the timing of pass release (including fakes) in relation to the target player and location may be a more accurate representation of the RDM performances in competition. From such an assessment, coaches can develop appropriate training programs which focus on the visual scanning, pattern recognition and pass timing/execution components of RDM.

SECTION FOUR: RELIABILITY OF THE AGILITY ASSESSMENT BATTERY

This section combines the information from the previous three sections of the thesis, and provides pilot information on the reliability and validity of the netball-specific agility assessment battery developed in this thesis. Unfortunately due to time constraints for access to elite non-injured netball players, the reliability of the full battery was only measured on five netball players, limiting the statistical analyses that could be conducted.

CHAPTER 13

RELIABILITY AND VALIDITY OF A NETBALL-SPECIFIC AGILITY ASSESSMENT BATTERY

Prelude

There are typically a wide variety of performance assessments used by coaches and strength trainers to assess players' agility. However, no one study has devised a test battery that assesses all three components of agility (technical, physical and perceptual). The three previous sections of this thesis addressed limitations within the literature and developed assessments that provide insight into the change of direction and perceptual/decision making ability of players. This culminated with the development of an ecologically valid netball-specific agility assessment battery, inclusive of technical, physical and perceptual analyses. However, tests need to be reliable as well as valid. The aim of this study was to determine the reliability of the netball-specific agility assessment battery. A standard test-retest design was undertaken, however, due to various limiting factors associated with the testing (e.g. player availability, fatigue and injury status of players resulting from mid-season testing, etc.) only five players were able to complete all the testing. A second approach was therefore undertaken by focusing on individual tasks within the assessment battery. While the interaction of the technical, physical and perceptual components of agility are crucial for the improved understanding of agility performances in players, the individual tasks also provide valuable information regarding individual strengths and weakness within each component of agility. Therefore, for the purposes of this preliminary study the reliability regarding the compartmentalized tasks associated with the assessment battery were also investigated.

Introduction

The ability to assess individual player capabilities when performing agile movements is of interest and importance to coaches of all levels and across a variety of sports. While the term *agility* is typically used loosely by many coaches and strength and conditioners (commonly used as a general term in reference to change of direction movements), agility is more complex. The working definition of agility developed by Sheppard et al. [1] reflected its multi-factorial nature. Agility was defined as "a rapid, whole-body movement with a change in direction or velocity in response to external stimuli". Additionally, Young et al. [5] developed a deterministic model supporting the complexity of agility (see Figure 30) where the success of an agile performance is a direct result of both perceptual/decision-making factors and change of direction factors (i.e. technical and physical characteristics). Young et al.'s model and Sheppard et al.'s definition of agility lead to the concept of agility as composed of technical, physical and perceptual qualities all of which should be assessed individually and as a whole.

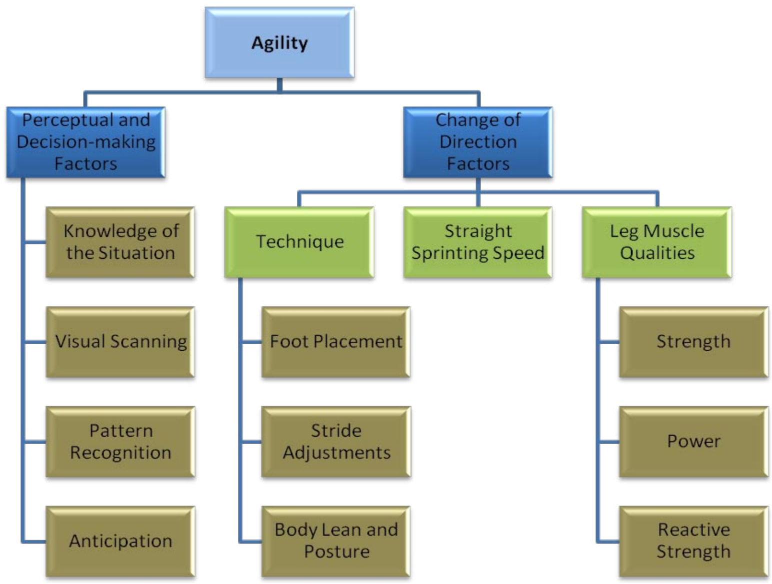


Figure 30: Deterministic model of agility adapted from Young et al. (2002).

Agility has been tested in many different ways over the decades; most commonly using change of direction (COD) speed (i.e. how fast a player is able to complete a combination of movements where at least one change of direction is required). While performance times provide valuable information regarding the physical capabilities of players (e.g. leg power), the actual technical strategies that players employ are of importance yet have often not been addressed in research. Such technical-based information can provide coaches and strength and conditioners insight into the appropriate strategies and associated cues required to elicit superior (i.e. faster and more effective) change of direction performance.

Another component of COD ability is the assessment of leg strength qualities, typically achieved by the utilization of various single and double-leg jumping tasks which aim to quantify leg power. A double-leg vertical jump and variations of it (e.g. countermovement jump, squat jump, etc.) have often been the tests of choice due to their high reliability and ease of administration [14, 72]. However, the majority of sports require unilateral leg power across multiple directions (i.e. vertical, horizontal and lateral). While some researchers [75, 76, 83] have begun to integrate single-leg jumping tasks (e.g. single-leg vertical jump, single-leg squat jump, etc.) into their testing protocol, they often still lack a multi-directional focus which is characteristic of sporting performance. Only recently researchers [16, 17] have begun to compare leg power measures between legs and across multiple directions. The information available from such testing protocols provides coaches and strength and conditioners with normative data as well as prognostic/diagnostic information pertaining to leg asymmetries (i.e. greater imbalances between legs increases the potential for injury [82]) within players.

While the majority of agility assessments address the physical qualities of players (e.g. performance times, leg power measures, etc.) through pre-planned movement patterns (e.g. t-test, 505 test, hexagon test, etc.), they lack the reactive decision-making element that is fundamental to most team and many individual sports (e.g. netball, tennis, squash, etc.). According to the Young et al.'s model a true test of agility needs to incorporate the perceptual decision-making component so the task is applicability to the sport. Perceptual assessment tasks can sometimes differentiate cognitive processes from the technical and physical aspects of the performance [23, 24, 104] providing better diagnostic information as to the needs of the player. Previous research focused on determining the perceptual/decision-making abilities of players has used video occlusion to determine anticipation and pattern recognition capabilities [105, 106]. While the accuracy of player movement responses is often used as an indicator of the awareness to anticipatory cues presented by the opposition, both physical and technical components are absent in the assessment. Additionally, while the use of video as a form of stimulus presentation may increase the reliability of such tasks across players, the ecological validity is low as environmental cues that the player would rely on in competition are eliminated with the two-dimensional stimulus presentation [26, 97].

The interaction of the technical, physical and perceptual agility components within the context of the sport is often lost when tested in the highly controlled environment associated with sports performance analysis. The further players are removed from the sporting context, the less validity the assessment and associated performance will have with the actual competition performance. Therefore, an assessment battery was needed that was able to effectively assess all three components of agility in a sport-specific context. The aim of this study was to determine the reliability of a netball-specific agility assessment battery (N-SAAB) that addressed technical, physical and perceptual agility components.

Methods

Data collection for the full assessment battery took place mid-season for netball players. A netball squad of 11 provincial players performed the assessment battery on two occasions; however six players reported injuries at the time of testing. As a result, only the data collected for the five non-injured players was used for analyses. While the interaction of these three components was of paramount interest when assessing the agility of players, the results from the small sample size attained for the assessment battery limited the knowledge gained from this preliminary study. As a result, a more thorough understanding of the three components was needed and therefore, the tasks were compartmentalized. Data from a second squad of players (n = 12) was used to determine the reliability of four individual tasks associated with the assessment battery.

Experimental approach to the problem

The netball-specific agility assessment battery (N-SAAB) was used in tandem with four individualized assessment tasks [multi-directional single-leg countermovement jumps (SLCM), ground-based 180˚ turn and sprint (180˚ gbCOD), aerial 180˚ catch and pass (180˚ aCOD) and reactive passing] as a preliminary assessment of the test-retest reliability of measures associated with player technical, physical and perceptual/decision-making capabilities in a sport-specific context. The test-retest reliability of these assessments was determined over two testing sessions separated by one week for all players. The average of the two best trials of the N-SAAB, the SLCM jumps and gbCOD tasks were used for analyses. Twelve trials were recorded and averaged together for the reactive passing task and analyses. Three trials each of the 180˚ gbCOD and 180˚ aCOD tasks were randomly selected for comparison of agreement between testers. Reliability statistics were calculated based on these procedures.

Subjects

The 2010 Auckland provincial netball training squad (n = 5, age = 16.2 ±0.8 years, body mass: 71.2 ±6.6 kg, and height: 1.79 ±4.6 m) performed the N-SAAB. The 2009 New Zealand national under-21 training squad (n = 12, age: 19.3 ±1.1 years, body mass: 77.1 ±11.6 kg, and height: 1.79 ±0.1 m) performed the individual multi-directional SLCM jumping tasks, 180˚ gbCOD task and the reactive passing task. Inter-rater analyses for the technical component were conducted on three trials from the 180˚ gbCOD task (under-21 players) and three trials from the 180˚ aCOD task as a portion of the N-SAAB (Auckland provincial players). The Human Research Ethics Committee of AUT University approved all procedures before commencing the study. Informed written consent was obtained prior to testing.

Equipment

Testing equipment for the N-SAAB consisted of two high speed cameras collecting at 300 Hz (Casio EX-F1, Casio Computer Co., LTD, Tokyo, Japan) placed perpendicular to each other as well as a detachable regulation-size netball (chest-height) and a detachable regulation-sized netball bungee (elevated at fingertip height for each player) hung over the rim of the netball hoop via a rubber cord (see Figure 31). Individual assessment testing equipment consisted of a Bertec force plate collecting at 1000 Hz (vertical direction) and three 2 m long tape measures taped to the netball court (horizontal and lateral directions) (see Figure 32) for the SLCM jumps. For the 180˚ gbCOD task, two 300 Hz high speed cameras (Casio EX-F1, Casio Computer Co., LTD, Tokyo, Japan) were placed perpendicular to each other in line with the player's starting position (see Figure 33). The reactive passing task required a single high speed camera (300 Hz) positioned perpendicular to the passing lane between the player, target player and passive defender (see Figure 34). A switch belt (worn by the target player) connected to an LED light facing the camera was used to identify the start of each trial.

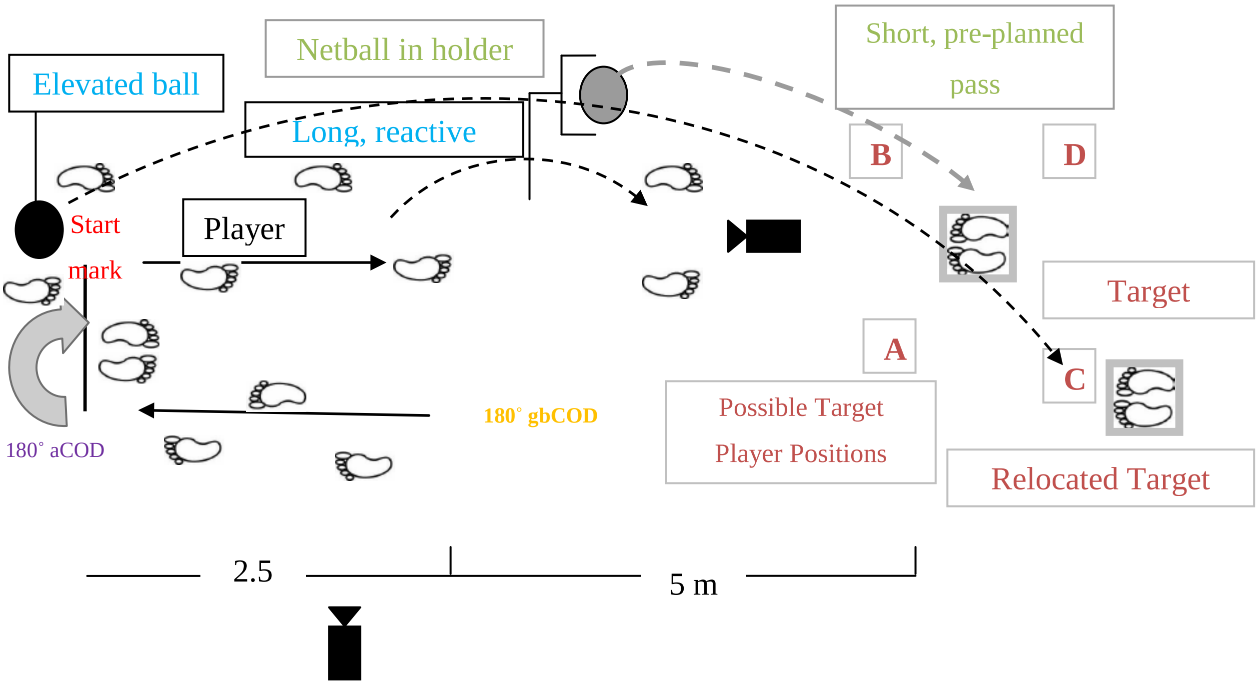


Figure 31: Netball-specific agility assessment battery testing set-up.

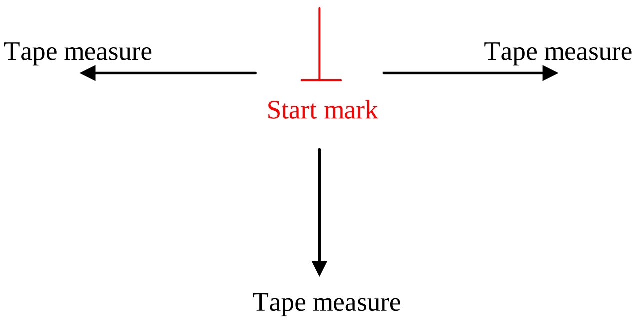


Figure 32: Multi-directional single-leg countermovement jump assessment set-up for the horizontal and lateral directions.

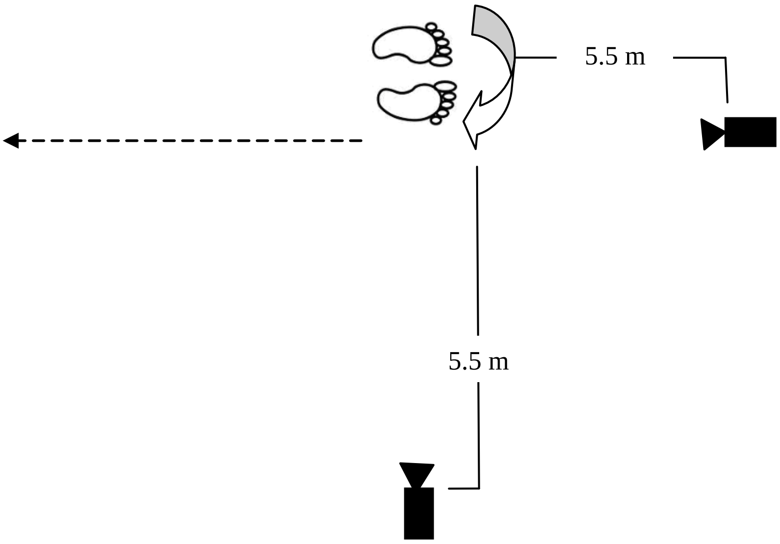


Figure 33: Ground-based change of direction assessment set-up.

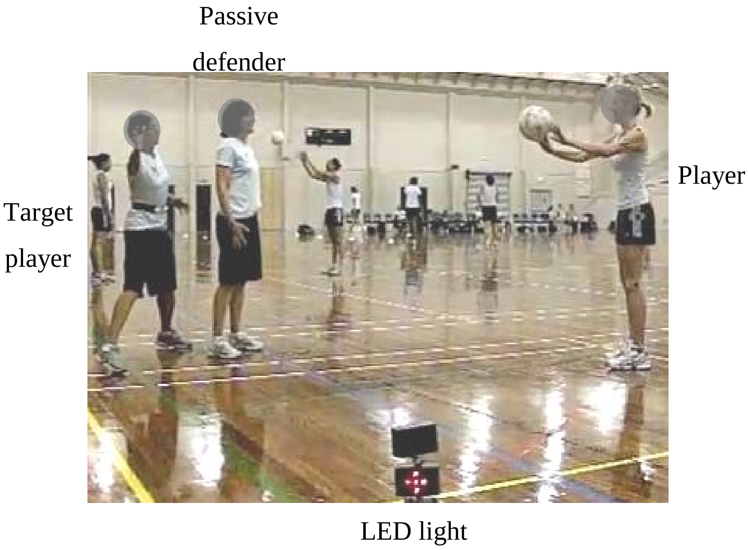


Figure 34: Reactive passing assessment set-up.

Assessments

Netball-specific agility assessment battery (N-SAAB)

The N-SAAB consisted of a netball-specific agility task and multi-directional single-leg countermovement jumps (jumps are detailed in the individual assessment tasks section). For the agility task, players began in a split stance behind a designated start mark. When ready, the player sprinted approximately 2.0 m, leaping forward for a netball positioned in a holder (approximately chest height) at the end of the 2.5 m distance. The player completed a pass to a target player (short, planned pass) positioned a further 5 m in front of the ball holder. Following the pass, players completed a 180˚ gbCOD (towards the camera) followed by a sprint back towards the start mark. Once at the start mark, the player jumped up to grab the second netball elevated (fingertip height for each player) via a detachable bungee looped over the netball ring and completed a 180˚ aCOD prior to a bilateral landing. Upon landing, the player completed a pass (long, reactive pass) to a target player (now relocated to one of four positions as outlined in A-D of Figure 31). Three successful trials were recorded per player. Little instruction or feedback was provided to players throughout the task in order to elicit the players' 'natural' change of direction technique. Players were, however instructed to "perform the task as quickly and accurately as possible, as if you were in an actual netball game" to elicit a maximal effort.

Individual assessment tasks

Single-leg countermovement jumps (SLCM): Players were required to perform SLCM jumps in the vertical, horizontal and lateral directions off both the dominant and non-dominant legs. For the vertical direction (SLCM-V), players stood on a single leg in the centre of the force plate with their hands on their hips and their toes at the designated start line. Players sunk down and rapidly extended the standing leg jumping as high as possible, landing on two feet (back on the force plate). For the horizontal (SLCM-H) and lateral jumps (SLCM-L), players stood on a netball court with their hands on their hips and foot at the designated start mark. For the SLCM-H jumps, players jumped as far forward from the start mark as possible, landing on both feet parallel to the tape measure. For the lateral trials (SLCM-L), players jumped as far possible to the opposite side of the body along the tape measure (e.g. standing on the right leg required players to jump as far to the left as possible), landing on two feet. When three successful trials were completed on the first leg (hands remained on the hips throughout, the legs were not tucked in towards the body while airborne and balance maintained for three seconds upon landing), the player completed three trials on the other leg then moved on to the next direction.

Ground-based change of direction (180˚ gbCOD): Players began at a designated start-mark in a parallel stance. When ready, the player performed a rapid 180˚ ground-based turn towards the cameras followed immediately by a 2.5 m straight sprint. Three successful trials were recorded per player. Players were given little instruction or feedback throughout the task in order to elicit the players' 'natural' technique for changes of direction. Players were, however instructed to "perform the task as quickly and accurately as possible, as if you were in an actual netball game" to elicit a maximal effort.

Reactive passing: Players began at a designated mark in a 'natural' stance. When ready, the target player moved out from behind the passive defender and into one of five randomly assigned locations (directly right, directly left, upper right, upper left and vertically). The player completed a pass as soon as the passing location was identified. If the defender was able to intercept or tip the ball during flight, she was allowed to do so. When the target player began to move into the new direction, she released the switch on her belt, thereby illuminating the LED light for the camera (signalling the start of the trial). Twelve trials were recorded per player. A trial was considered successful if both the target player and passive defender were 'ready' for the pass. Players were instructed to "perform the task as quickly and accurately as possible, as if you were in an actual netball game" to elicit a maximal effort.

Aerial change of direction (180˚ aCOD): This task consisted of the portion of the N-SAAB from two-steps prior to the 180˚ aCOD jump through the release of the long, reactive pass to the target player. Three successful trials were recorded per player. A trial was considered successful if the ball was not dropped and if balance was maintained throughout the landing. Again, players were given little instruction or feedback throughout the task in order to elicit the players' 'natural' technique for change of direction. Players were, however instructed to "perform the task as quickly and explosively as possible, as if you were in an actual netball game" to elicit a maximal effort.

Procedures

Testing took place on a regulation indoor sprung wooden netball court. Upon arrival to the initial testing session, players' age, height, body mass and leg dominance were recorded. Following a 10-minute standardized team netball-specific warm-up (including walking lunges, side lunges, sprints varying from 5 m to 10 m, and total body stretching exercises), players were introduced to the task(s) and allowed practice trials until they felt comfortable performing each task. No more than three practice trials were performed by any of the players for any of the tasks. The order of assessments was reproduced on both testing occasions. The N-SAAB testing sessions involved the netball-specific agility task, followed by the SLCM-V, SLCM-H and finally the SLCM-L task. The individual assessment testing sessions involved SLCM-V, SLCM-H, SLCM-L, 180˚ gbCOD, and finally the reactive passing task.

Data analyses

The N-SAAB was segmented into six subdivisions, each representing one *primary* component of agility (technical, physical or perceptual). The following variables were of interest:

1. Catch and release time - short (C&R-short) represented the time in seconds from chest height ball possession during the forward leap through to ball release to the target player (*physical*).

2. Ground contact time (GCT) represented the time in seconds from the first ground contact (first point of the shoe to contact the ground) following the forward leap through to the takeoff of the same foot (i.e. the support phase) where the last point of the shoe left the ground (*physical*).

3. Ground-based change of direction time (gbCODt) represented the time in seconds from ground contact (first point of the shoe to contact the ground) of the plant foot through to the first ground contact in the new direction (*physical*).

4. Aerial change of direction technique (180˚ aCOD) was analyzed for inter-rater agreement for the individual assessment task by manually advancing the video frames and identifying the extent that key technical features were employed throughout the movement task. These key technical features were identified in previous experimental

work (see Chapter 7) where players were observed over four movement phases (approach, takeoff, airborne and landing) for a 180˚ aCOD task (*technical*).

5. Catch and release time – long (C&R-long) represented the time in seconds from elevated ball possession during the vertical jump through to ball release to the relocated target player (*perceptual*).

6. An average symmetry index (ASI) was calculated (see equation 1) for each player as the percent difference between legs (jump height, or jump distance) when performing SLCM jumps in the vertical, horizontal and lateral directions (*physical*). Equation 1 used to determine the ASI was:

$$\text{ASI} = |(\text{right leg/left leg}) \times 100 - 100|$$

Both the agility assessment battery and the individual assessment tasks evaluated multi-directional SLCM jumps. For these trials, jump height for the SLCM-V trials was calculated via force plate data and customized software (Labview, National Instruments Corporation 2008, version 1.3.0.1) using equation 2 based on the time in the air:

$$\text{Jump height} = \frac{9.81\,(\text{time}_{AIR})^2}{8} \times 100$$

Jump distance for SLCM-H and SLCM-L trials were measured as the distance on the tape measure equal to the point on the foot nearest the start-mark. High speed video was analyzed using Quick Time 7 Pro (Apple Inc.) software.

The individual assessments consisted of four tasks, each reflective of one *primary* component of agility (technical, physical or perceptual). Variables of interest for the assessment tasks included:

1. An average symmetry index (ASI) for each player was calculated as outlined earlier using equation 1.
2. The inter-rater reliability for assessing the ground-based and aerial change of direction abilities in players through the extent that key technical features were employed by each player when performing 180˚ gbCOD and 180˚ aCOD movements (*technical*). These features specifically targeted the player's effectiveness at completing dynamic

approaches, turns and subsequent movements. The inter-rater reliability for the technical analyses assessed the consistency of the ratings assigned to individual players by two coaches (with backgrounds in biomechanics and/or netball) with the ratings of the author of this thesis. Each rater analyzed three players performing the 180˚ gbCOD task and aCOD task. For the purposes of this study, ground-based and aerial-based change of direction performances were analyzed by manually advancing the video frames and identifying the extent that key technical features were employed throughout the movement task. These key technical features were identified in previous experimental work (see Chapters 4, 5 and 7) where players were observed over four movement phases (initial movement, turn, takeoff and first-foot ground contact) for a 180˚ gbCOD task, and four movement phases (approach, takeoff, airborne and landing) for a 180˚ aCOD task.

3. Ground-based change of direction time (gbCODt) represented the time in seconds from player movement initiation through to the first ground contact in the new direction for the 180˚ gbCOD task) (*physical*).
4. Ground-based change of direction 2.5 m time (gbCOD 2.5) represented the time in seconds from the first timing light through to the second following the gbCOD movement (*physical*).
5. Movement time (MT) represented as the time in seconds from player movement initiation through to ball release for the reactive passing task (*physical*).
6. Decision time (DT) represented as the time in seconds from LED illumination through to player movement initiation in the reactive passing task (*perceptual*).
7. Total time (TT) represented as the time in seconds from LED illumination through to ball release in the reactive passing task (*physical*).
8. Appropriateness of player passes (APP) presented as a percentage score out of 12 passes, where a higher percentage was reflective of a more appropriate pass (*perceptual*). Pass appropriateness was determined by the whether the pass was released to the correct location and whether the pass was completed, missed, or tipped/intercepted by the defender. One point was awarded for each pass that was completed (caught by the target player) to the correct location. No points were awarded for interceptions (caught by the defender), missed passes (too high for the player to reach), incorrect passes (approximately 5 cm or more away from the target player's hand), or passes tipped by

the defender. A percent score out of twelve was used to determine the reliability for appropriateness of passes with a higher percentage reflecting more appropriate passing.

Statistical analyses

Means and standard deviations were calculated for all quantitative data. The average of the two best trials of the N-SAAB, the SLCM jumps, gbCOD and aCOD tasks were used for analysis. Twelve trials were recorded and averaged together for the reactive passing task and its analysis. Three trials each of the 180˚ gbCOD and 180˚ aCOD tasks were randomly selected for comparison of agreement between testers.

The reliability for performance times and ASI measures were quantified using the coefficient of variation (CV) and intraclass correlation coefficient (ICC) [107]. Ninety percent confidence intervals (90%) were used throughout. Due to the small sample sizes, an inter-rater reliability analysis was performed using inferential Kappa statistical interpretations to determine agreement among raters for the qualitative portions (technical analysis of ground-based and aerial change of direction) wherein a score of <0 = poor agreement, 0 – 0.20 = slight agreement, 0.21 – 0.40 = fair agreement, 0.41 – 0.60 = moderate agreement, 0.61 – 0.80 = substantial agreement, and 0.81 – 1.00 = almost perfect agreement. Paired t-tests were used to determine if significant differences were present between sessions for C&R-short, GCT, gbCODt, gbCOD 2.5, C&R-long, ASI, MT, DT and TT. Statistical significance was set at $p \leq 0.05$. The magnitudes of effects for both the N-SAAB and individual assessment tasks were explained using Cohen's effect sizes.

Results

The main findings regarding the reliability of each of the three components of agility are outlined below. The findings associated with the N-SAAB are presented first, followed by the individual assessment findings.

N-SAAB

Mean performance scores for the N-SAAB along with a summary of the test-retest reliability measures and ASI magnitudes for the SLCM jumps are shown in Table 29. Greatest variability both within sessions and between sessions was associated with catch and release times (CV = 6.4 to 33.3%, ICC = -0.64 to 0.24) with the second session having significantly faster catch and release times for the long pass (40%, p = 0.01). With regards to SLCM jumps, all three directions decreased in jump distance/height in the second session when compared to the first, with exception of the dominant leg for the SLCM-V jumps which remained the same. The highest ASI's were associated with the vertical direction (6.2 – 8.7%) while the lowest ASI was associated with the horizontal direction (2.8 – 3.3%). Lateral jump distances were significantly larger for the dominant leg in the first session (20%, p = 0.02) and neared significance for the non-dominant leg (18%, p = 0.08) when compared to the second session.

Individual assessment tasks (as grouped by component of agility)

Technical

The average inter-rater agreements for the key technical features of the ground-based and aerial-based change of direction performances are shown in Table 30. While the 180˚ gbCOD task had slightly lower agreement (0.80 and 0.83) as compared to the aCOD task, all scores were substantially or almost perfect in agreement between raters. In terms of single criteria analysis, the inter-rater agreement ranged from 0.67 to 1.00.

Physical

Mean performance scores for the 180˚ gbCOD task, reactive passing task and each jumping direction along with a summary of the test-retest reliability measures and ASI magnitudes for the SLCM jumps are shown in Table 31. With regards to the gbCOD task, considerable variability (i.e. CV > 10%, ICC = 0.33; ES = 2.0) was associated with gbCODt with significantly faster gbCODt (33.8%, p < 0.001) in the second session. In contrast while significantly different between sessions, low variability was associated with gbCOD 2.5 (CV = 4.2%, ICC = 0.11) with the first session having significantly faster times (5%, p <0.001).

Concerning the SLCM jumps, the vertical direction had the largest mean ASI's (9.0 and 10.4) for both testing sessions. However, there were no significant differences in jumping distance/height or ASI's between legs or sessions in any of the three directions. All variables had CV's less than 10% and only one variable had an ICC less than 0.70 (SLCM-H ND). The SLCM-V (dominant leg) was associated with the least variability (CV = 3.6%, ICC = 0.93) between sessions.

Table 29: Test-retest (n = 5) reliability measures for the variables associated with the netball-specific agility assessment battery (N-SAAB).

Variable	Session 1 mean ±SD	Session 1 ASI	Session 1 CV	Session 2 mean ±SD	Session 2 ASI	Session 2 CV	Between session % change in mean	Between session CV	Between session ICC	Between session Cohen
gbCODt (s)	0.57 ±0.09	N/A	10.6%	0.58 ±0.09	N/A	5.2%	2.1	15.0%	0.06	-0.1
GCT (s)	0.70 ±0.24	N/A	9.5%	0.60 ±0.08	N/A	6.8%	-11.0	33.2%	-0.20	0.6
SLCM - V (m) D	0.11 ±0.01	6.2	5.2%	0.11 ±0.02	8.7	5.2%	0.0	0.0%	1.00	0.0
SLCM - V (m) ND	0.11 ±0.02		3.1%	0.10 ±0.02		3.4%	-3.6	6.1%	0.88	-0.5
SLCM - H (m) D	1.63 ±0.22	2.8	1.2%	1.43 ±0.20	3.3	0.8%	-12.6	8.1%	0.72	-1.0
SLCM - H (m) ND	1.63 ±0.19		0.8%	1.45 ±0.22		1.1%	-11.2	8.4%	0.66	-0.9
SLCM - L (m) D	1.59 ±0.17[1]	4.3	1.6%	1.27 ±0.17[1]	5.6	2.2%	-20.1	3.8%	0.92	-1.9
SLCM - L (m) ND	1.62 ±0.22		1.1%	1.33 ±0.23		3.1%	-18.7	7.8%	0.79	-1.3
C&R – short (s)	0.40 ±0.12	N/A	21.5%	0.33 ±0.08	N/A	6.4%	-18.0	23.3%	0.24	0.7
C&R – long (s)	0.99 ±0.28[2]	N/A	16.1%	0.59 ±0.13[2]	N/A	12.9%	-39.3	33.3%	-0.64	1.8

ASI = average symmetry index, CV = coefficient of variation, gbCODt = ground-based change of direction time, GCT = ground contact time, SLCM–V = single-leg countermovement jump (vertical), SLCM–H = single-leg countermovement jump (lateral), SLCM–L = single-leg countermovement jump (lateral), D = dominant leg, ND = non-dominant leg, C&R – short = catch and release time for the short, pre-planned pass, C&R – long = catch and release time for the long, reactive pass.
Significant differences: [1]dominant leg SLCM jump distances between sessions, [2]catch and release time for the long, reactive pass between sessions

Table 30: Inter-rater (n=3) reliability for the technical analysis of the two change of direction movement tasks for three players.

COD Task	Key technical feature	Testers A and B	Testers A and C	*Mean inter-rater scores*
180˚ gbCOD task	*Backward moving centre of mass*	0.67	0.67	***0.67***
	Head leads body through turn	1.00	0.78	***0.89***
	Small rotational inertia	0.78	0.56	***0.67***
	Full extension of takeoff leg	0.67	1.00	***0.83***
	Large takeoff distance and arm drive	0.89	1.00	***0.94***
	Optimal performance outcome: First ground contact parallel to intended direction	0.78	1.00	***0.89***
	Mean comparison rating	***0.80***	***0.83***	*N/A*
180˚ aCOD task	*Deep knee flexion prior to takeoff*	0.78	0.67	***0.72***
	Rotation prior to takeoff	0.89	0.89	***0.89***
	Narrow arm drive	0.78	0.78	***0.78***
	Knee drive through takeoff	1.00	0.78	***0.89***
	Rapid head turn	1.00	0.78	***0.89***
	Ball at chest	1.00	0.89	***0.94***
	Lower body rotation while airborne	1.00	1.00	***1.00***
	Optimal performance outcome 1: Full 180 completed prior to a *bilateral landing*	1.00	1.00	***1.00***
	Mean comparison rating	***0.94***	***0.86***	*N/A*

COD = change of direction, gbCOD = ground-based change of direction, aCOD = aerial change of direction.

Table 31: Test-retest reliability measures for the variables pertaining to the physical component of agility: ground-based change of direction time, and jumping distance/height measures and asymmetry variables for the multi-directional single-leg countermovement jumps.

Variable	**Session 1**			**Session 2**			**Between session**			
	mean ±SD	**ASI**	**CV**	**mean ±SD**	**ASI**	**CV**	**% change in mean**	**CV**	**ICC**	**Cohen**
gbCODt (s)	0.94 ±0.19[1]	N/A	12.6%	0.62 ±0.12[1]	N/A	11.2%	-33.8	17.4%	0.33	2.0
gbCOD 2.5 (s)	0.64 ±0.04[2]	N/A	5.6%	0.67 ±0.04[2]	N/A	6.1%	5.2	4.2%	0.11	-0.8
SLCM - V (m) D	0.22 ±0.03	9.0	7.8%	0.22 ±0.04	10.4	7.5%	1.9	3.6%	0.93	0.0
SLCM - V (m) ND	0.22 ±0.03		6.5%	0.21 ±0.03		6.2%	-1.2	5.5%	0.78	-0.3
SLCM - H (m) D	1.47 ±0.22	4.5	5.5%	1.52 ±0.13	3.2	3.4%	3.8	6.3%	0.76	0.3
SLCM - H (m) ND	1.48 ±0.23		4.1%	1.52 ±0.16		4.3%	3.9	7.9%	0.67	0.2
SLCM - L (m) D	1.48 ±0.11	6.0	3.9%	1.49 ±0.13	5.2	4.4%	3.5	2.9%	0.84	0.1
SLCM - L (m) ND	1.48 ±0.15		3.1%	1.48 ±0.15		4.5%	0.0	4.8%	0.78	0.0
DT	0.21 ±0.11	N/A	58.2%	0.21 ±0.10	N/A	57.7%	5.5	53.8%	-0.57	0.0
MT	0.16 ±0.03	N/A	17.7%	0.16 ±0.05	N/A	16.3%	5.3	8.8%	0.61	0.0
TT	0.36 ±0.11	N/A	23.2%	0.38 ±0.12	N/A	26.7%	4.3	27.5%	-0.43	-0.2

gbCODt = ground-based change of direction time, ASI = average symmetry index, CV = coefficient of variation, ICC = intraclass correlation coefficient, SLCM–V = single-leg countermovement jump (vertical), SLCM–H = single-leg countermovement jump (lateral), SLCM–L = single-leg countermovement jump (lateral), D = dominant leg, ND = non-dominant leg, DT = decision time, MT = movement time, TT = total time
Significant differences: [1]gbCODtbetween sessions, gbCOD 2.5 times between sessions.

Perceptual/Decision-making

Mean performance scores for the reactive passing task along with a summary of the test-retest reliability measures are shown in Table 31. While the greatest inconsistency in performance between sessions was in the decision times of the reactive pass (CV = 53.8%, ICC = -0.57), there were no significant differences between sessions for any of the perceptual/decision-making performance times. Decision time for the reactive passing task had greater variability than MT and TT, both among players (CV = 59.2% to 57.7%) and between sessions (CV = 53.8%, ICC = -0.57). While mean DT, MT and TT increased slightly (0.006 to 0.015 s), the increase in time was negligible.

Passing appropriateness percentages for the reactive passing task ranged from 33% to 100% for the first session and 50% to 100% for the second session. All players improved passing appropriateness percentage from session one to session two (see Table 32).

Table 32: Inter-session pass appropriateness for each player (n = 12) during the reactive passing assessment task.

Player	Session 1	Session 2
1	67%	83%
2	33%	83%
3	100%	100%
4	50%	83%
5	17%	100%
6	67%	100%
7	67%	100%
8	67%	83%
9	67%	83%
10	100%	100%
11	33%	50%
12	50%	67%
Average	***60%***	***86%***

Discussion

The reliability associated with the N-SAAB and each individual assessment task pertaining to each component of agility is discussed fully in the ensuing sections.

N-SAAB

As a sport-specific agility assessment battery addressing all three components of agility had not been published in research literature prior to this thesis, this assessment battery provides a baseline for such assessments to develop from. Due to the relatively small sample sizes, the reliability analyses in this preliminary assessment were expected to be improved with further refinement of the battery as well as improved samples of participants (i.e. increased sample size, out of season assessment, etc.). However several findings in the present analyses are interesting, specifically relating to the interaction of the three components (which emphasizes the need for a single assessment battery that assesses all three components together).

The high variability associated with performance times in general are not surprising given the high validity of the task to netball and the natural variability of movement in sport [100]. As the long, reactive pass required the player to identify the appropriate passing direction while completing an aerial turn, the earlier and more rapidly the head is rotated around (aCOD key technical feature 5) following ball possession may allow for the perceptual component of agility to be initiated earlier than when the head is rotated at a slower pace or later in the aerial phase [5]. Therefore, while the pass may be completed to the appropriate direction, training that emphasizes the technical features associated with such movements may lead to improved pass execution (i.e. decision time and movement time).

Regarding SLCM jump performances, the greatest variability was associated with the horizontal and lateral directions (CV = 3.8 to 8.4%, ICC = 0.66 – 0.92). This was in contrast to the findings reported by Maulder et al. [17] and Meylan et al. [16] where the vertical direction had the greatest amount of variability (CV = 3.3 – 4.1% and 6.7 to 7.2%, respectively). While these two previous studies used data collected from a contact mat and a force plate for all directions, the present study recorded the distance jumped along a tape measure which may have increased the manual error for the horizontal and lateral directions. As a result, it is recommended that a force plate or contact mat be used for such analyses where possible. Additionally, SLCM jump distance all tended to decrease from the first session to the second session in the present study. While players were tested in-season (one and two weeks following a national tournament) during team training sessions, the potential for fatigue is relatively high. As the same tester recorded jump distances for both testing sessions in an attempt to minimize manual error, the likelihood that fatigue influenced player performance from the first to second session is high. As multi-directional SLCM jumps assessments have previously been reported as being relatively reproducible, assessing players outside of their regular competition season is recommended for increased reliability between sessions.

The improved performance times (GCT = 15%, C&R - short = 19%, C&R – long = 40%) from session 1 to session 2 indicated there may have been a learning effect present in the performance of the assessment battery. While this task was representative of movements netball players commonly perform throughout competition [27], the performance of such a task still appears to require a reasonable amount of familiarization prior to data collection. As players become more familiar with the assessment task (i.e. such a task can be easily integrated into training programmes) the variability between sessions may decrease as well as the learning effect.

For the purposes of this reliability study, the assessment battery was compartmentalized into various tasks which targeted the three components of agility. While ideally a single task that incorporates all three components in a sport-specific approach is desirable for increased transference to the sport, the limited access to players at the time of testing required a slightly modified approach. Therefore the results of the individual assessment tasks (grouped according to the primary component of agility) are discussed in the following sections.

Individual assessment tasks

Technical

To the knowledge of the authors, a detailed analysis of the effectiveness of players' technical performances has not been published to date. As a result, a method for identifying and analyzing the extent that key technical features are present in a given performance was needed. Previous research conducted by the authors has identified five technical features that were thought to contribute to a more effective ground-based COD performance (see thesis Chapters 4 and 5) and seven features thought to contribute to a more effective aerial-based COD performance (see thesis Chapter 7). Based on this information, a detailed technical template was developed for both COD tasks and was used by the primary researcher during the analysis of all player performances as well as the two coaches in the inter-rater analysis. While the analysis of technical performance can be highly subjective and will often vary greatly between testers, the analysis template was used to ensure consistent scoring between the three testers. As such, the overall reliability (inter-rater) of this portion of the analysis was relatively high (0.80 to 0.94). These findings indicated that the criteria used to describe each of the technical features were clear and easily observable.

Physical

The relatively low reliability associated with the gbCODt (gbCODt: CV = 17.4%, ICC = 0.33) may be attributed to a number of reasons. There is a large amount of movement variability in sport regardless of the level of skill [99, 100]. As all players were instructed to "perform the task as quickly and accurately as possible, as if you were in an actual netball game" the low reliability between sessions may be reflective of the need to further investigate the individual technical strategies employed by players through such qualitative analyses as performed in this study. Additionally, similar to the N-SAAB, the second session had significantly faster gbCODt which may indicate a learning effect. More time may be needed to familiarize players to the gbCOD task prior to data collection. Higher reliability between gbCOD 2.5 times was found when compared to that of gbCODt. As the gbCODt were calculated from high speed video and gbCOD 2.5 times from timing lights, technological error may also have contributed to the variance.

Surprisingly, there was a paucity of literature regarding between session reliability for SLCM jumps. While reliability studies conducted by Meylan, et al. [16] and Maulder et al. [17] most closely related to the present study (i.e. multi-directional SLCM jumps), Meylan et al.'s measures of reliability pertained to trials within a single testing session and jump height/distance measures were reflective of the two best trials for each participant (i.e. ASI magnitudes were not calculated). While male participants were used in Maulder et al.'s [17] study, the between session reliability measures and ASI calculations were consistent with the present study. In contrast to Maulder et al.'s [17] findings of greater reliability associated with the horizontal direction (CV = 1.9 – 2.0%, ICC = 0.80 – 0.95), the present study found greatest reliability in the vertical direction (CV = 3.6%, ICC = 0.93). This difference in direction-specific reliability may be related to the specific demands of the participants in their sporting context (i.e. sub-elite netball players in the current study versus players involved in a "wide variety of sports" in Maulder et al.'s study). Additionally, higher ASI's resulted in both testing sessions for the present study (3.2 to 10.4%) when compared to that of Maulder et al. [17] (1%). However, these ASI's were indicative of non-injured players and none of the ASI's were above the 15% working threshold suggested in literature [68, 81-83] as needing to be addressed in training.

Perceptual/Decision-making

Perceptual/decision-making ability has been assessed through a variety of methods ranging from decision time and response time [94, 95] to gaze behaviours with eye-tracking goggles [97]. In this study, decision time, movement time, total time and pass appropriateness were used to assess the perceptual/decision-making ability of the players. The low reliability of the three temporal variables (DT: CV = 53.8%, ICC = -0.57; MT = 8.8%, ICC = 0.61; and TT = 27.5%, ICC = -0.43) supports the contention reported in previous research that there is generally a large amount of variability in sport-specific movement tasks [100, 101, 108]. While the percentage of appropriate passes was relatively low (squad average = 60%) in the first testing session, by the second session all players had improved their appropriateness (squad average = 86%). This finding coincides with the increase in mean decision time, movement time and total time from session 1 to session 2. While the increase in perceptual performance times for the relatively simple reactive passing task was quite small (0.006, 0.009, and 0.015 s respectively) it appears that this slight increase in time taken to perceive and react to the stimulus (i.e. knowledge of the situation, visual scanning, pattern recognition and anticipation) was beneficial to the execution of the appropriateness of the pass. While the standardization of the test could have been increased, it would have decreased the validity of the assessment task to the sport. Therefore, to maintain high validity, the lower reliability of the temporal characteristics is expected.

Movements in sport have a large amount of variability, especially in team-based court and field sports [100] as players are reacting to each other, the ball, and the boundary lines. Therefore, a testing battery that presents high validity to a sport will have similarly high variability. As with any assessment, the importance of replicating the actual movement patterns as much as possible often out-weigh the decreased reliability associated with such a test as transference to the sport is of greater interest. As an assessment battery encompassing the technical, physical and perceptual qualities of players had not been published in the research literature previously, it was hoped that the approach taken in this study would foster more research in this area, whereby assessment batteries that provide better prognostic and diagnostic information are developed.

Practical applications

A wide variety of assessment tasks are used by strength and conditioners when attempting to assess agility. While these assessments often focus on the physical component by using performance times as indicators of change of direction ability, leg power capabilities and reactive elements of the sport, a sport-specific assessment battery that targets the technical, physical and perceptual components is needed. It is believed that such a holistic approach gives greater insight into the needs of players and focuses the individualization of programmes to better effect.

The current study investigated the reliability of a netball-specific agility assessment battery as well as various netball-specific assessment tasks that targeted each of these three components. Little research has given attention to the technical strategies employed by players that may elicit superior performances in sport. The technical feature templates associated with this battery of tests provided coaches and strength trainers with increased understanding of the technical features associated with such complex movement tasks as well as providing a fairly reliable (0.80 to 0.94 agreement between testers) method of assessing the presence of key technical features associated with both ground-based and aerial change of direction tasks. Additionally, reasonable reliability (CV = 2.9 to 7.9%) was associated with the multi-directional SLCM jumps, providing a valuable prognostic/diagnostic assessment for leg power imbalances as performed in sport. It would seem assessments of this nature could be used effectively and reliably to diagnose players strength and weaknesses.

While high variability resulted from both the assessment battery as well as portions of the various assessment tasks in this study (e.g. reactive passing assessment, gbCODt, etc.), the greater ecological validity/sport-specificity of these particular tasks and ease of administration are thought to be desirable for providing information to coaches. As performance was improved from the first session to the second in almost all assessments, a relatively large learning effect may be present. While a greater familiarization period may improve the consistency of these tasks between sessions, often the time available to assess players is relatively limited and as a result additional time may not be feasible in the team assessment setting. These considerations need to be taken into account with regards to assessment development.

The reliability of the reactive passing task in particular could be improved through increased standardization (i.e. video projection of the passing direction, LED stimulus to identify the passing direction, etc.) of trials, however the associated validity to the sport would be compromised. The low reliability of the reactive passing task and gbCOD task (performance times) would provide little insight into players’ strengths and weaknesses when monitoring throughout the season as a monitoring tool. However, such an assessment may still provide coaches and strength trainers with valuable information regarding player capabilities when used as a cross-sectional assessment task. The reader needs to be cognizant of this limitation and make decisions around test selection and utilization of information accordingly. Further development and refinement of the netball-specific agility assessment battery is needed to increase the functional use of such a comprehensive battery in sport.

Conclusion

As the N-SAAB had low reliability, the use of such a sport-specific assessment tool may be more appropriately used as a cross-sectional analysis of individual player capabilities rather than as a monitoring tool throughout the season. Minor adjustments to the assessment battery can easily be made to increase reliability; however such adjustments would consequently decrease the validity of the battery to the sport. The practitioner must be aware of this and select the most appropriate assessment battery based on the specific needs of players and coaches at the time of testing.

CHAPTER 14

SUMMARY AND PRACTICAL APPLICATIONS

Summary

Fundamental to this thesis has been the definition of agility presented by Sheppard et al. [8] and the deterministic model of agility developed by Young and colleagues [5] wherein three main components (technical, physical and perceptual) were identified as critical determinants of agility. In terms of diagnosis of agility capability, it was identified by the author that no one assessment had included all three components into a single sport-specific agility assessment battery. This thesis attempted to contribute original knowledge regarding the assessment of agility specific to netball. An assessment battery was designed to identify individual player strengths and weaknesses across three primary components of agility (technical, physical and perceptual/decision-making). As each component encompassed a wide range of specific features, a survey was developed (Appendix 1) and administered to netball coaches and staff to gain a better understanding of the areas that were of greatest importance to the development of players' agility. From this survey, a netball-specific testing protocol for the agility assessment battery was developed (Appendix 2).

Sections one, two and three each focused on the separate components of agility and their contribution to the assessment battery. The technical component of agility has received the least amount of attention in research to date; therefore, a large portion of this thesis was dedicated to increasing the knowledge surrounding the technical analysis of various ground-based and aerial change of direction techniques that are commonly performed by netball players throughout a game. Within the technical component (See Section 1), several studies were conducted to determine the kinematics and technical features that appeared to be associated with superior ground-based and aerial change of direction movements. When the kinematics of straight acceleration (SA) performances were compared to that of acceleration following a rapid change of direction (180^{o} change of direction acceleration - CODA), several features differed between tasks. First, as the goals of each task differ [i.e. SA - attain maximum velocity as quickly as possible, CODA – accelerate following/between rapid directional change(s)], the body positioning and postures also differed greatly between tasks (i.e. a more erect posture at takeoff and decreased step length and knee lift for CODA when compared to SA performances). Intuitively these differences between tasks make sense as the CODA involves repositioning the body after a turn and therefore the kinematic differences are a direct result of this. In terms of the comparison between faster and slower players regarding the CODA and SA tasks, faster CODA performances were associated with abbreviated step length, more erect torso and decreased knee lift thereby allowing a player to maintain balance while rapidly positioning the free leg into the intended direction.

A qualitative analytic approach was used to develop key technical feature templates for ground-based and aerial change of direction (COD) performance analyses. A total of five key technical features were identified for superior (first ground contact parallel to the new direction) 90-180˚ ground-based COD performances: 1) lowering and initiating movement into the intended sprinting direction; 2) head leading the body through the turn; 3) arms and legs close to the body when turning (i.e. small rotational inertia); 4) near full extension of the takeoff leg (i.e. large takeoff distance); and 5) intense driving action of the arms. Seven features were thought to contribute to a superior (full rotation completed prior to a bilateral parallel landing) 180˚ aerial COD performance: 1) deep hip and knee flexion through the approach; 2) initiating rotation prior to takeoff; 3) high arm drive through takeoff; 4) free leg drive through takeoff; 5) rapid head turn following ball possession; 6) ball held close to the body at lower chest height; and 7) aggressive lower body rotation while airborne.

While movements and body positioning specific to both the sport and playing position may alter some of the features outlined in this thesis, these features are likely to contribute to the safe and effective performances of similar movement tasks over a wide variety of sports and/or playing positions. Regardless of the individual key technical features used, the template presented in this thesis provides a means for coaches and strength training professionals to both identify and prioritize specific features within a player's performance that are found to be absent or performed to a lesser degree than might be desired. Information of this nature is valuable for the refinement of individual players' training programmes, the overall development of superior performing players and for coaches who have little experience in understanding the mechanical determinants of various movements. As a result of the thesis studies a number of technical reports and fact sheets were created for Netball New Zealand for the education of their coaches.

As illustrated in Young's deterministic model of agility [5], the technical qualities that a player possesses can also dependent upon the physical capabilities of that player. If a player is performing all of the recommended technical features, yet the performance times remain below average, it is possible that the physical capabilities of the player are lacking. Through multi-directional unilateral leg power assessments, leg power profiles can be created and the magnitudes and imbalances between legs can be identified (see Section two). Some of the main findings of this section were that there appears some variation in the magnitude of the ASI depending on the variable and direction used to quantify the asymmetry. In terms of the threshold of asymmetry that is thought predictive of injury, it would seem that on average asymmetries of ~10% are expected in some variables (e.g. power output) for non-injured players. Asymmetries of 15% or greater may warrant closer attention dependent on the variable of interest, as inter-limb differences in distance and force would appear substantial. However, some individual inter-limb differences were as great as ~30% for players classed as non-injured. Coupling ASI data with raw data provides insight into not only the imbalances between legs, but also the ability of individual players to produce the multi-directional power and force. Decisions need to be made by the clinician or strength and conditioning practitioner as to which variables and directions are specific to the requirements of their sport and or positions. If in doubt, it may be best to develop a single-leg multi-directional leg power and ASI profile, which will provide information that can drive the individualization of programming.

The third component of agility to be addressed in this study was the perceptual decision-making component (see Section three). A reactive decision-making assessment was developed that had high ecological validity/sport specificity. The assessment enabled the identification of appropriate directional passing strategies as well as performance times (i.e. decision time and movement time). Performance times varied a great deal across players and testing sessions using this assessment. However, in sport performance times will also have high variability as each decision depends on the players reaction to a multitude of factors (teammate positioning, opponent positioning, boundary lines, time constraints, etc.). Therefore, by eliminating this element through increased standardization, validity to the sport is lost. Greater variability is often associated with increased validity/sport specificity and the reader needs to be cognizant of this limitation and make decisions around test selection and utilization of information accordingly. Reactive decision-making assessments and training drills should be performed in response to players' movements in a manner that they would be performed in competition (i.e. replicated pace, obstructions, external cueing, etc.). Additionally, assessments of this nature can be easily modified to meet the needs of the individual players (i.e. skill level) and coaches (i.e. focusing on specific aspects of RDM such as selecting the most appropriate pass from several options) by increasing or decreasing the number of options, the addition of defenders, or by adding a time constraint to the task.

The deterministic model of agility created by Young et al. [5] has been used as the foundation of this thesis and assisted in the development of the individual assessment tasks as well as the comprehensive N-SAAB. Throughout the development, analysis and evaluation of the assessments and their influence on the three main components of agility (technical, physical and perceptual), several adjustments to the deterministic model have been identified which more closely relate to those modifications presented in the universal agility components model presented by Sheppard and Young [8] (e.g. the inclusion of anthropometry and left-right muscle imbalances/asymmetry). The newly modified deterministic model of agility is presented in Figure 35.

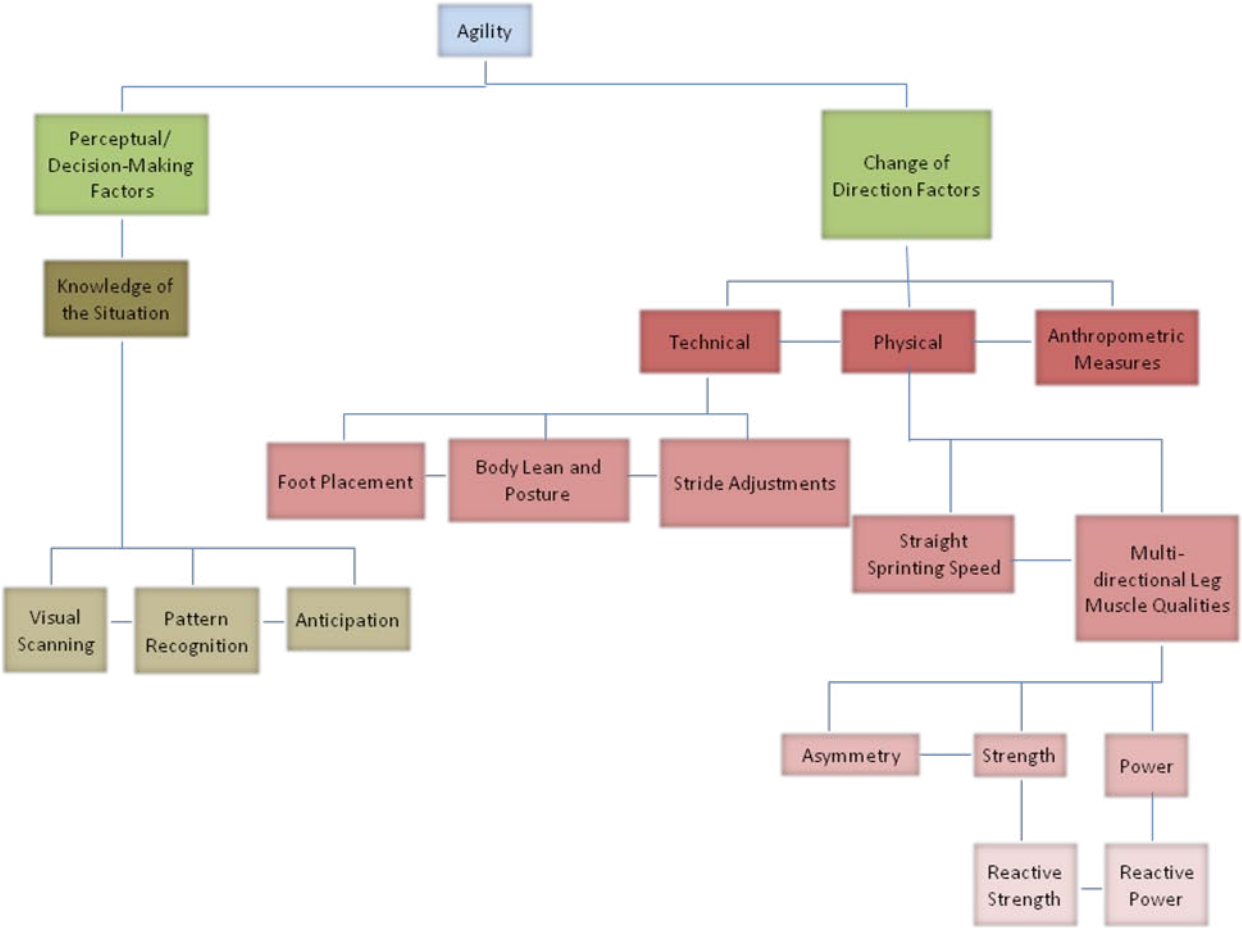


Figure 35: Key contributing components of agility (modified from Young et al., 2002; and Sheppar and Young, 2006).

This model emphasizes the inter-related nature of the sub-components of agility. For example within the technical component, foot placement will have an effect on body lean and posture which will in turn have an effect on the stride adjustments, and vice versa. This inter-connection of the sub-components has been added throughout the 'perceptual/decision-making factors' and 'change of direction factors' components. Additionally, to better reflect the multi-directional nature of agility in sport, the term "multi-directional" has been added to the leg muscle qualities sub-component within the physical component of agility. A re-organization within the multi-directional leg muscle qualities sub-component has also been presented. When assessing multi-directional leg muscle qualities in players, the identification of asymmetry magnitudes above the 10-15% threshold will help guide strength and power training programs. Once a base of strength/power has been developed and asymmetries have been minimized, reactive strength and power can be integrated into training programs.

Practical applications

A main aim of this thesis was to develop a battery of tests that improved the understanding of agility needs in netball. From the outset it was understood that this needed to be coach driven thus the initial survey, which provided the direction for the rest of the thesis. One of the biggest challenges thereafter was to ensure that the assessments and knowledge gained was of utility to coaches and strength and conditioning practitioners while still fulfilling academic requirements of a PhD. Developing profiles and templates that were user friendly and of ecological validity an important outcome to this thesis.

In terms of the technical component, when addressing specific technical weaknesses in players, it is recommended that training programmes be reflective of the key technical features associated with each individual movement task (e.g. SA, CODA, ground-based COD, aerial COD, etc.) as they relate to the sporting context. Templates have been developed that enable critical features of "ideal" movement patterns to be identified. These templates can serve many purposes from assessment and focusing training to better effect, to education and up-skilling of coaches and conditioners about netball specific movement patterns and the associated technical cues.

Comparing data and/or presenting data in different formats were also found to provide valuable information. For example, ranking and comparing the SA and CODA players provided insight into those players who performed well in a straight line but not so when changing direction and vice versa. Presenting data in such a fashion focuses programming on the needs of an individual.

As players are required to perform repeated bouts of explosive unilateral movements across a variety of directions in sport, assessment and training programs that target the physical weaknesses and imbalances of players should include multi-directional unilateral explosive movements. This author and other researchers have found that the shared variance between vertical, lateral and horizontal movements is small to moderate, indicating that they are relatively independent motor qualities. Being powerful in one direction does not necessarily transfer to other directions. Therefore the development of multi-directional unilateral power profiles is thought important for netball players. When implementing such profiles, it is easy to quantify the ASI of players. This also needs to occur in all three directions as the shared variance between ASI's in the vertical, horizontal and lateral were trivial. Coupling the power profile and the ASI data will provide information about the individual leg strength/power needs of a player in terms of injury prevention and performance. Where possible force plates should be used however in many situations this is impractical and jump heights and distances will suffice.

Training that targets both decision and movement times of players in a sport-specific context are important to the understanding and enhancement of reactive decision-making ability in netball players. Such assessments are beneficial for developmental through elite-level players as individual player's strengths and weaknesses can be identified that might otherwise have been overlooked. Those players presenting less than optimal performance times or passing appropriateness in the assessment should have additional reactive decision-making training targeting these areas integrated into their training sessions as soon as possible. It is important to remember, that decision time, movement time and passing appropriateness are inter-related characteristics within reactive decision-making and must not be separated in training as transference to the sport will be decreased. Therefore, training drills that emphasize one aspect of reactive decision-making while maintaining the other two should be implemented accordingly as indicated from the agility assessment battery. However, as discussed above this area presents a great challenge to the practitioner given that high ecological validity and therefore context specific information is associated with high variability – low reliability.

Throughout this thesis, data has been presented as squad means. However, the importance of individual player results (i.e. performance times, kinematics, key technical feature inclusions, asymmetry magnitudes, and passing appropriateness and success) is masked when data is grouped in such a manner. For optimal prognostic/diagnostic purposes, data should remain individualized when assessing player strengths and weaknesses. Players' individual results compared to squad averages provide great insight into where the player needs to focus. Also radar plots or other types of graphics can be designed to indicate to players and coaches where players need to focus.

Future directions

Agility encompasses many components and therefore central to this thesis was the development of an assessment battery that provided a greater understanding of the agility needs of netball players. Also another tenet was that the battery needed to be easily administered, of high ecological validity and reliability and give a holistic picture of a player's agility capability i.e. inclusion of all three components. These aims have been achieved to varying degrees throughout the thesis but a lot more work needs to be completed in this area.

As technical feature templates provide coaches with a cross-sectional snap-shot of the effectiveness of individual players' technical abilities, these templates can be of great use during player selection camps and for developmental purposes for players and coaches of all skill levels. Given the paucity of information in this area, future research needs to target the development of key technical feature templates for additional ground-based and aerial movement tasks across multiple sports.

With regards to the leg power and ASI profiling, the designs used in this study were principally cross-sectional. The next step is to use this profiling in terms of monitoring across various interventions to determine if particular loading and/or movements/exercises affect the profiles to a greater degree than other programmes. For example, it may be that certain exercises and/or movement patterns affect multi-directional power and the ASI to better effect and therefore practitioners need to know this if a best practice philosophy is to be implemented. Future research needs to investigate the efficacy of multi-directional eccentric training, dedicated pre-habilitation training, integrated prevention and conditioning programmes, etc.

Most notably, improvements can be made to the reactive decision-making aspect within the netball-specific agility task. As greater standardization is needed in the current reactive decision-making assessment, a proposed modification to the reactive passing task has been provided (see Figure 36) (dimensions will be determined through pilot testing). Replacing the target player with an adjustable 3-direction target arm (see Figure 37) is thought to maintain high validity to the sport, yet decrease the amount of variability associated with the target player observed in the current assessment task. The performance of the test is as follows; 1) the player begins facing away from the target arm, during which time the target arm is set to the appropriate randomly assigned location (right, left or straight up) by the tester; 2) the player completes a 180˚ aCOD while grabbing an elevated netball; 3) upon ball possession, the player must identify the correct passing location (to the target arm) and complete a pass as quickly and accurately as possible. Performance times (decision time, movement time, and total time) as outlined in Chapter 12 of this thesis will be recorded via high speed video, while pass appropriateness will be recorded by the tester following each trial.

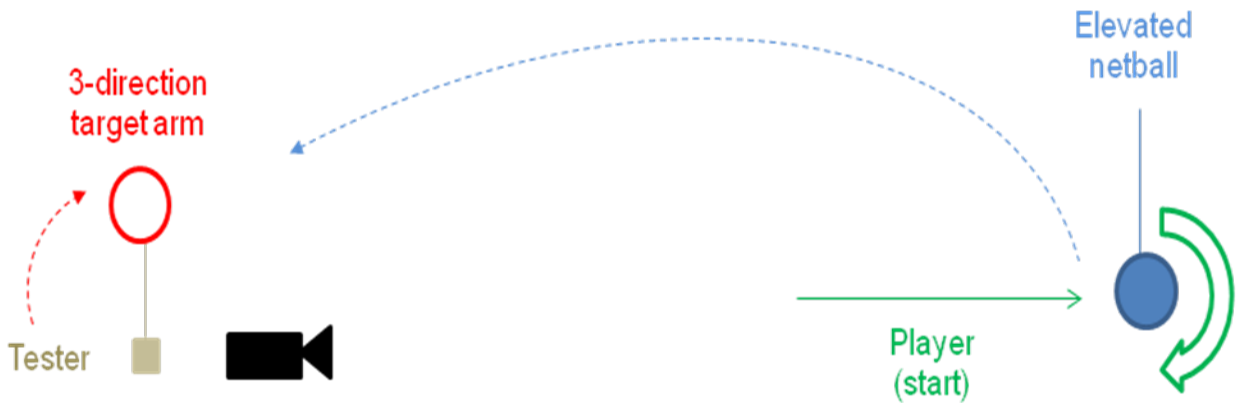


Figure 36: Schematic of the testing set-up for the proposed modified reactive decision-making portion of the netball-specific agility assessment battery and individual reactive passing task (as viewed from above).

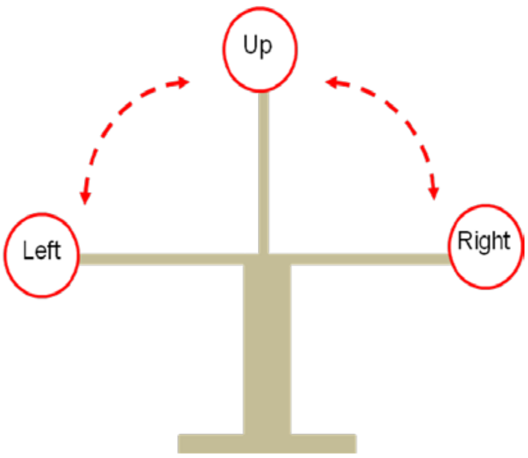


Figure 37: Diagram of the three-direction target arm for the proposed reactive decision-making assessment.

Finally the utility and value of this assessment battery needs to be determined by implementation and utilization across netball players of many skill levels. Over time with critique from end users the testing battery will be refined and amended.

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APPENDICES

Appendix 1. **Sample of the agility survey.**

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Assessing and Developing Agility in Netball Players

This questionnaire is the first part of a series of Jennifer Hewit's ISRRNZ Netball New Zealand Doctoral studies looking into what coaches feel are the three main elements of performance that determine how agile a netball player is. Technique, muscular qualities and decision-making are all thought to interact with each other, enabling the player to complete a complex movement. Unfortunately, these three qualities have yet to be studied together, much less in a netball specific study. The purpose of the entire series of studies is to combine an assessment of technique, muscular qualities and decision-making into one study, creating a testing battery that will be able to determine if a netball player is lacking in any areas that may impede netball performance. Based on the results of the assessment a training program will be created, targeting and refining these areas of agility that have shown the need for improvement. The overall aim of the study is to increase the netball specific movement efficiency through our agility training model.

The first part of this process is to survey coaches as to what they think is important in terms of agility in netball players. The survey has been given to netball coaches and team advisors that are well known to NNZ because of your high level of netball coaching expertise. From these questions, we are hoping to determine which player positions might benefit the most from this agility study. We are also interested in what movements you consider fundamental and necessary for a player to master in order to excel in netball. From your responses, we will determine what muscular qualities are essential for these movements. Finally, we are interested in the decisions that players in these positions might be required to make, as well as any cues they might use to make their decisions. Your responses will help us direct our agility study so that it can have the most benefit and impact for Netball New Zealand coaches and players.

Please note that your participation in this survey is voluntary. By signing the attached consent form you are agreeing to complete the survey. Individual coach responses and opinions will be kept confidential, and only the researchers will see the actual responses. A summary of responses without any identification of who gave the response will be provided to Netball New Zealand at the end of the study so we can discuss the next steps of the study.

Thank you for sharing your time and expertise with us and for assisting us with our research.

1. Please recommend the player positions that you think will benefit from this research the most. We ask that you limit your response to no more than two positions, due to the scope of the study.

First choice:

Second choice:

2. Please list the **technical skills of agility** that you feel are most important, regarding the above position/s. For example, the movement patterns that you feel are fundamental to the position, and if mastered would give the athlete a decisive edge over the competition. Please feel free to list as many skills and benefits as you'd like for each of the two positions.

Position	Technical Skill(s)	Benefit(s) to the game

3. Please list any **training drills** that are commonly used to enhance the technical skills of agility of the players in the above listed skills or scenarios.

Technical Skill	Training Drill(s)

4. Please list the **decision-making cues** or scenarios that you feel are most important, regarding the positions you listed above. For example, body position cues of the opponent or teammates, or scenarios that are common in netball that might be of high-risk for an interception, etc.

Position	Scenario	Cue(s)	Possible Outcome(s)

5. Please list **any training drills that are commonly used to refine the decision-making ability** or cue identification of the positions listed. For example, decreasing the amount of time taken to make a decision, training the players on the best decisions for these scenarios, recognizing body positions, etc.

Position	Training Drill	Aim of Drill

Appendix 2. Technical report 1 – Needs analysis of agility in New Zealand netball players.

Hewit, J., Cronin, J.B., Hume, P.A., & Button, C. (2010). *Understanding ground-based change of direction in sport.* To be submitted to *Journal of Strength and Conditioning Research*.

Author contributions - JH: 83%, JC: 10%, PH: 5%, CB: 2%.

Overview

Background: Agility has three distinct qualities (technical, physical and perceptual-decision making) which should be trained and tested in an environment that is as similar as possible to the actual sporting context. Netball players may possess strengths and weaknesses in each or all of these three different qualities, but it would advantage players to be proficient in all of these areas in order to excel in agility performance. Therefore, a battery of tests that is able to differentiate performance in each of these qualities is highly desirable. From the results of such an assessment, an appropriate technical, strength and conditioning and/or perceptual-decision making training program can be implemented, increasing the potential for player improvement.

Aim: To gain a better understanding of the technical and decision-making cues important to netball.

Methods: A total of 52 Netball New Zealand personnel (including coaches, strength and conditioning coaches, and team advisors) were asked to complete a survey via email, telephone, or one-on-one interview to determine: 1) The netball playing positions that might benefit the most from agility research; 2) The current technical training methods for agility employed by New Zealand netball coaches; 3) The technical areas of agility that are of greatest value to New Zealand netball coaches; and, 4) The decision-making skills that are of greatest value to New Zealand netball coaches.

Results: 1) The netball playing positions that might benefit the most from agility research were wing attack and goal defence; 2) The current technical training methods for agility employed by New Zealand netball coaches include cone drills, marking drills, and speed ladder drills; 3) The technical areas of agility that were of greatest value to New Zealand netball coaches were fast, sharp change of direction movements in the horizontal, lateral and

vertical directions as well as rapid accelerations and decelerations; 4) The decision-making skills that were of greatest value to New Zealand netball coaches were awareness of the ball, teammates and opponents, evasion, and interception timing and accuracy.

Practical implications: The wing attack and goal defence playing positions were chosen as most important for agility research, which should be inclusive of rapid changes of direction including rapid accelerations and decelerations in the horizontal and lateral directions both on the ground and in the air.

Introduction

An athlete's performance and success in many sports is typically determined by their ability to complete agile movements i.e. starting, stopping and changing direction rapidly [8, 109]. Such movements may be focused on the body as a whole (completing a change of direction while sprinting, initiating a vertical jump from a forward or lateral sprint, etc.), while others may focus on specific limbs and more refined motor skills specific to the sport (dribbling a soccer ball around an opponent, catching and initiating a pass while in the air in netball, etc.). The actual accomplishment of such tasks requires the athlete to complete a sequence of perceptual and physical events:

1. Identify and perceive critical information about the situation.
2. Activate the correct muscles in the order needed to initiate the desired movement.
3. Control the muscle activation throughout the movement.
4. Control and transfer the speed and velocity produced in the preceding movements.
5. Create appropriate force and impulse.

Therefore, as proposed by many researchers, but yet to be comprehensively addressed, agility performance involves the integration of cognitive processes, physical demands and technical skills [1, 3, 4, 9, 12, 110]. Young et al. [5] attempted to detail the determinants of agility in a model as depicted in Figure A. Agility performance has been divided into change of direction (COD) ability, which has physical and technical demands, and also psychomotor ability which is typified by perceptual-decision making demands. Authors have investigated the physical/physiological determinants of agility [4, 7, 57, 68], while less research has reported the technical demands of certain COD movements [1, 5, 10] and there is a paucity of research on the perceptual-decision making aspects of agility. Given this model and the status of the literature, this report discusses each of these three areas and their importance and integration in agility performance.

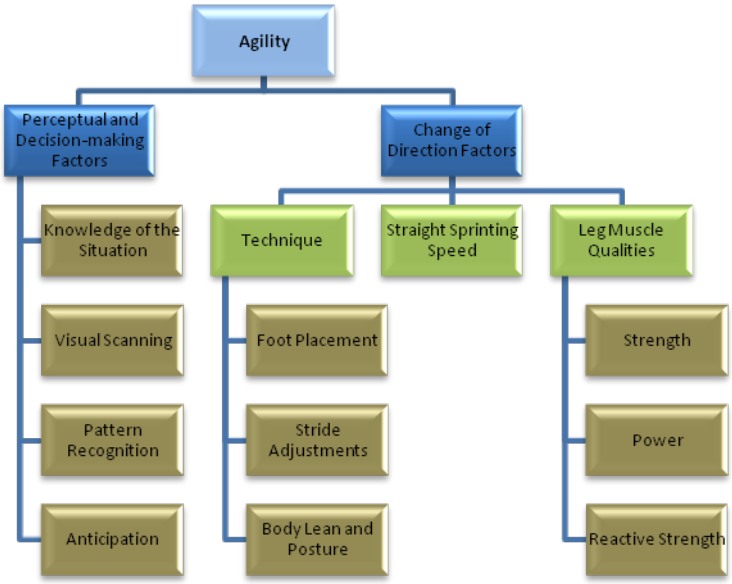

Figure A: Deterministic model of agility (adapted from Young, 2002).

The sport of netball is comprised of a total of seven players per team (two teams) on the court at a time. Each of these players has a specified area of play (see Figure B) that they are allowed to roam throughout the entirety of a game (4 x 15 minute quarters), with only two players per team (Goal Shooter and Goal Attack) being allowed to score points. The restricted area of play requires some players (e.g. mid-court and attacking players) to travel at high horizontal velocities feeding the ball to teammates and intercepting opponents' passes, while other players (e.g. end-court players) are required to be more vertically mobile and able to move rapidly while navigating in a small space.

With such a wide range of technical, physical, and perceptual characteristics required for all seven player positions throughout the course of a game, a survey was designed to gain a better understanding of the technical and decision-making aspects of netball. The first main objective of the survey was to determine the two player positions that would benefit the most from agility research. Additionally, the movement and decision-making qualities that are thought specific and/or desirable to those player positions were of interest.

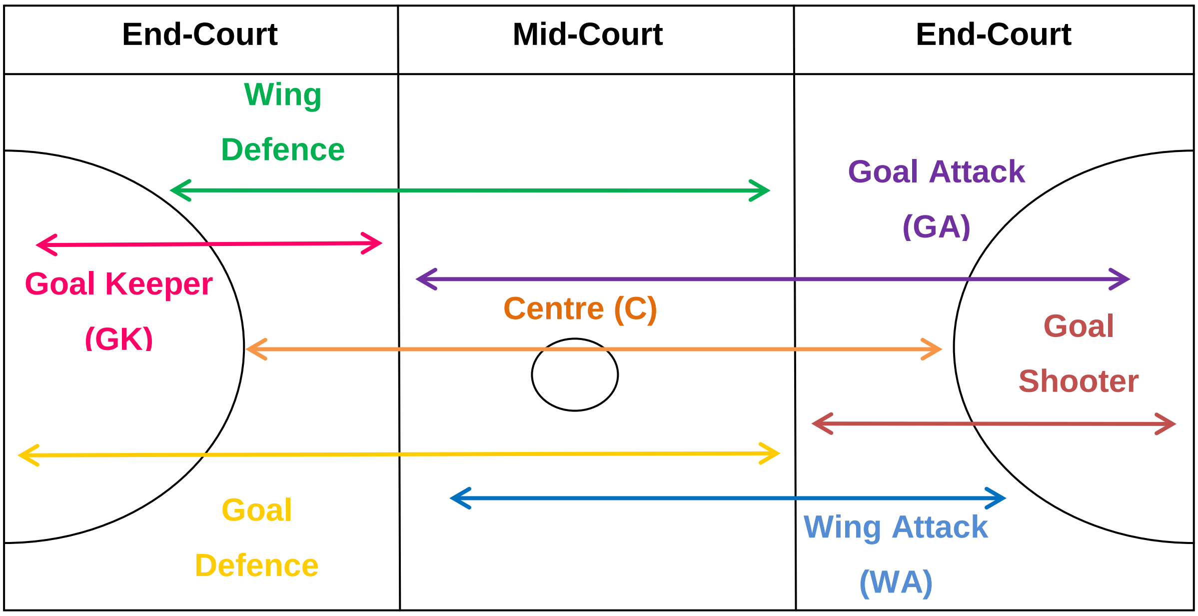

Figure B: Netball player positions and designated areas of play.

Methodology

Development of survey

In order to gain a better understanding of the technical and decision-making aspects of netball, a survey was designed in consultation with Leigh Gibbs and Ruth Aitken from Netball New Zealand.

Procedures

The survey (see Appendix 1) was administered via email, telephone, and one-on-one interviews.

Participants

Fifty two New Zealand netball personnel (see Table A) were contacted to participate in the survey. A total of 18 completed surveys were obtained giving a 35% response rate.

Table A: Survey sample population.

New Zealand netball personnel	Surveys administered	Completed surveys received	Completed surveys %
Coaches	28	9	32
Strength and conditioning coaches	14	5	36
Team advisors	10	4	40
Total	***52***	***18***	***35***

Data analyses

The feedback given in the completed surveys was categorised and summarised according to the frequency of responses.

Results

The majority (45%) of the completed surveys indicated that the wing attack was the primary position of interest, with the goal defence (33%) being the secondary position of interest (see Figure C). The most common responses from the scoping survey concerning the elements of each of the three main components of agility that are of highest importance/concern to New Zealand netball coaches are outlined in Table B.

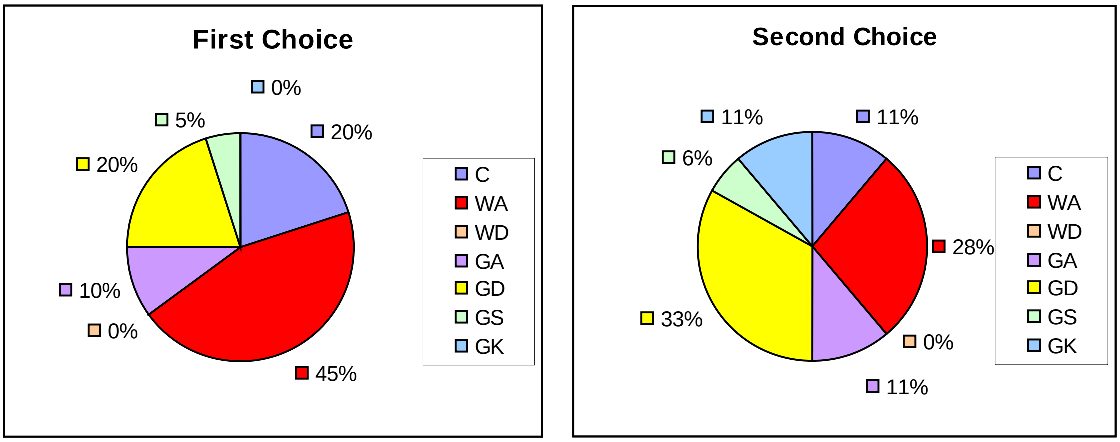

Figure C: First and second choice player positions of focus for the agility assessment battery.

Table B: Summarized coaches' responses from the agility survey.

Agility component	Element
Technical	Fast, sharp COD (rapid deceleration and explosive acceleration)
	Forward, backward, lateral and aerial COD
	Time taken to complete COD tasks
Physical	Single-leg countermovement jumps (vertical, horizontal and lateral)
	10-m straight sprinting speed (splits taken at 2.5-m and 5-m)
Perceptual	Awareness of the ball, team mates, and opponent
	Interception timing and accuracy
	Evasion
	Confidence in physical abilities

In summary the survey results showed that:

1) The netball playing positions that might benefit the most from agility research were wing attack and goal defence;
2) The current technical training agility methods employed by New Zealand netball coaches included cone drills, marking drills and speed ladder drills;
3) The technical areas of agility that were of greatest value to New Zealand netball coaches were fast, sharp COD in the horizontal, lateral and vertical directions as well as rapid accelerations and decelerations;
4) The decision-making skills that were of greatest value to New Zealand netball coaches were awareness of the ball, teammates and opponents, evasion, and interception timing and accuracy.

Discussion

The first main objective of the survey was to determine the two player positions that would benefit the most from agility research. Given the survey responses, the ensuing research will focus on the movement patterns that are commonly performed primarily by the wing attack with the movement patterns of the goal defence of secondary importance where applicable. Given that the available sample population of these two positions is relatively small, players from all seven positions will be included for the development of the assessment battery and initial intervention. All of the seven player positions require similar movements so the increased sample size will potentially strengthen the results, as well as increase the agility of the team as a whole.

It is also apparent that rapid changes of direction in all directions, both in the air and on the ground, are common movements performed in a netball game. Awareness of the situation (including the ball, team-mates and opponents) throughout the game has also been identified as an essential component to a successful performance. Therefore, this research will aim to include these movement patterns and scenarios into the final agility assessment battery.

Conclusion

The wing attack and goal defence playing positions were of greatest importance for agility research that is inclusive of rapid changes of direction including rapid accelerations and decelerations in the horizontal and lateral directions both on the ground and in the air.

Acknowledgements

Special thanks are given to the Netball New Zealand coaches, strength trainers and staff for their cooperation, participation and assistance.

Appendix 3. Technical report 2 – Netball-specific agility assessment battery testing protocol and initial results.

Overview

Background: Agility can be broken into three distinct qualities (technical, physical and perceptual) which should be trained and tested in an environment that is as similar as possible to the actual sporting context. Netball players may possess strengths and weaknesses in each or all of these three different areas, but it would advantage players to be proficient in all of these areas in order to excel in agility performance. Therefore, a battery of tests that is able to differentiate performance in each of these qualities is highly desirable. From the results of such an assessment, an appropriate technical, strength and conditioning and/or perceptual training program can be implemented, increasing the potential for player improvement.

Aim: To develop a valid and reliable agility assessment tool that differentiates between the technical, physical and perceptual components of netball agility.

Methods: Agility testing data were collected during the January 2009 New Zealand under 21 (NZU21) netball training camp. Initial analysis is provided with complete analysis of video footage and force plate measures to follow.

Initial results: A low shared variance between horizontal and lateral jump distances indicates that these two tests are relatively independent of each other (i.e. a good lateral jump distance wasn't necessarily coupled with a good horizontal jump distance). Asymmetries between legs (for both the jump and change of direction tests) showed that the right leg average was greater than the left leg by ~5%, with most asymmetries being less than 10%.

Initial practical implications for coaches: Directional jump distances will give insight as to multi-directional strengths and weakness in the player's leg power. Differences in sprinting speed and change of direction measures also indicate possible technically-based strengths and weaknesses. In combination with the power measures and video analysis, these results will offer better diagnostic information for trainers to individualise programmes.

Introduction

Agility has been defined in many different ways, however, it is clear from the definitions that there are technical (body positioning and control of movements), physical (power, reactive strength), and perceptual (response to a stimulus) components, all of which are inter-related [1, 2, 4, 48, 53]. The deterministic model of agility proposed by Young et al. (2002) (see

Figure D) is centered on this multi-factorial approach to agility which indicates a variety of measures that contribute to agility performance. As illustrated in this model, the ability to perceive and physically and accurately react to a stimulus are the two main factors that distinguish a movement as being "agile". Within each of these main determinants are frameworks of technical, physical and perceptual characteristics that contribute to either movement proficiency or knowledge of the situation. Based on this model, it can be deduced that if one of these technical, physical or perceptual components are lacking, the overall agility performance could be compromised.

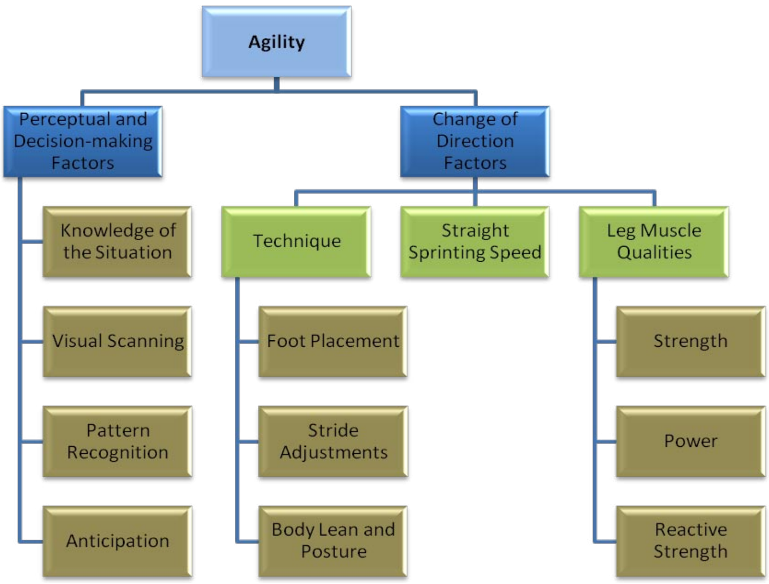

Figure D: Deterministic model of agility (adapted from Young, 2002).

The preliminary objectives of the current research were to:

1. Determine the validity and reliability of the individual tests as determinants of agility performance;
2. Determine the technical movement strategies that are being implemented, as well as determine the movement strategies that are a result of superior (i.e. faster, more powerful, and more accurate) performances.

Methods

Participants

A total of 22 netball players from the NZU21 squad participated in this study. Prior to completing a standardised netball warm-up, the age (19.33 ±1.11 years), height (178.95 ±5.81 cm), body mass (77.10 ±11.62 kg), and leg length (91.73 ±4.01 cm) were recorded for each player. Once the testing procedures were explained, each player was allowed up to three practice trials per test in order to familiarise themselves with the movements.

Testing set-up

Testing took place on a regulation indoor sprung wooden netball court. Testing occurred in two blocks with the first block being comprised of single-leg counter movement jumps off a force plate, a 5 m straight sprint and a reactive passing drill. Slight adjustments were made to the testing set-up for the second block of assessments which consisted of a ground-based and aerial change of direction test. The testing set-ups are illustrated in Figures E and F. Testing equipment included dual beam timing gates (Swift Performance Technologies, NSW, Australia) to collect the sprinting times of the players, two high speed video cameras (EX F1, Casio Computer Co., Ltd, Japan) sampling at a rate of 300 Hz to record the movement strategies and reaction times of the players and a force plate (AM6500, Bertec Corp., Ohio, USA) sampling at 1000 Hz to collect the jump /leg power measures of interest, while jump distances were recorded manually via measuring tape for the horizontal and lateral jumps.

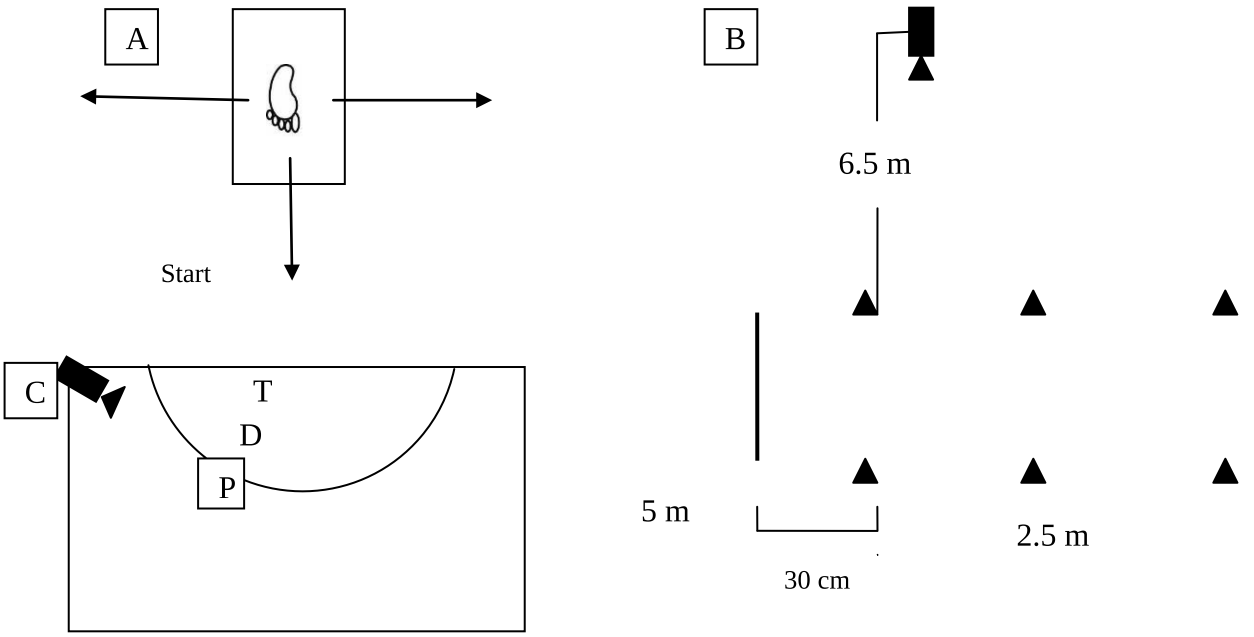

Figure E: Testing set-up for the single-leg countermovement jumps (A), straight sprint (B) and reactive passing tests (C).

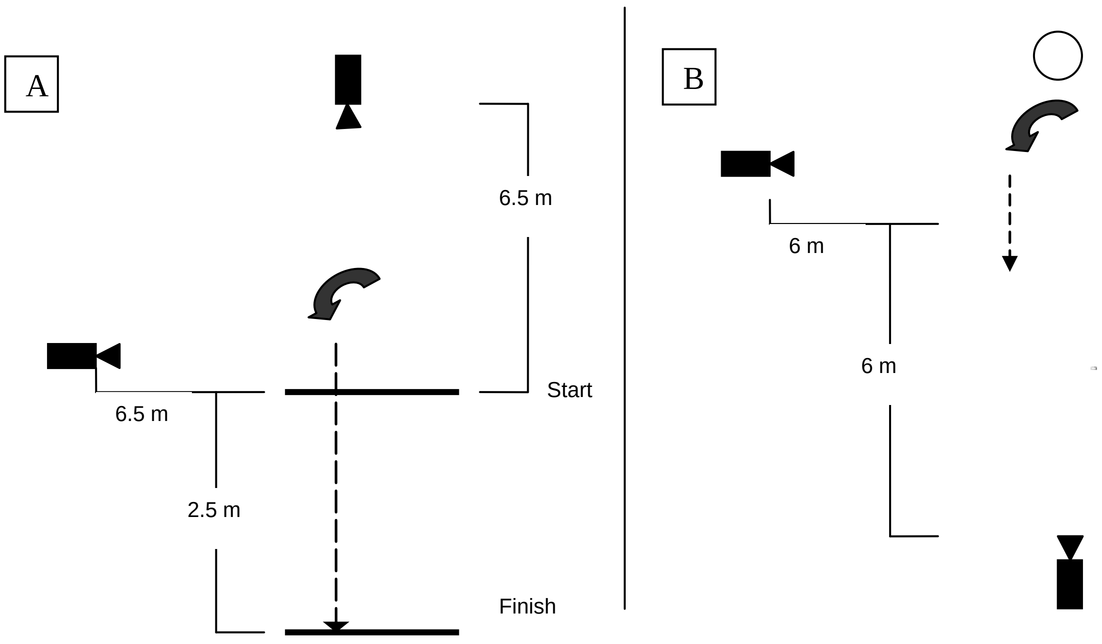

Figure F: Testing set-up for the ground-based (A) and aerial (B) change of direction tests.

Procedures

The following gives a brief outline of the five different tests performed, as well as the analysis progress to this point (C = complete and included in this report, IP = in progress).

Single-leg countermovement jumps (SLCM)

Players completed three successful trials of three different SLCM jumps on each leg (18 jumps total); vertical, horizontal (forward), and lateral (sideways). A trial was considered successful if both hands remained on the hips throughout, if the player landed on two feet and if there was no additional hop upon landing. Players began standing in the centre of the force plate on a single leg. When ready, the player sunk down to approximately 100° of knee flexion then immediately extended the legs, jumping as far as possible in the designated direction. The lateral trials required the player to jump in the opposite direction of the leg they were standing on.

<u>Analysis progress:</u>

Horizontal and lateral jump distances analysed (C)

Vertical, lateral and horizontal power measures (IP)

Straight sprinting speed (SS)

Players completed three successful trials of a 5 m straight sprint. Players began at the start mark (see Figure E.B) with feet parallel to the line. A trial was considered successful if the first step was in the forward direction (no false start). A camera was placed midway between the first and second timing gates to record the movement strategies during the initial acceleration phase of the sprint.

<u>Analysis progress</u>:

2.5 m split times and 5 m sprint times analysed (C)

Video analysis of first 2.5 m movement strategies analysed (IP)

Reactive decision-making (RDM)

Prior to testing, the head and assistant coaches were asked to confidentially assign a decision-making ability score (on a scale of 1-10) to each player. The actual test began with the player holding a netball at a designated spot on the circle edge. A target player (T) and passive defender (D) were located in the shooting circle, both facing the player. The target player wore a switch-belt connected to an LED signal in front of a high speed camera. The target began the trial by pressing the signal button (signalling the start of the trial and beginning of the decision time) then releasing and stepping into one of five randomly selected passing directions (left, right, upper left, upper right, and vertical). As soon as the player was able to determine the movement direction of the target, a pass would be made in that direction. If the passive defender was able to intercept the pass (minimal movement), she was allowed to do so. A total of 12 trials were completed by each player.

Analysis progress:
Video analysis of decision and passing accuracy (IP)
Video analysis of option presented, reaction times, and decision times (IP)
Comparison of coaches' decision-making ability scores to actual performance (IP)

Ground-based change of direction (gbCOD)

Players completed six trials (three to the left, and three to the right) of a 180° change of direction followed by a 2.5 m sprint. The player began behind the start mark, feet parallel, with their back to the timing gates (see Figure F.A). In response to an LED signal, the player completed a 180˚ turn to the left/right as fast as possible, followed by a maximal sprint through the timing gates. Two high speed cameras were positioned in front of and in the turning direction (left/right) of the player.

Analysis progress:
2.5 m sprint times analysed (C)
Video analysis of movement strategies analysed (IP)
Video analysis of reaction time analysed (IP)

Aerial change of direction (aCOD)

Players completed six trials (three to the left, and three to the right) of a 180° change of direction in the air while grabbing an elevated netball. The player began with a 2-step approach, followed by a turning jump (left/right), landing facing the reverse direction (see Figure F.B). While in the air, the player was required to grab a netball elevated (via bungee cord) to just above their head. Two high speed cameras were positioned in front of and in the turning direction (left/right) of the player.

Analysis progress:
Video analysis of movement strategies analysed (IP)
Refined aerial agility testing protocol (IP)

Results

Initial correlational analysis has shown that there was minimal influence of height, leg length or body mass on any of the variables. The horizontal (see Table C) and lateral jump distances were not strong predictors of 2.5 and 5 m sprinting times. The horizontal and lateral jump distances had a relatively low shared variance ($r = 0.7$, ≈ 50% shared variance), indicating that these two tests are relatively independent of each other. That is, those that had good lateral jump distances didn't necessarily have good horizontal jump distances.

Table C: Average single-leg horizontal (H) and lateral (L) jump distances (cm), with the percent difference between legs for each.

Player	Left leg (H)	Right leg (H)	% Difference (H)	Left leg (L)	Right leg (L)	% Difference (L)
Squad average	***149.33***	***153.64***	***4.5 %***	***145.34***	***153.81***	***5.8 %***
A	158	166.25	5.0	155.5	159.5	2.5
B	139	147	5.4	155	160.5	3.4
C	168	179.5	6.4	142.75	160.25	10.9
D	152.5	161	5.3	153.5	156	1.6
E	157.5	176.5	10.8	149	156	4.5
F	148.5	164.5	9.7	150.75	155.5	3.1
G	161	179.5	10.3	149	163	8.6
H	159.5	159.5	0.0	155	159.5	2.8
I	135.75	140.75	3.6	131.5	137.25	4.2
J	156.5	153.5	1.9	147.5	158	6.6
K	147.5	140	5.1	126.25	140	9.8
L	146	151.5	3.6	138.5	150	7.7
M	147	143.5	2.4	148.5	160.5	7.5
N	149	159.5	6.6	153.5	154	0.3
O	165	164.5	0.3	148	147.5	0.3
P	135.5	135.5	0.0	128	147.5	13.2
Q	185	192.5	3.9	169.25	165.75	2.1
R	157.5	149	5.4	152.5	165.5	7.9
S	156	153.5	1.6	164.5	166.5	1.2
T	121	121.5	0.4	117	147	20.4
U	124	132	6.1	131.5	135.5	3.0
V	115.5	109	5.6	130.5	138.5	5.8

Highlighted in green: asymmetries greater than 10%

Highlighted in yellow: players that have jump distances below the squad average

Table C indicates the squad averages and those players that scored less than the squad average are highlighted in yellow. For both tests the right leg average was greater than the left leg by ~5%. The asymmetries (imbalance) between the left and right legs in each direction were also calculated. Most asymmetries were less than 10% in both directions and those that had greater than 10% are highlighted in green and this asymmetry may be worthwhile investigating by the physiotherapist or trainer in those identified players.

With regards to the sprint times, there was a strong relationship (r = 0.85) between the 2.5 m and 5 m straight split times, indicating that only one of the two distances is needed for testing purposes (see Table D). Once more squad averages are shown and those players slower than the squad average highlighted in yellow.

Table D: Average straight sprinting times (seconds).

Player	2.5 m sprint	5 m sprint
Squad average	**0.80**	**1.26**
A	0.78	1.22
B	0.79	1.23
C	0.84	1.33
D	0.79	1.28
E	0.72	1.19
F	0.78	1.25
G	0.85	1.31
H	0.81	1.25
I	0.78	1.23
J	0.76	1.26
K	0.77	1.24
L	0.82	1.28
M	0.83	1.28
N	0.76	1.26
O	0.86	1.31
P	0.81	1.31
Q	0.74	1.16
R	0.86	1.33
S	0.78	1.25
T	0.79	1.22
U	0.89	1.36
V	0.78	1.30

Highlighted: Players with slower times than the squad average.

The relationship between the 2.5 m straight sprint and gbCOD 2.5 m sprint was less than 0.38, indicating that those who had fast straight sprint times, didn't necessarily have fast sprint times immediately following a change of direction (see Table E). The greater the % difference indicates a greater difference between the gbCOD ability and SS ability. Once more squad averages are shown and those players slower than the squad average highlighted in yellow.

Table E: Average 2.5 m times for the gbCOD (GB) and the straight sprint (SS), with percent differences between the two 2.5 m sprint times.

Player	GB	SS	% Difference
Squad average	***0.65***	***0.80***	***19.1***
A	0.66	0.78	15.4
B	0.61	0.79	23.4
C	0.63	0.84	24.4
D	0.66	0.79	17.1
E	0.63	0.72	13.2
F	0.62	0.78	21.2
G	0.67	0.85	21.8
H	0.69	0.81	15.4
I	0.65	0.78	17.3
J	0.68	0.76	11.2
K	0.63	0.77	18.8
L	0.69	0.82	15.9
M	0.65	0.83	21.7
N	0.65	0.76	15.1
O	0.69	0.86	20.3
P	0.63	0.81	22.2
Q	0.61	0.74	17.6
R	0.61	0.86	29.7
S	0.66	0.78	15.4
T	0.62	0.79	22.2
U	0.66	0.89	25.8
V	0.67	0.78	14.1

Highlighted: players with slower times than the squad average.

Lastly, asymmetries (differences between legs) appear to be direction, and task-specific. There were no players that showed asymmetries greater than 10% in more than one of the directions (gbCOD or the SLCM jumps) (see Table F).

Table F: Asymmetries (% difference) between legs for the gbCOD (GB), lateral (L), and horizontal (H) SLCM jumps.

Player	% Difference (GB)	% Difference (H)	% Difference (L)
Squad average	**3.2**	**4.5**	**5.8**
A	0.0	5.0	2.5
B	1.7	5.4	3.4
C	1.6	6.4	10.9
D	4.5	5.3	1.6
E	4.7	10.8	4.5
F	1.6	9.7	3.1
G	4.4	10.3	8.6
H	1.4	0.0	2.8
I	1.5	3.6	4.2
J	1.5	1.9	6.6
K	1.6	5.1	9.8
L	6.0	3.6	7.7
M	0.0	2.4	7.5
N	10.3	6.6	0.3
O	4.3	0.3	0.3
P	3.2	0.0	13.2
Q	6.3	3.9	2.1
R	1.7	5.4	7.9
S	3.1	1.6	1.2
T	1.6	0.4	20.4
U	3.1	6.1	3.0
V	6.2	5.6	5.8

Highlighted: asymmetries greater than 10%.

Practical implications

While the findings in this report are based on initial data analysis, some interesting observations have been made. It is not surprising that the horizontal and lateral jump distances were not able to predict sprinting performance, as sprinting over such a short distance does not require the use of long, explosive stride lengths. This finding does however support the multidimensional nature of agility and how individual variables are unable to explain the concept. The jump measures will give insight as to multi-directional strengths and weakness in the player's leg power. In combination with the vertical jump, these results will offer better diagnostic information for trainers to individualise programmes. This is also true of the SS and COD measures. From the correlational and individual results some players had good SS ability but had poor COD ability. This has given insight into how to focus programmes on player strength and weaknesses. Video and force plate data, combined with the findings presented here will further develop our understanding of the underlying mechanisms that create agile performance.

Acknowledgements

Special thanks are given to the NZU21 coaching team and players for their hard work, cooperation, patience and assistance.

Appendix 4. Fact Sheet 1 – Straight and change of direction acceleration

NETBALL NEW ZEALAND
Poitarawhiti Aotearoa

ACCELERATING FROM A STATIC START AND FOLLOWING A CHANGE OF DIRECTION

Rapid accelerations over short distances are often required throughout the course of a netball game. These explosive sprints may not always occur in a straight line or from a static start. With the fast-paced nature of netball and defined areas of play, players are often required to rapidly change direction and accelerate into an open space ahead of their opponent. Therefore, it is important for players to be equally proficient at straight acceleration (SA) from a static start as well as following a change of direction (change of direction acceleration - CODA). This fact sheet outlines key technical and training points for 2.5 m SA and CODA for New Zealand netball players. *Please note that this test is not netball specific (i.e. head up, arm position for catching etc.) but does give an indication of first step quickness. A netball specific 2.5 m test should be used to determine the difference between a player's netball technical and sprint ability.*

Key technical features for straight acceleration (SA)

<u>Optimising step length and step frequency</u>: Optimising the contribution of step length (SL) and step frequency (SF) is important for initial acceleration. That is, greater propulsive forces will be achieved by greater ground contact times, but will negatively affect SF. Conversely high SF will allow propulsive forces to be applied more regularly but the magnitude of the force will be less and result in decreased SL.

<u>Increased forward lean</u>: A forward lean of approximately 45˚ allows the centre of mass (COM) to move ahead of the base of support (forefoot) creating instability and greater horizontal forces propelling the body forward [34].

<u>Ground contact point behind COM</u>: Contacting the ground with the forefoot (the heel should not contact the ground when accelerating) at or behind the COM when accelerating limits the braking forces upon impact, thereby allowing for purely propulsive forces throughout the contact phase [109].

<u>Synchronized arm and leg drive</u>: Both arms and legs should be aggressively driven parallel to the body, increasing vertical and horizontal propulsion.

Figure G: Example of "superior" SA 2.5 (top row) and CODA 2.5 (bottom row) sprinting performances.

Additional key technical features for change of direction acceleration (CODA)

Moving the COM into the intended direction of travel: Moving the COM outside of the base of support into the direction of travel assists in the transfer of momentum into the new direction.

Head leads the body: Initiating the turn with the head, allows for earlier visual identification of opponents and teammates positioning, thereby allowing for increased time to make an appropriate decision.

Small rotational inertia when turning: Keeping the arms and legs close to the body when turning decreases the rotational inertia (resistance to rotate), allowing the body to rotate more rapidly.

First ground contact in direction of sprint: The first ground contact should be as close to parallel to the new sprinting direction as possible, allowing for a faster acceleration in a straight line.

Large takeoff distance: In addition to assisting in overcoming inertia, a greater distance from the takeoff foot to the COM (takeoff distance) increases the ground contact time and amount of propulsive force produced prior to takeoff [28].

Full extension at takeoff: By allowing the takeoff leg to fully extend before leaving the ground, a greater amount of propulsive force can be generated [50]. *Note, if a subsequent COD is performed, an abbreviated extension at takeoff is more beneficial as the leg can be repositioned into the new direction sooner.*

Interpreting netball players' SA and CODA 2.5 m sprinting performances for training

While some players may naturally perform sprinting tasks with the listed technical features, others may only include a few – or none at all. Some players may excel when sprinting out of a turn while others may be more proficient from a static start. A study was conducted for Netball New Zealand to examine the strengths and weaknesses of sub-elite netball players' sprinting techniques. Twenty-two netball players from the NZ-U21 2009 training squad completed three trials of a 2.5 m straight sprint from a static start, and three trials of a 180˚ ground-based COD followed immediately by a 2.5 m straight sprint. Instructions were kept to a minimum in order to record each player's "natural" sprinting strategies. Results (sprint times) are shown in Table G with practical recommendations provided for those players needing to focus training on SA ability and those players needing to focus training on CODA ability based on the key technical features listed above. Individual player performance times may not always accurately reflect the overall COD performance as additional factors that contribute to an agility performance are not specifically analyzed in the table (e.g. physical components, flexibility, body size, etc.).

Table G: 2.5 m straight acceleration sprinting times (SA 2.5) and following a 180˚ change of direction (CODA 2.5). Players are ranked for each task from fastest to slowest times.

Player	*SS 2.5 (s)*
A	0.72
B	0.74
C	0.76
D	0.76
E	0.77
F	0.78
G	0.78
H	0.78
I	0.78
J	0.78
K	0.79
L	0.79
M	0.79
N	0.81
O	0.81
P	0.82
Q	0.83
R	0.84
S	0.85
T	0.86
U	0.86
V	0.89

Player	*COD 2.5 (s)*
L	0.61
T	0.61
B	0.61
G	0.62
M	0.62
A	0.63
E	0.63
N	0.63
R	0.64
F	0.65
C	0.65
Q	0.65
K	0.66
H	0.66
I	0.66
V	0.66
S	0.67
J	0.67
D	0.68
O	0.69
U	0.69
P	0.69

Observations	*Recommendations*
Players D and J – Sprinting times indicate these players were able to accelerate quickly from a static start, however they were not as proficient accelerating following a rapid COD.	Players should focus on improving their ground-based COD technique: • Move COM into the new direction • Keeping arms and legs close to the body when turning • Large takeoff distance • First ground contact parallel to the sprinting direction
Players L, M, and T – Sprinting times indicate that these players were able to accelerate quickly out of a turn, however they were less proficient accelerating from a static start.	Players should focus on improving their first step quickness speed: • High step frequency combined with large step length • Increase forward lean (approximately 45˚) • Large takeoff distance • Intense arm and leg drive
Player S, U, and V – Players ranked in the bottom third of the squad for both sprinting tasks.	Players should focus on improving both their ground-based COD technique as well as their first step quickness speed. Training should incorporate accelerating from a static start as well as following a rapid COD.

Appendix 5. Technical report 3 – Preliminary change of direction assessment and initial findings

Overview

While agility is a difficult and complex concept to define, it can be broken down into three distinct qualities (technical, physical and perceptual) which need to be trained and tested in an environment that is as similar as possible to the actual sporting context. Netball players will possess strengths and weaknesses in different areas, but players need to be proficient in all of these areas in order to excel. Therefore, a battery of tests that is able to differentiate performance in each of these qualities is highly desirable. From the results of such an assessment, an appropriate technical, strength and conditioning and/or perceptual training program can be determined and implemented, increasing the potential for player improvement. Prior to developing an assessment battery, preliminary information was gathered through the use of a survey (see Technical Report 1) as well as through a preliminary change of direction movement assessment in order to better address those areas of agility in netball that are of highest importance and/or concern to coaches.

Aim: The aim of this report is to develop an understanding of three fundamental change of direction movements commonly performed by netball players throughout a game. From this preliminary information, a more comprehensive agility assessment battery will be developed.

Introduction

The concept of agility has been defined in many different ways, due to its complex nature. However, all definitions seem to be in agreement in that agility is comprised of a whole body, quick, accurate and repeatable response to a stimulus that involves at least one controlled change of direction or velocity [1, 2, 4, 48, 53]. It is clear from this definition that agility has technical (body positioning and control of movements), physical (power, reactive strength), and perceptual (response to a stimulus) components, all of which are inter-related. Young et al. (2002) proposed a deterministic model (see Figure H) centered on this multi-factorial approach to agility which indicated a variety of factors that contribute to an agility performance.

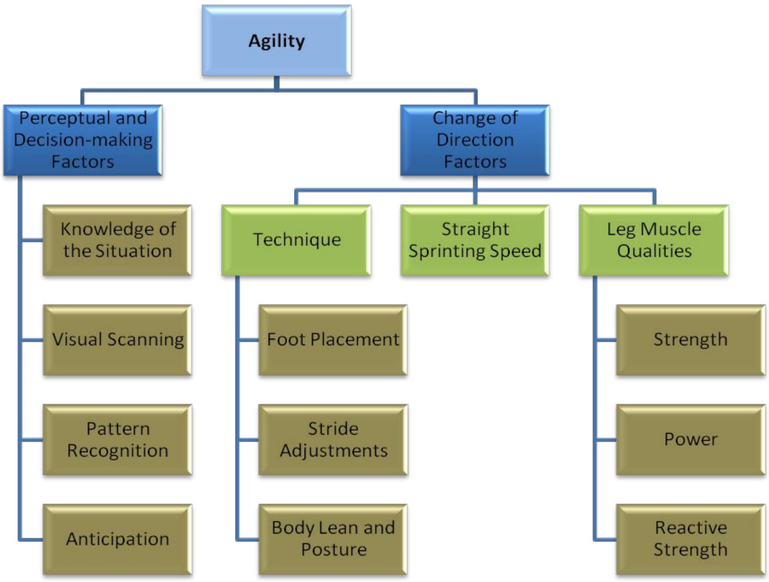

Figure H: Deterministic model of agility (adapted from Young, 2002).

The deterministic model illustrates decision-making and change of direction ability as the two main factors that distinguish a movement as being "agile". Within each of these main determinants are frameworks of technical, physical and perceptual characteristics that contribute to either movement proficiency or knowledge of the situation. Based on this model, it can be deduced that if one of these technical, physical or perceptual components are lacking, the overall agility performance could be compromised.

The preliminary objective of this research was to investigate whether faster movement times are a result of specific technical characteristics. A change of direction test, inclusive of three individual movement tasks, was used to examine the technical aspects of movement characteristics.

Methods

A total of 18 netball players (comprised of wing attack and goal defence positions) volunteered to participate in this study; seven from New Zealand's Trans-Tasman Franchise League (ANZ Championship Trophy) and a combined 11 from New Zealand's Premier League (Lois Muir Challenge) and National Provincial Championship League (NPC).

Prior to completing a self-selected netball warm-up, the age, height, body mass and leg length were recorded for each player. Once the testing procedures were explained, each player was allowed up to three practice trials per test in order to familiarize themselves with the movements.

Testing took place on a regulation indoor sprung wooden netball court. The testing set-up is illustrated in Figure I. Two dual beam timing gates (Swift Performance Technologies, NSW, Australia) were placed on the court five meters apart to collect movement times of the players. Two video cameras (MVX 200i, Canon Inc., USA) sampling at a rate of 25 Hz (50 fields/second) were positioned perpendicular to each other.

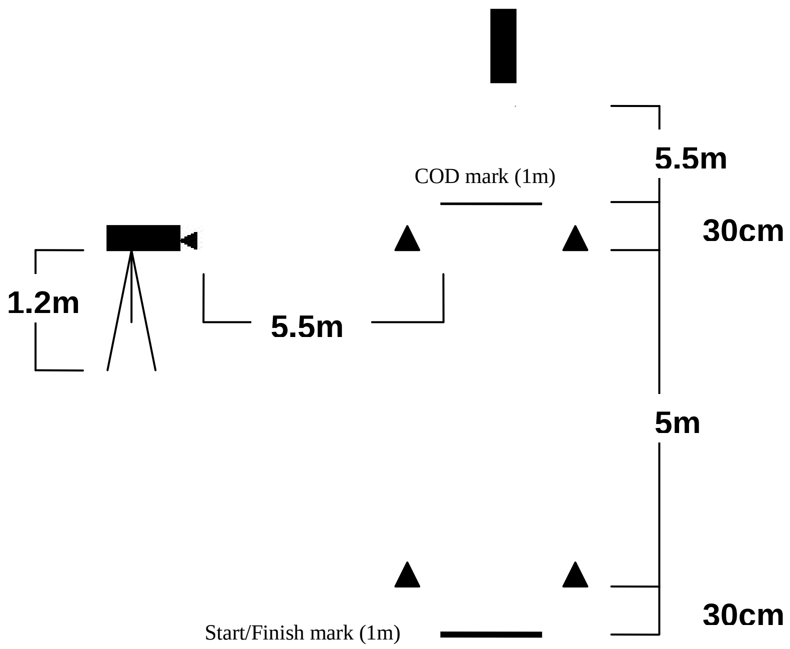

Figure I: Change of direction testing set-up.

Players completed three successful trials of three different change of direction (COD) tasks. Within each of the three tasks, was an additional modified version; therefore, 18 trials were recorded per player. A 60-second recovery period was allowed between trials. The order of the tests was randomized across players. A trial was considered successful if both feet crossed the COD line prior to initiating the turn. Three COD movements were selected based on survey responses concerning the technical aspects of agility that were of highest importance, as well as movements that netball players commonly use throughout a game.

Up and back (U&B)

The up and back (U&B) test (see Figure J) started with the player standing behind the start mark with feet parallel, facing forward. When ready, the player sprinted maximally towards the second timing gate. Once across the COD mark, the player completed a left turning COD as quickly as possible, followed by a maximal sprint back through the first gate. No instructional cues were given to the player other than to complete the task as quickly as possible. The modified version of the U&B test required the player to look behind them on the return sprint, as if to receive a pass. No other instructional cues were given.

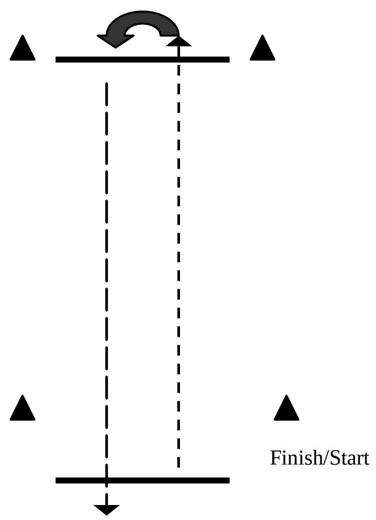

Figure J: Up and back test.

Backward facing 180˚ COD (COD-180)

The backward facing 180˚ COD (COD-180) test (see Figure K) started with the player standing behind the COD mark, feet parallel, with their back to the timing gates. When ready, the player completed a 180˚ turn to the left as fast as possible, followed by a maximal sprint through the far gate. No instructional cues were given to the player other than to complete the task as quickly as possible. The modified version required the player to perform an unspecified number of small amplitude bounces prior to the start. This was aimed at determining if the bouncing movement that netball players commonly use in their ready position is assisting in their performance.

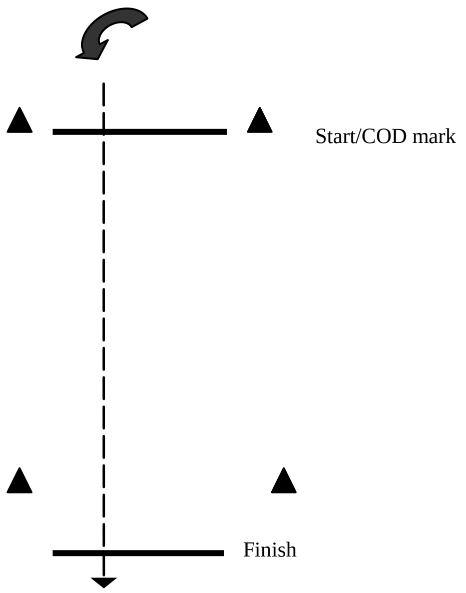

Figure K: COD-180 test.

Laterally facing 90˚ change of direction (COD-90)

The laterally facing 90˚ change of direction (COD-90) test (see Figure L) started with the player standing behind the COD mark, feet parallel, facing the sagittal plane camera. When ready, the player completed a 90˚ turn to the left as fast as possible, followed by a maximal sprint through the far gate. No instructional cues were given to the player other than to complete the task as quickly as possible. The modified version once again employed the use of the small amplitude bounces prior to the start.

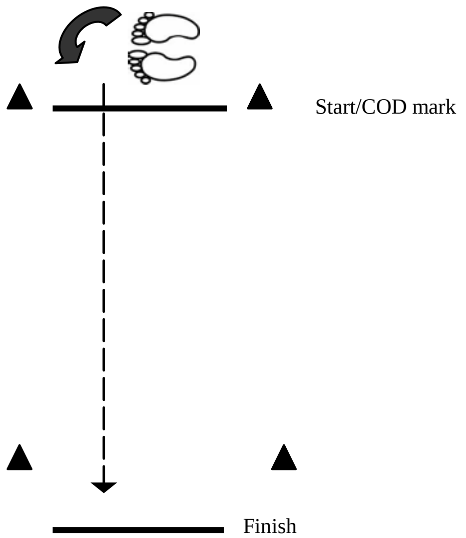

Figure L: COD-90 test.

Whether certain movement patterns, body positioning, limb positioning, etc. predicted superior performance in the chosen COD tests was analysed using Silicon Coach software. The dependent variable of interest was total movement time (TMt), designated as the time from when the player passed through the starting gate until passing through the finishing gate, as determined by the dual beam timing system. Independent variables included:

- The body segment that initiated the COD movement, i.e. shoulders, hips, knee, etc. (segMVMT)
- Strategy used to initiate and complete the change of direction
- Body segment angles throughout the takeoff and touchdown phases of the change of direction
- Change of direction time (s) (CODt) [time to the nearest hundredth of a second from when the plant foot strikes the ground, to the first (step) and second (stride) push off in the new direction]
- Step distance (m) from the plant foot to the first (step) and second (stride) foot strike in the new direction

Results

No one technique factor explained the differences in COD ability between tasks. Only mass and time taken to complete the COD movement task were significantly different over all three tasks (see Table H). The time from COD movement initiation through the first and second ground contacts in the new direction (COD-step and COD-stride, respectively) differed significantly for the 90° turn and sprint task only. The small amplitude bouncing prior to the COD significantly improved speed for the 90° task ($p < 0.001$), and neared significance for the 180° turn and sprint task ($p = 0.068$). High variability within players' technique occurred for all three tasks.

Table H: Qualitative and quantitative results (mean ±SD) for the three COD tests.

Variables	**90° Turn**	**180° Turn**	**Up and Back**
Fast group	1.140 s ±0.032*	1.183 s ±0.042*	3.171 s ±0.051*
Slow group	1.353 s ±0.133*	1.327 s ±0.051*	3.474 s ±0.091*
Significantly different independent variables	Mass CODt -step CODt-stride	Mass	Mass
Techniques employed for change of direction	Sidestep (R/L) Squat Pivot Leg Flexion	Jump-Twist Pivot	Crossover Sidestep Sidestep-Jump Pivot
Effect of bounce on movement time	Decreased movement time (5.2%, $p < 0.001$)	Decreased movement time (2.4%, $p = 0.068$)	Not assessed

*****p = < 0.001.

Practical implications

The techniques used to change direction rapidly during the COD tasks varied considerably across players. The ability to overcome the inertia (resistance to change) associated with one's mass seems to play a large role in the overall execution of the COD tasks. This needs to be kept in mind in terms of player selection if COD speed is desirable, or coaches and conditioners need to ensure that players are as lean as functionally possible. While a variety of movement strategies were employed by the players, a single superior COD technique was not able to be determined from this sample.

The small amplitude bounces commonly used by netball players in games while defending, contributed to a faster overall movement time. This bouncing technique utilizes the stretch-shortening cycle, resulting in a more highly explosive movement at the beginning of the COD task. While further research is needed to assess the effect of the small amplitude bounces on total movement time (reaction to a stimulus as well as movement), the results from this study indicate a probable performance enhancement when the bounces were incorporated.

Appendix 6. New Zealand Sports Medicine and Science Conference Abstract (2008)

ASSESSING CHANGE OF DIRECTION TECHNIQUES IN NETBALL

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Background: Agility is comprised of both perceptual-decision making and change of direction components. With regards to change of direction it has been proposed by Young et al., 2002 that this quality can be further divided into technical as well as leg strength components. Identifying strengths and weaknesses in each of these components and individualizing programmes to address player limitations is required to improve agility.

Aim: This study compared the kinematics and kinetics of three common netball tasks utilising change of direction, in an attempt to determine if specific technical characteristics result in superior change of direction performance.

Methods: Eighteen netball players (wing attack and goal defence positions) from the Trans-Tasman ANZ Championship (n = 7), and Lois Muir Challenge League (n = 11), volunteered to participate in this study. Each player performed three trials of three different randomly ordered change of direction (COD) tasks: a) 5 m up and back sprint; b) 90° turn and sprint, followed by a three trials using a bouncing start; and, c) 180° turn and sprint, followed by a three trials using a bouncing start. Two digital video cameras and dual beam timing lights were used to quantify the variables of interest: total movement time; body segment angles of the first two steps in the new direction; distance from the takeoff foot to the contralateral ground contact of the first and second steps in the new direction; and, vertical and horizontal displacements throughout the change of direction. Independent t-tests were used to determine any significant differences ($p < 0.05$) between the variables for each of the movements sorted into fast and slow groups.

Results: Only the COD movement time and mass, differed significantly for each COD task (see Table I). The time from COD initiation through the first (CODt-step) and second (CODt-stride) ground contacts in the new direction differed significantly for the 90˚ turn only. A variety of movement strategies were observed to initiate the COD as detailed in

Table I. The bouncing start significantly improved speed for the 90˚ turn ($p < 0.001$) and neared significance for the 180˚ turn ($p = 0.068$). Only two subjects were in the fast group for all three tasks.

Conclusions: No one technique factor could explain the differences in COD ability between tasks. Rather the inertia (mass) of the player seemed to have the greatest effect on movement time. There seems a great deal of variability in COD strategies between players which has interesting coaching implications. Small amplitude bouncing seems to improve movement time but more research is needed. Player COD ability appears to be movement specific.

Acknowledgements: Thanks are given to the netball players who participated in the study and to the ISRRNZ and Netball New Zealand who funded the PhD scholarship that is supporting the lead author.

References

Young, W., James, R., & Montgomery, I. (2002). Is muscle power related to running speed with changes of direction? *Journal of Sports Medicine and Physical Fitness*, *42*, 282-288.

Table I: Qualitative and quantitative results (mean ±SD) for the three COD tests.

Variables	90˚ Turn	180˚ Turn	Up and Back
Fast group	1.140 ±0.032 s*	1.183 ±0.042 s*	3.171 ±0.051 s*
Slow group	1.353 ±0.133s*	1.327 ±0.051 s*	3.474 ±0.091 s*
Significantly different independent variables	Mass, CODt -step, CODt-stride	Mass	Mass
Techniques employed for COD	Sidestep (R/L), Squat, Pivot, Leg Flexion	Jump-Twist, Pivot	Crossover, Sidestep, Sidestep-Jump, Pivot
Effect of bounce on movement time	Decreased movement time (5.2%, p < 0.001)	Decreased movement time (2.4%, p = 0.068)	Not Assessed

***p = < 0.001**

Appendix 7: Fact sheet 2 – 90˚ ground-based change of direction.

NETBALL NEW ZEALAND
Poitarawhiti Aotearoa

90˚ GROUND-BASED CHANGE OF DIRECTION

Rapid change of direction (COD) movements are commonly performed throughout netball games. However, a wide variety of strategies are often used by players to complete such complex movement tasks. The 90˚ ground-based COD technique can be considered as a sequence of phases – A) initial movement, B) turn, C) 1st foot takeoff and D) second foot takeoff (see Figure M). There are various key technical features within each phase that produce faster and more efficient COD performances. This fact sheet outlines critical features for the 90˚ ground-based COD task for New Zealand netball players.

Good technique for a 90˚ ground-based COD task

A. Initial movement: Rapid shallow squatting while moving the body weight, or centre of mass (COM) into the new direction enables a more powerful explosive force into the ground at takeoff.

B. Turn: Arms and legs are kept close to the body through the turn (small rotational inertia i.e. less resistance to turn). This allows for a faster rotation into the new direction. When the arms and legs are extended away from the body, the player will turn slower.

C. 1st foot takeoff: Moving the COM ahead of the takeoff (TO) foot will increase the player's horizontal force into the ground.

D. 2nd foot takeoff: A full extension of the takeoff leg will allow force to be applied over a longer period of time, increasing velocity. Intense driving action of the arms will stop the rotation of the body and assist in the straight line acceleration.

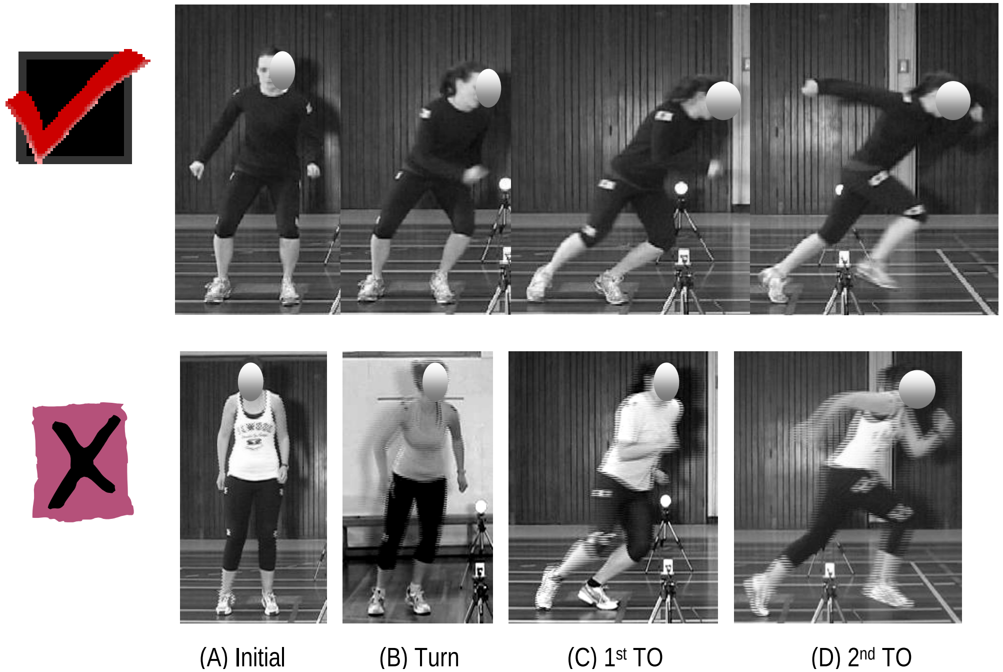


Figure M: Example of "superior" (top row) and "lesser skilled" (bottom row) individual features of a 90˚ ground-based COD task.

Interpreting netball players' 90˚ ground-based COD strategy for training

While some players may naturally perform this COD task with the features listed above, others may only include a few – or none at all. Therefore, Jennifer Hewit conducted a study to examine the extent to which these key technical features were employed by sub-elite netball players, and the effect it had on their individual COD performance. Elite netball players from the 2007 ANZ Championship league (n = 3), and local NPC players (n = 4) were asked to complete three trials of a 90˚ ground-based COD. Instructions were kept to a minimum in order to record each player's "natural" COD strategy. The results are shown in Table J. Additionally, practical applications have been provided for how training might be addressed based on the inclusion or absence of these features.

Table J: Extent of key technical feature employment for the 90° ground-based COD ("+" fully present, "OK" observed but not to the full extent, and "-"not present).

Phase	***Initial movement***		***Turn***	***1st foot takeoff***	***2nd foot takeoff***		***COD times***	
Player	***Lowering COM prior to the turn***	***Moving COM into new direction***	***Small rotational inertia***	***Large TO distance at 1st TO***	***Full knee and hip extension at 2nd TO***	***Intense driving arms***	***Average CODstep (s)***	***Average CODstride (s)***
A	+	+	+	+	+	+	0.46	0.84
B	OK	OK	OK	+	+	+	0.51	0.97
C	OK	-	OK	+	+	+	0.56	0.87
D	+	+	+	+	+	+	0.59	0.92
E	OK	+	OK	+	+	+	0.69	1.07
F	+	+	OK	-	+	+	0.79	1.13
G	-	+	-	-	+	+	0.80	1.07

Players are ranked according to their CODstep time which represents the time taken from movement initiation through the first ground contact in the new direction (e.g. turning velocity). CODstride represents the time taken from movement initiation through the second ground contact in the new direction (e.g. first step quickness).

Results interpretation and practical applications for training

Individual player performance times may not always accurately reflect the inclusion of the key technical features of interest as additional factors that contribute to an overall agility performance are not specifically analyzed in this table (e.g. physical components, flexibility, body size, etc.). However, several observations and recommendations can be made from this table:

Player A	Had the fastest CODstep time and had all the key technical features present.
Players D and E	The majority of scores were positive, but the players had a slower turning (CODstep) time → players must complete all critical features outlined in the table faster.
Player G	Had the slowest CODstep time → player must work on technique (e.g. lowering COM, reducing inertia, etc) to improve COD ability/COD time.
Player F	Had a small takeoff distance and slower COD times → player must focus on 1st step quickness out of a turn – reduce stride length and increase stride frequency.
Players B and C	Initial movement could benefit from technique training around lowering and moving the COM in the direction of travel.
Players B and C	The arms and legs were relatively wide through the turn → focus training on turning technique e.g. arms and legs close to axis of rotation (i.e. pivot foot).

For any questions and/or further information about ground-based COD tasks, please contact Jennifer Hewit: jkhewit@gmail.com.

Appendix 8: Fact sheet 3 - 180˚ ground-based change of direction.

NETBALL NEW ZEALAND
Poitarawhiti Aotearoa

180˚ GROUND-BASED CHANGE OF DIRECTION

Rapid change of direction (COD) movements are commonly performed throughout netball games. However, a wide variety of strategies are often used by players to complete such complex movement tasks. The 180˚ ground-based COD task can be considered as a sequence of phases – A) initial movement, B) turn, C) 1st foot takeoff and D) 1st ground contact (see Figure N). There are many similarities between the 180˚ ground-based COD task technique and the 90˚COD task technique. However, the additional 90 degrees that must be rotated prior to ground contact during the 180˚ task requires certain adjustments to be made, most notably during the initial and final phases. There are various critical features within each phase that produce faster and more effective COD performances. This fact sheet outlines key technical features for the 180˚ ground-based COD task for New Zealand netball players.

Good technique for a 180˚ ground-based COD task

Initial movement: A rapid shallow squat combined with moving the body weight/centre of mass (COM) backwards enables for a more powerful explosive force into the ground at takeoff.

Turn: Arms and legs are kept close to the body through the turn (small rotational inertia i.e. less resistance to turn). This allows for a faster rotation into the new direction. When the arms and legs are extended away from the body, the player will turn slower.

1st Foot takeoff: A full lateral extension of the takeoff (TO) leg will allow force to be applied over a longer period of time, increasing velocity. Additionally, moving the COM ahead of the TO foot will increase the player's velocity in the new direction.

1st ground contact: A ground contact that is near parallel to the intended direction allows for greater force to be applied into the ground resulting in increased force into the intended direction of travel. When the foot contacts the ground short of parallel, an additional step or pivot is required before straight line acceleration can be performed.

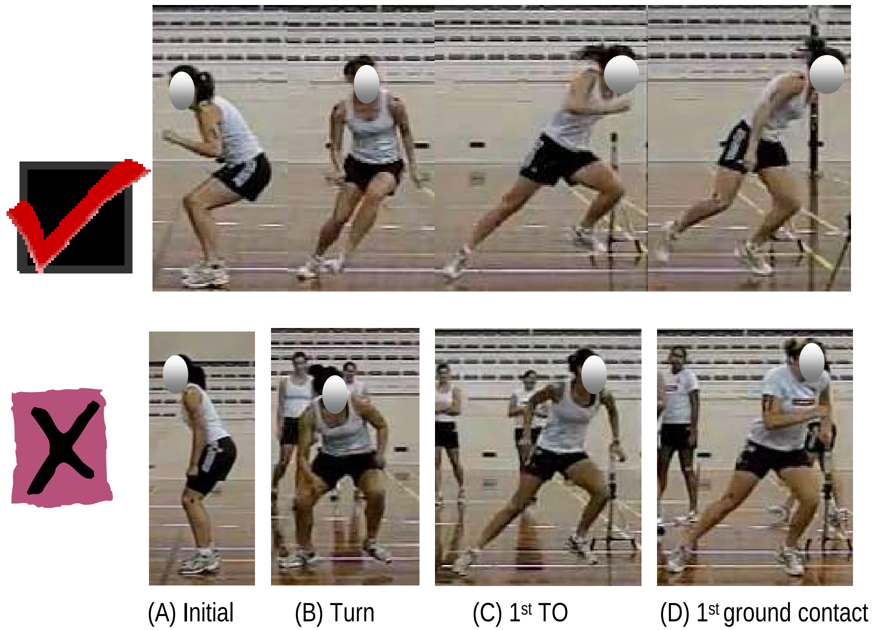


Figure N: Example of "superior" (top row) and "lesser skilled" (bottom row) individual features of a 180˚ ground-based COD task.

Interpreting netball players' 180˚ ground-based COD strategy for training

While some players may naturally perform this COD task with the features listed above, others may only include a few – or none at all. Therefore, Jennifer Hewit conducted a study to examine the extent to which these critical features were employed by sub-elite netball players, and the effect it had on their individual COD performance. Twenty-two netball players from NZ-U21 2009 training squad were asked to complete three trials of a 180˚ COD. Instructions were kept to a minimum in order to record each player's "natural" COD strategy. The results are shown in Table K. Additionally, practical applications have been provided for how training might be addressed based on the inclusion or absence of these features.

Table K: Extent of key technical feature employment for the 180° COD ("+" fully present, "OK" observed but not to the full extent, and "-"not present). Players are ranked according to their CODstep time, which represents the time taken from movement initiation through the first ground contact in the new direction (e.g. turning velocity).

	Initial movement	Turn	1st foot takeoff		1st ground contact	COD Time
Player	***Backward moving COM***	***Small rotational inertia***	***Full lateral extension at T.O.***	***Large T.O. distance***	***1st GC in intended direction***	***CODstep***
A	+	**OK**	+	+	-	0.49
B	+	**OK**	+	-	-	0.58
C	+	-	-	-	+	0.59
D	-	+	+	+	+	0.84
E	-	-	**OK**	+	+	0.86
F	+	+	+	+	**OK**	0.89
G	+	+	+	+	+	0.90
H	**OK**	+	+	+	+	0.90
I	+	-	**OK**	**OK**	-	0.91
J	+	+	+	+	**OK**	0.92
K	+	**OK**	+	+	+	0.93
L	+	**OK**	**OK**	**OK**	+	0.93
M	+	+	+	**OK**	**OK**	0.95
N	+	+	+	**OK**	-	0.97
O	-	+	+	**OK**	+	0.99
P	+	+	+	**OK**	**OK**	1.01
Q	+	+	+	+	+	1.01
R	+	+	+	+	+	1.05
S	**OK**	+	-	-	-	1.06
T	+	**OK**	**OK**	**OK**	+	1.14
U	+	**OK**	+	+	-	1.20
V	+	**OK**	**OK**	**OK**	**OK**	1.23

For any questions and/or further information about ground-based COD tasks, please contact Jennifer Hewit: jkhewit@gmail.com.

Results interpretation and practical applications for training

Individual player performance times may not always accurately reflect the inclusion of the key technical features of interest as additional factors that contribute to an overall agility performance are not specifically analyzed in this table (e.g. physical components, flexibility, body size, etc.) However, several observations and recommendations can be made from this table:

- *Players P, Q, and R* – the majority of scores were positive, but the players had slower turning (CODstep) time⟶ players must complete all critical features outlined in the table faster.
- *Player V* – had the slowest COD time⟶ player must work on technique e.g. decreasing rotational inertia, increasing TO distance and completing a full turn prior to ground contact) to improve COD ability/COD time.
- *Player S* – had a small TO distance, limited extension at TO, and is unable to full rotate before ground contact⟶ player must focus on increasing step length out of a turn or flexibility training.
- *Player C* – the arms and legs were relatively wide through the turn combined with a small TO distance ⟶ player must focus on turning technique (i.e. keeping the arms and legs close to the body) as well as 1st step quickness out of a turn.
- *Player E* – initial movements could benefit from technique training centred around moving the COM in the direction of travel while the arms and legs remain close to the body.

Appendix 9. Technical report 4 – Developing an aerial change of direction test for netball players.

Overview

Background: Agility has three distinct qualities (technical, physical and perceptual) which should be trained and tested in an environment that is as similar as possible to the actual sporting context. Netball players may possess strengths and weaknesses in each or all of these three different areas, but it would advantage players to be proficient in all of these areas in order to excel in agility performance. Therefore, a battery of tests that is able to differentiate performance in each of these qualities is highly desirable. From the results of such an assessment, an appropriate technical, strength and conditioning and/or perceptual training program can be implemented, increasing the potential for player improvement.

Aim: To develop an aerial change of direction assessment that is representative of the aerial manoeuvres commonly performed throughout a netball game.

Methods: Aerial agility testing data were collected during a single training session in November 2009 from five players in the LG Mystics Auckland-based training squad. The aerial change of direction (aCOD) task involved a run to catch a bungee suspended ball whilst completing a 180˚ aerial change of direction before landing. Initial video analyses were conducted and results are provided in this report (A complete analysis inclusive of additional ANZ Championship teams will follow).

Initial results: Initial results from the aCOD task have indicated that there are several critical features that should be employed to elicit a superior performance. Notably, it appears that a more aggressive rotation of the lower body while airborne (which is representative of the individual player's core strength) is needed to complete the desired 180˚ rotation prior to ground contact.

Initial practical implications for coaches: While the majority of movements throughout the approach and takeoff phases are both aggressive and fully employ the various critical features, the mid-air phase appears to be where less efficient performances deviate. The inclusion of a rapid rotation of the lower body through the flight phase may be most crucial to the success of the performance. It is important to note that the rotation seen in the flight phase is a result of the rotation developed at take-off. Therefore, based on this preliminary analysis, additional dynamic core strengthening combined with an emphasis on rapid upper and lower body rotation at take-off when performing aCOD manoeuvres may improve player aerial performance.

Introduction

Agility has been defined in many different ways, however, it is clear from the definitions that there are technical (body positioning and control of movements), physical (power, reactive strength), and perceptual (response to a stimulus) components, all of which are inter-related [1, 2, 4, 48, 53]. The deterministic model of agility proposed by Young et al. (2002) (see Figure O) is centered on a multi-factorial approach which indicates a variety of measures that contribute to agility performance. As illustrated in this model, the ability to perceive and accurately react physically to a stimulus are the two main factors that distinguish a movement as being "agile". Based on this model, it can be deduced that if one of these technical, physical or perceptual components are lacking, the overall agility performance could be compromised.

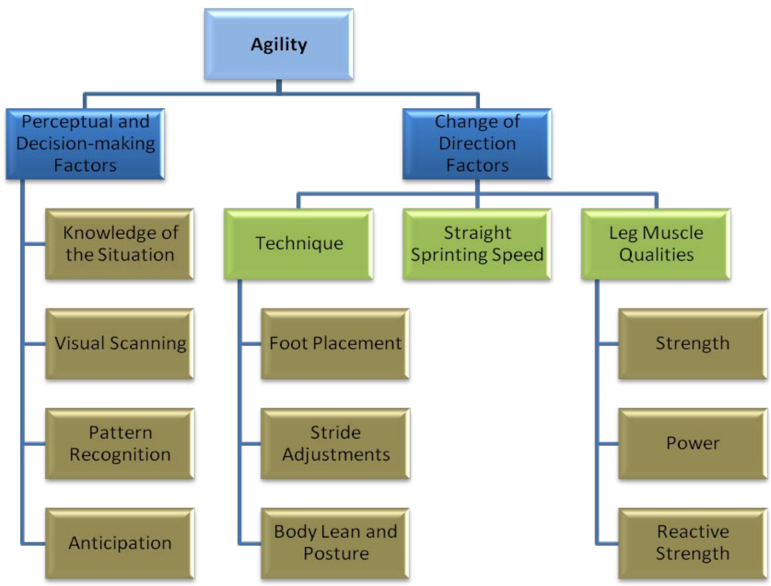


Figure O: Deterministic model of agility (adapted from Young et al., 2002).

The preliminary objectives of the current research were focused within the technical component of agility. Previously, the strategies employed by netball players when performing a ground-based change of direction (gbCOD) task were analysed in an attempt to determine those critical features that contribute to the superior gbCOD performances [55]. In the sport of netball, however, many agile movements are performed while airborne. Therefore, the current research presented in this report is reflective of the strategies employed by various netball playing positions while completing a 180˚ aerial change of direction (aCOD) task.

Objectives

The main objectives of this study were:

3. Determine the aCOD specifications for the various positions, as commonly performed by this sample of players (e.g. ball height, approach length, approach direction.
4. Determine the technical movement strategies that are being implemented, as well as determine the movement strategies that are a result of superior (e.g. safer, more powerful, more accurate, etc.) performances.

Methods

Participants

A total of five netball players from the 2010 ANZ Championship Auckland-based LG Mystics training squad participated in this study. Written informed consent was obtained from each participant prior to data collection.

The aerial change of direction task

As one of the goals of this testing session was to refine the aCOD test and to determine the specifications that are most similar to that of a game situation, following an explanation of the testing procedures, each player was asked to perform trials of the task until they felt comfortable with the set-up (e.g. approach distance, ball height, etc.).

The aerial change of direction (aCOD) task involved both running from 2-3 m and from a static start to catch a bungee suspended ball at either head or extended hand height whilst completing a 180˚ aerial change of direction before landing. The player began in a track start at a distance away from the ball that she felt was adequate for the necessary approach length. When ready, the player began her approach, driving upward with the non-weight baring leg at takeoff to grab the elevated ball. The player attempted to complete a 180° turn in the air to either the left or right (to face down court) before landing bilaterally to afford increased directional options for the subsequent pass.

Testing set-up

Testing took place on an indoor netball court throughout the players' standardised strength and conditioning session. Testing equipment included a regulation game sized netball elevated from a basketball rim via a bungee cord (see Figure P), and high speed video camera (EX F1, Casio Computer Co., Ltd, Japan) sampling at a rate of 300 Hz to record the movement strategies of the players while performing the aCOD manoeuvre. The testing set-up is illustrated in Figure Q.

Figure P: Netball elevated by bungee cord.

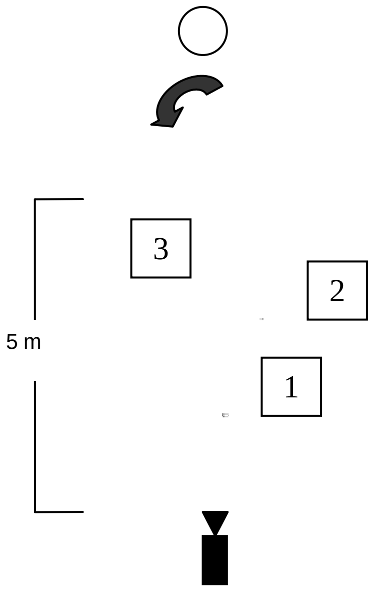


Figure Q: Testing set-up for the aerial change of direction test.

Testing procedures

Upon arrival to the testing session, the age (years), height with shoes (m), body mass with shoes (kg), leg length measured with shoes from the greater trochanter to the floor (m), and leg dominance determined by which leg the player used to regain balance after an unexpected slight perturbation applied while standing, were recorded for each player. Each player was already warmed up as the testing session took place concurrently with the strength and conditioning session. A task familiarization period consisting of at least three trials was given to each player prior to data collection in order to determine the most game-specific approach distance and ball height. Prior to each familiarisation trial, the ball height was adjusted based on player feedback. Players completed a total of six successful trials (three turning to the right and three to the left). Adequate recovery time was allowed between each trial (approximately 30-seconds).

On average, each player performed approximately 5-10 trials prior to data collection. High speed video data of three trials per turning direction (left and right) was then collected for each player.

Results

Player characteristics

The players had an average age of 25.8 ±6.1 years, standing height of 1.81 ±0.09 m, body mass of 79.7 ±9.8 kg, and leg length of 0.94 ±0.05 m. All players were right-leg dominant with primary playing positions including one each of Centre, Wing Attack and Goal Defence, and two Goal Attacks.

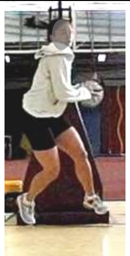
The aerial change of direction task

Individual player and position preferences for the approach angle, distance, and height of the ball varied a great deal. Based on high speed video, Table L shows the extent that each player employed each respective critical feature as taken from their best individual performance. The best performance was selected based on the player’s landing, i.e. the trial nearest to a full 180˚ turn and/or a bilateral landing, as these two features would decrease the potential for injury.

Table L: Extent of critical feature employment for the 180° COD ("+" fully present, "OK" observed but not to the extent described, and "-"not present) (n.b. only one twisting strategy is needed - contact twist or cat-twist).

	Approach			*Takeoff*			*Mid-air*					*Landing*		
Player	**Player performance**	**Knee flexion**	**Intense arm drive**	**Player performance**	**Hip rotation (contact-twist)**	**Knee drive**	**Player performance**	**Head turn**	**Segmental rotation (cat-twist)**	**Ball at chest**	**Lower body rotation**	**Player performance**	**Bilateral, parallel landing**	**Full turn**
A		–	–		**OK**	**OK**		**OK**	–	**OK**	–		–	–
B		+	+		+	+		+	–	**OK**	–		+	–

(Table L continued)

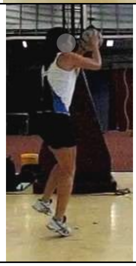
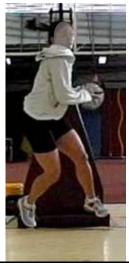
	Approach			*Takeoff*			*Mid-Air*					*Landing*		
Player	**Player performance**	**Knee flexion**	**Intense arm drive**	**Player performance**	**Hip rotation (contact-twist)**	**Knee drive**	**Player performance**	**Head turn**	**Segmental rotation (cat-twist)**	**Ball at chest**	**Lower body rotation**	**Player performance**	**Bilateral, parallel landing**	**Full turn**
C		+	**OK**		**OK**	+		–	–	+	–		–	–
D		+	+		+	+		+	–	+	–		–	–
E		+	+		+	+		+	+	**OK**	+		+	+

There are two main strategies commonly employed by various athletes (e.g. gymnasts, divers, etc.) when performing aerial twists. The first (contact twist) initiates the twist prior to leaving the ground through rotation at the hips as well as the upper body [58]. The second technique (cat-twist) initiates the twist while airborne through a piking or arching motion at the hips [58, 65]. This allows the body to rotate segmentally as opposed to as a whole in the contact twist strategy. The strategy most appropriate for netball players may be more dependent upon the physical characteristics (leg strength and power, core strength, etc.) that each individual player possesses.

In the present sample, only one player was able to successfully complete a full 180˚ turn prior to landing. Regardless of which twist strategy was employed, it appears that a more aggressive rotation of the lower body is needed to complete the rotation prior to landing. The players that were unable to complete the full rotation were also commonly observed to have a unilateral landing, increasing the impact force upon landing and therefore, the potential for lower limb injury.

Initial results from the aCOD task have indicated that there are several key technical features that should be employed to elicit a superior performance. These technical features, their biomechanical and/or netball specific rationale as well as a still photo representing a superior and less effective performance have been displayed in Table M.

Table M: Key technical features of the 180˚ aCOD movement task (n.b. only one twisting strategy is needed – contact twist or cat-twist).

Phase	Player performance		Key technical feature	Biomechanical rationale
	Superior	*Less effective*		
Approach			1.Deep knee flexion	Rapid squatting motion enables explosive force and power application – for every action there is an equal and opposite reaction.
			2.Arm drive close to body	Increased linear momentum at takeoff resulting in greater vertical jump height
Takeoff			3.Hip rotation prior to takeoff (contact twist)	Effective transfer of angular momentum through takeoff
			4.Intense knee drive	Increased takeoff velocity resulting in greater vertical jump height
Mid-air			5.Rapid head turn	Visualisation of options and opposition
			6.Rapid segmental rotation (cat-twist)	Counter-rotation of upper and lower body allows player to grab ball while initiating turn early on with increased stability
			7.Ball positioned at chest	Protection of ball and preparation for pass
			8.Rapid lower body rotation	Legs rotated around for full turn prior to ground contact, allowing for decreased toque on the lower limbs at landing

(Table M continued)

(Table M continued)

Phase	Player performance		Key technical feature	Biomechanical rationale
	Superior	*Less effective*		
Landing			9.Bilateral, parallel landing	Decreased torque on knees upon impact, able to step with either foot following touchdown
			10.Full turn	Preparation for multiple options upon landing (e.g. various passes or step directions)

Discussion

For standardisation purposes separate testing protocols are being developed for both the end-court and mid-court/attacking players based on the feedback obtained from the players and coach throughout the initial testing session as well as a second testing session with additional players. The initial suggested testing protocols are (see Table R):

A)Approach and takeoff: The mid-court/attacking players' movements onto the ball are predominantly horizontal in nature when compared to the more vertical requirements of the end-court players. Therefore, the mid-court/attacking players will perform a longer approach (greater step length for each stride) prior to their single-leg takeoff from a mark positioned at approximately 50% of their standing height. In contrast, the end-court players will be required to perform a single-leg takeoff from a mark positioned approximately 15% of their standing height.

B)Ball height: In order to more accurately replicate the ball positioning from a pass, the height of the ball will also vary according to player position. A ball placed at face-height will be used for the predominantly horizontal mid-court/attacking players, while a ball elevated to the fingertips of the extended arms will be used for the end-court players.

C)Performance indicator: A measure of the individual player performances is needed to determine where each player falls within the squad as well as within the larger population of interest. As flight time and change of direction time will vary depending on the height jumped, the nature of the landing will be used as the indicator of superior (bilateral and parallel) and lesser skilled performances.

Table R: Summary of aCOD testing protocols.

	Mid-court/attacking	**End-court**
Approach length (% of standing height)	50%	15%
Ball height	Face	Fingertips of extended arms
Landing	Bilateral and parallel	

Practical implications

While the findings in this report are based on initial data analyses, some interesting observations have been made. It appears that the majority of movements throughout the approach and takeoff phases are both aggressive and fully employ the various critical features that are thought to substantially contribute to an overall superior aCOD performance. It is, however, during the take-off and the subsequent mid-air phase where the performance begins to weaken. The rapid rotation of the lower body through either the takeoff or flight phase is the precursor for a complete 180˚ turn, bilateral and balanced landing [58, 65]. It appears that this portion of the movement task (ultimately reliant upon the individual player's strength and power capabilities) may be most crucial to the success of the performance. Therefore, based on these preliminary analyses, additional dynamic core strengthening combined with an emphasis on rapid upper and lower body rotation when performing aCOD manoeuvres will improve player aerial performance. Additional data collection and analyses will further develop our understanding of the underlying mechanisms that create agile aerial performances.

Acknowledgements

Special thanks are given to the LG Mystics coaching team and players for their hard work, cooperation, patience and assistance during the development and data collection for the protocols.

Appendix 10. **Sports Performance Institute New Zealand Conference Abstract (2010)**

DEVELOPING A NETBALL SPECIFIC AERIAL CHANGE OF DIRECTION ASSESSMENT TASK

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Background: Changes of direction in sport are not limited to ground-based movements, but often occur while airborne. Surprisingly, aerial change of direction (aCOD) technique has received little research attention. The identification of player technical strengths and weaknesses when performing a netball specific aCOD maneuver will provide coaches and strength and conditioners with valuable information to improved programme design and player performance.

Aim: To analyse the aCOD strategies of netball players to determine key technical features that are consistently present in superior performances, but absent in lesser skilled performances.

Methods: Five elite level netball players (NZ 2010 ANZ Championship Netball League), and 43 sub-elite level netball players (n = 22 NZ 2009 National Under-21 netball training squad, n = 11 NZ 2010 National Under-17 netball training squad, and n = 10 2010 regional netball players) participated. Players performed three trials of a 180º aCOD task requiring them to jump up and grab a detachable netball (elevated at fingertip height for each player) and complete a 180º turn prior to landing. A high speed video camera recorded the aCOD task. Performances were rated from frame by frame analysis of the video as either 'superior' (the player successfully completed a full 180º turn prior to a bilateral landing), 'average' (if only one of either the full turn or bilateral landing was completed), or 'below average' (both the full turn and bilateral landing were not completed).

Results: A total of nine key technical features were consistently observed during superior performances, but lacking in below average performances: (1) deep knee flexion through the final ground contact in the approach; (2) rotating about the takeoff leg prior to leaving the ground; (3) driving both arms up towards the ball, no more than shoulder width apart; (4) driving the free leg up towards the ball at takeoff; (5) following possession of the ball, rapidly rotating the head into the new direction; (6) holding the ball close to the body at chest height in preparation for a quick release pass; (7) rapid rotation of the lower body throughout the airborne phase to elicit a full 180˚ turn; (8) full 180º turn completed prior to ground contact; and (9) bilateral landing (both feet contacting the ground simultaneously).

Practical Applications: Nine key technical features provide coaches and strength and conditioning professionals insight into the fundamental characteristics that appear to be consistently associated with the successful performance of a 180˚ aCOD task.

Acknowledgements: Thanks are given to the netball players who participated in the study and to SPRINZ and Netball New Zealand who funded the PhD scholarship supporting the lead author.

Appendix 11: Fact Sheet 4 – 180˚ aerial change of direction

NETBALL NEW ZEALAND
Poitarawhiti Aotearoa

180˚ AERIAL CHANGE OF DIRECTION

Rapid change of direction (COD) movements are commonly performed throughout netball games while airborne. However, little is known as to which COD techniques result in the most effective aerial COD (aCOD) movements as it is such a complex movement task. The 180˚ aCOD task can be considered as a sequence of phases – A) approach, B) takeoff, C) airborne, and D) landing (see Figure R). There are various key technical features within each phase that produce faster, more effective and potentially safer aCOD performances. While some players may naturally perform the aCOD task with the key technical features, others may only include a few – or none at all. A study was conducted for Netball New Zealand to examine the extent to which the key technical features were employed by sub-elite netball players, and the effect of technique on their individual aCOD performance. Twenty-two netball players from NZ-U21 2009 training squad completed three trials of a 180˚ aCOD. Instructions were kept to a minimum in order to record each player's "natural" COD strategy. This fact sheet outlines key technical features for the 180˚ aCOD task for New Zealand netball players.

Key technical features for a 180˚ aerial change of direction (aCOD) task

Approach: Shallow squat on the weight-bearing leg during the approach allows a more powerful force into the ground to be applied prior to takeoff. Initiating rotation with the weight-bearing leg allows the body to begin the 180˚ turn prior to leaving the ground [58].

Takeoff: Driving the arms (within shoulder distance) and free leg upwards as the weight-bearing leg (takeoff leg) extends rapidly assists in moving the centre of mass vertically at takeoff [28].

Airborne: The head turns rapidly into the new direction immediately following ball possession allowing for early visual scanning and identification of possible passing options. The ball is positioned close to the body at lower chest height to increase speed of body rotation and in preparation for a rapid pass release. The lower body is rotated into the new direction in preparation for landing.

Landing: Both feet contact the ground simultaneously with a bilateral (2-footed) landing and feet facing 180˚ compared to the takeoff position. When a full 180˚ turn is not completed prior to landing, or a single leg contacts the ground first a greater turning force (torque) must be absorbed upon landing, increasing the potential for injury in the landing leg.

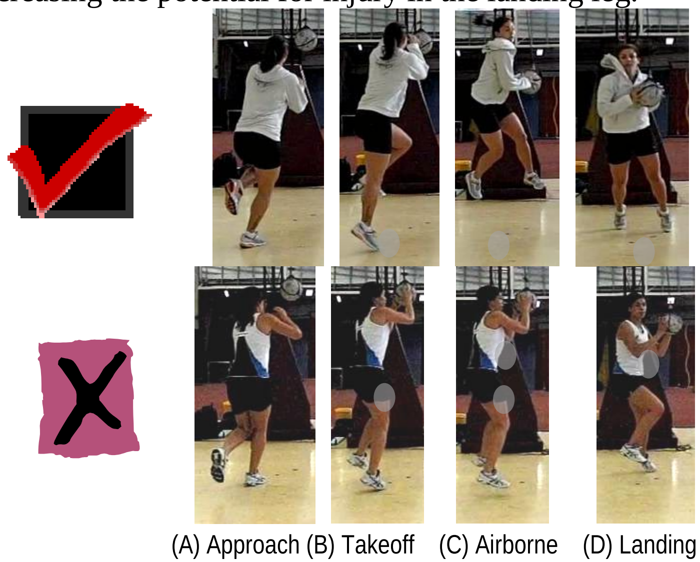

Figure R: Example of "superior" (top row) and "lesser skilled" (bottom row) 180˚ aCOD task.

Interpreting netball players' 180˚ aCOD strategy for training

Table O shows the extent that each key technical feature is employed for the 180˚ aCOD task, where "+" represents the feature being fully present, "OK" represents the feature being observed but not to the full extent described above, and "-"represents the lack of the feature in the performance. Players have also been ranked according to the effectiveness of their landing, where: "Superior" represents a bilateral landing combined with a full 180˚ turn completed prior to ground contact, "Average" represents either a bilateral landing or 180˚ turn completed prior to ground contact, and "Below Average" represents a unilateral landing and less than 180˚ turn completed prior to ground contact). Practical recommendations are provided in Table P for those players needing technical assistance.

Table O: Analysis of the key technical features for the 180˚ aCOD task for each player.

	Approach		**Takeoff**		**Airborne**			**Landing**		
Player	***Deep knee flexion***	***Rotation prior to takeoff***	***Arm drive within shoulders***	***Free leg knee drive***	***Rapid head turn***	***Ball close to body at chest height***	***Aggressive lower body rotation***	***Bilateral, parallel landing***	***Full 180˚ turn completed***	*Category*
A	+	+	OK	+	+	+	+	+	+	Superior
B	+	+	OK	OK	-	OK	+	+	+	
C	OK	OK	+	-	+	-	-	+	+	
D	+	+	+	+	+	-	+	+	-	Average
E	OK	OK	+	+	+	+	OK	+	-	
F	+	+	+	OK	+	OK	OK	+	-	
G	+	+	+	OK	+	OK	-	+	-	
H	+	+	OK	-	-	OK	+	+	-	
I	OK	+	+	OK	-	-	-	+	-	
J	-	-	+	-	-	OK	-	+	-	
K	+	+	+	+	-	+	+	-	-	Below average
L	+	+	+	OK	+	+	-	-	-	
M	+	+	+	+	+	-	-	-	-	
N	+	+	+	+	+	-	-	-	-	
O	+	+	+	OK	-	OK	-	-	-	
P	+	+	+	OK	-	-	-	-	-	
Q	OK	+	+	OK	-	-	-	-	-	
R	OK	OK	+	OK	OK	-	-	-	-	
S	OK	+	OK	-	-	-	-	-	-	
T	-	-	+	-	-	OK	-	-	-	
U	-	-	OK	-	OK	OK	-	-	-	
V	-	-	+	-	-	-	-	-	-	

Table P: Practical recommendations for players needing technical assistance in the 180˚ aCOD task.

Observations	***Recommendations***
Players E, F and G – The majority of scores were positive, with the exception of a moderate rotation of the lower body while airborne.	Players should focus on being more aggressive when rotating the lower body prior to ground contact: • Rapid head turn • Aggressive lower body rotation while airborne
Player U – Lacked all 9 key technical features of the aCOD task.	Players should focus on improving aerial technique in general: • Initiating rotation prior to takeoff • Aggressive extension of the weight-bearing leg at takeoff • Driving the free leg upwards at takeoff • Rapid head turn while airborne • Lower body rotation while airborne
Player J, R, T and V – Were unable to rotate the full 180˚ prior to ground contact due to limited lower body involvement throughout the movement task.	Players must focus on improving lower body technique throughout the entire movement task: • Initiating rotation prior to takeoff • Aggressive extension of the weight-bearing leg at takeoff • Driving the free leg upwards at takeoff • Aggressive lower body rotation while airborne

For any questions and/or further information about ground-based COD tasks, please contact Jennifer Hewit: jkhewit@gmail.com.

Appendix 12. Technical Report 5 – Assessing leg power capabilities in netball players

Overview

Background: Agility has three distinct qualities (technical, physical and perceptual-decision making) which should be trained and tested in an environment that is as similar as possible to the actual sporting context. Netball players may possess strengths and weaknesses in each or all of these three different qualities, but it would advantage players to be proficient in all of these areas in order to excel in agility performance. Therefore, a battery of tests that is able to differentiate performance in each of these qualities is highly desirable. From the results of such an assessment, an appropriate technical, strength and conditioning and/or perceptual-decision making training program can be implemented, increasing the potential for player improvement.

Aim: To gain a better understanding of the individual player technical and physical strengths and weaknesses when performing movement tasks thought important to netball.

Methods: A total of 22 New Zealand national under 21 netball squad members participated in this study. Each player performed three successful trials of each of the following tests: 1) single-leg countermovement jumps, 2) 5 m straight sprint, 3) 180˚ ground-based change of direction. Where a single leg was tested (i.e. single- leg countermovement jumps and 180˚ COD task) three trials were performed on each leg for unilateral comparisons.

Results: 1) Players with high percent differences between legs (greater than 10%) when performing single-leg countermovement jumps in various directions may have a greater potential for injury, 2) leg power appears to be directionally specific, 3) straight sprinting performance is not necessarily indicative of sprinting performance following a rapid change of direction, 4) there appears to be various characteristics associated with superior (i.e. faster) change of direction performances.

Practical implications: Jump specific training in the specific direction of weakness should be incorporated for players with large asymmetry magnitudes. Players ranking below average in ground-based change of direction technique (i.e. critical features) and sprinting speed following a rapid change of direction may benefit from additional change of direction technique training. Those players ranking below average in the straight sprint may benefit from first step quickness training.

NZ-U21 Leg asymmetry index

The purpose of this sheet is to highlight any asymmetries/imbalances between legs following explosive jumping and COD tasks. It is thought that the greater the difference between legs, the more likely the incidence of injury, with many clinicians using a 10% threshold. Player data (see Table Q) has been presented to show:

1. The spread of imbalances between legs
2. The lowest, average, and highest imbalances between legs (ASI-Average Symmetry Index) for players by rank
3. Those players scoring below average in each test

Training information that can be gained from this table is:

1. Players that might benefit from training that addresses directional specific imbalances
2. Players that might may be at a higher risk of injury due to greater leg imbalances

Note: *The shaded region indicates those players that fall below the squad average (ASI of 4.5% ±1.5). The players highlighted in red have a leg imbalance of greater than 10% in one of the direction-based tests. The player highlighted in blue has no percent difference greater than 10%, however, she does have a higher ASI with similar percent differences across various activities.*

Table Q: Individual player leg imbalances and asymmetries.

SUBJ	% DIFF (Legs)	% DIFF (H)	% DIFF (L)	ASI (%)
A	1.4	0.0	2.8	1.4
B	4.3	0.3	0.3	1.6
C	3.1	1.6	1.2	2.0
D	0.0	5.0	2.5	2.5
E	1.5	3.6	4.2	3.1
F	0.0	2.4	7.5	3.3
G	1.5	1.9	6.6	3.3
H	1.7	5.4	3.4	3.5
I	4.5	5.3	1.6	3.8
J	3.1	6.1	3.0	4.0
K	6.3	3.9	2.1	4.1
L	1.6	9.7	3.1	4.8
M	1.7	5.4	7.9	5.0
N	3.2	0.0	13.2	5.5
O	1.6	5.1	9.8	5.5
P	10.3	6.6	0.3	5.7
Q	6.0	3.6	7.7	5.8
R	6.2	5.6	5.8	5.9
S	1.6	6.4	10.9	6.3
T	4.7	10.8	4.5	6.6
U	1.6	0.4	20.4	7.5
V	4.4	10.3	8.6	**7.8**

Observations:

It is interesting to note how the ASI is comprised in the bottom third of players: 1) players with high ASI's that are made up primarily of one direction (e.g. player U); 2) players with high ASI's that are comprised of relatively equal percent differences in each direction (e.g. player R); and, 3) players with a high ASI's that have a percent difference of or near 10% in more than one direction in a couple of tasks (e.g. player V). The practical significance of these findings is unclear but addressing imbalances in those players with large deficits intuitively seems good practice. It may be worth documenting injury rates and matching to ASI over the course of the year.

NZ-U21 Direction-based jump distances

The purpose of this sheet is to highlight the strengths and weaknesses regarding player multi-directional single-leg power/jumping capabilities. Player data (Table R) has been presented to show:

1.The spread of jump distances

2.The longest, average and shortest jump distances of players by rank order

3.Those players scoring below average in each test

Training information that can be gained from these tables are:

1.Players that might benefit from horizontal power training

2.Players that might benefit from lateral power training

Note: *The shaded region indicates those players that fall below the squad average (HJ = 151.48 cm ±17.64 and LJ = 149.57 cm ±10.83). The players highlighted in red rank below average in the horizontal jump distance test, but above average in the lateral jump distance test. While the players highlighted in blue performed relatively average in the lateral jump distance test, the performed above average in the horizontal jump distance test.*

Table R: Individual players' average (AVE) horizontal (H) and lateral (L) jumping distances.

SUBJ	H Ave
K	188.75
S	173.75
V	170.25
T	167.00
B	164.75
D	162.13
A	159.50
I	156.75
L	156.50
G	155.00
C	154.75
P	154.25
M	153.25
Q	148.75
F	145.25
O	143.75
H	143.00
E	138.25
N	135.50
J	128.00
U	121.25
R	112.25

SUBJ	L Ave
K	167.50
C	165.50
M	159.00
H	157.75
D	157.50
A	157.25
V	156.00
I	154.75
F	154.50
P	153.75
L	153.13
G	152.75
T	152.50
S	151.50
B	147.75
Q	144.25
N	137.75
R	134.50
E	134.38
J	133.50
O	133.13
U	132.00

<u>Observations:</u>

It was interesting to note that just because you have good leg power in one direction does not necessarily translate to having good leg power in other directions in many cases e.g. players M, H, etc. Leg power would seem to be directionally specific and needs to be trained accordingly. Obviously those players in the bottom half and particularly bottom third would benefit from jump specific training in the specific direction of weakness.

NZ-U21 2.5 m sprinting and change of direction times

The purpose of this sheet is to highlight the strengths and weaknesses regarding player straight sprinting speed (SSS) and change of direction (COD) abilities. Player data (Table S) has been presented to show:

1. The spread of times
2. The fastest, average, and slowest players by rank order

3.Those players scoring below average in each test

Training information that can be gained from these tables are:

1.Players that might benefit from COD technique training

2.Players that might benefit from speed/first step quickness training

Note: *The shaded region indicates those players that fall below the squad average (0.65 s ±0.03 and 0.84 s ±0.04, respectively) for each test. The players highlighted in red rank in below average in the COD test, but above average in the SSS test. The players highlighted in blue rank below average in the SSS test, but above average in the COD test.*

Table S: Individual players' average (ave) performance times for a 2.5 m sprint following a 180˚ change of direction and a 2.5 m straight sprint.

SUBJ	gbCOD AVE
H	0.61
M	0.61
K	0.61
L	0.62
U	0.62
T	0.63
O	0.63
N	0.63
S	0.64
E	0.65
P	0.65
F	0.65
I	0.66
D	0.66
C	0.66
J	0.66
V	0.67
R	0.67
G	0.68
A	0.69
B	0.69
Q	0.69

SUBJ	2.5 SSS
T	0.72
K	0.74
G	0.76
P	0.76
O	0.77
D	0.78
L	0.78
E	0.78
C	0.78
R	0.78
H	0.79
I	0.79
U	0.79
A	0.81
N	0.81
Q	0.82
F	0.83
S	0.84
V	0.85
B	0.86
M	0.86
J	0.89

Observations:

Those players in red have performed above average in the straight sprinting test, however, when a 180° COD was performed immediately before the straight sprint, their squad ranking fell below average, indicating that the COD techniques/strategies may be sub-optimal. Therefore, these players may benefit from additional COD technique training (e.g. player G).

On the other hand, those players in blue, though relatively slow in the straight sprint, have performed above average when performing a 180° COD prior to a straight sprint. This indicates that these players may benefit from training that is focused on first step quickness and straight line speed from a static start (e.g. player M).

NZ-U21 Ground-based change of direction strategies

The purpose of this sheet is to highlight the features within the faster change of direction (COD) performances that are thought to be important, or key, to superior COD performance (i.e. faster COD time and more energy efficient). Player data has been presented to show:

1. The spread of COD times from movement initiation through the first (CODstep) and second (CODstride) ground contacts in the new direction
2. The fastest, average, and slowest COD performances (based on CODstep time) by rank order
3. The employment of each key technical feature for each player (where "+" represents the feature being fully present, "OK" represents the feature being present but not fully employed, and "–" represents a lack of the feature being present in the performance)

Training information that can be gained from these tables are:

1. Players that might benefit from COD technique training
2. Players that might benefit from first step quickness training following a rapid COD

Key technical features:

Note: The key technical features are listed in the centre of the table with the biomechanical rationale as to why this feature would improve a COD performance to the right (see Table T). To help you better visualise the feature being explained, still photos from the actual performances are shown to the right of each key technical feature, with the more efficient/faster performance on the far left.

Observations:

All of the players used a sidestepping technique to execute the 180° COD while turning to the left as well as to the right. This strategy was preceded by aligning the body to an angle near perpendicular to the sprint (through a single or double leg pivot, or a small turning jump). Once near perpendicular, the leading leg (the leg nearest to the sprinting direction) opened up at the hip, completing the rotation into the new direction. The trail leg (the leg used to push-off) was extended at the hip, knee and ankle while remaining perpendicular to the new direction through take-off. It is important to note, that an intense driving action of the arms through the COD also appears to contribute to a superior COD performance, however, the driving action must be performed in line with the body as opposed to lifting the arms away from the sides as some players exhibited.

Table T: Key technical features for a 180˚ ground-based change of direction task.

Examples: "Above Average" vs. "Below Average" key technical features		***Key technical feature***	***Biomechanical rationale***
		Deep squat (i.e. sinking centre of mass (COM))	Applying force into the ground
		Backward-moving COM	Applying force in the direction of travel (i.e. getting the COM mass moving in that direction)
		Arms and legs close to the body when turning	Less rotational inertia (the resistance to turn) when the mass is arranged close to the axis of rotation(i.e. foot) ($I = mr^2$)
		Full lateral extension of the take-off leg	Applying a force over a longer time (impulse) or distance (work) will result in greater velocity ($F \times t = m \times v$)
		Large take-off distance (distance the COM is ahead of the take-off foot)	Equals large step length and increased velocity ($v = SL \times SF$)
		First ground contact parallel to the direction of travel	Applying force in the direction you wish to travel

Player Data:

Note: *The shaded regions indicate those players that have shown COD performances faster (green) and slower (blue) than the squad average (CODstep of 0.742 ±0.135 s) (see Table U).*

Table U: Individual technical performance evaluation according to the key technical features of a 180° ground-based change of direction task, where '+' = fully employed feature, 'OK' = feature was present but not to the extent outlined above, '-' = feature was missing from the performance.

Player	*Deep squat*	*Backward moving COM*	*Small rotational inertia*	*Full lateral extension at T.O.*	*Large T.O. distance*	*1st GC in intended direction*	*CODstep (s)*	*CODstride (s)*
U	-	+	OK	+	+	-	0.531	0.882
I	+	OK	+	-	-	-	0.563	0.854
M	+	-	+	+	OK	+	0.575	0.871
N	OK	+	OK	+	+	-	0.599	0.869
T	+	+	+	+	+	+	0.633	0.872
C	-	+	OK	OK	OK	+	0.65	0.946
L	+	+	+	+	+	OK	0.664	0.898
D	+	+	OK	OK	OK	OK	0.676	0.942
P	-	+	-	-	-	+	0.685	1.008
E	OK	-	+	+	+	+	0.692	0.99
O	+	+	+	+	+	+	0.697	0.965
G	-	+	OK	+	-	-	0.715	1.0545
J	-	-	-	OK	+	+	0.744	1.078
H	+	OK	+	+	+	+	0.763	1.019
V	-	+	+	+	OK	-	0.784	1.069
B	+	+	OK	OK	OK	+	0.795	1.127
S	+	+	+	+	+	OK	0.865	1.143
R	-	+	-	OK	OK	-	0.895	1.209
Q	-	+	+	+	OK	OK	0.94	1.226
F	+	+	+	+	OK	OK	0.944	1.224
A	-	+	+	+	+	+	0.958	1.258
K	+	+	OK	+	+	+	0.961	1.239

Observations:

It is interesting to note the occurrences of "+" and "-" in the faster third compared to that of the bottom third. Those players that have shown to employ the critical features highlighted in this report, but have presented slower COD times may first need to focus on completing the movements faster (e.g. players K and F), whereas those with a larger number of minuses may first need to focus on including these features in their performance prior to increasing the velocity at which they are performed (e.g. players P and R). Players that have shown to have smaller take-off distances (step length) combined with slower sprint times may benefit from first-step quickness training, especially following a rapid COD, as these players are not as proficient at accelerating out of a tight turn (e.g. players G and I). Overall, these six critical features should be taught and practised consistently by all players, regardless of their performance times.

Appendix 13. New Zealand Sports Medicine and Science Conference Abstract (2009)

LEG ASYMMETRIES DURING VARIOUS DIRECTION-BASED MOVEMENTS TASKS IN NETBALL PLAYERS

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Background: Leg asymmetry refers to the difference in performance measures between legs when performing certain unilateral movement tasks. It is thought that a greater difference between legs increases the potential for injury. Identifying player strengths and weaknesses of various explosive movement tasks as well as the magnitude of asymmetry should improve programme design and player performance.
Aim: The purpose of this study was to quantify the magnitude of leg asymmetry in four different explosive movement tasks.
Methods: Twenty-two elite netball players (NZ-U21 squad) participated in this study. Leg dominance was determined prior to completion of the movement tasks. Players performed three trials on each leg of the following movement tasks: horizontal (H), lateral (L) and vertical (V) single-leg countermovement jumps (SLCM), and a 180° COD followed by a 2.5 m sprint. Jump distance/height (via tape measure/force plate data) was collected for the jumps while a high speed video camera was used to record the COD task. Variables of interest included peak force, peak power and jump height/distance for the three SLCM tasks, while the time from movement initiation through the first ground contact in the new direction was of interest for the COD task.
Results: The average asymmetry index (ASI) between legs for each movement task was: 4.5 ±3.2 (H), 5.8 ±4.8 (L), 7.1 ±5.8 (V), 3.2 ±2.5 (COD) with a combined ASI of 5.7 ±2.8 between legs for all four movement tasks. The shared variance between the three jumping assessments was small (r^2 = 0.02 to 0.06), indicating that these tests were relatively independent of each other (e.g. those that performed well in the lateral jump didn't necessarily perform well in the horizontal or vertical directions.
Conclusions: It seems that leg power is directionally specific and developing leg power in one direction results in little transference to other directions. The magnitude of asymmetry in a non-injured population for the four tasks was less than 7.5 % indicating thresholds of acceptable asymmetry. Asymmetries appear to be direction and task-specific with only one player having asymmetries greater than 10% in more than one direction. These findings have implications for assessment and programming.

Acknowledgements: Thanks are given to the netball players who participated in the study and to the ISRRNZ and Netball New Zealand who funded the PhD scholarship that is supporting the lead author.

Appendix 14: Fact Sheet 5 – Leg Power Asymmetry

NETBALL NEW ZEALAND
Poitarawhiti Aotearoa

LEG POWER ASYMMETRY

A variety of functional performance assessments are often used by strength and conditioners as well as clinicians to; identify player strengths and weakness, determine injury potential, develop training programs, or determine readiness to return to play. The use of a single-leg countermovement jump (SLCM) in several different directions can provide greater insight into a netball player's leg power profile than other tasks focusing primarily on leg power in only one direction. When leg power is compared between legs, an average symmetry index (ASI) can be determined. A greater magnitude of asymmetry between legs (10 to 15% or more) is commonly associated with a greater potential for injury [82, 87]. This fact sheet outlines the magnitude of imbalance between legs (asymmetry) during three different direction-based movement tasks commonly performed by netball players, and how leg power varies across jumping directions and tasks.

Direction-based movement tasks used to test leg power asymmetry

A study was conducted to examine the magnitude of leg asymmetry in non-injured sub-elite netball players. Seventeen netball players from the NZ-U21 2009 training squad completed three trials per leg of three different direction-based movement tasks:

Vertical single-leg countermovement jump (SLCM-V): Beginning on one leg in the centre of the force plate (hands on hips), each player flexed at the hips and knees (eccentric phase) and then rapidly extended (concentric phase) their leg jumping as high as possible, landing simultaneously on both feet.

Horizontal single-leg countermovement jump (SLCM-H): Similar to the SLCM-V task, with the exception of attempting to jump as far forward off the force plate as possible.

Lateral single-leg countermovement jump (SLCM-L): Similar to the SLCM-V task, with the exception of attempting to jump as far to the side (laterally) of the force plate as possible. For this task, the jump was directed to the opposite side from the weight-bearing leg.

Players were required to keep their hands on their hips throughout and maintain balance upon landing. Peak power was calculated by a force plate for the SLCM jumps. The results are shown in Table V. Practical applications have been provided for how training may address based on the magnitudes observed.

Main findings

A) Power can have a high level of asymmetry which may be attributed to having greater sensitivity as a measure because power is the product of both *force* and *velocity* (P = F x v).
B) ASI appears to be directional-specific, where the magnitude of asymmetry is dependent upon whether the leg power is vertical, lateral or horizontal in nature.
C) Players presenting ASI magnitudes lower than 10% in one direction, may not necessarily perform equally well in the other two directional-based tasks.
D) Players with large asymmetries magnitudes in more than one direction (highlighted in blue) may be at a greater risk of potential injury due to the large imbalance across multiple directions. A prospective follow-up of these types of players is needed to confirm the risk associated with a high ASI and injury in netball players.

Results interpretation and practical applications for training

Table V: Leg power asymmetry (%) for each player (n= 17) who performed all three types of jumps.

Player	Position	SLCM-V	SLCM-H	SLCM-L
A	*MID-COURT/ATTACKING*	3.2	30.1	15.4
C		24.6	5.7	7.2
D		10.7	12.0	11.2
E		15.2	4.3	14.3
G		1.8	11.0	2.5
H		18.1	9.4	10.2
I		7.0	7.8	11.3
J		3.4	5.1	0.9
K	*MID/ END*	0.5	28.6	12.1
L		5.6	6.9	6.2
M		6.5	11.3	14.9
O	*END-COURT*	10.1	2.3	24.2
P		2.3	4.8	6.3
Q		0.5	6.5	8.5
R		2.6	22.4	20.5
T		0.1	4.1	24.9
U		4.3	10.7	10.7
Squad mean ±SD		*8.1 ±8.6*	*11.3 ±7.9*	*11.7 ±7.6*

Observations	***Recommendations***
It is important to note that a 10% ASI is considered atypical and should be addressed. However, regardless of the magnitude of asymmetry, balance between legs is thought important. A player with a low ASI magnitude may still incur an injury, while a player with a larger magnitude may not. This 10% threshold is used as a guideline to distinguish between those players that may be at greater risk to injury. Examples of training guidelines are provided below.	
Players E, H, M, and R – ASI magnitudes greater than the 10% threshold in at least two directions.	Players should focus on decreasing the leg power imbalance between legs particularly in the directions observed to have magnitudes greater than 10%.
Players A, D, and K – Frequently perform high-velocity horizontal and lateral tasks in a game and have also presented ASI magnitudes greater than 10% in these directions.	Players should focus on decreasing the leg power imbalances in the horizontal and lateral directions through various dynamic directional-specific training exercises.
Player O – Frequently performs movement tasks which are predominantly vertical in nature throughout a game and has also presented an ASI magnitude greater than 10% in this direction.	Player should focus on decreasing the leg power imbalance in the vertical direction through various dynamic directional-specific training exercises.

For any questions and/or further information about ground-based COD tasks, please contact Jennifer Hewit: jkhewit@gmail.com.

Appendix 15. Technical Report 6 – Developing a reactive decision-making passing task for netball players

Overview

Background: There are three distinct inter-related qualities (technical, physical and perceptual) that are thought essential to the success of an agility performance. Players that consistently display proficient and effective performances in all three areas are likely to be at an advantage. However, it is likely that player ability will vary across the three components. Therefore, a battery of tests that is able to differentiate performance in each of these qualities is highly desirable. To maximize transference into competition, it is important to train and assess players in an environment that is as similar to the actual sporting context as possible. This is especially important for the perceptual decision making component.

Aim: To develop a reactive decision-making assessment that is representative of the demands and manoeuvres commonly performed throughout a netball game.

Methods: Reactive decision-making testing data were collected during a single training session in January 2009 from 22 players in the Netball New Zealand national under 21 training squad. The reactive decision-making (RDM) task involved a player passing to a target player that was obstructed from view by a passive defender. The total time (TT) to perceive and complete the RDM task was composed of decision time (DT) (time from target player movement initiation to pass initiation) and movement time (MT) (time from pass initiation to ball release). High speed video analyses were conducted. Passes were categorised as incomplete if in the missed pass the ball was either beyond an estimated 5 cm distance from the target player's hand, or the ball was thrown to the incorrect location, or an interception/tip by the passive defender occurred. A frequency count of the total number of incomplete passes out of 12 attempts was noted. The percent of incorrect versus intercepted passes from the total incomplete passes for each player was calculated.

Mean and standard deviations for DT, MT and TT times were averaged across all 12 trials for each player. Players were ranked according to TT (where 1 was the fastest time) and ranked according to the APP (where 1 was the most appropriate pass score). Players were then categorised according to the following:

Blue = ranked above (i.e. faster) the median ranking for both DT and TT and below the median ranking for MT.

Red = ranked below (i.e. slower) the median ranking for both DT and TT and below the median ranking for MT.

Green = A difference of more than 12 rank places between APP and TT where the TT rank was better than the APP rank (i.e. a faster total time).

Yellow = A difference of more than 12 rank places between APP and TT where the APP rank was better than the TT rank (i.e. a more appropriate pass).

Initial results: Individual player RDM times varied from 0.290 ±0.08 s to 0.538 ±0.011 s for the TT taken to complete the pass following stimulus presentation. Decision time accounted for the majority (0.238 ±0.05 s) of TT – approximately 60 ±0.07% of the average TT (0.395 s ±0.06). The remaining portion of TT is attributed to MT, which averaged 0.156 ±0.03 s across the 22 players. The mean number of incorrectly completed passes of the total 12 trials available was 1.1 ±1.8 and the mean number of intercepted passes of the total 12 trials available was 2.3 ±1.6. The mean APP score was 8.5 ±2.0 completed out of 12. Four players ranked above the median (i.e. faster) for both DT and TT and below the median for the MT (i.e. slower). Five players ranked below the median (i.e. slower) for DT and TT and above the median (i.e. faster) for MT. Four players ranked better in APP, whereas four players ranked better in the TT of the pass. Surprisingly, only two players successfully completed all passes to the correct location without an interception.

Initial practical implications for coaches: Players presenting faster than average MT didn't necessarily present equally superior TT. Training which is able to target the time taken to perceive and initiate movement in response to the decision may be important when enhancing the RDM ability in netball players. Additionally, it would be advantageous for all RDM training drills to be performed in response to player movements as they would be performed in competition (e.g. actual player involvement as opposed to video or computerised scenarios).

Introduction

Due to its complex nature, agility has been defined in many different ways. What is consistent across many of these definitions is that there are technical (body positioning and control of movements), physical (power, reactive strength), and perceptual (response to a stimulus) components, all of which are inter-related [1, 2, 4, 48, 53]. Young et al. (2002) illustrated the inter-relationship of these three components as they contribute to an agility performance (see Figure S). The ability to perceive and accurately react physically (change direction) to a stimulus are the two main factors that distinguish a movement as being "agile". If one of these technical, physical or perceptual components are lacking, the overall agility performance could be compromised.

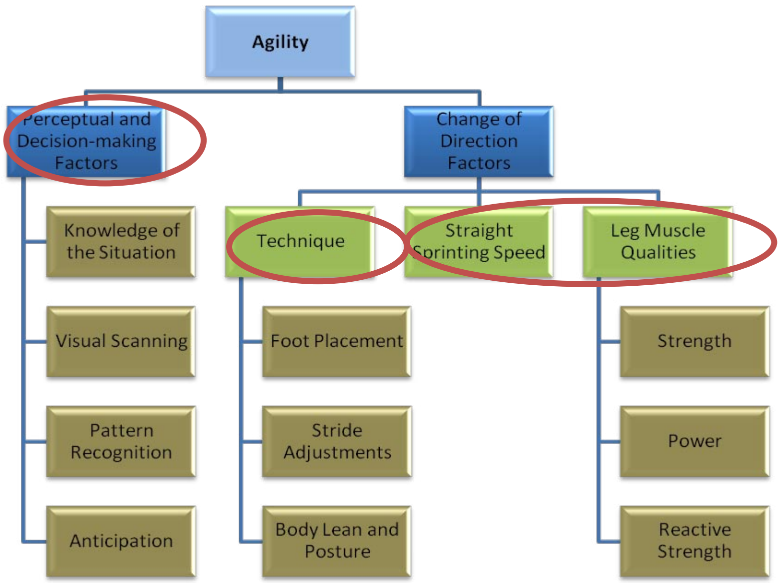

Figure S: Deterministic model of agility (adapted from Young, 2002) with the three main components of agility (technical, physical and perceptual) circled.

The preliminary objectives of the current research were focused within the perceptual/decision-making component of agility. There has been a paucity of research investigating the RDM abilities of netball players in a sport-specific context. Therefore, the current research presented in this report is reflective of the decision and movement times presented by various netball playing positions while completing a netball-specific reactive passing task.

Objectives

The main objectives of this study were to:

1. Determine rank order according to their total time (TT) to perceive and complete the RDM task, decision time (DT) (time from target player movement initiation to pass

initiation), movement time (MT) (time from pass initiation to ball release) and appropriateness of the player's pass (APP).

2. Determine those players scoring below the median rank in TT, DT, MT and APP.
3. Identify players that might benefit from decision/reaction time training, and those that might benefit from movement time training.

Methods

Participants

Reactive decision-making testing data were collected during a single training session in January 2009 from 22 players in the Netball New Zealand national under 21 training squad. Written informed consent was obtained from each participant prior to data collection.

Testing set-up

Testing took place on an indoor netball court throughout the players' standardised strength and conditioning session. Testing equipment included a regulation game sized netball, an LED signal and switch belt, and a high speed video camera (EX F1, Casio Computer Co., Ltd, Japan) sampling at a rate of 300 Hz to record the decision and movement times of the players while performing the RDM task. The testing set-up is illustrated in Figure T.

Figure T: Testing set-up for the RDM task where "T" represents the target player, "D" represents the passive defender, and "P" represents the player or testing subject.

Testing procedures

Upon arrival to the testing session, the age, height, and body mass were recorded for each player. All players were already warmed up as the testing session took place concurrently with the strength and conditioning session. A task familiarization period consisting of no more than three trials was given to each player prior to data collection. A total of 12 consecutive trials were recorded for each player. In order to increase the reliability between players, the same target player (head coach) was used for each player, as was the passive defender (assistant coach).

The reactive decision-making task

The reactive decision-making (RDM) task involved a player passing to a target player that was obstructed from view by a passive defender. The total time (TT) to perceive and complete the RDM task was composed of decision time (DT) (time from target player movement initiation to pass initiation) and movement time (MT) (time from pass initiation to ball release). Appropriateness of the player's pass (APP) was defined as within 5 cm of the hand of the target player.

Each player began at a designated mark placed just outside of the shooting circle, holding a netball at lower chest-height in preparation for a pass. A target player, positioned just behind a passive defender, was located 5 m from the player (inside of the shooting circle). Both the target player and the passive defender were positioned facing the player; therefore the defender had her back to the target player (see Figure T). A high speed video camera was placed perpendicular to the line from the player to the target player. The target player wore a switch-belt connected to an LED signal which was placed facing the camera. The target player began by pressing the signal button (illuminating the LED) and releasing it (dimming the LED) immediately prior to moving into one of five randomly selected passing directions (left, right, upper left, upper right, and vertical). The dimming of the LED signalled the start of the trial for the camera and the beginning of the decision time. As soon as the player was able to determine the movement direction of the target player, a pass would be made in that direction. If the passive defender was able to intercept the pass (with minimal movement), she was allowed to do so. A total of 12 trials were completed by each player.

Analyses of data

Video for each player was assessed by one researcher. By manually advancing the video frames, the movement times and the appropriateness of the pass were determined. Passes were categorised as incomplete if in the missed pass the ball was either beyond an estimated

5 cm distance from the target player's hand, the ball was thrown to the incorrect location, or an interception/tip by the passive defender occurred. A frequency count of the total number of incomplete passes out of 12 attempts was noted. The percent of incorrect versus intercepted passes from the total incomplete passes for each player was calculated.

Mean and standard deviations for DT, MT and TT times were averaged across all 12 trials for each player. Players were ranked according to TT where 1 was the fastest time. Players were also ranked according to the APP where 1 was the most appropriate pass score. Players were then categorised according to the following:

Blue = ranked above (i.e. faster) the median ranking for both DT and TT and below the median ranking for MT.

Red = ranked below (i.e. slower) the median ranking for both DT and TT and below the median ranking for MT.

Green = A difference of more than 12 rank places between APP and TT where the TT rank was better than the APP rank (i.e. a faster total time).

Yellow = A difference of more than 12 rank places between APP and TT where the APP rank was better than the TT rank (i.e. a more appropriate pass).

Results

Tables W shows the DT, MT and TT as averaged across all 12 trials for each player. Individual player RDM times varied from 0.290 ±0.08 s to 0.538 ±0.011 s for the TT taken to complete the pass following stimulus presentation. Decision time accounted for the majority (0.238 ±0.05 s) of TT – approximately 60 ±0.07% of the average TT (0.395 s ±0.06). The remaining portion of TT is attributed to MT, which averaged 0.156 ±0.03 s across the 22 players. The mean number of incorrectly completed passes of the total 12 trials available was 1.1 ±1.8 and the mean number of intercepted passes of the total 12 trials available was 2.3 ±1.6. The mean APP score was 8.5 ±2.0 completed out of 12.

Table W: Player squad mean, standard deviation and percentage for decision time (DT), movement time (MT) and total time (TT), as well as the score for the appropriateness of the player's pass (APP).

Player	DT (s) mean ±SD	DT %	MT (s) mean ±SD	MT %	TT (s) mean ±SD	APP score (completed out of 12)
1	0.214 ±0.09	74%	0.076 ±0.02	26%	0.290 ±0.08	6
2	0.150 ±0.07	49%	0.157 ±0.03	51%	0.307 ±0.08	10
3	0.195 ±0.08	61%	0.128 ±0.02	40%	0.322 ±0.08	6
4	0.172 ±0.05	52%	0.156 ±0.01	48%	0.328 ±0.06	12
5	0.143 ±0.09	43%	0.187 ±0.02	57%	0.330 ±0.09	8
6	0.196 ±0.09	57%	0.148 ±0.02	43%	0.344 ±0.08	8
7	0.204 ±0.05	57%	0.155 ±0.01	43%	0.360 ±0.05	5
8	0.195 ±0.14	53%	0.175 ±0.02	47%	0.370 ±0.14	10
9	0.227 ±0.04	61%	0.144 ±0.03	39%	0.371 ±0.04	10
10	0.230 ±0.04	62%	0.143 ±0.03	38%	0.373 ±0.05	11
11	0.239 ±0.07	61%	0.156 ±0.03	40%	0.395 ±0.08	9
12	0.244 ±0.04	60%	0.164 ±0.02	40%	0.408 ±0.06	4
13	0.261 ±0.11	64%	0.147 ±0.04	36%	0.408 ±0.11	10
14	0.246 ±0.04	59%	0.168 ±0.02	41%	0.414 ±0.04	5
15	0.267 ±0.10	64%	0.153 ±0.05	37%	0.419 ±0.09	7
16	0.250 ±0.08	58%	0.183 ±0.02	42%	0.433 ±0.09	11
17	0.310 ±0.12	71%	0.125 ±0.03	29%	0.436 ±0.12	8
18	0.294 ±0.09	66%	0.151 ±0.02	34%	0.445 ±0.08	12
19	0.308 ±0.08	67%	0.15 ±0.03	33%	0.458 ±0.08	8
20	0.285 ±0.10	62%	0.177 ±0.02	38%	0.462 ±0.09	10
21	0.283 ±0.08	60%	0.186 ±0.03	40%	0.469 ±0.08	10
22	0.325 ±0.13	60%	0.212 ±0.08	39%	0.538 ±0.11	8
Squad Mean ±SD	***0.238 ±0.05***	***60 ±0.07***	***0.156 ±0.03***	***40 ±0.07***	***0.395 ±0.06***	***8.5 ±2.0***

Four players highlighted in blue ranked above the median (i.e. faster) for both DT and TT and below the median for the MT (i.e. slower). Five players highlighted in red ranked below the median (i.e. slower) for DT and TT and above the median (i.e. faster) for MT. Four players highlighted in yellow ranked better in APP, whereas four players highlighted in green ranked better in the TT of the pass (see Table X).

Table X: Player squad ranking for decision time (DT), movement time (MT), total time (TT) and pass appropriateness (APP), where 1 represents the fastest times for the squad and more appropriate passes completed, respectively.

Player	TT	DT	MT	APP
1	1	8	1	17
2	2	2	14	6
3	3	4	3	19
4	4	3	12	1
5	5	1	21	10
6	6	6	7	18
7	7	7	11	21
8	8	5	17	11
9	9	9	5	7
10	10	10	4	3
11	11	11	13	12
12	12	12	15	22
13	13	15	6	8
14	14	13	16	20
15	15	16	10	14
16	16	14	19	4
17	17	21	2	13
18	18	19	9	2
19	19	20	8	15
20	20	18	18	5
21	21	17	20	9
22	22	22	22	16

Note: Blue = ranked above (i.e. faster) the median ranking for both DT and TT and below the median ranking for MT; Red = ranked below (i.e. slower) the median ranking for both DT and TT and below the median ranking for MT; Green = A difference of more than 12 rank places between APP and TT where the TT rank was better than the APP rank (i.e. a faster total time); Yellow = A difference of more than 12 rank places between APP and TT where the APP rank was better than the TT rank (i.e. a more appropriate pass).

The percent of incorrect versus intercepted passes are identified as the light and dark shaded areas respectively in Figure U. Surprisingly, only two players (Players 4 and 18) successfully completed all passes to the correct location without an interception.

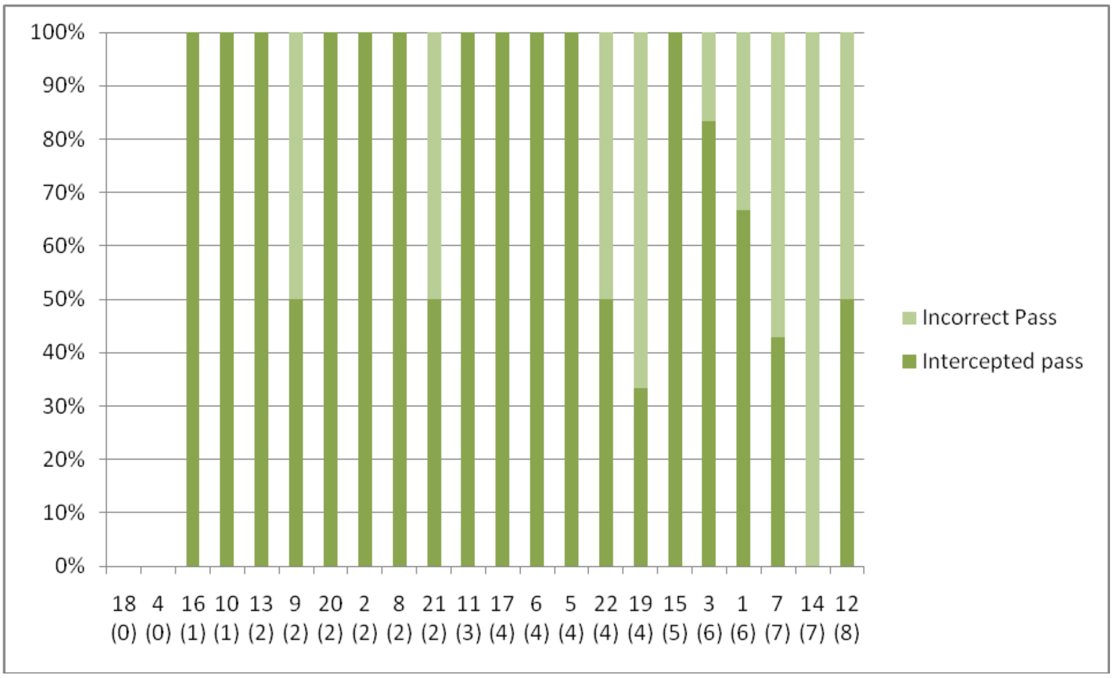

Figure U: Percent of incorrect versus intercepted passes from the total incomplete passes for each player. (Note: the total number of incomplete passes out of 12 attempts is in parentheses following each player's number).

Discussion

Initial results from the RDM task have indicated that the time taken to make a decision (decision time, DT) has a greater influence on the overall RDM task than the time taken to complete the pass (movement time, MT). While the total time taken to perceive and complete the RDM task is a combination of the MT and DT, the total time taken appears to be predominantly influenced by the perceptual component as opposed to the physical. Those players that presented above the median (i.e. faster) DT also consistently presented above the median (faster) TT. In contrast, those players presenting faster than the median MT didn't necessarily present equally superior TT.

The start of decision time was determined by the target player's release of the LED button prior to her moving into the intended direction. As the button was likely not released at the same time prior to movement for each trial, the potential for error is present. However, an attempt to minimize this error was taken by using the same target player for each trial. Using a player to determine the start of a task will naturally have greater variability when compared to using additional equipment (e.g. video projection) for the players to react to. However, video projections of players will eliminate a portion of the cues displayed by the target that the player uses to determine the appropriate passing location [97]. Therefore, the small amount of variance that results from using a target player is less of a concern than the inaccuracies that would result from using more reliable means of target simulation. That is, greater reliability would reduce the validity (game-like context) of the assessment.

Players highlighted in red (Player 11, 13, 15, 17, 18, and 19) in Table V, performed below the median TT for the RDM test, with a corresponding below average DT. This indicates that the time taken to perceive the visual information from the target's movement and identify the correct passing direction may be sub-optimal in these players. Whilst the task employed in this study was necessarily very simple in relation to perceptual demand and decision-making, it is possible that these players may benefit from additional perceptual training (i.e. reactive movement drills where multiple options are present). Players highlighted in blue (Players 1, 5 and 8), though relatively slow when completing the pass, have performed above the median when perceiving and identifying the visual information of the task as well as in the overall RDM task total time. This indicates that these players may benefit from training that is focused on decreasing movement time (i.e. quicker passing).

Of the 22 players, only two (Players 4 and 18) were able to successfully complete all 12 passes to the correct location without an interception. Of those players that had passes that were either intercepted or completed to the incorrect location, one player's incomplete passes were all released to an incorrect location. As her DT, MT and TT ranks were all below the median ranks, it is recommended that additional training that emphasizes not only completing the pass quicker, but also rapidly identifying the correct passing location is added to her current training programme. Additionally, several players were able to complete their passes rapidly (i.e. ranked in the top third out of the squad for TT) (Players 1, 3, and 6), but had the majority of their incomplete passes intercepted. This indicates that these three players might benefit from additional training that emphasizes more effective ball placement when passing to avoid interference by the opposition.

Training which is able to target the time taken to perceive and initiate movement in response to the decision is thought to be important to enhancing the RDM ability in netball players. Additionally, it is essential that all RDM training drills are performed in response to player movements as they would be performed in competition (e.g. actual player involvement as opposed to video or computerised scenarios). While all players can benefit from both forms of training (movement and reactive), the players highlighted in this report are thought to be in need of specific RDM training more so than some other players and therefore training should be addressed and implemented as soon as possible.

Acknowledgements

Special thanks are given to the 2009 New Zealand under 21 netball training squad, coaching team and players for their hard work, cooperation, patience and assistance during the data collection and analysis process.

Appendix 16: Fact Sheet 6 – Reactive decision-making

NETBALL NEW ZEALAND
Poitarawhiti Aotearoa

REACTIVE DECISION-MAKING

Agility is a complex movement pattern that is comprised of three main components – technical, physical and perceptual. In terms of the perceptual decision making component, the ability to react rapidly and accurately to both teammates' and opponents' movements in netball contribute greatly to the overall success of the performance. Unfortunately due to the complex nature of netball, effectively assessing a player's ability to make decisions in competition is a difficult task. The development of a netball-specific reactive decision-making (RDM) assessment task can provide greater insight into a player's decision times and movement times. When these variables are compared across players, a player ranking system can be developed wherein specific characteristics consistently attributed to those players displaying faster times with greater accuracy can then be identified and integrated into both team and individual training sessions [9]. A study was conducted to examine the reactive decision-making abilities of sub-elite netball players. Twenty-two netball players from the NZ-U21 2009 training squad completed nine trials of the RDM task. This fact sheet outlines the reactive decision-making task, the variables investigated, and practical applications for the focus of training based on the interpretation of these variables have also been provided.

Reactive decision-making task and performance times

Task set-up and execution: A target player (T) positioned just behind a passive defender (D) is located near the baseline of a standard netball court, with the player (P) located just outside of the shooting circle facing both the target player and passive defender (see Figure V). When ready, the target player (T) steps out from behind the defender (D) to a randomly selected location (see Figure X) automatically switching an LED light identifying the start of the trial for a high speed camera placed perpendicular to the passing direction. The player (P) completes a pass as quickly and accurately as possible once the direction of the target player (T) is known to her. The passive defender (D) is allowed to attempt an interception or tip with limited movement, however the main purpose of the defender is to obstruct the player's (P) view of the target player (T) as would be the case in a game. Players' (P) performance times and passing accuracy are recorded for analysis.

Performance time variables and passing accuracy:

Decision time (DT): Time from target player (T) movement initiation to player (P) passing movement initiation.
Movement time (MT): Time from player (P) passing movement initiation to ball release.
Total time (TT): Time from target player (T) movement initiation to ball release.
Passing accuracy (A): Points awarded for the accuracy of each pass where: 2 points = catch from a direct pass, 1 point = catch from a lobbed pass (as this sort of pass is easier to intercept), and 0 points = missed pass, interception, pass tipped by defender (D), or incorrect pass.

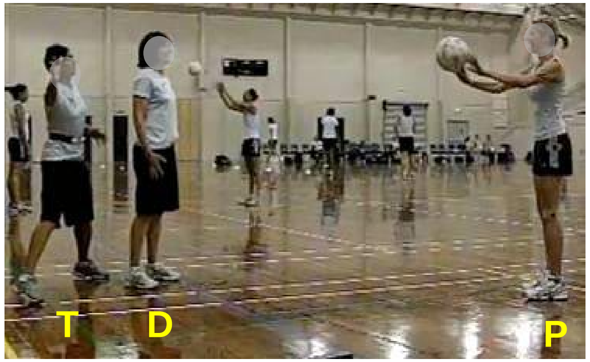

Figure V: Reactive decision-making task.

Target player movement options:

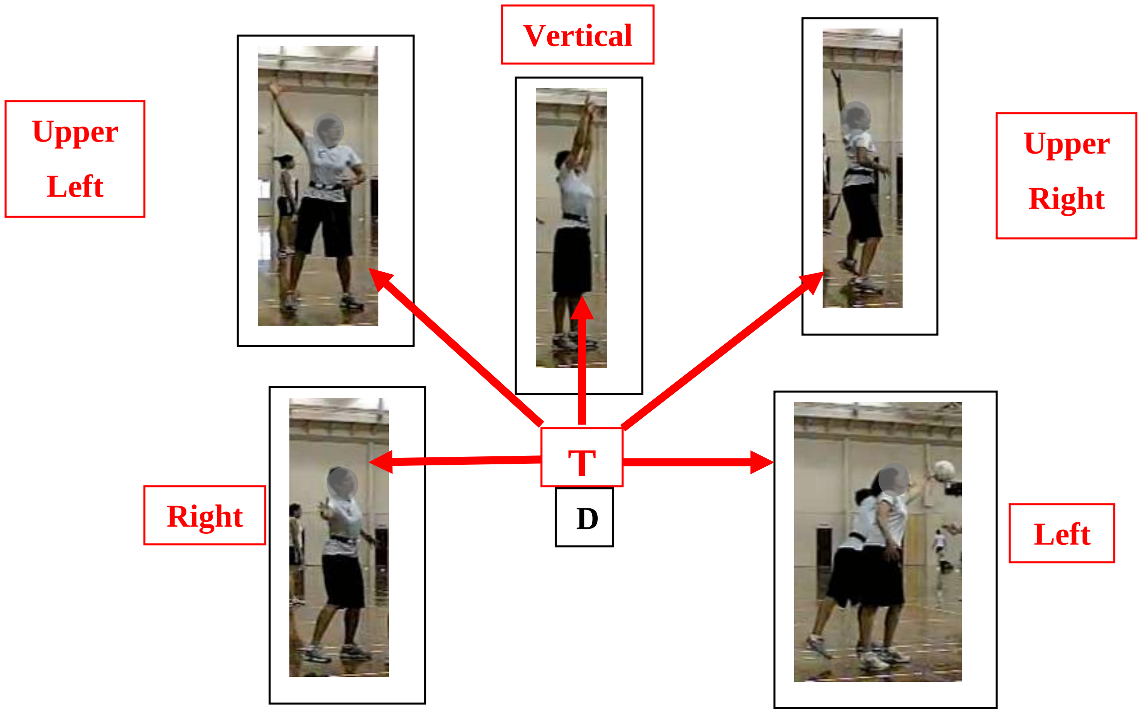

Figure W: The five different movement options for the target player (T) to relocate to (randomly assigned), thereby identifying the passing direction for the player (P).

Results interpretation and practical applications for training

Player reactive decision-making performance times ranked from fastest to slowest are shown in Table Y. Interpretations of the movement time performances and practical applications for how training might be addressed based on the performance times have also been provided.

Table Y: Ranked reactive decision-making performance times for decision time (DT), movement time (MT) and total time (TT).

The red line indicates the squad averages ±SD (0.233 s ±0.059, 0.161s ±0.021, and 0.394 s ±0.062), respectively for each variable. The players highlighted in yellow rank below average for both DT and TT, but above average for MT. The players highlighted in blue rank below average in MT, but above average for both DT and TT.

Player	DT
A	0.098
B	0.143
C	0.150
D	0.172
E	0.195
F	0.195
G	0.196
H	0.204
I	0.227
J	0.230
K	0.239
L	0.244
M	0.245
N	0.250
O	0.261
	0.267
Q	0.283
R	0.285
S	0.294
T	0.308
U	0.310
V	0.325

Player	MT
U	0.125
E	0.128
J	0.143
I	0.144
O	0.147
G	0.148
T	0.150
S	0.151
P	0.152
H	0.155
D	0.156
K	0.156
C	0.156
L	0.164
M	0.168
F	0.175
R	0.177
N	0.183
Q	0.186
B	0.187
A	0.190
V	0.212

Player	TT
A	0.288
C	0.307
E	0.322
D	0.328
B	0.330
G	0.344
H	0.359
F	0.370
I	0.371
J	0.373
K	0.395
O	0.408
L	0.408
M	0.414
P	0.419
N	0.433
U	0.436
S	0.445
T	0.458
R	0.462
Q	0.469
V	0.537

Observations	*Recommendations*
DT appears to have a greater influence on TT than MT as all players that performed faster than average in DT also had above average TT, while those that had faster than average MT didn't necessarily have faster than average TT.	
Players highlighted in yellow performed slower than average in the RDM test (TT), with a corresponding below average DT, indicating that the time taken to perceive the visual information from the target's movement and identify the correct passing direction may be sub-optimal.	These players (e.g. T and U) may benefit from additional perceptual training that includes reaction training with multiple options present.
Players highlighted in blue, though relatively slow when completing the pass (i.e. MT), have performed faster than average when perceiving and identifying the visual information of the task (i.e. DT), as well as in the overall RDM task total time.	These players (e.g. A and B) may benefit from training that is focused on decreasing movement time through reaction time training focused on pass execution speed.

While there might be the potential for some players to improve their reactive decision-making performance by placing a stronger emphasis on either DT or MT within their current perceptual training programme, a complete separation of DT and MT training from one another is not recommended.

> "Avoid training activities in which ONLY decision-making OR movement speed are practiced in isolation. This type of training separates perception from action in an unnatural way which could possibly result in less fluidity and more mistakes due to an inability to transfer motor skills. A better strategy is to include more decision-making activities within physical practice so that players aren't just robotically running off movement patterns without thinking about it."
>
> Dr Chris Button (University of Otago)

References

Farrow, D., Young, W., & Bruce, L. (2005). The development of a test of reactive agility for netball: A new methodology. *Journal of Science and Medicine in Sport*, *8*(1), 40-48.

For any questions and/or further information about ground-based COD tasks, please contact Jennifer Hewit: jkhewit@gmail.com.

Appendix 17. Technical Report 7 – Task-specific agility assessment battery initial findings.

Overview

Background: Agility has three distinct qualities (technical, physical and perceptual/decision-making) which should be trained and tested in an environment that is as similar as possible to the actual sporting context. Individual players possess strengths and weaknesses in each or all of these three different qualities. Overall agility performance may be compromised when a player is found to be consistently lacking in one or more of these three areas of agility. Therefore, a battery of tests that is able to differentiate performance in each of these qualities is highly desirable. From the results of such an assessment, an appropriate technical, strength and conditioning and/or perceptual-decision making training program can be implemented, increasing the potential for player improvement.

Aim: To gain a more thorough understanding of individual player technical, physical and perceptual strengths and weaknesses when performing movement tasks thought important to netball.

Methods: A total of 10 'Super 12' New Zealand netball squad members participated in this study. Each player performed the netball-specific agility assessment battery (N-SAAB) which consisted of: a) three successful trials each of single-leg countermovement jumps in the vertical, horizontal and lateral directions; and b) three successful trials of a composite netball-specific agility task (N-SAT). The N-SAT included ground-based and aerial-based change of direction manoeuvres, physical strength characteristics through body alignments and control, and perceptual characteristics through reactive passing.

Results: The new N-SAAB is able to differentiate individual player strengths and weakness across the three main components of agility; technical, physical and perceptual: 1) there appears to be various characteristics associated with superior (i.e. faster and more effective) ground-based change of direction performances; 2) there appears to be various characteristics associated with superior (i.e. balanced landing with a full 180˚ turn completed prior to ground contact) aerial-based change of direction performances; 3) players with high percent differences between legs (greater than 10%) when performing single-leg countermovement jumps in various directions (a player that is strong in one direction isn't necessarily strong in all directions) may have a greater potential for injury; and, 4) players scoring below average in a dynamic passing portion where the target location is both known and unknown prior to ball possession may benefit from specific reactive decision-making training.

Practical implications: Players ranking below average in ground-based or aerial-based change of direction technique (i.e. critical features) may benefit from additional change of direction technique training. Jump specific training in the specific direction of weakness should be incorporated for players with large asymmetry indexes. Those players ranking below average in the dynamic passing portion may benefit from reactive decision-making training and reactive movement training.

A compilation of testing feedback for the new netball-specific agility assessment battery

The purpose of this assessment was to determine the technical, physical and perceptual strengths and weaknesses of individual netball players while performing tasks that are commonly required in netball.

The purposes of this article are to:

1. Outline the rationale of the inclusion of each aspect of the assessment task as they relate to the three main components of agility.
2. Determine asymmetries/imbalances between legs following explosive single-leg jumping. It is thought that the greater the difference between legs, the more likely the incidence of injury, with many clinicians using a 10% threshold.
3. Determine individual player strengths and weaknesses within each component of agility and provide training information that may be used to address those weaknesses.

Player data have been presented to show:

1. The spread of player results for each aspect of the netball-specific agility assessment battery (N-SAAB).
2. The lowest, average, and highest imbalances between legs (ASI-Average Symmetric Index) for players by rank within the squad.
3. The fastest, average and slowest reactive decision-making performance times for players by rank within the squad.
4. The superior, average and less effective change of direction performances (ground-based and aerial based) for players by rank within the squad.

Training information that can be gained from this information is:

1. Players that might benefit from training that addresses directional-specific leg imbalances.
2. Players that might may be at a higher risk of injury due to greater leg imbalances.
3. Players that might benefit from training that addresses ground-based and/or aerial-based technical qualities.

4. Players that might benefit from training that addresses reactive decision-making and/or reactive movement qualities.

Netball-specific agility assessment battery

Agility is a complex concept that is multi-factorial in nature. Within agility, there appears to be three main inter-related components (technical, physical, and perceptual/decision-making) that substantially contribute to the overall success of the movement performance (see Figure X) [5]. It can therefore, be deduced that if one or more of these three components is found to be consistently lacking, or even missing, the overall agility performance is likely to be compromised. However, if these potential weaknesses can be identified and addressed in training, a competitive advantage may be gained. It is therefore important to design and implement an agility assessment task that is able to differentiate between the technical, physical and perceptual components of agility in a sport-specific testing environment.

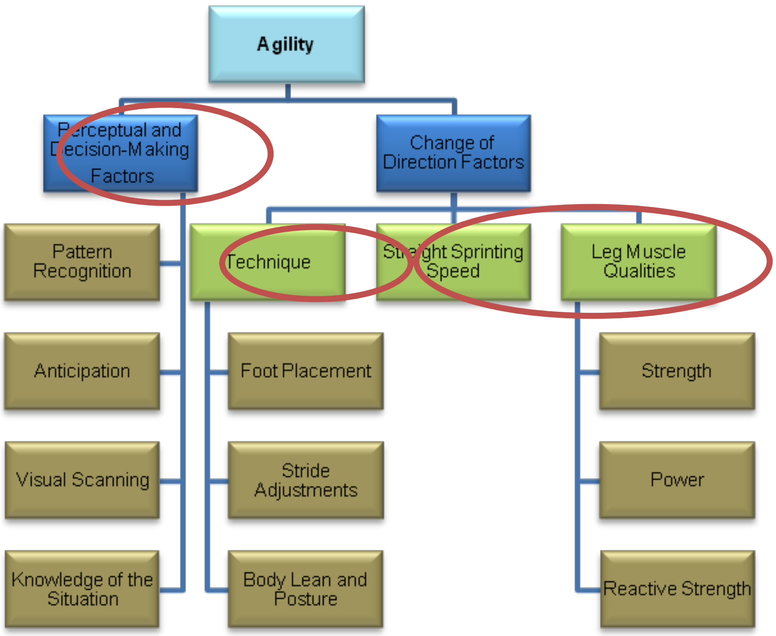

Figure X: Deterministic model of agility (adapted from Young et al., 2002) with the three main components of agility circled (perceptual, technical and physical).

Participants

A total of 10 ‘Super 12’ 2010 netball squad members volunteered to participate in this study (see Table Z). Two subjects reported recent lower limb injuries and voluntarily withdrew from portions of the single-leg jumping assessments as it may have aggravated their injury and affected their performance at the time of testing. The human research ethics committee of AUT University approved all procedures prior to commencing the study. Each participant completed a written informed consent prior to participation.

Table Z: Subject characteristics.

Variable	Squad mean ±SD
Age (yrs)	24.7 ±4.9
Height (m)	1.73 ±0.13
Body Mass (kg)	79.3 ±7.2

Equipment and testing set-up

Testing equipment for the single-leg countermovement jumps (SLCM) consisted of a single high speed camera (Casio EX-F1, Casio Computer Co., LTD, Tokyo, Japan) collecting at 300 Hz and a tape measure laid out on the court. The camera was placed 4 m from the designated start-mark to capture the time in the air for vertical jump trials, with the tape measure extending from the start-mark towards the camera (see Figure Y) to measure the distance jumped for the horizontal and lateral jump trials.

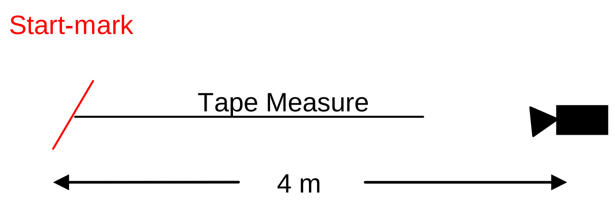

Figure Y: Single-leg countermovement jump set-up.

Testing equipment for the netball-specific agility task (N-SAT) consisted of two high speed video cameras (Casio EX-F1, Casio Computer Co., LTD, Tokyo, Japan) collecting at 300 Hz. The cameras were placed perpendicular to each other and at 7 m and 7.2 m away from the players' designated start-mark (see Figure Z). A takeoff mark was placed 2.5 m from the start-mark. A detachable regulation-size netball placed in a netball holder, positioned at approximately chest-height (see Figure AA), was located 3.7 m from the designated start-mark. A target player was positioned 5.2 m beyond the netball holder with one of the cameras located between the start-mark and target player at 7.2 m from the start-mark. A second detachable regulation-size netball was elevated at fingertip height for each player and hung over the rim of the netball hoop via bungee cord (see Figure AB).

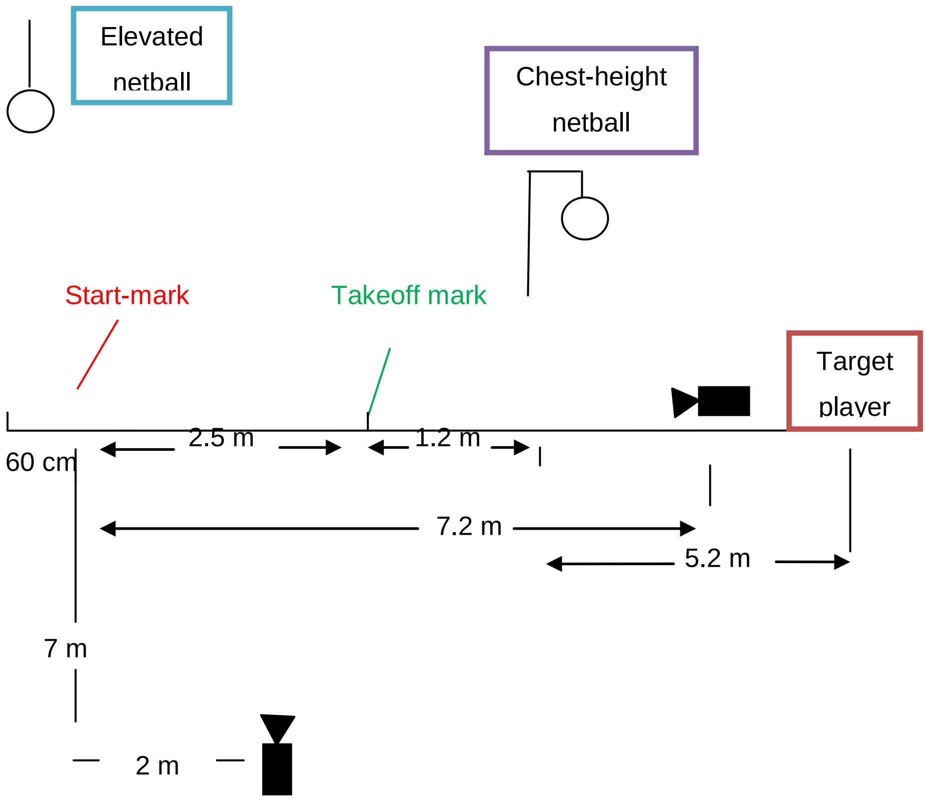

Figure Z: Netball-specific agility task set-up.

Figure AA: Chest-height netball holder.

Figure AB: Elevated netball bungee.

Procedures

Testing took place during a single testing session for each squad on a regulation indoor netball court. Upon arrival, the age, height and body mass of each player were recorded. Each player performed a 10 minute dynamic, netball-specific warm-up with their team and allowed to practice the SLCM and N-SAT until they felt comfortable. No more than three practice trials were taken by any of the players.

Single-leg countermovement jumps

Players were first required to perform SLCM jumps in the vertical, horizontal and lateral directions. Beginning with the vertical direction (SLCM-V), then horizontal (SLCM-H) and the lateral direction (SLCM-L), players stood on a single leg with their hands on their hips behind the designated start-mark. For the vertical trials, players stood with the outside of the standing leg (testing leg) facing the camera. For the horizontal trials, players began with the toes of the testing leg to the start-mark. For the lateral trials, players stood with the inside of the testing leg to the start-mark. When ready, the player sunk down and rapidly extended jumping as high (for the vertical direction) or as far (for the horizontal and lateral directions) as possible, landing on both feet. A trial was considered successful if the hands remained on the hips throughout, if the leg was not tucked into the body while airborne (for the SLCM-V), and if balance was maintained upon landing. Three successful trials on each leg were recorded for each jumping direction.

Netball-specific agility task

Players began at the designated start-mark in a split stance. When ready, the player sprinted 2.5 m, leaping from the takeoff mark and grabbing the chest-height netball while airborne. Upon landing, the player completed a pass as quickly and accurately as possible to the target player positioned in front of her. Following the ball release, the player completed a 180˚ ground-based turn and sprinted back towards the start-mark. While the player's back was turned, the target player relocated to one of five previously determined random locations (45˚ to the front-left, 45˚ to the front-right, 45˚ to the back left, 45˚ to the back right, or remaining in the centre). At the start-mark, the player jumped up to grab the elevated netball while airborne, completing a 180˚ aerial turn before landing facing the target player once again. Upon landing, the player completed a pass as quickly and as accurately as possible to the relocated target player. Three successful trials were recorded for each player. A trial was considered successful if the player maintained control of the ball and balance through the landing. All players were required to perform the task as quickly as possible.

Netball-specific agility assessment battery rationale

Each aspect of the N-SAAB has been included based on the ability to determine player strengths and weaknesses in one or more of the three main components of agility. These N-SAAB aspects, their components of agility, and corresponding rationale for inclusion within the battery have been presented in Table AA.

Table AA: N-SAAB aspects, their components of agility and corresponding rationale for inclusion in the N-SAAB.

N-SAAB aspect	Associated component of agility	N-SAAB inclusion rationale
Horizontal landing strategy	Technical	2-footed landing (bilateral) allows for more options upon landing and increased impact absorption, while a split stance landing allows for the use of a pivot to change directions
	Physical	Lack of leg strength would cause collapsing into the weight-bearing leg upon contact (deep knee flexion), or multiple steps upon landing
Catch and release time: chest-height (ball contact to ball release)	Physical	Increased strength allows for a pass to be completed while airborne, thereby decreasing the time taken to complete the pass.
	Perceptual	Early recognition of the correct passing option allows for an earlier ball release
Passing strategy: chest-height	Technical	A pass completed from the chest allows for larger muscle groups to be used than one thrown from the hip. Lowering the ball to the hip also increases the catch and release time.
	Physical	Increased strength allows for the ball to be released while still airborne as opposed to lowering the ball prior to passing following landing
Passing accuracy: chest height	Technical, Physical, and Perceptual	The ability to identify and complete an effective pass to the correct target relies on the technical, physical and perceptual abilities of the player
Ground contact time (horizontal landing ground contact to first ground contact in the new direction following the 180˚ ground-based turn)	Physical	The ability to immediately move off of the landing position (with no additional steps) greatly decreases the time in contact with the ground through the use of elastic energy and transfer of momentum
Change of direction time (last ground contact prior to planting to begin turning to first ground contact in the new direction following the 180˚ ground-based turn)	Technical	A player is able to turn faster and re-align themselves with the new direction more effectively and quickly when specific critical features are performed rapidly.
	Physical	Increased strength assists in slowing the body from its original direction and transfer that momentum through the turn and into the new direction
Turning strategy: ground-based	Technical	Several critical features are required to perform a faster ground-based change of direction (e.g. "small rotational inertia" - turning with the arms and legs close to the body, etc.)
	Physical	The ability to control the body through the turn and accelerate into the new direction requires core and lower body strength.
Turning strategy: aerial-based	Technical	Several critical features are required to perform a faster aerial-based change of direction (e.g. "knee drive through takeoff " – aggressively driving the free leg upwards to increase the height of the jump and afford more time in the air to complete the turn, etc.)
	Physical	Increased strength assists with the ability to control the body through the approach, turn and landing phases of an aerial task.
Catch and release time: elevated-height (ball contact to ball release)	Physical	Increased strength allows for a pass to be completed while airborne, thereby decreasing the time taken to complete the pass.
	Perceptual	Early recognition of the correct passing option allows for an earlier ball release

(see Table AA continued)

N-SAAB aspect	Associated component of agility	N-SAAB inclusion rationale
Passing strategy: elevated-height	Technical	A pass completed from the chest allows for larger muscle groups to be used than one thrown from the hip. Lowering the ball to the hip also increases the catch and release time.
	Physical	Increased strength allows for the ball to be released while still airborne as opposed to lowering the ball prior to passing following landing
Passing accuracy: elevated-height	Technical, Physical, and Perceptual	The ability to identify and complete an effective pass to the correct target relies on the technical, physical and perceptual abilities of the player
SLCM average symmetry index (ASI)	Physical	A greater asymmetry between legs (10% or more) has been associated with an increased risk of injury. Netball players are required to perform single-leg movements in multiple directions and therefore an ASI for each direction is necessary to fully assess leg balance/imbalance.

Results and observations

Individual player results for the N-SAAB are displayed in Table AB. The variables highlighted in red are thought to be desirable characteristics of a superior agility performance. For the two sections labelled "Turning Strategy (ground-based)" and "Turning Strategy (aerial-based)" the players have been awarded a "+" if the feature listed was employed to the full extent, an "OK" if the features was observed but not to the full extent, and a "-" if the feature was not present in the performance.

Table AB: N-SAAB individual player results.

Super 12 – Aztec 2010 Squad												
N-SAAB Variable			**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**
Horizontal landing strategy		*Limited knee flexion*			√		√	√	√	√	√	√
		Deep knee flexion	√	√		√						
		Bilateral (2-feet)										
		Unilateral (1-foot)	√	√	√	√	√	√	√	√	√	√
		Stuck landing	√			√	√					
		Over-run landing		√	√			√	√	√	√	√
		Split stance	√	√	√	√	√	√	√	√	√	√
		Square stance										
	Catch & release time (chest-height ball)		0.332	0.339	0.381	0.405	0.388	0.281	0.356	0.309	0.357	0.283
Passing strategy (chest-height ball)		*Release prior to landing*										
		Landing with immediate, high release				√		√		√		
		Landing with delayed, lowered release	√	√	√		√		√		√	√
		Chest pass	√	√	√		√	√	√	√	√	√
		Hip pass				√						
	Passing accuracy (chest-height ball) (# caught out of 3)		3	3	3	3	3	3	3	2	2	3
	Ground contact time		0.846	0.968	0.846	0.721	0.743	0.803	0.875	0.825	0.941	0.877
Turning strategy (ground-based)		*Pivot*										
		Stepping (2+ steps taken to turn)	√	√	√	√	√	√	√	√	√	√
	Change of direction time (CODt)											
	Ground-based change of direction critical features	*Backward moving centre of mass*	-	-	+	-	-	*OK*	*OK*	+	+	+
		Head leads body through turn	-	-	+	-	*OK*	+	*OK*	+	+	+
		Small rotational inertia	*OK*	*OK*	+	-	-	*OK*	*OK*	+	+	+
		Full lateral extension of takeoff leg	-	*OK*	-	*OK*	*OK*	-	+	-	*OK*	-
		Large takeoff distance	-	*OK*	-	-	*OK*	-	*OK*	-	*OK*	-
		Ground contact parallel to new direction	-	+	-	-	-	-	-	-	-	-

(see Table AB continued)

N-SAAB Variable			A	B	C	D	E	F	G	H	I	J
Turning strategy (elevated ball)		*Straight approach*	√		√					√	√	√
		Angled approach		√		√	√	√	√			
		Unilateral takeoff (single-leg)	√	√	√			√	√	√	√	√
		Bilateral takeoff (double-leg)				√	√					
	Aerial-based change of direction critical features	*Deep knee flexion prior to takeoff*	-	OK	OK	+	+	+	+	+	+	+
		Rotation prior to takeoff	+	+	+	OK	OK	OK	+	+	+	+
		Narrow arm drive	+	+	-	+	+	+	+	+	+	+
		Knee drive through takeoff	+	+	+	-	OK	+	+	+	+	+
		Rapid head turn	+	+	OK	+	+	+	+	+	OK	+
		Ball at chest	+	+	+	OK	-	OK	+	OK	+	-
		Lower body rotation while airborne	-	-	-	+	-	OK	+	+	-	-
		Bilateral landing (2-footed)				√			√		√	
		Unilateral landing (1-footed)	√	√	√		√	√		√		√
		Full 180˚ turn completed before landing										
		Incomplete 180˚ before landing	√	√	√	√	√	√	√	√	√	√
	Catch and release time (elevated ball)		0.652	0.522	0.89	0.954	0.825	0.623	0.624	0.601	0.741	0.618
Passing strategy (elevated ball)		*Release prior to landing*										
		Landing with immediate, high release										
		Landing with delayed, lowered release	√	√	√	√	√	√	√	√	√	√
		Chest pass			√	√		√				√
		Hip pass	√	√			√		√	√	√	
	Passing accuracy (elevated ball) (# caught out of 3)		3	3	3	3	3	3	3	3	3	2
SLCM jump ASI's (<10% desirable)		Vertical	n/a	13.7	6.9	2.3	14.8	3.1	3.8	4.1	n/a	7.7
		Horizontal (forward)	n/a	0.3	0.4	4.5	1.9	10.1	8.7	4.0	1.8	9.4
		Lateral	n/a	7.5	8.0	0.7	6.9	5.0	7.6	9.3	3.8	10.3

Player rankings within the squad for catch and release performance times (chest-height ball and elevated ball catch and release movements) are shown in Tables AC and AD. Interestingly, the four slowest catch and release performances for the elevated ball also ranked as the four slowest for the chest-height ball. Additionally, those players performing faster than the squad average for the chest-height ball, didn't necessarily rank equally fast among the squad for the elevated ball catch and release. Those players ranking below average in the chest-height ball task (where the location of the target is known) should have training integrated that focuses on reactive movement time and completing the pass prior to landing (e.g. players D and E), while those players ranking below average in the elevated ball task (where the location of the target is unknown prior to ball possession) should have training integrated that focuses on reactive decision-making (e.g. players C and E).

Table AC: Player rankings among the squad for catch and release time (chest-height ball) where the shaded players are those players performing below the squad average of 0.342 s.

	C & R time
F	0.281
J	0.283
H	0.309
B	0.329
A	0.332
G	0.356
I	0.357
C	0.381
E	0.388
D	0.405

Table AD: Player rankings among the squad for catch and release time (elevated ball) where the shaded players are those players performing below the squad average of 0.705 s.

	C & R time
B	0.522
H	0.601
J	0.618
F	0.623
G	0.624
A	0.652
I	0.741
E	0.825
C	0.890
D	0.954

Table AE shows the player rankings within the squad for ground contact performance times (GCT). Elastic energy is stored in the leg muscles when the player contacts the ground [56]. As long as this energy is utilised immediately (i.e. short GCT) the player is able to explode into the new direction without having to generate as much additional force. Therefore, those players with below average GCT's (e.g. players B, and I) should work on transferring the energy and momentum from the original direction through the turn and into the new direction.

Table AE: Player rankings among the squad for ground contact time where the shaded players are those players performing below the squad average of 0.845 s.

	GCT
D	0.721
E	0.743
F	0.803
H	0.825
A	0.846
C	0.846
G	0.875
J	0.877
I	0.941
B	0.968

Table AF shows the player rankings within the squad for a 180° ground-based change of direction performance. Players are ranked primarily according to their change of direction time (CODt) and secondarily by the inclusion of the critical features listed in Table 3. Of particular note, while Tabitha is successful at incorporating the majority of the critical features, she must work on completing these movements faster for her CODt to improve. On the other hand, several players (i.e. players A, D, and E) must focus on including these features to a greater extent in their COD performance. Finally, various players need to work on extending out of the turn and accelerating straight into the new direction (i.e. players F, J, H and C).

Table AF: Player rankings within the squad for ground-based change of direction technique, where the shaded players represent those players performing below the squad average of 0.671 s for CODt.

Ground-based critical features							
Player	**Backward moving centre of mass**	**Head leads body through turn**	**Small rotational inertia**	**Full extension of takeoff leg**	**Large takeoff distance**	**First ground contact parallel**	**CODt (s)**
F	OK	+	OK	-	-	-	0.544
J	+	+	+	-	-	-	0.570
G	OK	OK	OK	+	OK	-	0.579
H	+	+	+	-	-	-	0.617
C	+	+	+	-	-	-	0.646
I	+	+	+	OK	OK	-	0.670
B	-	-	OK	OK	OK	+	0.711
D	-	-	-	OK	-	-	0.721
E	-	OK	-	OK	OK	-	0.803
A	-	-	OK	-	-	-	0.845

Table AG shows the player rankings within the squad for a 180˚ aerial-based change of direction performance. Players are ranked according primarily to their landing (e.g. bilateral with a completed 180˚ turn) and secondarily by the inclusion of the critical features listed in Table AB. Unfortunately, no player was able to successfully complete a full 180˚ turn prior to landing. All players can benefit from training that is targeted at completing such a movement task. Additionally, several players (i.e. players A, J, C and E) had the majority of scores positive, with the exception of rotating the lower body while airborne. In order to complete an effective landing, players must be more aggressive when rotating the lower body around prior to ground contact.

Table AG: Player rankings within the squad for an aerial-based change of direction technique.

Aerial-based critical features									
Player	**Deep knee flexion**	**Rotation prior to takeoff**	**Narrow arm drive**	**Knee drive**	**Rapid head turn**	**Ball at chest**	**Lower body rotation**	**Bilateral landing**	**Full 180˚ turn**
G	+	+	+	+	+	+	+	+	-
I	+	+	+	+	OK	+	-	+	-
H	+	+	+	+	+	OK	+	-	-
D	+	OK	+	-	+	OK	+	+	-
B	OK	+	+	+	+	+	-	-	-
F	+	OK	+	+	+	OK	OK	-	-
A	-	+	+	+	+	+	-	-	-
J	+	+	+	+	+	-	-	-	-
C	OK	+	-	+	OK	+	-	-	-
E	+	OK	+	OK	+	-	-	-	-

Player rankings for average leg symmetry indexes (ASI) within the squad are shown in Table AH. Players showing a substantial percent difference between legs when performing single-leg countermovement jumps (i.e. greater than 10%) are considered to be atypical and the asymmetry should be addressed in training [82, 87]. It is important to note that a player performing well in one direction, may not necessarily perform equally well in the other two. For example, player F had squad rankings of 2 and 3 for the vertical and lateral directions, respectively with both ASI magnitudes being well below the 10% threshold, but ranked last among the squad for the horizontal direction with an ASI magnitude of 10.1%. This observation is quite disconcerting given that this player is classified as a mid-court/attacking player, performing a large number of high velocity single-leg horizontal movements.

Table AH: Ranked vertical, horizontal and lateral single-leg countermovement jump (SLCM-V, SLCM-H, and SLCM-L, respectively) leg asymmetry where the shaded players have an asymmetry greater than 10%.

Player	**SLCM-V**	***Player***	**SLCM-H**	***Player***	**SLCM-L**
D	2.3	*B*	0.3	*D*	0.7
F	3.1	*C*	0.4	*I*	3.8
G	3.8	*I*	1.8	*F*	5.0
H	4.1	*E*	1.9	*E*	6.9
C	6.9	*H*	4.0	*B*	7.5
J	7.7	*D*	4.5	*G*	7.6
B	13.7	*G*	8.7	*C*	8.0
E	14.8	*J*	9.4	*H*	9.3
I	N/A	*F*	10.1	*J*	10.3

Summary and conclusions

The new netball-specific agility assessment battery (N-SAAB) has the ability to provide coaches and players with information about individual player strengths and weaknesses with two assessment tasks that other agility assessment tools have not been able to do without the use of multiple assessments tasks. From the information available from the N-SAAB, training may be easily adjusted to address the specific components of agility that are found to be lacking within each player, potentially providing the team with a competitive edge.

The perceptual component of agility can now be assessed using a netball-specific assessment tool targeting reactive decision-making. Those players performing below the squad average for a chest-height ball task where the target location is known prior to ball possession, should have training that focuses on completing the pass earlier on (i.e. while still airborne) as opposed to waiting until ground contact has been made. While those players performing below the squad average for an elevated ball task where the location of the target is unknown prior to ball possession, should have training that focuses on reaction time and identifying the appropriate passing option earlier.

As netball is highly dependent upon both ground-based and aerial manoeuvres, the N-SAAB is able to assess both qualities within a player in a netball-specific environment. Players ranking below the squad average for GCT prior to a 180˚ ground-based COD (gbCOD), can benefit from training that targets transferring energy and momentum from the original direction through the turn and into the new direction. This can be achieved through the inclusion of several critical features found to be consistently associated with superior (faster and more effective) gbCOD performances. Additionally, specific components of the gbCOD can be identified that are likely to contribute to a lesser-skilled performance (e.g. rotating with the arms and legs close to the body, fully extending the legs when accelerating out of the turn, etc.).

The aerial COD task (aCOD) appears to be more difficult, as no player was able to successfully complete a 180˚ turn prior to ground contact. Therefore, all players within this squad can benefit from training which targets such a movement task. It is particularly important for players to aggressively drive the legs upward through the takeoff (increasing the time spent in the air and the amount of time available to complete the rotation), and rapidly rotate the lower body around while airborne, allowing for a complete 180˚ turn to be completed prior to landing. When the turn is not completed before ground contact, or when a single-foot (unilateral) ground contact is employed the potential for injury increases as the amount of turning force (torque) is greatly increased upon impact.

Finally, the physical component of agility can be assessed across multiple directions through an average leg symmetry index (ASI), as well as through observation of the body alignment and positioning throughout the netball-specific agility task (N-SAT). For example, collapsing into the weight-bearing leg upon impact may be an indication of a lack of strength or use of the stretch-shorten cycle. Additionally, muscle imbalances between legs are able to be assessed through single-leg countermovement jumps in the vertical, horizontal and lateral directions. This information provides a valuable insight into the multi-directional strengths and weaknesses of players. It is important to recognise that a player performing well in one direction may not necessarily perform equally well in the other two. Therefore, ASI magnitudes that are found to be greater than or equal to the working threshold of 10%, should be addressed in training (through unilateral strength and power training across all three directions) immediately to decrease the potential for injury. When possible, the use of force plates for determining directional-specific ASI magnitudes should be used, as they can provide additional information about leg force and power capabilities as opposed to only jump height and distance measures.

Acknowledgements

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Appendix 18. Technical Report 8 – An individualized agility profile for netball players.

Overview

Background: An agility profile provides coaches and strength and conditioning professionals with information regarding individual player strengths and weaknesses as determined by assessment of a netball-specific agility task. Agility can be divided into three main components that contribute to the success of these movement tasks; technical, physical and perceptual. If a player is found to be lacking in one or more of these areas her overall agility performance may be compromised. Therefore an assessment tool is needed to determine the complete agility performance of individual players so that any weaknesses within a player's profile can be addressed in training.

Aim: To provide coaches and strength and conditioners with a framework by which agility profiles (technical, physical and perceptual) can be developed that identify the strengths and weaknesses of each player and guide coaching/programming to better effect.

Methods: A total of 10 netball players from Auckland's 2010 Under 17 netball squad participated in this study. Each player performed the netball-specific agility assessment battery (N-SAAB) which consisted of; a) three successful trials of a netball-specific agility task (N-SAT), and b) three successful trials each of single-leg countermovement jumps in the vertical, horizontal and lateral directions. The N-SAT included both ground-based and aerial-based change of direction movement tasks, physical strength qualities (i.e. body alignments and control), and perceptual characteristics (i.e. planned and reactive passing).

Results: ***Technical:*** The N-SAAB was able to differentiate individual player strengths and weakness across the three main components of agility. No player was able to release the ball while airborne prior to a bilateral (two-footed) landing. Players E, I and C need additional training that focuses on acceleration technique out of a rapid ground-based change of direction (gbCOD). While Player G needs additional technical training that focuses on completing the gbCOD movements into the turn more effectively. Rapid rotation of the lower body while airborne was lacking in all players' for the aerial-based change of direction (aCOD) performances. ***Physical:*** Leg asymmetry magnitudes of greater than 10% were recorded in the vertical (C = 10.8%, A = 11.0%, E = 14.7% and I = 23.3%) and horizontal (H = 10.8% and I = 12.1%) directions. ***Perceptual:*** While all passes were successfully completed to the upper left position of the target player, passes to the immediate left of the target player had the highest number of incorrect/incomplete passes. One player (Player F) was unable to successfully complete any of her three passing trials while Players H and I ranked in the bottom three of the squad for each of their passes. As these three players lacked a rapid head turn while airborne, it is recommended that this feature be emphasized in training.

Practical implications: All players can benefit from additional technical training which emphasizes the six gbCOD and nine aCOD key technical features. The inclusion of these features will also help decrease players' catch and release time as the target location will be identified earlier due to the rapid head turn immediately following ball possession. A bilateral landing is the recommended landing technique due to the impact force being absorbed by both legs, as well as affording players more options upon landing. Finally, those players identified as having substantial differences in power between legs would benefit from directional-specific leg power training. However, any observed imbalances should be addressed immediately in training to decrease the potential for injury.

A complete agility profile for netball players

The purpose of this assessment was to provide coaches and strength and conditioning professionals with a complete agility profile highlighting the strengths and weakness of individual players when performing tasks that are commonly required in netball.

The purposes of this report are to:

1. Outline the assessment tasks as performed by the players.
2. Determine and articulate individual player strengths and weaknesses within the technical, physical and perceptual characteristics of the performance and provide training information that may be used to address those weaknesses.

Player data has been presented to show:

1. The spread of player results for each aspect of the netball-specific agility assessment battery (N-SAAB).
2. The lowest, average, and highest imbalances between legs (ASI-Average Symmetric Index) for players by rank within the squad.
3. The fastest, average and slowest reactive decision-making performance times for players by rank within the squad.
4. The superior, average and less effective change of direction performances (ground-based and aerial based) for players by rank within the squad.

Training information that can be gained from this analysis is:

1. Players that might benefit from training that addresses directional-specific leg imbalances.
2. Players that might be at a higher risk of injury due to greater leg imbalances or that may not yet be ready to return to play following an injury.
3. Players that might benefit from training that addresses specific ground-based and/or aerial-based technical qualities.
4. Players that might benefit from training that addresses reactive decision-making and/or reactive movement qualities.

Netball-specific agility assessment battery

An agility performance is inclusive of a rapid change in direction and/or velocity in response to an external stimulus where the whole body is affected [1]. There are three main qualities of agility (technical, physical and perceptual) that a player must possess to successfully (safely and effectively) perform and agility task (see Figure AC) [5]. However, when one or more of the components of agility are found to be consistently lacking or absent from the performance, the overall agility performance is likely to be compromised and the potential for injury is increased. If these potential weaknesses in performance can be identified and addressed in training, an advantage over the competition may be gained. Therefore, a netball-specific agility assessment is needed to adequately differentiate between the technical, physical and perceptual characteristics within each player's performance.

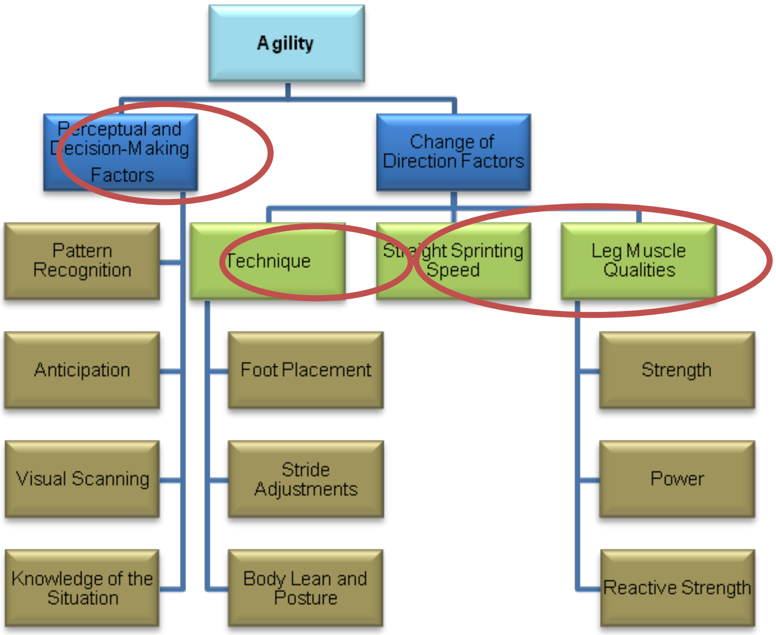


Figure AC: Deterministic model of agility (adapted from Young et al., 2002) with the three main components of agility circled (perceptual, technical and physical).

Subjects

A total of 10 players from Auckland's 2010 Under 17 netball squad participated in this study, the subject characteristic of which can be observed in Table AI. While five players had been recovering from injury at the time of testing, all players had been cleared to participate in this testing by their coach as they had all competed in a national tournament one week prior. The human research ethics committee of AUT University approved all procedures prior to commencing the study. Each participant completed a written informed consent prior to participation and were asked to notify the tester if they found that any of the tasks began to aggravate their injury, wherein they were allowed to withdraw from the testing.

Table AI: Subject characteristics.

Variable	Squad mean ±SD
Age (yrs)	16.2 ±0.8
Height (m)	1.78 ±4.1
Body Mass (kg)	72.3 ±6.2

Equipment and testing set-up

Testing equipment for the single-leg countermovement jumps (SLCM) consisted of a single high speed camera (Casio EX-F1, Casio Computer Co., LTD, Tokyo, Japan) collecting at 300 Hz and a tape measure laid out on the court (see Figure AD). The camera was placed 4 m from the designated start-mark to capture the time in the air for vertical jump trials. The tape measure was anchored to the floor at the start mark and extended perpendicular to the camera to measure the distance jumped for the horizontal and lateral jump trials.

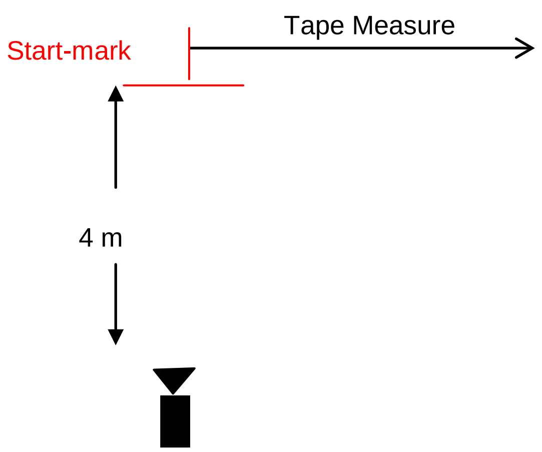


Figure AD: Single-leg countermovement jump set-up.

Testing equipment for the netball-specific agility task (N-SAT) consisted of two high speed video cameras (Casio EX-F1, Casio Computer Co., LTD, Tokyo, Japan) collecting at 300 Hz. The cameras were placed perpendicular to each other at 7 m and 7.2 m away from the players' designated start-mark (see Figure AE). A takeoff mark was placed 2.5 m from the start-mark. A detachable regulation-size netball placed in a netball holder, positioned at approximately chest-height, was located 3.7 m from the designated start-mark. A target player was positioned 5.2 m beyond the netball holder with one of the cameras located between the start-mark and target player at 7.2 m from the start-mark. A second detachable regulation-size netball was elevated at fingertip height for each player and hung over the rim of the netball hoop via bungee cord.

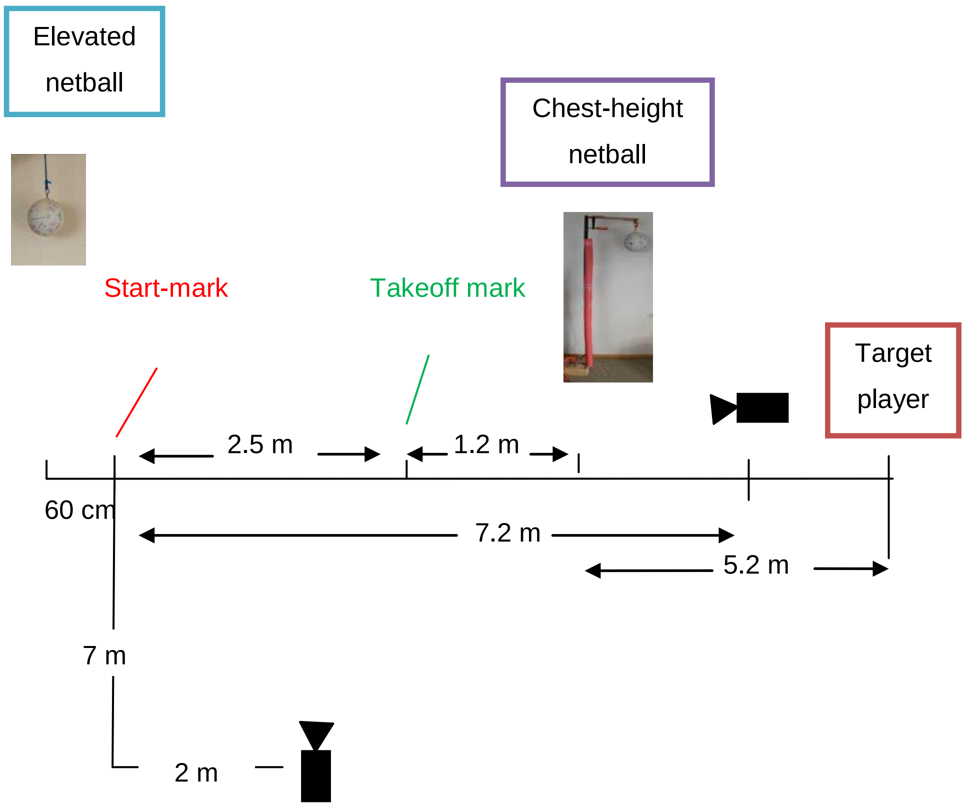


Figure AE: Netball-specific agility task set-up.

Procedures

Testing took place during a single testing session for each subject on a regulation indoor netball court. Upon arrival, the age, height and body mass of each player were recorded. Each player performed a 10 minute dynamic, netball-specific warm-up with their team and was allowed to practice the SLCM and N-SAT until they felt comfortable. No more than three practice trials were taken by any of the players.

Single-leg countermovement jumps

Players were required to perform SLCM jumps in the vertical, horizontal and lateral directions. Beginning with the vertical direction (SLCM-V), then horizontal (SLCM-H) and the lateral direction (SLCM-L), players stood on a single leg with their hands on their hips behind the designated start-mark. For the vertical trials, players stood with the outside of the standing leg (testing leg) facing the camera. For the horizontal trials, players began with the toes of the testing leg to the start-mark. For the lateral trials, players stood with the inside of the testing leg to the start-mark. When ready, the player sunk down and rapidly extended jumping as high (for the vertical direction) or as far (for the horizontal and lateral directions) along the tape measure as possible, landing on both feet. Jump height was measured from high speed video footage using the following formula based on time in the air:

$$\text{Jump height} = \frac{9.81\,(\text{time}_{AIR})^2}{8} \times 100$$

Jump distance was measured from the location of the foot nearest the start mark via tape measure. A trial was considered successful if the hands remained on the hips throughout, if the leg was not tucked into the body while airborne (for the SLCM-V), and if balance was maintained upon landing. Three successful trials on each leg were recorded for each jumping direction.

Netball-specific agility task

Players began at the designated start-mark in a split stance. When ready, the player sprinted 2.5 m, leaping from the takeoff mark and grabbing the chest-height netball while airborne. Upon landing, the player completed a pass as quickly and accurately as possible to the target player positioned in front of her (i.e. catch and release – short phase). Following the ball release, the player completed a 180˚ ground-based turn and sprinted back towards the start-mark (i.e. gbCOD phase). While the player's back was turned, the target player relocated to one of four previously determined random locations (45˚ to the front-left, 45˚ to the front-right, 45˚ to the back left, or 45˚ to the back right). At the start-mark, the player jumped up to grab the elevated netball while airborne, completing a 180˚ aerial turn before landing facing the target player once again (i.e. aCOD phase). Upon landing, the player completed a pass as quickly and as accurately as possible to the relocated target player (i.e. catch and release – long phase). Three successful trials were recorded for each player. A trial was considered successful if the player maintained control of the ball and balance through the landing. Players were instructed to "perform the task as quickly and accurately as possible, as if you were in an actual netball game" to elicit a maximal effort.

Variables of interest for the N-SAAB include:

Technical

1. The extent that key technical features were employed by each player when performing ground-based and aerial-based change of direction movements. These features specifically target the player's effectiveness at completing dynamic approaches, turns and passes.

Physical

2. Catch and release time (C & R time) for both the short (planned) pass and the long (reactive) pass represents the time (in seconds) from ball possession through ball release.
3. Ground contact time (GCT) represents the time (in seconds) from the first foot touchdown following ball possession in the chest-height catch through the take-off of that foot prior to the gbCOD.
4. An average symmetry index (ASI) for each player represented as the percent difference between legs when performing single-leg countermovement jumps in the vertical, horizontal and lateral directions. The following formula was used to determine the ASI:

$$ASI = (|right\ leg/left\ leg|) \times 100 - 100$$

Perceptual

5. Passing accuracy the long (reactive) pass presented as a percentage score out of 3 passes, where a higher percentage is reflective of better accuracy.
6. Catch and release times (with passing accuracy) for each player were also ranked across each of the four passing options.

Results and observations

TECHNICAL

Catch and release phase

Technical observations of individual player approach/landing and passing strategies during the chest-height and elevated ball catches are shown in Table AJ. Most notably, no player was able to perform either of the ball catches with a bilateral landing and half of the players needed at least one additional step after contacting the ground from the horizontal leap. As a bilateral landing is both safer (increased base of support for force absorption) and creates more opportunities upon landing (allowed to step with either foot in multiple directions) than landing on a single foot, this is the technique that should be emphasized in training for all players regardless of position.

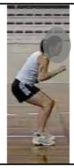
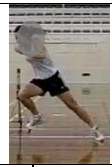
Table AJ: Catch and release technique for the short (planned) pass and the long (reactive) pass (note: features highlighted in red text are the desired performance characteristic).

Technical feature of interest		Players
Horizontal landing strategy (planned pass)	*Limited knee flexion* *Deep knee flexion*	E, G, I, D, C, J, A, F H, B
	Bilateral landing *Unilateral landing*	-------------- All players
	Stuck landing (1 step) *Over-run landing (2+ steps)*	B, D, C, J, F H, E, G, I, A
	Split stance landing *Square stance landing*	All players --------------
Passing stragey (planned pass)	*Ball released in air* *Land prior to ball release* *Land with delayed ball release*	-------------- All Players --------------
	Ball released from chest-height *Ball released from one hip*	All players --------------
Approach strategy (reactive passs)	*Straight* *Angled*	E, G, I, D, C, J, A, F H, B
	Single-leg takeoff *Double-leg takeoff*	H, E, G, D, C, J, F B, I, A
Passing strategy (reactive pass)	*Ball released in air* *Land prior to ball release* *Land with delayed ball release*	-------------- J, A H, E, G, B, I, D, C, F
	Ball released from chest-height *Ball released from one hip*	H, E, G, B, D, C, J, A, F I

Ground-based change of direction phase

Table AK shows the player rankings within the squad for a 180° ground-based change of direction performance. Players are ranked primarily according to their change of direction time (CODt) and secondarily by the inclusion of the key technical features listed in the table. Of particular note, while F is successful at incorporating the majority of the key technical features, she should work on completing these movements faster for her CODt to improve. Several players (E, C and I) have successfully incorporated the key technical features concerning the movements leading into the turn (i.e. backward moving COM, head leading the body, and a small rotational inertia) however, the features concerning extending out of the turn appear to be lacking (i.e. full lateral extension at takeoff combined with a large takeoff distance). These players should focus on increasing the hip extension of the takeoff leg while maintaining a lateral lean into the new direction. In contrast, Player G's acceleration phase includes a full lateral extension of the takeoff leg combined with a large takeoff distance. However, her initial movements leading into the turn appear to be less than optimal. Therefore, this player needs additional technical training for rapid changes of direction focusing on the initial portion of a turn.

Table AK: Player rankings within the squad for ground-based change of direction technique, where the shaded players represent those players performing below the squad average of 0.723 s ±0.1 for CODt.

Superior Performance						
Player (CODt)	**Backward moving centre of mass (COM):** The player begins the movement by first moving the COM outside of the base of support in the direction of travel (i.e. backwards). This will cause the body to move into that direction in order to maintain balance. Also loading of the leg muscles via a deep squat is observed.	**Head leads body:** Early visual identification of the opposition, teammates and available options will allow more time for the player to determine which option is most appropriate.	**Small rotational inertia:** Keeping the arms and legs close to the body (axis of rotation) through the turn allows the player to turn faster.	**Full lateral extension of takeoff leg:** Applying force over a longer time (impulse) will result in increased velocity (f x t = m x v)	**Large takeoff distance:** Large takeoff distance (distance from the COM to the takeoff leg) equals a large step length (SL) which results in increased velocity (v = SL x Step frequency). *Note: When completing additional changes of direction immediately following the initial 180˚ turn, a large takeoff distance in not desired - a higher step frequency will be more beneficial.	**First ground contact parallel to the desired direction of travel:** Applying a force in the same direction as the desired direction of travel will allow the player to accelerate (Force = mass x acceleration) faster into that direction.
J (0.486)	**OK**	**OK**	-	+	+	-
D (0.527)	**OK**	-	+	+	+	-
E (0.587)	+	**OK**	**OK**	-	-	**OK**
C (0.650)	+	**OK**	**OK**	-	-	+
B (0.765)	+	+	+	+	+	-
A (0.807)	**OK**	+	**OK**	+	+	-
G (0.810)	-	-	-	**OK**	+	+
F (0.814)	+	+	+	+	+	**OK**
I (0.885)	+	+	+	-	-	+
H (0.895)	+	+	+	**OK**	**OK**	**OK**

Aerial-based change of direction phase

Table AL shows the player rankings within the squad for a 180˚ aerial-based change of direction performance. For the analysis of the movement, players are ranked according primarily to their landing technique (e.g. bilateral with a completed 180˚ turn) and secondarily by the inclusion of the key technical features listed in the table. Unfortunately, no player was able to successfully complete a full 180˚ turn prior to bilateral landing. Therefore, players were ranked solely based on the inclusion of the remaining seven key technical features.

All players can benefit from training that is targeted at completing such a movement task. The rotation of the lower body while airborne is one of the features that play a large role in the successful completion of the rotation. This feature was also absent in all of the players' performances. Therefore, emphasis should be given to aggressively rotating the lower body around while airborne. Finally, head rotation and ball positioning also appear to be less than optimal in the majority of performances. An early rotation of the head into the new direction allows the player to identify teammates and opponents prior to landing, thereby increasing the amount of time she has to make an appropriate decision for any subsequent movements. Holding the ball close to the body at lower chest-height allows for a quick release pass, as the upper body muscles are in a pre-loaded state.

Table AL: Player rankings within the squad for an aerial-based change of direction technique.

Superior Performance									
Player	**Deep flexion prior to takeoff (TO):** Greater hip and knee flexion at TO result in greater ground reaction forces (GRF) as well as utilization of the stretch-shortening cycle which increases TO velocity and vertical height jumped allowing more time in the air for the body to rotate.	**Rotation prior to TO:** Early initiation of rotation allows the body to begin the 180° turn prior to becoming airborne.	**High arm drive:** A high arm drive through the TO assists in moving the centre of mass (COM) vertically, increasing vertical height of the jump.	**Free leg drive through TO:** Driving the free leg upwards as the weight-bearing leg (TO leg) extends rapidly, assists in moving the COM vertically at TO.	**Rapid head turn:** Early visual identification of the opposition, teammates and available options will allow more time for the player to determine which option is most appropriate.	**Ball at chest height and close to body:** The ball is positioned close to the body for decreased rotational inertia, and at lower chest height in preparation for a rapid pass release.	**Lower body rotation while airborne:** The lower body is aggressively rotated around to complete the rotation prior to ground contact.	**Bilateral landing:** The large impact force of landing is absorbed by both legs simultaneously as opposed to one. Additionally, more options are available for the player as she is able to move off of either foot.	**Full 180° turn completed prior to ground contact:** When a full 180° turn is not completed prior to landing, a greater turning force (torque) must be absorbed upon landing increasing the potential for injury.
G	+	**OK**	+	+	+	+	-	-	-
D	+	**OK**	+	+	**OK**	**OK**	-	-	-
C	+	+	+	**OK**	**OK**	**OK**	-	-	-
E	**OK**	-	**OK**	+	+	+	-	-	-
B	+	+	-	**OK**	**OK**	+	-	-	-
I	**OK**	+	**OK**	**OK**	-	**OK**	-	-	-
H	**OK**	+	**OK**	**OK**	-	-	-	-	-
A	**OK**	+	**OK**	-	-	-	-	-	-
F	**OK**	+	**OK**	-	-	-	-	-	-
J	**OK**	**OK**	-	-	-	-	-	-	-

PHYSICAL

Catch and release time

Player catch and release times for the short and long passes are shown in Figure AF. Interestingly, three out of the bottom-ranking four players for the planned pass, also ranked in the bottom four players for the reactive pass. As a rapid release of the ball (i.e. while still airborne or immediately following ground contact) will decrease the catch and release time, players should strive for early identification of the passing location (i.e. rapid head turn following ball possession), thereby allowing the pass to be completed earlier in the movement task. Additionally, those players ranking below average in both passing tasks, especially the reactive pass where the location of the target is unknown prior to ball possession, should have training that emphasizes decreasing reactive movement time (i.e. early target recognition).

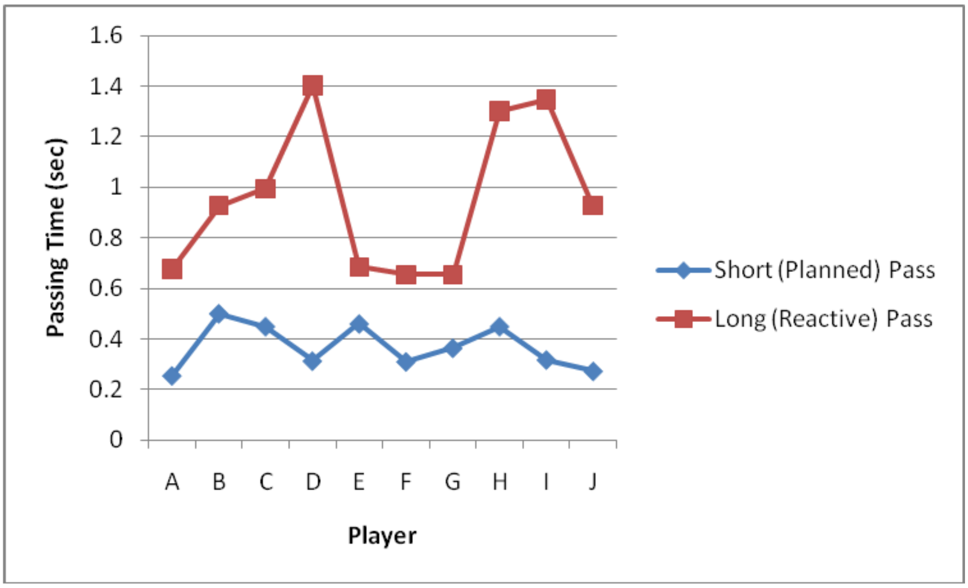


Figure AF: Catch and release times across the squad for the planned and reactive passes.

Ground contact time

Player rankings for ground contact performance times are shown in Table AM. A short GCT time is beneficial prior to a rapid gbCOD in netball. When elastic energy is stored in the leg muscles as the player absorbs the impact force, it can be used to explosively propel the player into the new direction. However, this stored elastic energy can only be used immediately; therefore a short GCT is thought necessary for increased force production at takeoff. If the GCT is long, the elastic energy will be released as heat [56]. Those players with below average GCT's (e.g. Players I, H, etc.) should work on decreasing the time in contact with the ground prior to a gbCOD.

Table AM: Player rankings among the squad for ground contact time where the shaded players are those players performing below the squad average of 0.798 s ±0.2.

Player ranking	Player (GCT)
1	J (0.469)
2	D (0.527)
3	C (0.665)
4	F (0.814)
5	A (0.815)
6	E (0.846)
7	B (0.853)
8	G (0.920)
9	I (0.988)
10	H (1.085)

Average symmetry indexes (ASI)

Player rankings within the squad for average leg symmetry index (ASI) magnitudes across all three directions (vertical, horizontal and lateral) are shown in Table AN. Substantial ASI magnitudes (greater than 10%) are considered atypical when performing single-leg countermovement jumps and training designed to decrease these magnitudes is recommended [82, 87] as percent differences between legs of this magnitude have been associated with an increased risk of injury. Additionally, ASI magnitudes are also able to give insight as to whether a player is ready to return to play following a leg injury, wherein a magnitude greater than 10% would indicate that the player is not yet ready to return to full competition. While three players (Players G, F, and A) opted not to perform the jumps in various directions due to recent injuries, a fourth recently injured player (H) was able to perform the jumps across all three directions (see Table AO). While all four players had competed in a national netball tournament one week prior to testing, the assessed ASI indicates that these players might be at risk of injury or further injury. All four players should continue with their rehabilitation training programme until their ASI magnitudes are decreased below 10%.

Table AN: Player rankings for single-leg countermovement jump ASI in the vertical (V), horizontal (H) and lateral (L) directions, where the shaded players have an ASI magnitude greater than 10%.

Player	**V**	***Player***	**H**	***Player***	**L**
B	0.7	*D*	1.3	*J*	0.5
J	1.3	*B*	2.4	*E*	1.9
H	1.9	*J*	3.1	*C*	3.7
D	4.4	*C*	7.5	*D*	4.3
C	10.8	*E*	7.9	*B*	6.2
A	11.0	*H*	10.8	*H*	7.1
E	14.7	*I*	12.1	*I*	8.5
I	23.3	*A*	N/A	*A*	N/A
G	N/A	*G*	N/A	*G*	N/A
F	N/A	*F*	N/A	*F*	N/A

Table AO: Players identified with recent injuries to the lower body.

Player	**Injury**	**Date injured**	**ASI**		
			V	**H**	**L**
H	Right ankle	2 weeks prior	1.9	10.8	7.1
G	Both ankles	5 weeks prior	N/A	N/A	N/A
A	Left ankle	Unknown	11.0	N/A	N/A
F	Left knee	4 months prior	N/A	N/A	N/A

As these directional-based jumping tasks are assessing independent qualities of each other, so it is important to note that a player performing well in one direction, may not necessarily perform equally well in the other two. For example, Player E had an ASI magnitude above the 10% threshold in the vertical direction (14.7%), but was below the threshold in the horizontal direction (7.9%) and well below the threshold in the lateral direction (1.9%). This observation is somewhat disconcerting as her main playing position is classified as an end-court player whose primary jumping direction is vertical. While any imbalances between legs should be addressed in training, those imbalances that are near or above the 10%

threshold and in the primary jumping direction performed during competition should be addressed immediately to decrease the potential for injury and/or improve performance.

PERCEPTUAL

Catch and release phase

Table AP shows the squad rankings for catch and release time for the reactive pass (long pass) across all four passing options. All passes were successfully completed to the upper left hand of the target player (see Table AQ), while the most errors were made when passing to the immediate left hand of the target player. Additionally, of the 5 total players that performed incomplete or incorrect passes, four had a passing accuracy of 66% while the remaining player (F) was unable to successfully complete any of her three passing trials. Player F should have her training focused on early recognition of the target (i.e. rapid rotation of the head while airborne; which was also found to be lacking in her aCOD performance). Of the successfully completed passes, A (100% accuracy score) ranked in the top two for each of her three passes while Players H and I (also 100% accuracy scores) ranked in the bottom three for each of their passes. The two latter players should have training that emphasizes completing the pass more quickly after the target has been identified as both players head turn and ball positioning while airborne were less than optimal.

Table AP: Player rankings among the squad (per passing option) for catch and release time (C & R) of the reactive long pass where those players shaded in orange have performed incomplete or inaccurate passes.

Squad rank	Upper left	Upper right	Left	Right
1	0.546 (A)	0.660 (F)	0.630 (G)	0.504 (J)
2	0.639 (E)	0.678 (G)	0.654 (A)	0.642 (F)
3	0.702 (G)	0.906 (J)	0.735 (F)	0.699 (A)
4	0.777 (C)	1.203 (B)	0.900 (D)	0.729 (E)
5	0.906 (B)	1.305 (I)	0.948 (J)	0.948 (B)
6	1.287 (H)	1.314 (H)	1.416 (E)	1.212 (C)
7	1.329 (D)	N/A (A)	1.689 (I)	1.479 (D)
8	1.389 (I)	N/A (E)	1.752 (H)	N/A (G)
9	N/A (J)	N/A (C)	N/A (B)	N/A (I)
10	N/A (F)	N/A (D)	N/A (C)	N/A (H)
Mean ±SD	*0.947 ±0.34*	*1.011 ±0.30*	*1.091 ±0.46*	*0.888 ±0.35*

Table AQ: Individual player passing accuracy for the long (reactive) pass as a percentage of correct passes.

Player	Passing accuracy
A	100%
B	100%
C	100%
D	66%
E	66%
F	0%
G	66%
H	100%
I	100%
J	66%

Summary and conclusions

Previous agility assessment tasks have only been able to address up to two out of the three main components of agility. However, the N-SAAB is able to provide prognostic and diagnostic information to coaches and strength and conditioners about individual player performances in all three areas of agility (technical, physical and perceptual). From the information available from the N-SAAB, training may be easily adjusted to address the specific components of agility that are found to be lacking within each player, potentially providing the team with a competitive edge.

<u>TECHNICAL</u>

Ground-based change of direction phase

When transitioning through the gbCOD manoeuvre, a total of six key technical features have been identified as contributing to a faster performance and should be coached throughout training sessions. The most common scenarios observed among players concerning the inclusion of the key technical features are; 1) the features are consistently present in the performance, but need to be performed at a faster rate, 2) the features leading into and including the turn are lacking but accelerating out of the turn is satisfactory, and 3) the features concerning acceleration out of the turn are lacking, but the features leading into and including the turn are satisfactory. As several players from the squad fall within each of these categories, it is recommended that training should emphasize all six features to ensure maximal transference into competition.

Aerial-based change of direction phase

The N-SAT also includes an aerial change of direction task. As the successful performance of this task is commonly lacking among netball players of all skill levels, it is recommended that the nine key technical features be integrated into the training programmes of all netball players. Of particular note is the importance of the lower body mechanics throughout the movement task, as this is where the height of the jump and rotation in the air originates. Special care should be taken to ensure that all players are including a purposeful driving action with the free leg and rotation of the stance leg at take-off, and an aggressive rotation of the body led by the head while airborne. When these features are not executed to the full extent, the rotation will not be completed prior to touchdown and increased torques will be applied to the leg(s) upon landing, thereby dramatically increasing the potential for injury

PHYSICAL

Catch and release phase

During the netball-specific agility task (N-SAT) portion of the assessment battery, each player was required to perform two catch and release sequences; one where the location of the target is known prior to ball possession (planned) and one where the target location is unknown prior to ball possession (reactive). Both scenarios require the player to grab the ball while airborne and complete the pass as quickly and effectively (i.e. safely and accurately) as possible. Unfortunately, no player was able to complete the pass while airborne for either task. Additionally, all players landed on a single leg for both tasks. Training should emphasize; 1) early target recognition through a rapid head turn following ball possession, and 2) landing with both feet simultaneously (bilateral landing). The bilateral landing will increase safety upon landing by dissipating the impact force across both legs, as well as creating more options upon landing (able to move in more directions off of either foot) if the pass was not performed while airborne.

Ground-based change of direction phase

The ground contact time (GCT) is important throughout the ground-based change of direction (gbCOD) as an abbreviated time allows for the usage of the stretch-shortening cycle to increase the amount of energy transferred into the new direction. When the GCT becomes excessive, elastic energy stored in the muscles is lost as heat and the player must generate additional force at takeoff. As the majority of the squad can benefit from decreasing GCT, it is recommended that training should emphasize a rapid contact and maximizing the amount of energy and momentum transferred into the new direction.

Average symmetry indexes (ASI)

Leg symmetry across multiple directions is thought desirable by both coaches and players, as greater imbalances are typically associated with an increased potential for injury and/or decreased performance. Those players identified as having asymmetry greater than 10% in one or more directions would benefit from directional-specific leg power training. However, any observed imbalances should be addressed immediately in training to decrease the potential for injury.

PERCEPTUAL

Catch and release phase

A total of five players performed at least one incomplete/incorrect pass out of the three trials. Of these four players, four only missed one pass, while the remaining player was unable to complete a pass to the appropriate location. Additionally, two players with 100% accuracy for reactive passing ranked in the bottom two for catch and release time for all three of their reactive passing trials. All three of these players lacked a rapid head turn while airborne, which would enable the target location to be identified earlier and the appropriate pass to potentially be release sooner than if the head remained in line with the body through the airborne phase. Therefore, it is recommended that these three players have additional training that emphasizes this key technical feature in order to increase the accuracy and speed of the reactive pass.

Acknowledgements

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