Development, reliability and effectiveness of the Movement Competency Screen (MCS)

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

May 2012

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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 two, three, four and five of this thesis have been published in peer-reviewed journals. Chapters eight, nine, ten and eleven have been submitted and are under review in peer-reviewed journals. Chapters six and seven will not be submitted to peer-reviewed journals. My contribution and the contributions of co-authors to each of these papers are outlined below. All co-authors have approved the inclusion of the joint work in this doctoral thesis. All journals have copyright permissions that allow our journal publications to be included in this thesis for educational purposes. All photos in this thesis are copyright to Matt Kritz. All figures used in this thesis are used with permission from the original authors/journals.

April 2012

Chapter publication reference	Author %
Chapter 2.1 Kritz, M. F., & Cronin, J. (2008). Static posture assessment screen of athletes: Benefits and considerations. *Strength and Conditioning Journal, 30*(5), 18-27.	85% MK, 15% JC.
Chapter 2.2. Kritz, M. F., Cronin, J., & Hume, P. A. (2009). Bodyweight squat: A movement screen for the squat pattern. *Strength and Conditioning Journal, 31*(1), 76-85.	80% MK, 10% JC, 10% PH.
Chapter 2.3. Kritz, M., Cronin, J., & Hume, P. A. (2009). Using the body weight forward lunge to screen an athlete's lunge pattern. *Strength & Conditioning Journal, 31*(6), 15-24.	80% MK, 10% JC, 10% PH.
Chapter 2.4. Kritz, M., Cronin, J., & Hume, P. A. (2010). Screening the upper-body push and pull patterns using body weight exercises. *Strength &*	80% MK, 10% JC, 10% PH.

Conditioning Journal, 32(3), 72-82.	
Chapter 3. Kritz, M., Cronin, J., & Hume, P. A. (Under review). Movement Competency Screen development. Submitted for publication in *Journal of Australian Strength and Conditioning, May 2012.*	80% MK, 10% JC, 10% PH.
Chapter 4. Kritz, M., Cronin, J., & Hume, P. A. (Under review). Movement Competency Screen reliability. Submitted for publication in *Journal of Australian Strength and Conditioning*, *May 2012.*	80% MK, 10% JC, 10% PH.

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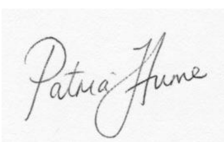
Prof. John Cronin (JC)



Prof. Patria Hume (PH)

ABSTRACT

Movement competency and subsequent production of muscular power is a fundamental concern for sport and health professionals when considering an athlete's long-term athletic development and injury prevention. The documentation and standardization of a whole body movement competency protocol is practically unexplored. The purpose of this project was to develop a movement-screening tool that would provide the strength and conditioning professional with a straightforward understanding of an individual's movement competency related to fundamental movement patterns performed in activities of daily living, sport and sport specific training.

The first experimental study (Chapter 3) was designed to determine content validity of a movement competency screen (MCS). Participants recommended that a movement competency screen should involve between 5-10 complex movements, use a combination of quantitative and qualitative analytic techniques, require no equipment to complete the movement screen and represent each of the fundamental movement patterns: squatting, lunging, upper body pushing, upper body pulling, trunk flexion, trunk rotation and single leg squatting.

The second experimental study (Chapter 4) investigated the intrarater and interrater reliability of the MCS. Intrarater reliability ranged from 0.73 to 1.00 with the overall average (Kappa = 0.93) indicating almost perfect agreement between raters. Interrater reliably for the MCS was 0.79 indicating substantial agreement.

The third experimental study (Chapter 5) explored participant perception of the effectiveness of the MCS. Utilizing a seven point Likert scale in a sixteen-question user satisfaction survey, participants indicated that overall they strongly agreed (6 ±0.9) that the MCS was an effective screening tool.

The final experimental study (Chapter 6) was a pilot study designed to investigate the construct validity of the MCS. There were trivial to moderate effect sizes with large confidence limits for the comparisons between the MCS score and the physical performance measures (lower limb power, running speed, upper

limb power) of the participants. The only clear effect was for the comparison between lower limb MCS scores and lower body power for females (moderate effect -0.88; CL ±1.05).

The final chapter (Chapter 7) of this thesis provides applied recommendations for using the MCS to determine movement competency and inform exercise prescription. How to use the MCS to screen movement competency is detailed as well as how the load levels determined by the results of an individual's MCS performance inform the exercise prescription process. In addition, a sample introductory training program is introduced, which was designed based on motor control theory, which has stated that to influence motor control movement repetition is considered best practice.

Further evidence of the applied significance and acceptance of the MCS was evident from its current application within the strength and conditioning and physiotherapy professions in New Zealand, Malaysia, Philippines, Australia, and North America. The MCS has also been utilized as an educative tool to shape the curricula of several sport and recreation papers within tertiary institutions in New Zealand. The MCS is currently used by High Performance Sport New Zealand within the strength and conditioning and physiotherapeutic disciplines to guide strength training and rehabilitation exercise prescription. National sporting organizations such as New Zealand Cricket, Netball New Zealand, Hockey New Zealand, Swimming New Zealand, and Yachting New Zealand use the MCS as part of their national talent identification and physical performance assessment battery.

ACKNOWLEDGEMENTS

Professor John Cronin. Thank you very much for your guidance and friendship. Your kind spirit has made this journey possible for both my family and myself. I will be forever grateful for your belief in my ability and your vision that strength and conditioning research should always lead to superior applied practice.

Professor Patria Hume. Thank you very much for your professionalism, time and energy. Your contribution has enriched this project a great deal.

Nicole Kritz. My north star, this PhD project has been a life changing experience for you and our magnificent children Mason, Maclain and Layla. I am indebted to you for your love and support. Thank you and I love you forever.

David Frost. Friendship is the essence of creation. You have made me a better man. I will always cherish the knowledge and guidance you have offered, and I will value your friendship forever.

Barry Kritz. A son does not realize the strength his father bestows upon him until he faces life's challenges. Thank you Dad for your strength, love and unconditional support.

Belinda Kritz. Thank you Mom for your love, support and belief in my ability to achieve.

Ruth Kritz. Thank you Mom for your unconditional love and support. Your pride in my success is forever motivational.

Rebecca Kritz. My little sister, thank you for your unconditional love. It means the world to me.

Andrew Kritz. My little brother, thank you for your support.

Granny and Grandpa Ross. I DID IT! Thank you for being my biggest fans.

Grandma Jean. Thank you for your endless support and faith.

The rest of my family and friends. There are too many of you to acknowledge in this publication but you know who you are, and I would like you to know that your support has motivated me to complete this great achievement.

High Performance Sport New Zealand. Thank you for the opportunity to live my passion in a world leading high performance sporting environment.

Sport Performance Research Institute New Zealand (SPRINZ), AUT University. Thank you for providing the necessary resources and funding via a scholarship to make this project a success.

Participants. I would like to extend a heartfelt thanks to the many willing participants who volunteered their time and energy to this research project. The MCS would not be what it is today without your contribution.

ABBREVIATIONS USED THROUGHOUT THIS THESIS

Variable Nomenclature	Variable definition
MCS	Movement Competency Screen
MCP	Movement Competency Paradigm
S&C	Strength and Conditioning
FMS	Functional Movement Screen
CL	Confidence Limits
SAS	Statistical Analysis Systems
SPSS	Statistical Package for the Social Sciences
SD	Standard Deviation

RESEARCH OUTPUTS RESULTING FROM THIS DOCTORAL THESIS

PEER REVIEWED JOURNAL PUBLICATIONS

Kritz, M. F., & Cronin, J. (2008). Static posture assessment screen of athletes: Benefits and considerations. *Strength and Conditioning Journal, 30*(5), 18-27.

Kritz, M. F., Cronin, J., & Hume, P.A. (2009). Bodyweight squat: A movement screen for the squat pattern. *Strength and Conditioning Journal, 31*(1), 76-85.

Kritz, M., Cronin, J., & Hume, P.A. (2009). Using the body weight forward lunge to screen an athlete's lunge pattern. *Strength & Conditioning Journal, 31*(6), 15-24.

Kritz, M., Cronin, J., & Hume, P.A. (2010). Screening the Upper-Body Push and Pull Patterns Using Body Weight Exercises. *Strength & Conditioning Journal, 32*(3), 72-84.

JOURNAL MANUSCRIPTS CURRENTLY UNDER PEER REVIEW

Chapter 3. Kritz, M., Cronin, J., & Hume, P.A. (Under review). Content Validation of the Movement Competency Screen. Submitted for publication in *Journal of Australian Strength and Conditioning, May 2012.*

Chapter 4. Kritz, M., Cronin, J., & Hume, P.A. (Under review). Reliability of the Movement Competency. Submitted for publication in *Journal of Australian Strength and Conditioning*, *May 2012.*

CONFERENCE PRESENTATIONS AND/OR PUBLICATIONS

Kritz, M. Movement Competency Paradigm: New Zealand Manipulative Therapy Association, *Rotorua*, New Zealand, 2011.

Kritz, M. Movement Competency Paradigm: YMCA Build Conference, Auckland, New Zealand, 2010

Kritz, M. Movement Competency Screen: YMCA Build Conference, Auckland, New Zealand, 2009

Kritz, M. Movement Competency Screen: Function to athletic. *Australian Strength and Conditioning National Conference*, Gold Coast, Australia, 2009.

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Kritz, M. Movement competency assessment of athletes. *New Zealand Academy of Sport High Performance Symposium,* Wellington 2008.

Kritz, M. Athlete periodization model. *New Zealand Academy of Sport High Performance Symposium,* Wellington 2008.

Kritz, M. Posture, and sports performance: Ethical considerations for the strength coach. *Australian Strength and Conditioning National Conference*, Gold Coast, 2007.

CHAPTER 1. INTRODUCTION

1.1 Thesis rationale

There has been an investment within the sport and health professions to better understand the movement competency of athletes and the impact athletes' movement competency has on athletic performance and the incidence of soft tissue injuries (Alentorn-Geli et al., 2009a, 2009b; Kiesel, Plisky, & Voight, 2007b; Myer, Chu, Brent, & Hewett, 2008; Paterno, Myer, Ford, & Hewett, 2004). Movement competency has been defined as the cognitive awareness and technical quality of an individual's movement strategies (M. Kritz, Cronin, & Hume, 2009a). The way an individual moves and subsequently activates muscles, influences joint loading (Hewett, Torg, & Boden, 2009; Myer, Ford, & Hewett, 2004), which can influence injury risk and can change the way metrics, such as strength and power are expressed during human movement tasks (Vanrenterghem, Lees, & Clercq, 2008). Factors that have been reported to influence an individual's movement competency include kinesthetic awareness, changes in muscle length, strength, stiffness and repeated movement patterns and/or sustained postures performed during activities of daily living and/or sport participation (Alentorn-Geli et al., 2009a, 2009b; Neely, 1998).

A review of sport and health research indicates poor movement competency may have a negative influence on the incidence and magnitude of injuries (Chaudhari et al., 2007; Kiesel, Plisky, & Butler, 2009; McLean et al., 2005; Minick et al., 2010; Myer, Ford, & Hewett, 2010). Yet, there does not appear to be an empirically valid and reliable battery of assessments designed to determine and standardize how an individual's movement competency is measured for the purpose of guiding exercise prescription and progressing physical adaptation to training. The research that has investigated injury mechanisms has reported a variety of movement tasks within their methodologies (Ford, Myer, & Hewett, 2003; Hewett, Snyder-Mackler, & Spindler, 2007; Paterno et al., 2010; Whatman, Hing, & Hume, 2011). However, little if any detail is provided regarding the validity of the movement tasks used in the aforementioned research. In addition, the research reviewed failed to provide guidelines on how to use the movement task in an applied situation for the purpose of assessing movement competency on a regular basis. The movement tasks typically used in medical screenings of athletes are rooted in physiotherapeutic ideology.

Physiotherapy assessment ideology historically utilizes muscular strength and extensibility as foundations for diagnosis based primarily on the isometric assessment of uniarticluar motion (Cook, 2003; Mottram & Comerford, 2008). Medical professionals who have formalized training and specific education in movement impairment syndromes subscribe to these methodologies and are well trained to utilize them. Although this type of assessment is accepted within the medical and physiotherapy profession, recent critics have claimed that traditional physiotherapy assessments fail to connect injury mechanisms to movement strategies performed during the execution of activities of daily living and/or sport participation and therefore lack an applied impact (Minick et al., 2010).

1.2 Originality of the thesis

There is only one movement screen that has achieved wide spread applied acceptance with limited empirical scrutiny. The Functional Movement Screen© (FMS) was developed for the purpose of improving the communication between sport and health professionals by providing information about an individual's functional movement ability using specialized equipment and seven fundamental movement tasks (Minick et al., 2010). The development of the FMS has not been reported as a peer reviewed tool. Recent studies that have investigated the reliability and effectiveness of the FMS have not reported the validity of the FMS. The lack of peer reviewed and empirically scrutinized movement-screening protocols is problematic when one considers the popularity of strength training in youth to elder populations and the nature and magnitude of soft tissue injuries in those populations (Radelet, Lephart, Rubinstein, & Myers, 2002; Swenson, Yard, Fields, & Comstock, 2009; Watson, 2001). Considering the large amount of research by sport and health professionals and the pragmatic interest by strength and conditioning professionals to standardize a movement screening protocol that can assist with identifying movement strategies related to common injury mechanisms, the objective of this thesis was to undertake original research to develop and standardize a movement competency screening protocol. Specifically this project aimed to ask professionals what they felt a movement screen for athletes should entail and then use a mixed empirical methodology to create a screening tool that could effectively provide an athlete with an opportunity to demonstrate their movement competency. Furthermore, to our knowledge this research project has undertaken original research by investigating how the movement screening tool was perceived by users post development and the relationship between the results of the developed movement competency screening tool to general athletic performance and the incidence and severity of injury within an elite athlete population.

1.3 Thesis organisation

The overarching purpose of this thesis was to develop a movement competency screening tool for strength and conditioning professionals that could effectively provide an athlete with an opportunity to demonstrate their movement competency. To address this purpose as a cohesive whole, the thesis consists of seven separate but inter-related chapters (See Figure 1). Chapter two is a review of the literature pertaining to how assessing specific movement patterns may provide an opportunity to better understand an individual's movement competency. Specifically, topics such as how a static standing posture (a popular screening task) assessment may provide insight into an individual's dynamic movement strategies and the theory that purports the use of fundamental movement patterns to screen an individuals' movement competency is explored. As such this chapter provides fundamental information for the ensuing studies/chapters. Chapters three (studies one and two), four (study three), five (study four) and six (study five) are the experimental studies that feature the development, reliability and effectiveness of the movement competency screen. Due to the dearth of empirical research that has investigated movement screens and the fact that the data from studies one and two was collected and analysed during the writing of the literature review, the author's felt that the literature reviewed for this thesis should focus on educating readers about the theory that underpins the use of fundamental movement patterns to screen movement function. Also, the fact that this thesis was undertaken as a collection of peer-reviewed publications there is some repetition in content between the review and experimental chapters. However, preludes are provided for each of the experimental studies/chapters to show the linkages between these studies/chapters and the literature reviewed where appropriate. The final discussion chapter consists of general conclusions and applied recommendations for sport and health practitioners about how the movement competency screen may be used to identify faults in gross fundamental movement and how that information may be used to inform exercise prescription. References have been collated at the end of the final chapter. The appendices present relevant peripheral material including informed consent forms, ethics approval and subject information sheets, the SAS code used for data analysis, and the MC 100 tool.

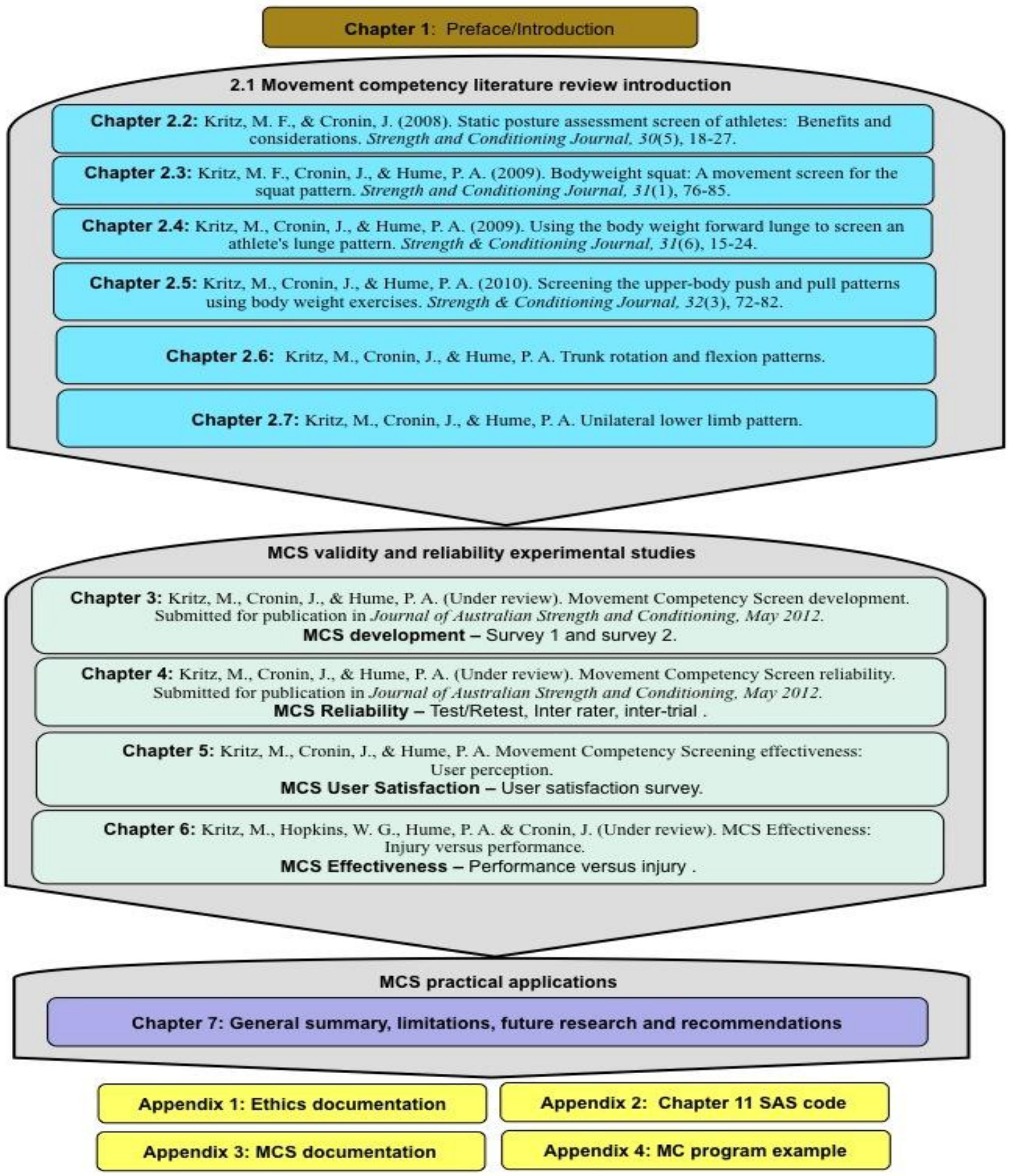

Figure 1. Overview of the PhD thematic sections and chapters to investigate the development, reliability and effectiveness of the Movement Competency Screen (MCS).

CHAPTER 2. LITERATURE REVIEW

2.1 Introduction

In recent years there has been a growing interest within the sport and health professions to assess the movement capability of athletes using various movement-screening tools designed to identify faulty movement patterns (Butler, Plisky, Southers, Scoma, & Kiesel, 2010; Kiesel et al., 2009; Kiesel, Plisky, & Voight, 2007a; Minick et al., 2010; F. G. O'Connor, Deuster, Davis, Pappas, & Knapik, 2011). The benefit of identifying faulty movement patterns in athletes may be intuitive, however, the research available that has investigated the use of movement to objectively assess movement competency is very limited.

There is research that has used “functional” movements to identify injury mechanisms (Alentorn-Geli et al., 2009a, 2009b; Kiesel et al., 2007b; Myer, Chu, et al., 2008; Paterno et al., 2004). However, the movements used in the aforementioned research are not part of a standardized empirically researched screening protocol. Rather, the movements used to assess movement function typically are considered sport specific and therefore valid because they attempt to replicate the movement and demand experienced by the individual in a sporting context (Hewett, Myer, Ford, et al., 2005; Hewett, Snyder-Mackler, et al., 2007). The purpose of this literature review is not to review concepts of athletic screening, the types that traditionally occur in athletic environments (e.g. medical, musculoskeletal, cardiac, etc.), or dissect information espoused by The World Health Organizations (WHO) as it relates to criteria for screening movement. Nor do we feel it necessary to discuss or review the global utilization of athletic screening that is underpinned by medical theory. The primary purpose of this literature review is to provide the reader with an understanding about movement competency from a strength and conditioning rather than a medical/physiotherapeutic perspective. This is achieved by discussing literature in and around fundamental movement patterns.

Fundamental or “primal” movement patterns as they have been referred to are movement patterns that have been identified to exist in varying degrees in activities of daily living, sport and sport specific training

(Chek, 2000; Cook, 2003; Kendall, McCreary, Provance, Rodgers, & Romani, 2005; Sahrmann, 2002). Shirley Sahrman, Gray Cook, and Paul Chek are recognized specialists who advocate that screening movement using movements that are common, familiar, and performed regularly in activities of daily living, sport and sport specific training. Such movements provide great insight into movement strategies that have been identified to contribute to mechanisms of soft tissue pain, discomfort and/or injury.

It is for the aforementioned reasons that this thesis was undertaken to develop a screening tool for strength and conditioning (S&C) professionals. Since S&C professionals are responsible for loading movement, the author's believe that a review of the literature pertaining to movements that are commonly loaded within a strength-training environment is fundamental to this thesis and the development of a screening tool. Such a review should enable a better understanding of what constitutes good movement related to the fundamental movement patterns used by S&C practitioners. To achieve this literature pertaining to posture and seven bodyweight movement tasks (squatting, lunging, upper body pushing, upper body pulling, trunk rotation, trunk flexion and single leg squatting) have been reviewed.

2.2 Static posture assessment screen of athletes: Benefits and considerations

Parts of this chapter have been published in Kritz, M. F., & Cronin, J. (2008). Static posture assessment screen of athletes: Benefits and considerations. Strength and Conditioning Journal, 30(5), 18-27.

According to many authors, posture is the alignment and maintenance of body segments in certain positions (Cook, 2003; Gracovetsky, 1988; Hrysomallis & Goodman, 2001; Kendall et al., 2005; Masse, Gaillardetz, Cron, & Abribat, 2000). Britnell et al., (2005) defined good posture as a state of muscular and skeletal balance, which protects the supporting structures of the body against injury or progressive deformity. In this review we shall consider posture as standing static posture, which has been defined as a situation where the centre of gravity of each body segment is placed vertically above the segment below. Bloomfield (1998), Roaf (1977) and Norris (1995) added that good posture is present when the line of gravity passes through the centre of each joint just anterior to the midline of the knee and through the greater trochanter, bodies of the lumbar vertebrae, shoulder joint, bodies of the cervical vertebrae, and the lobe of the ear, placing the body in equilibrium resulting in all internal forces equalling zero (Figure 2). A definition of optimal standing static posture that may resonate with the sport and health professional is when the least amount of physical activity is required to maintain body position in space and that which minimizes gravity stresses on body tissues (2002). Tables 1 and 2 detail a summary of the reported assessment criteria for static standing posture for each body segment from the front and side views.

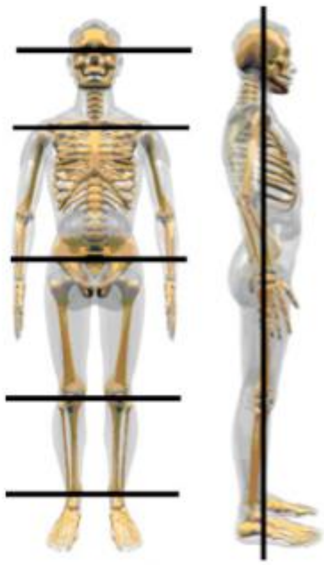

Figure 2. How optimal static standing posture is determined from the front and side viewpoint. Reproduced under copyright permissions for educational purposes, www.wikimedia.org.

Table 1. Optimal posture criteria when assessing a person from the front.

Anatomical region	(Kendall et al., 2005)	(Sahrmann, 2002)	(A. W. S. Watson & C. Mac Donncha, 2000)	(Bloomfield, 1998)
Head	Neutral position neither tilted nor rotated	NR	NR	Head erect
Shoulders	Level, not elevated or depressed	Positioned slightly below the horizontal axis through the first thoracic vertebrae	Straight, one shoulder is not higher than the other	Shoulders straight
Scapulae	Neutral position, medial borders essentially parallel and approximately 3 to 4 inches apart	Vertebral border of the scapula is parallel to the spine and is positioned approx. 3 inches from the midline of the thorax	NR	Spine straight
Thoracic spine	Straight	NR	Straight, no lateral curve of the spine	Spine straight
Lumbar spine	Straight	NR	Straight, no lateral curve of the spine	Spine straight
Pelvis	Level, both posterior superior iliac spines in the same transverse plane	Hips level	NR	Level
Hip joints	Neutral position, not adducted or abducted	Neutral position, not adducted or abducted	NR	NR
Lower Extremities:	Straight, not bowed or knock-kneed	Straight, not bowed or knock-kneed	Neutral position, neither internally or externally rotated	NR
Feet	Parallel or slight out-toeing. Outer malleolus and outer margin of the sole of the foot in same vertical plane so that the foot is not pronated or supinated. Tendo calcaneus should be vertical when seen in posterior view.	Neutral position with no signs of pronation or supination	NR	Feet pointed straight

(*NR = not reported)

Table 2. Optimal posture criteria when assessing a person from the side.

Anatomical region	(Kendall et al., 2005)	(Sahrmann, 2002)	(A. W. S. Watson & C. Mac Donncha, 2000)	(Bloomfield, 1998)
Head	Neutral position not tilted forward or back	NR	Neutral position not tilted forward or back	Neck erect, chin in
Cervical spine	Normal curve, slightly convex anteriorly	NR	NR	Chest elevated
Scapulae	Flat against the upper back	Flat against the upper back	Flat against the upper back	Shoulders centred
Thoracic spine	Normal curve, slightly convex posteriorly	Slight posterior curve	Normal curve, slightly convex posteriorly	Upper back normally rounded
Lumbar spine	Normal curve, slightly convex anteriorly	Forward convex curve	Normal curve, slightly convex anteriorly	Trunk erect, abdomen flat, lower back normally curved
Pelvis	Neutral position, anterior-superior spines in the same vertical plane as the symphysis pubis	Anterior superior iliac spine (ASIS) is in the same vertical plane as the symphysis pubis	NR	NR
Hip joints	Neutral position neither flexed nor extended	Neutral position neither flexed nor extended	NR	NR
Knee joints	Neutral position, neither flexed nor hyper extended	Neutral position, neither flexed nor hyper extended	Neutral position, neither flexed nor hyper extended	NR
Ankle joints	Neutral position, leg vertical and at a right angle to the sole of the foot	NR	Neutral position, leg vertical and at a right angle	NR

(*NR = not reported)

The benefit of good standing posture on movement efficiency has indirectly received much attention in the scientific literature. The focus of most posture research is related to health and productivity in the work place. The benefits of good posture may be assumed but not entirely understood. Bloomfield (1998), Britnell et al., (2005) and Dalton (2006) stated that the advantages of having good posture are both mechanically functional and economical, with the least use of energy occurring when the vertical line of gravity falls through the supporting column of bones where the body does not have to continually adjust its position to counter the forces of gravity. How this may be conceptualized in a strength-training environment may be when an athlete with rounded shoulder posture performing a pushing and pulling movement may need to first adduct and medially rotate the scapulae in order to be in the correct dynamic posture position. These anticipatory strategies that contribute to faulty movement patterns are less efficient, causing the athlete to expend extra energy in order to prepare to perform a safe and technically proficient pushing or pulling movement (Forthomme, Crielaard, & Croisier, 2008; Kebaetse, McClure, & Pratt, 1999). In addition, these anticipatory strategies have been purported to negatively influence power production (Meyer et al., 2008; Morriss & Bartlett, 1996; Wang & Cochrane, 2001). Faulty movement is a deviation from the ideal pattern of motion, which requires an alteration of the normal counterbalancing action of muscular synergists (Sahrmann, 2002). According to researchers, posture assessment indicates the presence of muscle impairments, which can be associated with movement impairments (Bloomfield, 1998; Britnell et al., 2005; Dalton, 2006; Grimmer, Dansie, Milanese, Pirunsan, & Trott, 2002; Hrysomallis & Goodman, 2001; Kendall et al., 2005; Roaf, 1977; Sahrmann, 2002; Watson, 2001; A. W. Watson & C. Mac Donncha, 2000).

2.2.1 Biomechanical factors of static and dynamic posture

In order to gain a more clear understanding into how standing static posture may influence movement a review of key biomechanical principles, such as equilibrium and the work-energy relationship, that influence movement efficiency is necessary. Equilibrium is a state characterized by balanced forces and torques (S. J. Hall, 2007). In other words there is no wasted energy or unnecessary force production to accommodate body segments that are out of alignment. A body that is in equilibrium would theoretically be able to produce forces more efficiently (S. J. Hall, 2007). This work-energy relationship involves force production over a distance. A baseball pitcher with limited range of motion in his shoulders and or hips would have difficulty producing the same work and power output as an athlete with greater shoulder and or hip range of motion. Any restriction, imbalance or malalignment within the musculoskeletal structure can affect optimal ROM and thus the quality of force production, force application and movement efficiency.

2.2.2 Sport specific postural adaptation

There are a variety of postural deviations observed in athletes that appear to be advantageous to the production and application of force (Bloomfield, 1998). Some coaches believe there is value in promoting certain abnormal postures due to the mechanical advantage that is gained in performance. The sport and health professional would be remiss if they did not consider the lack of practical research supporting the advantages of sport specific postures.

Only two researchers, Bloomfield (1998) and Watson (1983) , have devoted a significant amount of time investigating sport specific postures (see Table 3). Table 3 summarizes the postural deviations that are indicative of high-level athletes in certain sports based on Bloomfield and Watson’s research. Below is a detailed explanation as reported in the literature of some of the sport specific postures identified in Table 3, and how those postures either correlated to sport performance or the incidence of injury.

Table 3. Common postural deviations categorized by sport

Sport	Medial tibial torsion (Pigeon Toe)	Lateral tibial torsion (Duck feet)	Hyper extended Knees	Lordosis / Anterior Pelvic Tilt	Scoliosis	Flat back	Kyphosis	Round shoulders
American Football				X (Bloomfield)				
Australian Football				X (Bloomfield)				
Basketball	X (Bloomfield)			X (Bloomfield)				
Boxing	X (Bloomfield)						X (Bloomfield)	X (Bloomfield)
Field Hockey	X (Bloomfield)			X (Bloomfield)	X (Bloomfield)		X (Bloomfield)	X (Bloomfield)
Gaelic Football	X (Bloomfield)			X (Watson)				
Gymnasts				X (Bloomfield)				
Hurling				X (Bloomfield)	X (Watson)		X (Bloomfield)	X (Watson)
Judo							X (Bloomfield)	X (Bloomfield)
Lacrosse	X (Bloomfield)			X (Bloomfield)	X (Bloomfield)		X (Bloomfield)	
Racquetball	X (Bloomfield)							
Rugby	X (Bloomfield)			X (Watson)				
Soccer				X (Watson)			X (Bloomfield)	
Squash	X (Bloomfield)							

Swimming (Freestyle)	X (Bloomfield)		X (Bloomfield)		X (Bloomfield)		
Swimming (Backstroke)	X (Bloomfield)		X (Bloomfield)				
Swimming (Butterfly)	X (Bloomfield)		X (Bloomfield)				
Swimming (Breaststroke)		X (Bloomfield)					
Track & Field (Distance)					X (Bloomfield)		
Track & Field (Jumpers)				X (Bloomfield)			
Track & Field (Mid-Distance)				X (Bloomfield)			
Track & Field (Sprints)				X (Bloomfield) (Watson)			
Track & Field (Throwers)				X (Bloomfield)			
Volleyball	X (Bloomfield)			X (Bloomfield)			
Wrestling						X (Bloomfield)	X (Bloomfield)

*As reported in (Bloomfield, 1998) and (Watson, 1983b)

2.2.3 Shoulder girdle

The shoulder girdle, which is made up of the clavicles and the scapulae, is a complex structure that is capable of varied and impressive mechanical abilities (S. J. Hall, 2007). Even though the shoulder girdle is considered the most mobile joint in the human body, due to its structure and function, it requires substantial stability (Cook, 2003; S. J. Hall, 2007; Kendall et al., 2005). Athletes participating in sports that utilize the shoulder for performance such as swimming and throwing may be subjected to specific postural adaptations. Bloomfield (1998), noted that swimmers competing in sprint events (200 meters and shorter) had square shoulders, upright trunks, and possessed long clavicles and large scapulae. This postural adaptation, which appears to provide lower levels of flexion and extension, seems beneficial for accommodating an increased stroke rate. In contrast, distance swimmers, who are noted for longer stroke length, are observed with abducted scapulae and rounded shoulders, thus an increase in flexibility of the shoulder girdle (Figure 3) (Bloomfield, 1998). Overhead throwing athletes display abducted scapulae and rounded shoulder posture as well (Bloomfield, 1998). It has been alleged that this posture is in part due to an increased length of the serratus anterior muscle, which from a biomechanical perspective allows the throwing athlete to increase the time and distance that force can be applied (Sahrmann, 2002) again affording more impulse and work respectively as a result a harder or longer throw. Additionally athletes involved in contact sports have been observed with abducted scapulae and rounded shoulder posture. It is theorized that this posture is beneficial because it allows the athlete to assume a tuck or covered up position quickly while running into defenders (Bloomfield, 1998).

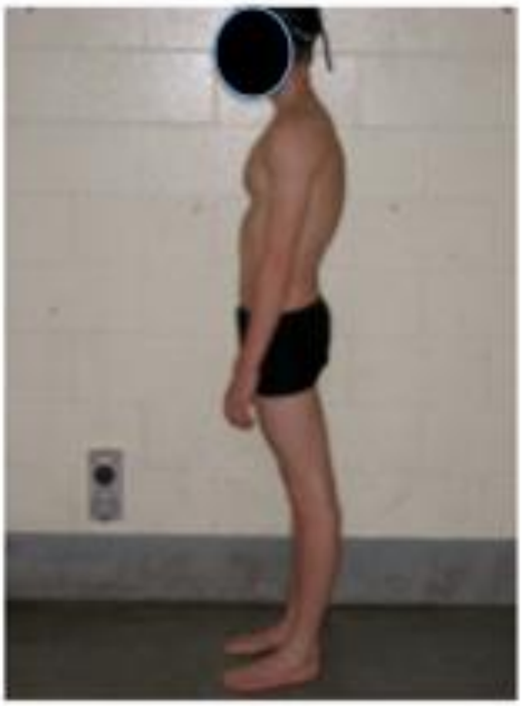

Figure 3. Static standing posture side view of a nationally ranked swimmer.

2.2.4 Lumbar and hip

The most commonly reported sport specific postural adaptations of the trunk and hip region are lordosis and anterior pelvic tilt (Bloomfield, 1998; Watson, 1983b, 2001). Lordosis is considered to be an increase in the anterior curve of the lumbar spine resulting in an anterior tilt of the pelvis (Kendall et al., 2005; Li, McClure, & Pratt, 1996; Roaf, 1977; Sahrmann, 2002; Watson, 1983b, 2001; A. W. Watson & C. Mac Donncha, 2000). Anterior pelvic tilt is a condition where the pelvis is positioned forward, resulting in flexion of the hip joint; the low back arches forward, creating an increased forward curve of the lumbar spine i.e., lordosis (Figure 4) (Kendall et al., 2005). Field sport athletes and sprint runners are typified by varying degrees of lordosis and anterior pelvic tilt (Bloomfield, 1998; Watson, 1983b). The results of Watson's investigation of posture and participation in sports involving 181 male athletes, 17 to 20 years of age, from 15 different sports are summarized in Table 4. The principle finding was that lordosis was significantly greater for those men who played football and soccer as compared with other sportsmen (Watson, 1983b). A secondary outcome of this study was the analysis of eleven soccer players over three years. The player's posture was assessed three times (beginning, middle and end) during the duration of the study. It was established that the lordosis of eight of the eleven players significantly increased with their participation in soccer (Watson, 1983b). An additional study by Watson (Watson, 1981) involving 61 rugby players from the under 15, under 16 and Senior rugby teams of an Irish school, observed lordosis as the most common postural deviation (28%).

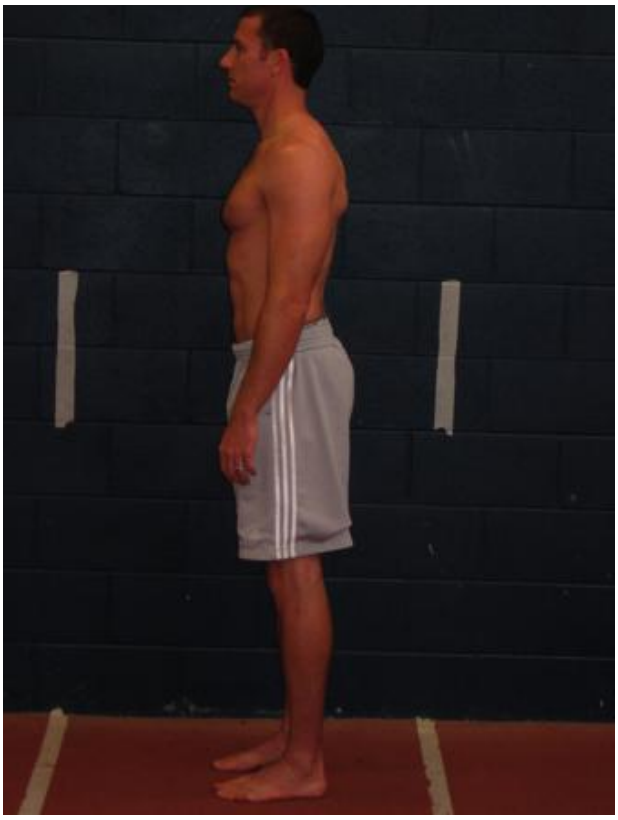

Figure 4. Athlete displaying lordotic posture with anterior pelvic tilt.

Table 4. Results of posture screening performed on 181 athletes

	Lordosis		
Posture rating	Soccer, Gaelic, Rugby (98)	Hurlers	Other sportsmen (83)
2 and below	9 (9%)	NR*	0
2.1 to 3.0	24 (24%)	NR*	15 (18%)
3.1 to 4.0	39 (40%)	NR*	28 (34%)
4.1 to 5	26 (27%)	NR*	40 (48%)
	Scoliosis		
Posture rating	Soccer, Gaelic, Rugby	Hurlers (23)	Other sportsmen (158)
2 and below	NR*	0	1 (.01%)
2.1 to 3.0	NR*	7 (30%)	16 (10%)
3.1 to 4.0	NR*	10 (43%)	31 ((20%)
4.1 to 5	NR*	6 (26%)	110 (70%)
	Abducted Scapulae		
Posture rating	Soccer, Gaelic, Rugby (15)	Hurlers (23)	Other sportsmen (143)
2 and below	0	5 (22%)	7 (.05%)
2.1 to 3.0	0	7 (30%)	29 (20%)
3.1 to 4.0	8 (53%)	8 (35%)	63 (44%)
4.1 to 5	7 (47%)	3 (13%)	44 (31%)
	Flat Feet		
Posture rating	Soccer, Gaelic, Rugby, Hurlers (80)		Other sportsmen (101)
2 and below	18 (23%)		20 (20%)
2.1 to 3.0	38 (48%)		30 (30%)
3.1 to 4.0	21 (26%)		32 (32%)
4.1 to 5	3 (.04%)		19 (19%)

Rating scale = (5) ideal posture, (4) minor deviation, (3) significant deviation, (2) marked deviation, (1) severe deviation (*NR = not reported) (Watson, 1983b)

Researchers and sports medicine professionals have attributed the lordosis observed in field sport athletes to adaptation from sport participation and specific training methods designed to strengthen muscles considered to contribute to performance (Bloomfield, 1998; Watson, 1983b, 2001). For example, specific training methods have been designed to overdevelop the psoas and iliacus muscles for improved kicking power and knee lift for improved running performance (Watson, 2001). The muscular adaptation to this type of training can increase the anterior tilt of the pelvis. The advantages of anterior pelvic tilt are believed to be an increased hip extension, allowing the running and jumping athlete to apply force over a longer time resulting in a greater impulse. However, athletes with increased anterior pelvic tilt and significant lumbar lordosis often experience an increased incidence of low back pain (Liao & Drury, 2000; Nadler, Wu, Galski, & Feinberg, 1998; Radelet et al., 2002; Sahrmann, 2002; Sinaki, Itoi, Rogers, Bergstralh, & Wahner, 1996).

2.2.5 Lower limb

It has been proposed that players involved in sports requiring quick steps within a short distance are likely to possess pigeon toe posture of the feet (see Figure 5) (Bloomfield, 1998). The reason for this postural adaptation is thought to be caused by tibial torsion shortening the hamstring muscle group, preventing the individual from taking long steps (Bloomfield, 1998). It has also been observed that swimmers (depending on stroke speciality) display pigeon toe (Figure 5) or duck foot posture and knee hyperextension (Figure 3) (Bloomfield, 1998). It is alleged that hyper-extended knees are the result of the cruciate ligaments of the knees being slowly stretched with the repetition of kicking (Bloomfield, 1998). While there is no experimental evidence to support the benefits of the aforementioned lower limb postural abnormalities in swimmers, it has been theorized that the pigeon toe posture affords greater propulsive force from the feet, and increased knee hyperextension allows for a greater kicking range of motion and hence more work performed during the kick.

Figure 5. Athlete with pigeon toe posture.

Although there is a lack of research supporting the advantages of postural deviations of the lower limb for improving sport performance, there is a significant body of research that has investigated the affects of these postures on the nature and magnitude of lower limb injury. Eighty male athletes who competed in Gaelic football and hurling over four years were involved in a four-year experimental design study, in which posture was assessed. Participants sustained on average 3.01 injuries per year or a combined 962 significant sport injuries over the four-year period. Participants who sustained ankle sprains had a higher incidence of postural defects of the ankle and knee (Watson, 1999). Several studies have reported overuse injuries of the lower extremity due to faulty alignment of the feet and knees, however it was not reported if the postural deviations were due to high level sport participation (Beynnon, Renstrom, Alosa, Baumhauer, & Vacek, 2001; Dubravcic-Simunjak, Pecina, Kuipers, Moran, & Haspl, 2003; Kaufman, Brodine, Shaffer, Johnson, & Cullison, 1999; Korpelainen, Orava, Karpakka, Siira, & Hulkko, 2001; Witvrouw, Bellemans, Lysens, Danneels, & Cambier, 2001).

2.2.6 Practical applications

Optimal standing static posture is when the least amount of neuromuscular activity is required to maintain body position in space and minimizes gravitational stresses on the body. The biomechanical rationale for achieving and maintaining optimal posture is to move efficiently, free of impairment and dysfunction. It is not clear if the sport specific postures discussed in this review are truly beneficial to sport performance or merely an adaptation of committed sport participation void of specific interventions designed to develop a balanced body. It is therefore not clear if loading sport specific postures will yield performance enhancements or increase the incidence of injury. Further research needs to be conducted to ascertain the benefit of training with sport specific postures. Due to the information reported in this review, it appears a relationship between static posture and dynamic movement may exist. Therefore, assessing static standing posture may enable the sport and health professional to identify areas of the body where muscle impairments may contribute to postural abnormalities that are associated with movement impairments. The information attained from a static standing posture assessment may assist the sport and health professional in developing specific strengthening interventions in order to enhance performance and possibly reduce the incidence of injury.

2.3 Bodyweight squat: A movement screen for the squat pattern

This chapter have been published: Kritz, M. F., Cronin, J., & Hume, P. A. (2009). Bodyweight squat: A movement screen for the squat pattern. Strength and Conditioning Journal, 31(1), 76-85.

2.3.1 Introduction

The bilateral squat (squat) is one of the most prevalent exercises reported in the sport science (Escamilla, Fleisig, Lowry, Barrentine, & Andrews, 2001; Flanagan, Salem, Wang, Sanker, & Greendale, 2003; Fry, Smith, & Schilling, 2003; Isear, Erickson, & Worrell, 1997; Walsh, Quinlan, Stapleton, FitzPatrick, & McCormack, 2007). The popularity of the squat is certainly a reflection of its practicality. Humans throughout time have used variations of the squat pattern to perform various tasks associated with activities of daily living (Abelbeck, 2002; Chek, 2000). A significant amount of research has been dedicated to establish the resisted squat as an effective exercise for enhancing strength and power performances (Abelbeck, 2002; Caterisano et al., 2002; Dionisio, Almeida, Duarte, & Hirata, 2006; Donnelly, Berg, & Fiske, 2006; Escamilla, 2001; Escamilla et al., 2001; Fry et al., 2003). However, given the prevalence of the squat pattern in activities of daily living and strength training programming what is not as well researched is the use of this fundamental movement to better understand an athlete's movement competency. It has been proposed that the ability to perform a bodyweight squat at or below 90 degrees of knee flexion with balance, symmetry and coordination is an indicator of overall movement quality (Cook, 2003). Conversely, the inability to perform a bodyweight squat at or below 90 degrees of knee flexion with balance, symmetry and control may imply generalized stiffness throughout the body, or restricted joint mobility and/or stability within the kinetic chain (Cook, 2003). This review discusses what has been reported in the literature to be proper bilateral squat kinematics. In addition, a biomechanical rationale is provided to substantiate the kinematics described.

A squat can be described as flexing at the hip and knee joints, and descending until the top part of the thigh at the hip joint is lower than the knee joint, then ascending by extending the knee and hip joints to return to the start position (Keogh, Hume, & Pearson, 2006). Each of the major joints of the lower body (i.e. foot, ankle, knee and hip) and the lumbar and thoracic spine of the upper body require degrees of stability and mobility to ensure a competent squat pattern occurs (Sahrmann, 2002). When screening the squat it is worthwhile to be familiar with each joints primary anatomical function and their contribution to movement efficiency. In addition, it is equally important for the sport and health professional to appreciate the change to force production and efficiency of movement when a break down in stability and mobility appear. The variables that may affect an athlete's ability to perform a deep bodyweight squat with symmetry, coordination and balance have been identified as anthropometrics, handedness, previous injury, lack of coordination, range of motion and balance (Abelbeck, 2002; Adrian & Cooper, 1995; Cook, 2003; Escamilla et al., 2001; Escamilla, Lander, & Garhammer, 2000; Flanagan et al., 2003; Harman, 2000; Sahrmann, 2002; Salem, Salinas, & Harding, 2003). Table 5 details what has been reported to be the proper position of each major segment and joint during the upward and downward phase of a bilateral squat. Figure 6 illustrates the variations detailed in Table 5. The sections below describe the kinematics of the squat with kinetic rationale where possible.

Table 5. Summary of the bilateral squat pattern screening criteria

Downward and upward movement phases of a bilateral body weight squat				
Anatomical Region	Baechle (Baechle, Earle, & Wathen, 2000)[A]	Bloomfield (1998)[B]	Kinakin (Kinakin, 2004)[C]	Summary[D]
Head	Neutral position	Held up	Neutral position	Neutral
Thoracic spine	Flat – maintain torso to floor angle	Angled slight forward and held straight	Flat – maintain torso and shin angle	Slightly extended
Lumbar spine	Flat – maintain torso to floor angle	Curved slightly inward	Flat – maintain torso to shin angle	Neutral
Hip joints	Flexed	Flexed	Flexed, remain under the shoulders	Flexed and aligned
Knees	Flexed – knees aligned over the feet	Flexed	Flexed, knees over the feet	Aligned with feet
Feet / Ankles	Shoulder width / remain on the floor	Shoulder width, toes pointing forward	Shoulder width stance	Flat not rolling in or lifting up

Figure 6. Bilateral squat pattern illustrating the MCS criteria

2.3.2 Head stability

There is little research that has investigated the effects of head position on squat kinematics and kinetics. Of the research conducted, it was found that when the head position and direction of gaze was directed downward a significant increase in hip and trunk flexion was observed (Figure 7) (Donnelly et al., 2006). Movement of the head with a downward direction of gaze during the squat can increase trunk flexion up to 4.5 degrees (Donnelly et al., 2006). Therefore the researchers stress the concern with maintaining proper direction of gaze, head alignment and minimizing head movement during squatting to decrease the amount of lumbar and thoracic flexion (Donnelly et al., 2006; Kendall et al., 2005; Sahrmann, 2002).

Figure 7. Squat pattern (A) Downward direction of gaze resulting in greater trunk flexion (B) Neutral direction of gaze resulting in a more optimal trunk position

2.3.3 Trunk mobility and stability

According to researchers, the angle of the trunk in relation to the ground should remain constant throughout the downward and upward phase of the squat movement demonstrating trunk stability and control (Baechle et al., 2000; Kinakin, 2004). When screening the trunk during movement, any forward movement and/or thoracic and/or lumbar flexion and extension (Figure 8a, 8b) are considered contraindications (Kendall et al., 2005; Kreighbaum & Barthels, 1996; Sahrmann, 2002). Given the prevalence of lower back pain and injuries experienced by athletes it is critical that lumbar stability be maintained, especially during loaded squatting movement tasks (Figure 8c) (S. M. McGill, 2006). When athletes perform a loaded squat with the load placed across the shoulders and do not prohibit the movement of the lumbar spine and maintain appropriate thoracic spine extension, an increase in compressive and shear forces of the lumbar spine has been observed (S. M. McGill, 1992, 2006). Loaded squatting with excessive lumbar extension (curved back) dramatically increases compressive forces (Walsh et al., 2007). A two degree increase in extension from a neutral spine position increased compressive stress within the posterior annulus by an average of 16% (Walsh et al., 2007). This is particularly important because researchers have found that some athletes significantly hyperextend when lifting heavier (60% and 80% of 1RM) loads (Walsh et al., 2007). Further research has demonstrated that the compressive strength of a vertebral body was reduced by 30% if ten loading cycles were applied with lumbar flexion (Adams & Dolan, 1995; Brinckmann, Biggermann, & Hilweg, 1988; Walsh et al., 2007). To this end, researchers maintain that a neutral lumbar spine position with appropriate thoracic extension is recommended when squatting under load to minimize the shear and compressive forces experienced by the lumbar spine (S. M. McGill, 1992, 2006; Walsh et al., 2007).

Figure 8. A squat pattern with (A) lumbar flexion present at the bottom of the movement (B) thoracic extension (C) neutral spine

2.3.4 Hip mobility

The hip joint is a ball-and-socket joint that is capable of motion in all three anatomical planes of motion: sagittal (flexion and extension), frontal (abduction and adduction) and transverse (medial and lateral rotation) (C. M. Hall & Brody, 2005). Due to the structure and anatomical function of the hip joint it has been classified as a mobility joint that does require significant stability for effective force production and transference (C. M. Hall & Brody, 2005). Activities such as running, throwing and hitting require coordination of the kinetic chain. As well as activities, such as loaded squatting, where the upper extremity is required to isometrically stabilize the trunk to support the lower extremities ability to generate the force necessary to extend the hip and knee (C. M. Hall & Brody, 2005). Hip range of motion is considerable with flexion between 0 and 135 degrees and extension between 0 to 15 degrees (C. M. Hall & Brody, 2005). During squatting mean hip range of motion has been reported to be 95 ±27 degrees of flexion (Hemmerich, Brown, Smith, Marthandam, & Wyss, 2006). Hip range of motion can appear greater if pelvic and lumbar motion are allowed to take place during squatting (C. M. Hall & Brody, 2005; Hemmerich et al., 2006).

Posterior movement of the pelvis during the descent and lumbar flexion at the bottom of the squat are movement strategies that have been reported to allow for greater hip mobility (Alter, 1996; C. M. Hall & Brody, 2005; Hemmerich et al., 2006; Kendall et al., 2005; Kinakin, 2004; Sahrmann, 2002).

However these strategies are contraindicated due to significant stress placed on the lumbar region of the spine. In addition, when hip mobility is poor it has been observed during squatting that a common compensatory pattern emerges in the form of increased trunk flexion (Kreighbaum & Barthels, 1996; S. M. McGill, 2006). Unfortunately, there was no data reported on the forces experienced by the hip joint during squatting with either a mediolateral rotation of the hip or a lateral dipping of the hip.

2.3.5 Knee stability

The knee joint is the largest joint in the body and is a modified hinge joint made up of the tibiofemoral and patellofemoral joints, which enable flexion in a posterior direction and extension in the anterior direction (Alter, 1996; Kendall et al., 2005). The knee has been classified as a stability joint due to its ligament and tendon structure and function as a hinge with limited mediolateral or anteroposterior movement capability (Cook, 2003; Escamilla, 2001; Escamilla et al., 2000; Kendall et al., 2005; Sahrmann, 2002). Given the knees predilection for stability, the mediolateral control of the knees during lower limb movement tasks like squatting is critical (Baechle et al., 2000; Bloomfield, 1998; Kinakin, 2004). The qualitative guideline often used to assess lower limb function is the position of the knee in relation to hip and ankle during loaded activities such as squatting, landing from a jump or running (Dahlkvist, Mayo, & Seedhom, 1982; Dionisio et al., 2006).

There is a plethora of research that has investigated how knee joint position influences the kinetics experienced by the kinetic chain (Abelbeck, 2002; Dahlkvist et al., 1982; Dionisio et al., 2006; Escamilla, 2001; Escamilla et al., 2001; Escamilla et al., 1998; Escamilla et al., 2000; Fry et al., 2003; Hattin, Pierrynowski, & Ball, 1989; Kingma, Bosch, Bruins, & van Dieen, 2004; Newton et al., 2006; Salem et al., 2003; Toutoungi, Lu, Leardini, Catani, & O'Connor, 2000; Wilk et al., 1996). It has been reported that during a loaded squat, failure to maintain knee alignment in relation to the hips and feet increases the stability requirement of the ligaments and tendons that support the knee (Abelbeck, 2002; Dahlkvist et al., 1982; Escamilla et al., 2001; Escamilla et al., 1998). The compressive (push together) and shear (resistance to sliding) forces created as a result of a misaligned joint experiencing load has been observed to weaken the support structures of the knee over time (Escamilla, 2001; Escamilla et al., 2001; Escamilla et al., 2000; Fry et al., 2003; Salem et al., 2003). It has been well documented that excessive shear forces can damage the cruciate ligaments and too much compressive forces can injure the menisci and articular cartilage (Escamilla et al., 2000). During a bodyweight squat patellofemoral compressive forces have been reported to be 3.75 - 4.6 times bodyweight and shear forces ranged from 1.5 to 3.5 times bodyweight (Dahlkvist et al., 1982; Escamilla, 2001; Escamilla et al., 1998; Escamilla et al., 2000; Hattin et al., 1989; Toutoungi et al., 2000; Wilk et al., 1996).

There have been a number of reasons reported in the literature as to why the knees may not maintain alignment with the hips and feet during a ground based lower limb movement task like squatting. A frequently reported explanation for the knees failing to maintain alignment has been faulty structure and function of the joints and musculature directly above and below the knee (Cook, 2003; Kendall et al., 2005; Sahrmann, 2002). The biarticular muscles, the hamstrings, and rectus femoris that attach to the hip and knee joints, as well as the gastrocnemius that attach to the knee and ankle joints, disadvantage the knee if they are underdeveloped and lack appropriate flexibility or are underutilized and activate in the wrong sequence (Alter, 1996). Two of the most commonly reported patterns of movement that may contribute to knee dysfunction and pain are medial or lateral motion of the knees when observing the squat from the front (Figure 9) and excessive anterior motion (Figure 10) when observing the squat from the side (Alter, 1996; Escamilla, 2001; Fry et al., 2003; Kendall et al., 2005; Kinakin, 2004; Sahrmann, 2002). Excessive mediolateral movement of the knees or vargus (Figure 9A) and valgus (Figure 9B) frontal plane movement have been in part attributed to poor pelvic stability and improper function of the rectus femoris, hamstrings and hip abductor and adductor muscles (Claiborne, Armstrong, Gandhi, & Pincivero, 2006; Sahrmann, 2002). The kinetic consequence of mediolateral movement of the knee during a squat pattern is not as well understood. Those studies that have quantified mean torque during vargus and valgus movement in the frontal plane generally use open chain movements (e.g. seated leg extension) not closed chain movements (e.g. bodyweight squat) (Claiborne et al., 2006).

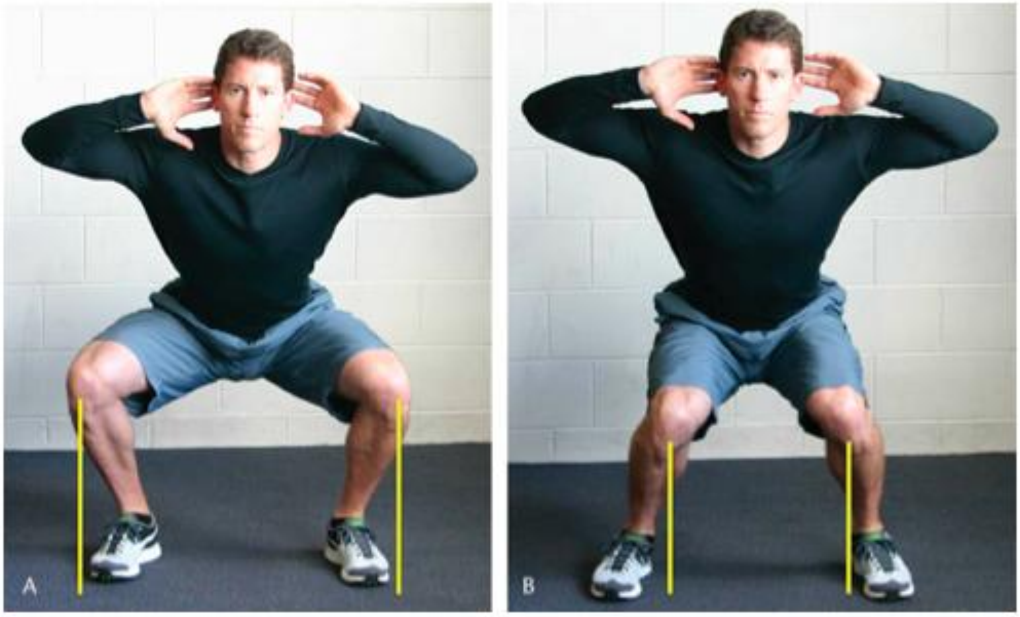

Figure 9. Squat pattern with (A) a varus lower leg position (B) a valgus lower leg position.

Figure 10. Squat pattern performed with excessive forward motion of the knees in front of the toes

Extreme anterior motion of the knees, where the knees move past the toes and in some cases where the heels elevate off the ground to accommodate this technique is strongly discouraged (Figure 10) due to the increased shear and compressive forces experienced at the knee (Fry et al., 2003). Conversely, aggressively restricting the knees to ensure they remain behind the toes during a squat is not advocated either. There is a natural degree of anterior motion that will occur with each individual during a squat movement task if all other kinematic variables are controlled. Aggressively restricting any anterior motion of the knees has been observed to dramatically increase the anterior lean of the trunk and shank (Fry et al., 2003). An increase in the forward lean of the trunk has been reported to increase the forces experienced by the lumbar spine (Fry et al., 2003). Increased forces experienced by the lumbar spine during squatting should not be considered a contraindication unless the lumbar spine is unable to maintain a stable position during the movement task. Later in this chapter, lumbar spine mechanics during squatting will be addressed in greater detail.

Another squat technique that has been reported to be a contraindication to the knee joint occurs when the centre of rotation for knee flexion is altered (Kreighbaum & Barthels, 1996). This may occur when the calf and the hamstrings muscles make contact during a deep squat (Figure 11A). The internal torque about the knee and hip occurs in the posterior direction during a deep squat given the majority of the athletes' mass is moving back and down. The torque about the hip and knee occurs posterior to the femur and as a result pulls back on the anterior cruciate ligament (ACL). If an athlete fails to control the descent of a deep squat and allow the hamstring and calf muscles to make contact in a ballistic fashion the posterior torque about the hip and knee has been reported to create a dislocating effect on the ACL (Kreighbaum & Barthels, 1996). However, if good knee alignment is maintained and the decent is controlled then the danger is mitigated and the centre of rotation at the knee is only marginally affected (Figure 11B) (Kreighbaum & Barthels, 1996).

The kinetics about the hip, knee and ankle related to hip, knee and ankle range of motion has been reported (Cibulka & Threlkeld-Watkins, 2005; Kendall et al., 2005; Osternig, Ferber, Mercer, & Davis, 2000; Sahrmann, 2002). A study involving 22 healthy male and female adults measured the kinetics of the hip, knee and ankle during a bilateral squat to a self-selected depth (SQ) and a squat to a chair (CSQ). For all participants the CSQ required greater hip, knee and ankle range of motion than the SQ. The maximum hip flexion angle obtained from the CSQ was 7.2% greater than that of the SQ ($p = 0.03$) (Flanagan et al., 2003). Consequently, the maximum knee flexion and ankle dorsiflexion angles for the SQ were 20.4% ($p = 0.005$) and 70.7% ($p = 0.001$) greater than those obtained from CSQ (18). Although the structure and function of the participant's hips was not reported, the authors of this study suggested that the technique used to perform CSQ versus the SQ might be worth investigating further. Based on the higher knee and ankle ranges reported, the authors thought that the SQ technique might not have controlled for anterior displacement of the knee, hence why higher knee and ankle flexion angles were recorded. In terms of the CSQ results, the authors further purported that due to the fact that sitting back onto a chair requires greater hip function; consequently, less knee and ankle flexion was observed. This has potentially strong implications for practitioners to understand how movement technique can be altered using props like chairs or benches to challenge the lower limb musculature in a different and potentially "safer" manner (Flanagan et al., 2003).

Figure 11. Deep squat pattern with (A) the hamstrings touching the calves at the bottom of the movement resulting in the center of rotation of the knee moving back to the area of contact (B) a controlled descent resulting in no contact between the hamstrings and calves musculature

2.3.6 Ankle mobility

The ankle joint complex consists of three joints: the talo-crural joint, the subtalar joint and the tibiofibular joint (Kendall et al., 2005; Vickerstaff, Miles, & Cunningham, 2007). The motions that take place at the ankle joint complex are dosiflexion, plantarflexion, inversion, eversion and axial rotation (Vickerstaff et al., 2007). Given the ankle's range in all three planes of motion and since none of the aforementioned motions take place exclusively at one joint, the ankle has been classified as a mobility joint requiring stability to provide unimpeded ranges of motion (Vickerstaff et al., 2007).

There are many factors, such as injury, that may influence an athlete's ability to perform a deep, balanced and coordinated squat. During the performance of a squat, ankle mobility is critical to ensure the muscular load experienced by the kinetic chain is appropriate (10). The ability of the athlete to maintain a flat and stable foot position during a deep squat provides the base for good ankle dorsiflexion (Alter, 1996; Cook, 2003). Ankle dorsiflexion is obviously greater when the knee is flexed due to the influence of the two-joint muscle, the gastrocnemius, which crosses both the ankle and knee joints (Alter, 1996). A benchmark ankle range of motion for a squat was not found, but during the stance phase in gait ankle range of motion was reported to be 25 degrees of motion; 15 degrees coming from plantar flexion and 10 degrees from dorsiflexion (Escamilla et al., 2001; Vickerstaff et al., 2007).

Stiffness in the ankle joint resulting in poor dorsiflexion range of motion may cause the muscles above and below the ankle to compensate (Alter, 1996; Cook, 2003; Sahrmann, 2002). Compensation may have negative implications to the stability required at the foot and knee for efficient mobility at the ankle to occur (Sahrmann, 2002). Dionisio and colleagues have reported that when performing a deep squat the centre of pressure in the foot moved toward the heel during the ascent (Dionisio et al., 2006). Allowing the heels to rise off the ground during a squat has been observed to create compensatory torques about the ankles, knees, hips and lumbar spine (Dionisio et al., 2006; Escamilla et al., 2001; Kingma et al., 2004). The compensatory torque has been reported to increase the torque experienced by the hip, knee and ankle during a competent squat (Alter, 1996; Escamilla, 2001; Escamilla et al., 2001; Escamilla et al., 1998; Sahrmann, 2002). With the heels raised off the ground during the ascent, the centre of pressure is restricted which may affect the athlete's ability to perform a balanced, controlled squat. Kovacs et al. reported mean force to be 2.1 and 1.5 times greater ($p < 0.05$) during ankle flexion and extension respectively, when performing a squat with the heels raised in contrast to the heels being firmly planted on the ground (Kovacs et al., 1999). The increased torque alone may not be a cause for concern during low threshold squatting movement tasks; however, the increased torque coupled with high loads sustained over a long period of time may contribute to unnecessary wear on the joints and over time degradations in performance may occur.

2.3.7 Practical applications

The literature reviewed promoted foot stability, ankle mobility, knee stability, hip mobility and trunk stability to enable proper squatting mechanics to be demonstrated. A foundational understanding of the kinematics and kinetics of the ankle, knee, hip, lumbar and thoracic spine and head has been provided. It was reported that a variety of movement strategies may be used to achieve a deep squat position and that attention should be given to how squat depth is achieved. Movement strategies that promote malalignment and poor body position may increase the compressive and shear forces at the ankle, knee, hip, lumbar and/or thoracic spine. It appears that a simple body weight bilateral squat may be used to better understand the movement strategy of an athlete before the sport and health professional prescribes a program that substantially loads the squat pattern.

2.4 Using the body weight forward lunge to screen an athlete's lunge pattern

This chapter has been published: Kritz, M., Cronin, J., & Hume, P. (2009). Using the body weight forward lunge to screen an athlete's lunge pattern. Strength & Conditioning Journal, 31(6), 15-24.

2.4.1 Introduction

The lunge pattern is one of seven movement patterns that is considered fundamental to activities of daily living, sport and sport specific training (Chek, 2000). Lunging forward in place is considered one of the most popular lunge pattern exercises, perhaps due to the fact that It has been reported to exaggerate the movement that occurs in the lower body during the gait cycle (Crill, Kolba, & Chleboun, 2004). A variety of lunge pattern exercises have been identified in the literature as effective movement tasks for assessing strength, flexibility and balance (Cook, 2003; Crill et al., 2004; Thijs, Tiggelen, Willems, De Clercq, & Witvrouw, 2007). However, the forward lunge has been the most commonly used lunging movement task and will be the focus of the literature review (Alkjaer, Simonsen, Magnusson, Aagaard, & Dyhre-Poulsen, 2002; Boudreau et al., 2009; Brandon, 2007; Crill et al., 2004; Hefzy, Al Khazim, & Harrison, 1997; M. Kritz et al., 2009a). Therefore, this review aims to investigate the relevance of the forward lunge to activities of daily living and sport preparation and participation. Further discussion will be dedicated to better understanding if the sport and health professional would benefit from using the forward lunge to better understand movement awareness and functional capacity related to lunge pattern movements. Existing empirical evidence highlighting the regions of the body that have been identified to be areas most susceptible to breakdowns in lunging technique are presented. Biomechanical rationale will be provided to assist the reader in understanding the consequences a faulty lunge technique may have on the incidence of injury and movement performance.

A forward lunge can in the simplest terms be described as an elongated forward step, flexing the lead hip and knee and dorsiflexing the lead ankle while lowering the body toward the floor (Flanagan, Wang, Greendale, Azen, & Salem, 2004; Graham, 2002, 2007). The forward lunge involves calcaneal eversion, talar plantar flexion and adduction, tibial internal rotation, knee flexion, extension and abduction, and hip flexion, extension and adduction (Crill et al., 2004). To better understand how a lunge pattern exercise may assist the sport and health professional with determining an athlete's movement competency, attention should be directed to the regions of the body most challenged by a lunging movement task. The variables that may affect the ability of an individual to complete a proper lunge pattern have been reported to be anthropometrics, handedness, previous injury, lack of coordination, range of motion and balance (Adrian & Cooper, 1995; Cook, 2003; Flanagan et al., 2004; Harman, 2000; Sahrmann, 2002). Table 6 summarizes the reported regions and assessment criteria for the forward lunge movement task. Figure 12 illustrates the summary information detailed in Table 6.

Figure 12. Optimal forward lunge technique, viewed from the side (A) and the front (B)

Table 6. Summarized lunge pattern screening criteria

Anatomical Region	**Optimal Viewing Position**	**Cook (Cook, 2003)**	**Brandon (Brandon, 2007)**	**Graham (Graham, 2002, 2007)**	**Summary**
Head	Front and Side	Centrally positioned	Central over feet, neutral position	Erect facing forward	Straight and centrally aligned
Thoracic spine	Side	Straight	Vertical, shoulder above hips	Erect, shoulders above hips	Straight or slightly extended
Lumbar spine	Side	Neutral	Neutral, no back extension to assist hip extension, remains tall and stable	Erect	Neutral
Hips	Front	Horizontally aligned	NR	Aligned with the lead knee and ankle	Horizontally aligned
Knees	Front and Side	Aligned with the hip and foot	Front knee points forward over the small toes and is above the ankle, back knee flexed	Front knee over the lead ankle	Front knee in line with the small toes and over the lead ankle
Ankles	Front and Side	Front - Aligned with the knee and hip. Side – directly under the knee	Aligned with the knee	Aligned with the knee	Aligned with the knee
Feet	Front and Side	Front foot flat back foot positioned on the toes aligned with the heel aligned with the knee	Front foot flat, back foot on the ball of the foot	Front foot flat, back foot on the ball of the foot	Front foot flat, back foot on the ball of the foot with toes flexed. Both feet aligned and balanced.

2.4.2 Head stability

There is no research that has investigated the effects of head position on lunge kinematics and kinetics. The only research found that investigated head position and direction of gaze on movement kinematics involved the bilateral back squat. Donnelly (Donnelly et al., 2006) found that when the head position and direction of gaze was directed downward a significant increase in hip and trunk flexion was observed during a squat (Donnelly et al., 2006). Movement of the head with a downward direction of gaze during a squat movement increased trunk flexion by up to 4.5 degrees (Donnelly et al., 2006). Although the position of the head during a forward lunge has yet to be empirically studied, intuitively a neutral head position with the direction of gaze focused straight would appear to be the preferred orientation of the head (Graham, 2002, 2007).

2.4.3 Trunk mobility and stability

The forward lunge provides an opportunity for the trunk (i.e. including thoracic and lumbar spine regions) to demonstrate mobility and lumbar spine to demonstrate stability (Graham, 2007). The desired position of the trunk during lunging movement tasks is similar to that of the squat. Lunging with excessive lumbar extension has been reported to dramatically increase compressive forces (Figure 13A) (S. M. McGill, 1992, 2006; Walsh et al., 2007). A two degree increase in extension from a neutral spine position increased compressive stress within the posterior annulus by an average of 16% as compared to maintaining a neutral spine position (Walsh et al., 2007). This is particularly important because researchers have reported that athletes hyperextend to a significant degree when lifting heavier (60% and 80% of 1RM) loads particularly when the hip flexor musculature was in a shortened state (Adams & Dolan, 1995; Brinckmann et al., 1988; Walsh et al., 2007). Researchers have also reported that the compressive strength of a vertebral body is markedly compromised when the lumbar spine experiences load in a flexed position (Figure 13B) (Dunn, Proctor, & Day, 2006; Gatton & Pearcy, 1999; Korpelainen et al., 2001; S. McGill, 2007; S. M. McGill, Grenier, Kavcic, & Cholewicki, 2003; Walsh et al., 2007). According to researchers the trunk should remain vertical with the shoulders over the hips and lumbar spine held in a neutral position (Figure 13C) (Graham, 2002, 2007).

Figure 13. Forward lunge with (A) extended, (B) flexed, and (C) neutral lumbar spine position

2.4.4 Hip mobility

As previous mentioned the hip joint is a ball-and-socket joint that is capable of motion in all three anatomical planes, sagittal (flexion and extension), frontal (abduction and adduction), and transverse (medial and lateral rotation) (C. M. Hall & Brody, 2005; S. J. Hall, 2007). One of the primary roles of the hip joint is to provide stability and mobility to facilitate effective force production by the lower limb for activities such as running and change of direction (C. M. Hall & Brody, 2005). When an athlete performs a forward lunge, the hips should remain parallel with the ground (Brandon, 2007). There should be no mediolateral rotation or lateral dropping of the hip (Brandon, 2007; Cook, 2003). The hips should be stabilized to support the mobility required to facilitate a lunging movement task. During a forward lunge mean hip range of motion has been reported to be 95 ±27 degrees of flexion (Hemmerich et al., 2006). Posterior movement of the pelvis and subsequent lumbar extension are movement strategies reported to allow greater hip mobility (C. M. Hall & Brody, 2005; Hemmerich et al., 2006; Kendall et al., 2005; Kinakin, 2004; Sahrmann, 2002). However, greater hip mobility achieved with poor pelvic and lumbar stability is contraindicated (Figure 13A) (C. M. Hall & Brody, 2005; Hemmerich et al., 2006). Forces at the hip during a forward lunge have been reported to be between 1.25 - 1.31 times bodyweight during the downward and upward phases of the movement task (Flanagan et al., 2004). Therefore, lunging with pelvic and lumbar instability not only increases lumbar shear forces by 10-30%, but it is also considered a lower back injury mechanism and should be addressed before aggressive loading is prescribed (Bono, 2004; Flanagan et al., 2004; Harris-Hayes, Sahrmann, & Van Dillen, 2009).

2.4.5 Knee stability

During a forward lunge the knee of the front and back leg should be in line with the hip and ankle during knee and hip flexion and extension (Baechle et al., 2000; Bloomfield, 1998; Cook, 2003; Kinakin, 2004). The knee joint is the largest joint in the body and is a modified hinge joint made up of the tibiofemoral and patellofemoral joints. These joints provide flexion in a posterior direction and extension in the anterior direction and are not designed to endure the excessive forces produced during poor mechanics. The poor lunging mechanics commonly observed are medial (Figure 14) and/or anterior movement of the knee in relation to the hip and foot (Figure 14) (Escamilla, 2001; Escamilla et al., 2001; Escamilla et al., 1998; Escamilla et al., 2000). The cause of medial movement of the lead knee during a forward lunge has been reported to be weak or poor activation of the biarticular muscles that attach to the hip/knee and knee/ankle namely the hip abductors, adductors, hamstrings and rectus femoris muscles, as well as the gastrocnemius (Claiborne et al., 2006; Sahrmann, 2002). When observing the forward lunge from the side, the athlete should appear to have stepped out far enough so that the lead knee is directly over the lead ankle and the heel remains in contact with the ground as the athlete's centre of mass is observed to be moving toward the ground (Graham, 2007). When the centre of mass appears to be moving more forward than down, and the heel of the front foot raises off the ground to assist the forward momentum, there is less mobility required of the hip and subsequently as a result there is greater patellofemoral force experienced by the knee (Figure 15) (Alkjaer et al., 2002). In addition, to the aforementioned mechanisms that negatively influence knee stability, weak or poorly activated gluteus muscles, over or under developed quadriceps muscles, and poor mobility in the hips and ankles will negatively influence the athletes' ability to perform a mechanically sound forward lunge (Alkjaer et al., 2002; Bennell, Talbot, Wajswelner, Techovanich, & Kelly, 1998; Brandon, 2007; Crill et al., 2004; Hefzy et al., 1997; Thijs et al., 2007).

Figure 14. Forward lunge with front knee medially collapsing on the descent

Figure 15. Forward lunge with front knee moving in front of the toes on descent

2.4.6 Ankle mobility

Considering the structure and function of the ankle joint detailed in previous chapters, ankle mobility is critical to accommodate good mechanics and alignment of the lead and trail leg during a forward lunge (Bennell et al., 1998; Cook, 2003). The inability to control the foot position at ground contact and/or a lack of ankle mobility has been reported to contribute to dysfunctional movement strategies such as turning out of the feet, turning in of the feet, dropping of the arch, and/or lifting of the lead heel off the ground during force production of the lower limb (Alter, 1996; Escamilla, 2001; Escamilla et al., 2001; Escamilla et al., 1998; Flanagan et al., 2004; Kovacs et al., 1999; Sahrmann, 2002). Although the above-mentioned faulty movement strategies have been thoroughly researched, the effects of malalignment on the kinetic chain during sport and sport specific training are not entirely understood. Kovacs et al. (Kovacs et al., 1999) and Flanagan et al. (Flanagan et al., 2004) found that various positions of the ankle and foot during activities of daily living (i.e. squatting and lunging) resulted in higher forces incurred at the knee and hip. Excessive force experienced by the knee and hip as a result of poor skeletal alignment has been considered a primary mechanism for connective tissue degeneration. It has therefore been recommended that the skeletal alignment of the lower limb be evaluated before the kinetic chain experiences strenuous loading (Bennell et al., 1998; Beynnon et al., 2001; Flanagan et al., 2004; Watson, 1999).

2.4.7 Practical applications

The lunge pattern is considered a fundamental pattern that is common to activities of daily living, sport and sport specific training to varying degrees. The forward lunge is a movement task that has been proposed to be a prognostic functional movement that may be used to screen an athlete's movement competency. To perform a forward lunge correctly, the trunk must remain stable with appropriate mobility present at the hips and ankles to support knee stability.

2.5 Screening the upper-body push and pull patterns using body weight exercises

This chapter has been published: Kritz, M., Cronin, J., & Hume, P. (2010). Screening the Upper-Body Push and Pull Patterns Using Body Weight Exercises. Strength & Conditioning Journal, 32(3), 72-82*.*

2.5.1 Introduction

The substantial use of the upper body in activities of daily living, sport and sport specific training requires sport and health professionals to intimately understand the fundamental movement patterns that govern upper body movement, if they are to enhance upper body strength and power and minimize the incidence of soft tissue injury. The fundamental patterns that facilitate upper body movement have been categorized as either upper body push or upper body pull, given the patterns of movement they involve (Cook, 2003; M. Kritz et al., 2009a; M. F. Kritz & Cronin, 2008). It has been reported that due to the structure and function of the upper limbs and trunk, screening the movement competency of the upper body push and pull pattern may assist sport and health professionals with identifying movement strategies that may be considered dangerous for the purpose of enhancing function and minimizing the incidence of injury (M. Kritz et al., 2009a; M. F. Kritz & Cronin, 2008). This chapter aims to summarize the biomechanical principles that govern upper limb movement competency. Two movement tasks, the standard push up (Figure 16) and the bodyweight bend and pull (Figure 17) will be introduced to help illustrate the biomechanical principles summarized in Tables 7 and 8.

Figure 16. Standard push-up

Figure 17. Bend-and-pull

Table 7. Screening criteria for the push-up

Anatomical region	Screening criteria
Head	Centred and held stable
Shoulders	Held back and down away from the ears
Elbows	Tucked to the side
Thoracic spine	Neutral – with fluid and controlled scapulae movement
Lumbar spine	Neutral
Hips	Aligned with the ankles, knees and shoulders
Knees	Aligned with the ankles and hips
Feet / Ankles	Aligned with the knees
Balance	Maintained
Depth	Chest touches the floor

Table 8. Screening criteria for the bend and upper pull pattern as observed during the bodyweight bend-and-pull movement task

Anatomical region	Screening criteria
Head	Centred and held stable
Shoulders	Held back and down away from the ears
Elbows	Tucked to the side
Thoracic spine	Neutral – with fluid and controlled scapulae movement
Lumbar spine	Neutral
Hips	Aligned with the ankles, knees and shoulders
Knees	Aligned with the ankles and hips and slightly bent
Feet / Ankles	Aligned with the knees
Balance	Maintained
Depth	Trunk appears to flex between 75-90 degrees

2.5.2 Head stability

Researchers have yet to investigate the effects of various head positions on the kinetics and kinematics of the push-up or bodyweight bend-and-pull. However, research has been conducted on the effects of head position on trunk mechanics during movement tasks involving the lower limb (Donnelly et al., 2006). Although not empirically reported the recommended position of the head during upper body movement tasks is a neutral position with the chin tucked slightly in and head held motionless (Baechle et al., 2000; Boyle, 2004; Kinakin, 2004). The head should not appear to be projected down (i.e. flexing the cervical spine) or held up (i.e. extending the cervical spine). Although empirical evidence is limited, the fact that many of the shoulder girdle muscles attach to the skull and vertebra of the neck, it may be considered reasonable to purport that the cervical spine could be exposed to unnecessary stress if the head is not held in a neutral position during fundamental movement tasks (Kendall et al., 2005; Sahrmann, 2002).

2.5.3 Trunk mobility and stability

The shoulder girdle plays an important role in facilitating upper body movement function. It is a complex structure consisting of the sternoclavicular, acromioclavicular and glenohumeral joints and the scapulothoracic interface (Figure 18). The scapulothoracic interface and glenohumeral joint have been identified to be of great importance when qualitatively screening upper body movement (Kibler, 1998; Kibler, Sciascia, & Dome, 2006; Ludewig, Hoff, Osowski, Meschke, & Rundquist, 2004). The scapulothoracic interface consists of the scapulae, the thorax and those muscles that provide stability and movement. The scapula is a flat blade lying along the thoracic wall. This functional design allows for smooth gliding along the thoracic wall and provides a large surface area for muscular attachment (Kibler, 1998; Sahrmann, 2002). There are many muscles in the upper body that are involved in shoulder girdle function. For example, the muscles that receive the most attention are the trapezius, serratus anterior and levator scapulae (Cools, Declercq, Cambier, Mahieu, & Witvrouw, 2007; Cools, Dewitte, et al., 2007; Cools, Geerooms, Van den Berghe, Cambier, & Witvrouw, 2007; Kebaetse et al., 1999; Kibler, 1998; Kibler, Sciascia, et al., 2006; Ludewig et al., 2004). However, the extrinsic muscles that attach along the lateral aspect of the scapula, the deltoid, biceps brachii and triceps brachii that provide gross motor activities for the glenohumeral joint should not be ignored (Kibler, 1998). The intrinsic muscles of the rotator cuff (Figure 19) attach along the entire surface of the scapula which contribute to shoulder movement and stability by providing compression of the humeral head into the glenoid socket (Kibler, 1998).

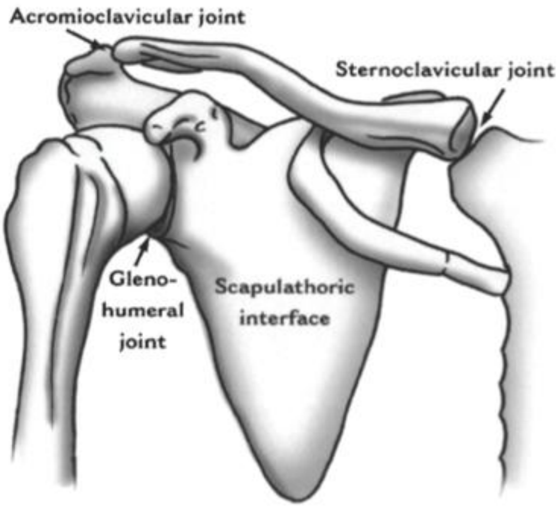

Figure 18. Shoulder girdle
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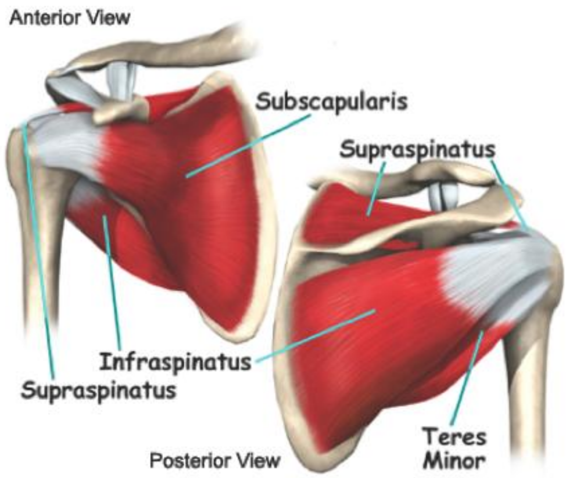

Figure 19. Rotator cuff muscles of shoulder girdle (copyright free images)
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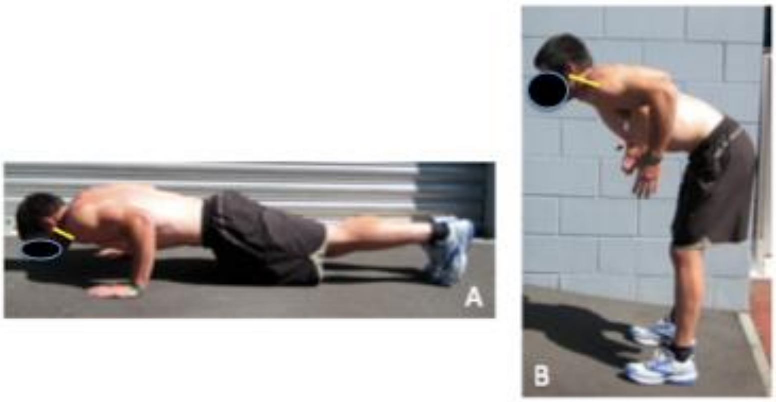
The numbers of muscles that contribute to shoulder girdle function highlight the complexity of the shoulder girdle. There has been a considerable amount of research that has investigated the optimal position of the scapula at rest and during movement (Cools, Dewitte, et al., 2007; Cools, Geerooms, et al., 2007; DiVeta, Walker, & Skibinski, 1990; Forthomme et al., 2008). Movement dysfunction of the scapula has been termed scapulothoracic dysfunction. Scapulothoracic dysfunction has been defined as alterations in the resting position of the scapula affecting shoulder girdle mechanics and is considered a major contributing factor to shoulder pain and impingement syndromes (Cools, Dewitte, et al., 2007; Sahrmann, 2002). It has been suggested that an athlete's standing posture (see Chapter 2) may be used to identify the resting position of the scapula (Kendall et al., 2005; M. F. Kritz & Cronin, 2008; Sahrmann, 2002). Weak or poorly activated scapula muscles may influence the resting position of the scapula (Cools, Dewitte, et al., 2007; Sahrmann, 2002). If the scapula is not in the correct starting position glenohumeral joint integrity may be compromised (Sahrmann, 2002). For optimal glenohumeral joint motion to occur, the head of the humerus must remain compressed and centred in relationship to the glenoid (Sahrmann, 2002). In order for this to occur, the muscles of the scapula must be conditioned to support good alignment and precise timing between the scapula and humerus (Kibler, 1998). This is referred to as scapulohumeral rhythm and is defined as the relationship between the scapulae and humerus during movement. The co-activation ratio of the trapezius and serratus anterior is thought to have significant influence on scapulohumeral rhythm and is key when determining shoulder dysfunction versus function (Cook, 2003; Cools, Declercq, Cagnie, Cambier, & Witvrouw, 2008; Cools, Declercq, et al., 2007; Cools, Dewitte, et al., 2007; Kibler, 1998; Sahrmann, 2002). Many suboptimal shoulder postures are reported to be a result of an over recruitment of the upper trapezius resulting in an overdevelopment of the upper trapezius as compared to the middle and lower areas of the trapezius (Kebaetse et al., 1999; Sahrmann, 2002). The co-contraction (i.e. force couple action) of the trapezius and the serratus anterior muscles can be effectively challenged using the aforementioned push-up and bodyweight bend-and-pull. When the shoulders are observed to elevate toward the ears during either of these movements there is considered to be greater contribution of the upper trapezius muscles to stabilize the shoulder girdle (Kibler, 1998; Ludewig et al., 2004; Meyer et al., 2008; Sahrmann, 2002). For example, an athlete with pronounced kyphotic posture may present with the upper area of the trapezius considerably more hypertrophied than the middle and lower area of the trapezius, serratus anterior and levator scapula muscles (Bloomfield, 1998; Kendall et al., 2005; M. F. Kritz & Cronin, 2008; Sahrmann, 2002). Kyphotic posture is often observed in athletes participating in sports that require significant use of the upper body such as baseball, swimming, water polo, tennis, gymnastics, wrestling and volleyball (M. F. Kritz & Cronin, 2008). Figure 20 illustrates how over recruited upper trapezius muscles may negatively influence the kinematics of the push-up and bend-and-pull movement tasks. The athlete in Figure 20 demonstrates how the scapulae are forced to elevate toward the ears to provide the protraction and retraction necessary to facilitate the movement task. This movement strategy has been reported to negatively affect the alignment of the humerus within the glenoid, compromising the compression of the humerus in the glenoid resulting complex shoulder instability and potentially limited glenohumeral joint range of motion during fundamental movement tasks. Shoulder instability has been reported to contribute to shoulder impingement pathologies (Kebaetse et al., 1999; Kendall et al., 2005; Sahrmann, 2002), which is why the function of the upper body during push and pull pattern exercises is mainly focused on shoulder position, specifically whether the shoulders can be held down and away from the ears during loaded and unloaded upper body movement tasks (M. Kritz, Cronin, & Hume, 2010).



Note: The line highlights the shoulders elevating toward the ears during both push and pull patterns.

Figure 20. Faulty push and pull pattern mechanics

However, the scapulae should not appear to be 'stuck' in the attempt to keep the shoulders down away from the ears during upper body movement. The scapula should appear to be moving apart (protracting) and together (retracting) during push and pull pattern movement tasks. The protraction and retraction of the scapulae is intensely required during sport performance. The protraction and retraction of the scapulae influences the proximal to distal sequencing of velocity, energy and forces that contribute to many fundamental sport specific actions. For example, in an overhead throwing movement over half of the total kinetic energy and forces that are generated come from the lower body and are transmitted up through the hips and lower back and delivered to the shoulder, arm and hand to complete the kinetic chain (Kibler, 1998). Proper scapulae retraction and protraction provide the most advantageous anterior trunk muscle tension. This provides efficient force transfer from eccentric to concentric motion of the anterior muscles of the trunk and concentric to eccentric motion of the posterior muscle of the trunk for the efficient performance of movements like overhead throwing, tennis serving, the recovery phase of the swimming stroke and many upper body strength training exercises (Kibler, 1998).

It is important to discuss the role of the lumbar and hip regions in supporting upper body movement tasks. It has been recommended that the muscles of the mid to lower back and hip region generate force and stiffen to stabilize the lumbar spine during upper body movement tasks (Freeman, Karpowicz, Gray, & McGill, 2006; S. M. McGill, 1992, 2006). If the lower back is not stabilized during upper body movement tasks, then the force required for shoulder function may be compromised (Freeman et al., 2006). Freeman et al. (2006) investigated the forces incurred by the lumbar spine during different kinds of push-ups and found that abdominal activity and lumbar spine loads increased with push-up intensity (i.e. standard push versus clap push-ups). Researchers have investigated the effects of flexion and extension on lumbar spine stability (S. M. McGill, 1992, 2006; S. M. McGill & Cholewicki, 2001; S. M. McGill et al., 2003). It has been reported that when the lumbar spine is flexed or extended to the end ranges of lumbar spine motion, the damaging effects of shear and compressive forces on the lumbar vertebrae are increased (S. McGill, 2007; S. M. McGill, 2006). Figure 21 features an athlete performing a push-up with lumbar extension and Figure 22 shows an athlete performing a bodyweight bend-and-pull with lumbar flexion. A stable lumbar spine is able to resist lumbar end range extension and flexion (S. M. McGill, 2006; S. M. McGill et al., 2003). An athlete that cannot control lumbar extension and/or flexion during either the push-up or a trunk bending movement task may require further lumbar stability assessment (Freeman et al., 2006; Lett & McGill, 2006; S. M. McGill, 2006; S. M. McGill et al., 2003).

Figure 21. Push-up with excessive lumbar extension.

Figure 22. Bend-and-pull with excessive lumbar flexion.

2.5.4 Lower limb stability

Data has yet to be reported on the effects of malalignment of the lower limb on the kinetics and kinematics of the push-up or the bodyweight bend-and-pull. However, actively controlling the alignment of the lower limb when it is primarily required to be static to facilitate a movement task such as the push-up and bodyweight bend-and-pull has been recommended (Baechle et al., 2000; Boyle, 2004; Kinakin, 2004).

2.5.5 Practical applications

The upper body push and pull patterns are fundamental patterns to sport and activities of daily living and therefore require an essential understanding of the structure and function of the head, trunk and lower limb. When performing upper body push and pull pattern movement tasks the athlete should demonstrate a centred and stable head position. The shoulders should appear to be held down and away from the ears with good scapulohumeral rhythm, observed by the controlling of the scapulae during protraction and retraction. The lumbar region of the spine should be stabilized in a neutral position during either the push-up or bodyweight bend-and-pull. The lower limb should be actively controlled to ensure it is aligned and held stable so that energy generated throughout the kinetic chain is efficiently utilized.

2.6 Trunk rotation and flexion patterns

2.6.1 Introduction

An important ability of the sport and health professional is to be able to qualitatively assess an athlete's movement efficiently (i.e. they know what looks right and what looks wrong with regard to "how" an athlete performs fundamental movement tasks). We know there is a wrong way to perform many exercises due to anecdotal experience and empirical injury research that has quantified the effects that moving poorly has on performance and the incidence of injury (Bak, 1996; Chaudhari & Andriacchi, 2006; Cowan et al., 1996). There have been a variety of biomechanical and kinesiology models that have validated the effects poor movement strategies have on the soft tissue structures (Abelbeck, 2002; Alexander, Crossley, & Schache, 2008; Alkjaer et al., 2002; Butler et al., 2010; Chaudhari & Andriacchi, 2006; Escamilla et al., 2001). It has been purported that when the mechanical demand (i.e. bodyweight or bodyweight plus an external load) exceeds soft tissue capacity, movement quality is sacrificed and the potential for non-contact soft tissue injuries increases (Burkhart, Ford, Myer, Heidt, & Hewett, 2008; Chaudhari & Andriacchi, 2006; Davis & Marras, 2000; Hewett, Myer, & Zazulak, 2008; Korpelainen et al., 2001). This is exemplified within lower back injury research, where the incidence of injury to the trunk and lower back is becoming increasingly common in sports (Bono, 2004; Hangai et al., 2009; Harris-Hayes et al., 2009; S. McGill, 2007). The sports that involve repetitive trunk rotation, flexion and extension report up to 45% of injuries to the lower back sustained during sport and sport specific training (Bono, 2004; Dubravcic-Simunjak et al., 2003; Dunn et al., 2006; Hoskins et al., 2009; Nadler et al., 1998; Standaert, 2008). Although the mechanical determinants of lower back injuries are multifactorial (Bono, 2004), there are gross movement strategies that have been reported to contribute more to the incidence of lower back pain and injury than sport performance (Harris-Hayes et al., 2009; Mulhearn & George, 1999; Nadler et al., 2001; Reeves, Cholewicki, & Silfies, 2006). These mechanical determinants include end range lumbar spine flexion, extension and/or rotation (S. McGill, 2007). In addition, sustained postures that violate the anatomical and biomechanical principles that support human movement are also associated with the mechanisms of lower back pain and/or injury (S. M. McGill & Cholewicki, 2001). Researchers have suggested that the inability to control or stabilize the lumbar spine during movement tasks that require lumbar stability to utilize the high forces and/or velocities generated by the upper and/or lower limb may be a result of a lack of strength, proprioceptive control and/or awareness of what constitutes correct trunk mechanics during movement (Bono, 2004; Hangai et al., 2009; Hoskins et al., 2009; Marras & Granata, 1995; S. McGill, 2007). This has been substantiated in the literature by researchers who have observed 20-50% of athletes who participate in sports that involve high rotational velocities and experience reporting pain and discomfort to the lower back (Bono, 2004; Dubravcic-Simunjak et al., 2003; Hangai et al., 2009; Hoskins et al., 2009).

Trunk flexion, extension and rotation are fundamental movement patterns that are commonly observed in sport and are subsequently frequently loaded in a strength-training environment. Training that involves the trunk musculature has been termed "Core" training (Arendt, 2007). The principles of "Core" training have been extensively discussed in research and practice and considered a polarizing topic by sport and health professionals (Arendt, 2007). This conjecture is evidenced by some researchers claiming there is a statistically poor relationship between core strength and athletic performance, "and should not be the focus of strength training" (Nesser, Huxel, Tincher, & Okada, 2008), while other researchers claim the "Core" is an integral anatomical region that should be trained specifically (Arendt, 2007; Hangai et al., 2009; Kibler, Press, & Sciascia, 2006; Li et al., 1996; Marras & Granata, 1995; S. McGill, 2007, 2010). Irrespective of one's perception of "Core" training and the effect the "Core" may or may not have on athletic performance, it is well supported that poor trunk mechanics during "Core" training is considered a mechanism of lower back pain and/ or injury that can be avoided (Arendt, 2007; Kibler, Press, et al., 2006; S. McGill, 2010). This chapter will review the literature that has reported the fundamental movement strategies associated with lower back pain and injury. In addition, two movement tasks, the lunge-and-twist (Chapter 4) and bodyweight bend-and-pull (Chapter 5) will be reintroduced as movement-screening tasks that may be used to assess trunk movement competency. Table 8 summaries the recommended screening criteria for the bend pattern, and Table 9 summaries the recommended screening criteria for the rotation pattern.

Table 9. Screening criteria for the rotation pattern observed during the lunge-and-twist movement task

Region	Screening Criteria
Head	Centred and held stable
Shoulders / Thoracic	Shoulders held down and away from ears
Spine	Rotation occurs through the thoracic spine
Lumbar	Neutral, stiff, resisting rotation
Hips	Horizontally aligned, directly under the shoulders during lunge, resisting rotation during twist
Knees	Aligned with the knee
Ankles	Aligned with the knee
Feet	Heel of lead leg in contact with the floor, trail foot flexed and balanced on forefoot
Balance	Maintained for each leg
Depth	Lead thigh parallel with the ground

2.6.2 Trunk flexion

Trunk flexion or bending is considered a fundamental movement pattern common to sport and sport specific training (Chek, 2000; Sahrmann, 2002). According to researchers the lumbar spine should not complete more than 50% of its motion into forward flexion before hip flexion is initiated (S. McGill, 2007; Sahrmann, 2002). Researchers are very interested in what happens to the soft tissue structures of the lumbar spine during forward bending (Bono, 2004; Gatton & Pearcy, 1999; S. McGill, 2007). Much of the lumbar spine research has been conducted using mathematical models, which are only as good as the data and assumptions used within the models (Gatton & Pearcy, 1999). Nonetheless, the current principle that governs the understanding of flexion oriented lower back injury mechanisms is that when the lumbar spine goes into flexion the structures both passive (i.e. vertebrae, discs, joints and ligaments) and active (i.e. the local and global muscles that support the spine) work sequentially. In other words, the lumbar vertebrae joint $L_{3/4}$ is deformed followed by $L_{4/5}$ and then L_5 / S_1 (Gatton & Pearcy, 1999). It is because of the inherent instability of the lumbar spine that sport and health professionals advocate the stabilizing of the lumbar spine during whole body movement tasks (Arendt, 2007; S. McGill, 2010; S. M. McGill & Cholewicki, 2001). An unstable lumbar spine is one that is unable to maintain the neutral position or natural lumbar curve of the spine during any movement, particularly that which involves the trunk. Lumbar spine middle to end range flexion increases the compressive forces, and middle to end range lumbar flexion with rotation and/or lateral trunk flexion increases the shear forces experienced by the lumbar vertebral discs (Bono, 2004; Congeni, McCulloch, & Swanson, 1997; Hangai et al., 2009; S. McGill, 2007). The aforementioned movement patterns are well documented mechanisms associated with herniated disc syndromes (Bono, 2004; Davis & Marras, 2000; Durall et al., 2009; Fenwick, Brown, & McGill, 2009; Gatton & Pearcy, 1999; S. J. Hall, Lee, & Wood, 1990; Hangai et al., 2009; S. M. McGill, 2006; Norris, 1995; Ross, Hall, Breit, & Britten, 1993; Sahrmann, 2002; Walsh et al., 2007).

Once an understanding of which patterns of movement are considered to be mechanisms of lower back injury a method for assessing an athlete's trunk movement competency would seem beneficial. The bodyweight bend-and-pull (Figure 22) is a complex movement task that provides the athlete with an opportunity to demonstrate their awareness and functional strength related to trunk flexion and upper body pulling mechanics (as previously discussed). An illustration of good bending mechanics for the bodyweight bend-and-pull is depicted in Figure 23. The mechanics in Figure 23 are considered good because the athlete achieves at least 70° of trunk flexion with slight knee flexion allowing the hip musculature to be loaded properly. As a result she can move back behind the centre of gravity maintaining the connection between the pelvis and the lumbar spine providing the stability required to maintain the lumbar spine's natural curve.

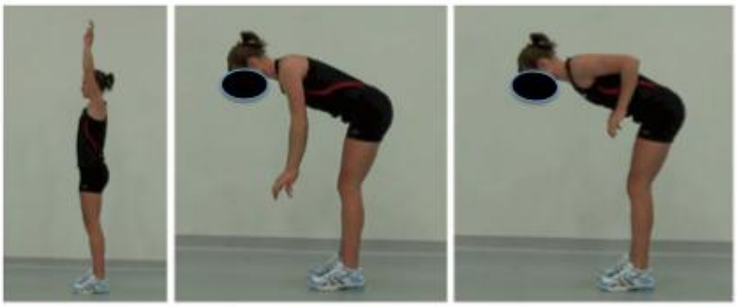


Figure 23. Correct bend pattern for the bodyweight bend-and-pull.

Conversely, Figure 24 illustrates poor bend pattern movement competency. The athlete in Figure 24 does not achieve at least 70° of trunk flexion, locks his knees prohibiting the hips from being actively involved in stabilizing the lumbar spine and bends through the lumbar spine.

Figure 24. Poor bend pattern for the bodyweight bend-and-pull.

2.6.3 Trunk rotation

Trunk rotation or twisting is the other very common trunk movement pattern observed in sport directly and indirectly. For example, it is a direct movement task found in the long axis stokes in swimming and sports that involve throwing and striking with angular velocities of the hips reported to be 662 ±148 °/s and angular velocities of the upper torso reported to be 1180 ±294 °/s (Harris-Hayes et al., 2009). Yet, the majority of sports that are considered non-rotational activities indirectly involve trunk rotation. Sports that involve actions like tackling, kicking, catching, sprinting and changes of direction indirectly require the trunk to rotate to varying degrees to facilitate the required movement task (Harris-Hayes et al., 2009; Hoskins et al., 2009; Marras & Granata, 1995; Norris, 1995). The overall range of lumbar spine rotation is approximately 13° as compared to thoracic spine rotation, which has been reported to rotate too greater than 30° (Marras & Granata, 1995; Sahrmann, 2002). The importance of lumbar stability has been previously discussed. The principles that govern lumbar stability for trunk flexion also apply to trunk rotational movement tasks, primarily because the lumbar spine is positioned between two regions of the body that are designed to rotate, the hips and thoracic spine. Researchers have reported that the primary role of the lumbar region is to be stiff and rigid, so the forces generated by the lower limbs during rotational activities can be transferred efficiently to the upper limbs to facilitate the rotational movement (Harris-Hayes et al., 2009; S. M. McGill, 1992; S. M. McGill & Cholewicki, 2001). This is not to say that the lumbar spine will not rotate to some degree during a rotational activity, as lumbar rotation within the mechanical capacity of the passive and active structures of the lumbar spine is considered safe. However, if an athlete performs a rotational movement task and does not attempt to resist lumbar rotation and allows the lumbar spine to rotate beyond its mechanical capacity, then pain and/or injury may likely occur (S. McGill, 2007; S. M. McGill, 2006; Norris, 1995). To further highlight how the kinetic chain interacts, when the thoracic and/or hip joints lack the required mobility to perform a specific movement task an increase in lumbar spine rotational velocity has been reported (Davis & Marras, 2000; Marras & Granata, 1995; S. M. McGill & Cholewicki, 2001). This additionally confirms that the body will adopt a movement strategy to ensure it completes the desired movement task, irrespective of the fact that the adopted movement strategy may be considered dangerous.

It can be observed from Figure 25 how the lunge-and-twist introduced in Chapter 4 may be used to assess an athlete's trunk rotation movement competency. By placing athletes in a lunge stance with one hip extended and the other hip flexed and then having them rotate toward the flexed hip, the stability and control of the lumbar region is challenged in a manner relevant to activities of daily living, sport and sport specific training (M. Kritz et al., 2009a). The athlete in Figure 25 demonstrates good rotational mechanics evident by a stable lumbar region with neutral spine maintained during rotation. Rotation appears to be initiated through the thoracic region of the spine with good thoracic mobility evident by the right elbow rotating well past the left knee.

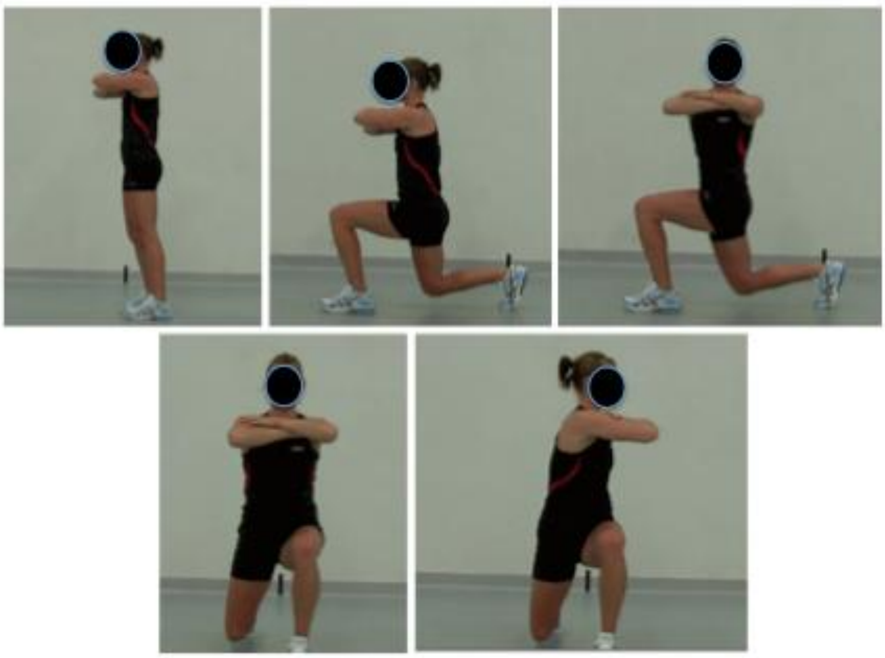


Figure 25. Correct trunk rotational competency

Conversely, the athlete in Figure 26 demonstrates poor trunk rotation movement competency, evident by excessive movement through the lumbar region with restricted movement through the thoracic region.

Figure 26. Incorrect trunk rotational competency

2.6.4 Practical applications

The bend-and-pull and lunge-and-twist offer the sport and health professional a method for screening trunk movement competency. Fundamentally, either movement task challenges athletes' ability to maintain a neutral lumbar spine position during either trunk flexion and/or rotation. Given the prevalence of bending and rotational movement in sport, it is understandable why these patterns are loaded during sport specific training (Kibler, Press, et al., 2006; Lachowetz, Evon, & Pastiglione, 1998; Stodden, Campbell, & Moyer, 2008). However, it is important to keep in mind that when athletes are required to perform a repeated movement task, they will employ a movement strategy that utilizes their strengths (S. M. McGill & Cholewicki, 2001). If their strength is the result of "risky" mechanics, or if fatigue causes the athletes to compensate to complete the task, the continued loading of the faulty pattern may prove unsafe. There can be many reasons why athletes may not be able to maintain a neutral lumbar spine (i.e. a position that reduces lumbar flexion and extension moments) when they bend forward or rotate their trunk. Some well-documented reasons are a lack of awareness, insufficient strength of the muscles that provide stability to the lumbar spine, structural dysfunction of the spine, previous injury, pain, poor sustained sitting posture, immobility in the hips and poor hamstring flexibility (Arendt, 2007; Bono, 2004; S. J. Hall et al., 1990; Hangai et al., 2009; Harris-Hayes et al., 2009; S. McGill, 2007; Nadler et al., 2001; Norris, 1995; Reeves et al., 2006; Ross et al., 1993). Hence, screening an athlete's ability to maintain a neutral spine during trunk flexion and rotation using the lunge-and-twist and bend-and-pull may provide the sport and health professional with an understanding of how aggressively the athlete should load the bending and rotational movement patterns.

2.7 Unilateral lower limb pattern

2.7.1 Introduction

Exercises performed on one leg have been programmed for athletes who participate in sports that require lower body power (Juan, 2001; Morrow, 1986). This is in part due to the functional specificity of single leg exercises, in that they require strength and neuromuscular control, which are characteristics identified to enhance sporting performance and reduce the incidence of lower limb injury (Hewett, Ford, Myer, Wanstrath, & Scheper, 2006; Hewett, Snyder-Mackler, et al., 2007; Juan, 2001; Morrow, 1986; Myer, Ford, Khoury, Succop, & Hewett, 2010; Myer, Paterno, Ford, & Hewett, 2008). In the pursuit of developing and enhancing an athlete's athletic ability and injury resiliency, sport and health professionals prescribe the loading of movement tasks on one leg in an effort to provoke a performance adaptation (Morrow, 1986). However, recent evidence suggests that care should be given to how an athlete performs a movement task prior to aggressive loading to ensure the adaptations experienced from training contribute to performance and not the mechanisms of lower limb injury (M. Kritz et al., 2009a, 2010; Quatman, Quatman, & Hewett, 2009; Swenson et al., 2009). It has therefore been suggested that sport and health professionals should recognize the movement strategies that are safe to aggressively load and which movement strategies if loaded aggressively would contribute to the mechanisms of injury (M. Kritz et al., 2009a, 2010; Quatman et al., 2009; Swenson et al., 2009).

It is common practice for sports medicine professionals to utilize single leg movement tasks to assess an athlete's functional movement ability. The single leg squat is a common unilateral lower limb movement task that has been regularly utilized in the literature for the purpose of assessing local muscular strength, control, proprioception and to better understand how an athlete's gait may be influenced by their unilateral movement competency (Alexander et al., 2008; Claiborne et al., 2006; Hewett, Ford, et al., 2006; Pantano, White, Gilchrist, & Leddy, 2005; Willson, Ireland, & Davis, 2006). It is considered of prognostic value because it adequately challenges lower limb unilateral joint function (i.e. ankle dorsiflexion, hip flexion and extension) while simultaneously requiring control of the kinetic chain (DiMattia, Livengood, Uhl, Mattacola, & Malone, 2005; Loudon, Wiesner, Goist-Foley, Asjes, & Loudon, 2002; Newton et al., 2006). Researchers have reported that the single leg squat can provide information about an athlete's relative lower limb unilateral strength, as well as the ability to control the alignment of the lower limb during a closed chain unilateral movement task (DiMattia et al., 2005).

In addition, the single leg squat has been used as a prehabilitation exercise due to the fact that it simultaneously challenges the strength of the gluteal, hip abduction, hip adduction, quadriceps and hamstrings muscle groups (Shields et al., 2005; Youdas, Hollman, Hitchcock, Hoyme, & Johnsen, 2007). In addition, the required coactivation of the hamstrings when a single leg squat is performed, with correct mechanics, has been purported to reduce anterior tibial shear forces and enhance the stability of the knee joint (Shields et al., 2005; Youdas et al., 2007). Furthermore, the single leg squat has been included in a battery of lower limb rehabilitation exercise used to assist with confirming an athlete's readiness to return to sport (Alexander et al., 2008; Beutler, Cooper, Kirkendall, & Garrett, 2002; Boudreau et al., 2009; Claiborne et al., 2006; DiMattia et al., 2005; Earl, 2004; Hewett, Ford, et al., 2006; Myer, Paterno, et al., 2008; Pantano et al., 2005; Shields et al., 2005; Zeller, McCrory, Kibler, & Uhl, 2003). The construct validity and intrarater reliability have also been reported with novice and experienced professionals (Alexander et al., 2008; Claiborne et al., 2006; DiMattia et al., 2005; Loudon et al., 2002; Pantano et al., 2005; Willson et al., 2006). Given the extensive use of the single leg squat within the literature for athletic development, functional assessment, injury prevention and rehabilitation, this chapter provides a summary of the recommended screening criteria for the single leg squat.

Although there is a plethora of research that has used the single leg squat to investigate lower limb injury mechanisms, there is a lack of specific kinematic information about the single leg squat for screening purposes. Therefore, information and inferences from previous chapters are repeated below to provide continuity and understanding. Table 10 summarizes the screening criteria for the single leg squat.

Table 10. Screening criteria for the single leg squat.

Region	Screening criteria
Head	Centred and held stable.
Shoulders / Thoracic Spine	Held down and away from the ears with the elbows in line with the ears from the frontal plane view. Thoracic spine should appear extended.
Lumbar	NEUTRAL, there should be no flexing or extending of the lumbar spine during the movement.
Hips	Should be horizontally aligned with no medial/lateral rotation in the transverse plane and no dropping of the hip on the stance leg or free leg.
Knees	Should be aligned with the hip and feet with no medio/lateral movement in the frontal or transverse plane.
Ankles	Aligned with the knee and hip.
Feet	In contact with the ground with no pronation or supination during the movement.
Balance	Maintained on each leg without a significant body weight shift over the stance leg.
Depth	Equal to or greater than 75 degrees of hip flexion.

2.7.2 Head stability

There is no research that has investigated the effects of head position on single leg squat kinematics and/or kinetics. However, research reported earlier on the head position during bilateral squatting found that when the head position and direction of gaze were directed downward a significant increase in hip and trunk flexion was observed (Donnelly et al., 2006). Movement of the head with a downward direction of gaze during the bilateral squat increased trunk flexion by up to 4.5° (Donnelly et al., 2006). Researchers have stressed that the direction of gaze, head alignment and stability during bilateral squatting is critical to decrease the amount of cervical, lumbar and thoracic flexion. (Donnelly et al., 2006; Kendall et al., 2005; Sahrmann, 2002). Since cervical, thoracic and lumbar flexions are contraindications for bilateral squatting, inferences can intuitively be made that these same contraindicators would exist for single leg squatting mechanics. However, the authors concur that further research needs to be conducted to confirm this idea.

2.7.3 Trunk and hip mobility and stability

According to researchers the angle of the trunk in relation to the ground should remain constant throughout the downward and upward phase of a squat movement task demonstrating trunk stability and control (Baechle et al., 2000; Kinakin, 2004). The trunk should remain stable with the thoracic spine slightly extended demonstrating mobility, while the lumbar spine is stabilized in its neutral position (Kendall et al., 2005; Kreighbaum & Barthels, 1996; Sahrmann, 2002). From the side, the trunk and spine should appear relatively parallel (Figure 26) at the bottom of the squat. The lumbar spine should not excessively flex at the bottom of the squat for reasons related to lumbar vertebrae disk injuries stated in previous chapters. However, it is important to note that greater than 90 degrees of hip flexion requires lumbar flexion due to anatomical restrictions that may occur between the acetabulum and the femoral head (Delp, Hess, Hungerford, & Jones, 1999). Regardless of an athletes' anatomical restrictions, the hip should be observed moving back and down as the trunk flexes forward from the hip with the lumbar spine held stable in its neutral position (Pantano et al., 2005; Shields et al., 2005; Willson et al., 2006; Zeller et al., 2003).

2.7.4 Knee stability

The knee should maintain alignment with the foot and hip during hip and knee flexion and extension and should not travel excessively in front of the toes (Figure 26) (Fry et al., 2003). The position of the knee during ground base movements has received much attention in the scientific literature as detailed in chapters three and four. Researchers have concluded that excessive medio/lateral frontal and transverse plane motion of the knee during a close chain unilateral lower limb assessment is an indicator of poor lower limb neuromuscular control (Chaudhari & Andriacchi, 2006; Hewett, 2008; Hewett, Myer, & Ford, 2005; Hewett et al., 2009; Osternig et al., 2000). Some researchers have remarked that the strength of the hip musculature responsible for the abduction and adduction of the femur during ground contact will influence an athlete's ability to align the knee with the hip and foot when the knee is dynamically flexed and extended between 0° and 90° of hip flexion (Chaudhari & Andriacchi, 2006; Claiborne et al., 2006; Delp et al., 1999; Earl, 2004; Myer, Ford, Palumbo, & Hewett, 2005; Myer, Paterno, et al., 2008).

2.7.5 Ankle mobility and foot stability

It is recommended that the foot of the stance leg remain in contact with the ground during the squat and not appear to pronate, supinate or plantar flex (Figure 26) (Abelbeck, 2002; Kovacs et al., 1999). Plantar flexion resulting in a heel raise during a single leg squat could mean several things. The athlete may not be aware that keeping the foot flat during the squat is recommended or they may have poor flexibility in their calf musculature (Kasuyama, Sakamoto, & Nakazawa, 2009). If the athlete's heel rises during the descent the screener may try placing a small block under the heel to see if the athlete's performance is enhanced. If the athlete squats better with a heel support, then further assessment may be warranted by a sports medicine professional. The free leg (i.e. the leg not in contact with the ground) should be primarily positioned behind the body. It has been suggested, and the authors agree, that an advantage of the free leg positioned behind the body during a single leg assessment simulates a common athletic position, which requires control of the body over a planted leg and challenges the strength of the trunk and hip musculature in the sagittal plane (Zeller et al., 2003). In addition to the aforementioned assessment criteria, it has been suggested that good unilateral movement competency occurs when an athlete can perform a controlled, fluid single leg squat to at least 75 degrees of hip flexion (Figure 27) (Hewett, Myer, Ford, & Slauterbeck, 2007). An example of fluid speed would be performing the single leg squat at a tempo of 2-1-2 (i.e. two second descent, one second pause at the bottom with a two second ascent). The authors concur that not all sporting situations require 75-degrees of hip flexion. However, given that the screen is done with bodyweight, the authors feel that achieving at least 75 degrees of hip flexion is a good indicator of relative body strength and range of motion, and it should be a benchmark before external mass is added to the athlete's body weight for more intense training.

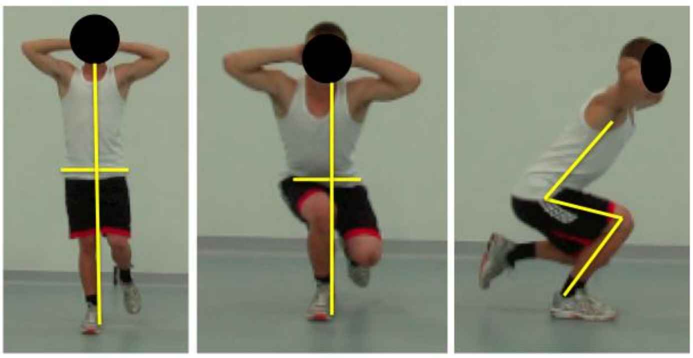


Figure 27. Single leg squat.

2.7.6 Practical applications

There is an expectation that the strength and conditioning specialist will design strength training programs that are specific to the needs of the athlete. Assessing an athlete's single leg squatting function prior to prescribing unilateral exercises can provide a framework from which athlete specific training programs can be designed. The single leg squat is a common assessment tool used by sport and health professionals. Due to the incidence of lower body injuries sustained by athletes world wide, sport and health professionals may benefit from using this test with novice to elite athletes to help ensure that training adaptation is contributing to performance and not the mechanisms of injury.

CHAPTER 3. CONTENT VALIDATION OF THE MOVEMENT COMPETENCY SCREEN

This chapter was submitted for publication in May 2012 and is currently under review.

3.1 Prelude

Based on the literature reviewed it was evident that movement competency and subsequent production of muscular power is a fundamental concern for sport and health professionals when considering an athlete's long-term development and injury prevention. The empirical validation of content for a whole body functional movement competency-screening tool had not been investigated. Therefore, the objective of this study was to develop and validate a movement competency screen, for sport and health professionals that challenge the fundamental movement patterns, which are commonly loaded in a sport and sport specific training environment.

3.2 Overview

Movement competency and subsequent production of muscular power is a fundamental concern for sport and health professionals when considering an athlete's long-term athlete development and injury prevention. The documentation and standardization of whole body functional movement competency protocols was relatively unexplored. The purpose of this study was to develop a whole body functional movement competency screen (MCS) for use by sport and health professionals. Participants (n = 124) comprising strength and conditioners, sport physiotherapists and biomechanists completed a pilot survey and two main surveys. A pilot survey confirmed the content and structure for survey 1 via feedback from five strength and conditioning specialists and five physiotherapists. Survey 1 (MCS development) ascertained what the structure and function of the MCS should entail via 18 questions answered by 22-strength and conditioning and 20 sport physiotherapy specialists. Survey 2 (MCS validation) invited 50 strength and conditioning, 50 sport physiotherapy and 50 sport biomechanics specialists to participate; a 48% response rate (n = 72; 41 + 21 + 10 respectively) was achieved. Twenty of the participants who completed survey 1 also completed survey 2, therefore a total of 104 participants provided 124 responses for the creation of the MCS. Survey 2 (MCS content validation) examined the agreement of sport and health professionals about the proposed MCS via 16 questions. Excellent percentage agreement (80% to 97%) was achieved regarding the opinions of participants about the structure, movement tasks (i.e. six tasks that challenge seven fundamental movement patterns) and screening criteria (i.e. categorized into seven body regions and two capacities) for the MCS proposed for use by sport and health professionals.

3.3 Introduction

There has been an investment within the sport and health professions to better understand the movement competency of athletes and the impact athletes' movement competency has on athletic performance and the incidence of soft tissue injuries (Alentorn-Geli et al., 2009a, 2009b; Kiesel et al., 2007b; Myer, Chu, et al., 2008; Paterno et al., 2004). Movement competency has been defined as the ability to move in a biomechanically efficient manner free of discomfort and pain (M. Kritz et al., 2009a). The way athletes move and activate their muscles influences joint loading and injury risk (Hewett et al., 2009; Myer et al., 2004) and can change the way metrics such as strength and power are expressed during the performance of sport specific tasks (Vanrenterghem et al., 2008). Factors that have been reported to influence athletes' movement competency include kinesthetic awareness, changes in muscle length, strength, stiffness and repeated movement patterns and/or sustained postures performed during activities of daily living and sport participation (Alentorn-Geli et al., 2009a, 2009b; Neely, 1998). Although sport and health professions advocate assessing athletes' movement competency before substantial sport training is prescribed (Chaudhari et al., 2007; Kiesel et al., 2009; McLean et al., 2005; Minick et al., 2010; Myer, Ford, & Hewett, 2010), surprisingly, the literature has yet to detail a standardized peer reviewed method for screening whole body functional movement competency.

A variety of methods and movement tasks have been utilized in sport science research investigating mechanisms of injury; most of which appear to be governed by physiotherapeutic philosophy (Alentorn-Geli et al., 2009a; Kiesel et al., 2007b; Paterno et al., 2010). Physiotherapy screening protocols historically involve muscular strength and extensibility as foundations for diagnosis based primarily on the isometric assessment of uniarticluar motion (Cook, 2003; Mottram & Comerford, 2008). Health professionals who have formalized training and specific education in movement impairment syndromes subscribe to these methodologies (Kendall et al., 2005; Sahrmann, 2002). However, these traditional screening protocols have been recently criticised (Minick et al., 2010) due to the lack of efficacy in relating injury mechanisms identified by traditional physiotherapeutic methodologies and fundamental movement competency (Minick et al., 2010).

The Functional Movement Screen© (FMS), developed by North American physiotherapists Gray Cook and Lee Burton, aims to improve the communication between sport and health professionals by providing information about an individual's functional movement ability using specialized equipment and seven whole body movement tasks (Minick et al., 2010). The development of the FMS has not been reported as peer reviewed. The reliability of the FMS was recently investigated (Minick et al., 2010) via ratings from one expert physiotherapist and one novice physiotherapist using videos of 44 individuals performing the FMS movement tasks. The majority of the FMS movement tasks had excellent or substantial agreement (e.g. squat 87.2% agreement, 0.80 Kappa) (Minick et al., 2010). The effectiveness of the FMS was examined with National Football League (NFL) athletes (n = 46) (Kiesel et al., 2007b) and the FMS predicted only 46 out of 100 injuries via the relationship between the athlete's FMS score and their incidence of injury (Kiesel et al., 2007b). The use of the FMS to guide exercise prescription and evaluate the effectiveness of training in 20 subjects has also been investigated (Frost, Beach, Callaghan, & McGill, 2010). The FMS scores (mean = 13) of the control (n = 20) group were not stable, so the influence of training on natural movement strategies could not be evaluated.

Except for the recent data on the inter-rater reliability (Minick et al., 2010) and efficacy (Frost et al., 2010) of the FMS, the lack of peer reviewed and empirically validated movement-screening protocols was puzzling. Therefore, the objective of this study was to use empirical methodologies to develop and validate a movement competency screen, for sport and health professionals, that challenges the fundamental movement patterns, which are commonly loaded in a sport and sport specific training environment.

3.4 Methods

3.4.1 Approach to the problem

This study involved a series of surveys to better understand from sport and health professionals what the structure and function of a whole body functional movement competency screen for athletes should entail. A pilot project prior to Survey 1 was undertaken to confirm that the content and structure of Survey 1 was intuitive to participants. Survey 1 (MCS content development) requested participants' opinions about what a movement competency screen should involve. Survey 2 (MCS content validation) requested participants' agreement or disagreement about the proposed content of the movement competency screen that was derived from the results of Study 1.

A modified Delphi technique was used to design the surveys. The Delphi technique is a group process using written responses for two or more surveys in order to try and achieve a consensus (Becker & Roberts, 2009). The Delphi technique is popular in health services research (Becker & Roberts, 2009) and provides the opportunity to survey opinions of individuals who would be difficult to bring together physically due to geographic or financial constraints. To accommodate the geography of international participants, a web platform was utilized to administer the surveys. Participants who completed Survey 1 and/or Survey 2 were required to complete an online consent form. After participants completed the consent form, they were sent a link to access the survey. Participants were given 45 days to complete and submit their survey(s).

3.4.2 Subjects

The sport and health professionals recruited for this study were comprised of strength and conditioning, sport physiotherapy and biomechanics specialists. These professionals were asked to participate based on their involvement with elite athletes and their familiarity with human anatomy, strength training and principles that govern human movement. Pre-existing professional relationships between the authors and elite sport organizations in New Zealand, Australia and United Kingdom were used to recruit participants. In addition, the North American National Strength and Conditioning (NSCA) website (www.nsca-lift.org) was used to further identify North American strength and conditioning and sport physiotherapy specialists. Proportional sampling was used during the recruitment of all participants. All identified professionals were sent an email asking for their involvement in this research project.

The pilot study involved five strength and conditioning specialists and five physiotherapists. The main study required participants to complete two surveys. Survey 1 (MCS development) invited 30 strength and conditioning and 30 sport physiotherapy specialists; an 87% (n = 42; 22 + 20 respectively) response rate was achieved. Survey 2 (MCS validation) invited 50 strength and conditioning, 50 sport physiotherapy and 50 sport biomechanics specialists to participate; a 48% response rate (n = 72; 41 + 21 + 10 respectively) was achieved. Twenty of the participants who completed Survey 1 also completed Survey 2; therefore, a total of 104 participants provided 124 responses for the creation of the MCS. AUT University Ethics Committee for Human Research approved the study and all participants completed an informed consent prior to data collection.

3.4.3 Procedures

Survey 1 consisted of 18 questions (3 closed-ended questions and 15 open-ended questions). Questions 1-3 focused on the framework of the screening tool, while questions 4-18 required participants to suggest the movement tasks and screening criteria they felt would best assess each of the fundamental movement patterns: squatting, lunging, upper body pushing and pulling, trunk bending, trunk rotation and gait.

After the results of Survey 1 were analysed, Survey 2 was created and sent to participants. According to the Delphi technique, the content of Survey 2 was based on the results or majority answers to Survey 1. The objective of Survey 2 was to measure participants' agreement on the ratings of the responses to 16 dichotomous questions. Survey 2 questions were designed to confirm the movement tasks and screening criteria recommended by Survey 1 participants. To assist Survey 2 participants, a video demonstration of each proposed movement task was provided.

3.5 Statistical analyses

Simple frequency and percentage analyses for responses to categorical (Survey 1) and dichotomous (Survey 2) questions were conducted. In addition, frequency, percentage of measurements and issues were calculated from data extracted from the open-ended questions in Survey 2.

3.6 Results

The results of Survey 1 are outlined in Table 12. Survey 1 participants identified that a movement competency screen (MCS) for athletes should involve between 5-10 complex movements (76%) and use a combination of quantitative and qualitative analytic techniques (73%). Twenty-four percent of participants suggested that no equipment should be required to facilitate the movement screen.

The bodyweight squat (44%) task with screening criteria focused on hip (20%) and ankle (16%) mobility; lumbar (15%) and knee stability (18%) was recommended to assess the squat pattern. The bodyweight forward lunge task (84%) with screening criteria focused on knee alignment (19%), lumbar stability (15%) and asymmetries between the left and right leg (15%) was recommended to assess the lunge pattern. The suggested forward lunge screening criteria stressed body control and joint stability (55%) over joint mobility (15%). The standard push-up (71%) with screening criteria that focused on thoracic spine mobility (35%) and scapulae control (22%) was recommended for assessing the upper body push pattern. The preferred movement competency tasks suggested to screen the upper body-pulling pattern varied; the chin-up (21%), bent over row (17%) and supine pull-up (17%) received the highest response rates. Similar to the push pattern screening criteria, thoracic spine mobility (30%) and scapulae function (25%) were the primary criteria suggested for the pull pattern. A standing forward trunk bend was the most popular movement task suggested to evaluate the trunk-bending pattern (65%). Lumbo-pelvic rhythm (27%), lumbar stability (22%) and hip mobility (20%) were the key issues recommended for evaluation during the screening of the bend pattern movement tasks. Standing (51%) and seated (49%) trunk rotation received nearly equal recommendation for screening the trunk rotation pattern. Participants believed that trunk rotation screening criteria should focus on where trunk rotation occurred (67%). Walking (40%) and running (38%) were the preferred movement tasks to screen gait; however, 11% of participants suggested using a single leg squat movement task to screen athletes' gait. Hip alignment (28%), lower limb imbalances (28%) and knee alignment (27%) were the primary gait screening criteria proposed. Survey 1 participants were asked to provide additional comments or suggestions about the content and structure of the movement competency screen. The majority of participants who completed the additional comments section suggested that the MCS should include a standing posture assessment.

Survey 2 participants (n = 72) (see Table 13) achieved over 90% agreement concerning the structure of the proposed movement competency screen (see Table 12 questions 1-4). The movement tasks recommended for assessing the movement competency of the athletes' squat, lunge, trunk rotation, and upper body push patterns (see Table 12 questions 5-10) also received over 90% agreement. The movement tasks recommended to assess trunk bending, upper body pulling and gait received over 80% agreement (see Table 13 questions 11-14). In addition, participants did agree that a standing posture assessment should be included in a movement competency screen for athletes (96%) (see Table 13 questions 15-16).

Given the results from the surveys, a thematic summary was extracted resulting in the whole body functional MCS. However, post-hoc analysis identified some inconsistencies with Survey 1 results. Even though Survey 1 participants recommended that the MCS should involve between 5-10 complex movements, participants responses to Survey 1 questions 5-18 revealed very few complex movements. The MCS detailed in Figure 28 was presented to Survey 2 participants who achieved substantial to excellent agreement about the proposed MCS movement tasks.

Table 11. Questions and response rates (number; %) for Survey 1 (n = 52).

Survey 1 Questions	**Strength & Conditioners (Number; %)**	**Physiotherapists (Number; %)**	**All raters (Number; %)**
(Q.1) What type of movements should the screen involve?			
Complex	22; 42%	17; 33%	39; 75%
Isolated	5; 10%	8; 15%	13; 25%
Total responses	27; 52%	25; 48%	52; 100%
(Q.2) How many movements should the screen entail?			
6-10	21; 40%	18; 35%	39; 75%
1-5	4; 7%	4; 8%	8; 15%
More than 15	0; 0%	3; 6%	3; 6%
11-15	2; 3%	0; 0%	2; 4%
Total responses	27; 51%	25; 49%	52; 100%
(Q.3) What type of analysis techniques should be used during the screen?			
Combination of qualitative and quantitative	15; 29%	17; 33%	32; 62%
Qualitative	9; 17%	6; 12%	15; 29%
Quantitative	3; 6%	2; 3%	5; 9%
Total responses	27; 52%	25; 48%	52; 100%
(Q.4) What equipment, if any, should be used to screen movement?			
No equipment	7; 13%	6; 11%	13; 24%
Two dimensional video	6; 11%	3; 5%	9; 16%
Measure stick	5; 9%	3; 5%	8; 13%
Wall grid	2; 4%	5; 9%	7; 13%
Goniometer	3; 5%	4; 7%	7; 12%
Analysis software	4; 7%	2; 4%	6; 11%
EMG	2; 4%	1; 2%	3; 5%
Swiss ball	1; 2%	0; 0%	1; 2%
Force plate	1; 2%	0; 0%	1; 2%
Three dimensional video	1; 2%	0; 0%	1; 2%
Total responses	32; 57%	24; 43%	56; 100%
(Q.5) Which movement(s) do you think effectively assess a squat pattern?			
Bodyweight squat	22; 23%	20; 21%	42; 44%
Overhead squat	14; 15%	8; 8%	22; 23%

Single leg squat	8; 8%	11; 11%	19; 21%
Half knee bend	0; 0%	5; 5%	5; 5%
Weighted squat	2; 2%	0; 0%	2; 2%
Posture	2; 2%	0; 0%	2; 2%
Wall squat	0; 0%	2; 2%	2; 2%
Thomas test	1; 1%	0; 0%	1; 1%
Duck walk	0; 0%	1; 1%	1; 1%
Total responses	49; 51%	47; 49%	96; 100%
(Q.6) What issue(s) would you be looking for when an athlete performed a squat pattern movement?			
Hip mobility	9; 6%	18; 13%	27; 20%
Knee alignment	8; 6%	16; 11%	24; 18%
Ankle mobility	7; 5%	14; 10%	21; 16%
Lumbar spine stability	4; 3%	16; 11%	20; 15%
Thoracic spine mobility	3; 2%	15; 10%	18; 13%
Foot stability	5; 3%	8; 6%	13; 9%
Head alignment	0; 0%	4; 3%	4; 3%
Hamstring flexibility	2; 1%	2; 1%	4; 3%
Relative strength	4; 3%	0; 0%	4; 3%
Total responses	42; 31%	93; 69%	135; 100%

Survey 1 Questions	**Strength & Conditioners (Number; %)**	**Physiotherapists (Number; %)**	**All raters (Number;%)**
(Q.7) Which movement(s) do you think effectively assess a lunge pattern?			
Forward lunge	23; 42%	25; 45%	48; 87%
Lateral lunge	3; 6%	2; 4%	5; 9%
Walking lunge	2; 4%	0; 0%	2; 4%
Total responses	28; 51%	27; 49%	55; 100%
(Q.8) What issues do the movement(s) you selected to screen the athlete's lunge pattern assesses?			
Knee alignment	14; 14%	5; 5%	19; 19%
Asymmetries	6; 6%	9; 9%	15; 15%
Lumbar spine stability	7; 7%	8; 8%	15; 15%
Head alignment	2; 2%	9; 9%	11; 11%
Hip mobility	8; 8%	3; 3%	11; 11%
Balance	3; 3%	7; 7%	10; 10%
Relative strength	4; 4%	6; 6%	10; 10%
Hamstring flexibility	5; 5%	2; 2%	7; 7%
Foot stability	4; 4%	2; 2%	6; 6%

Coordination	3; 3%	2; 2%	5; 5%
Ankle mobility	1; 1%	3; 3%	4; 4%
Quadriceps flexibility	2; 2%	2; 1%	3; 3%
Total responses	58; 50%	57; 50%	115; 100%
(Q.9) What movement(s) would best screen the upper body push pattern?			
Push-up	19; 35%	20; 36%	39; 71%
Bench press	8; 15%	2; 4%	10; 18%
Dumbbell bench press	2; 4%	2; 4%	4; 6%
Handstand push-up	2; 4%	0; 0%	2; 3%
Total responses	31; 56%	24; 44%	55; 100%
(Q.10) What issues do the movement(s) you selected to screen the athlete's push pattern assess?			
Thoracic spine mobility	20; 28%	8; 11%	28; 35%
Scapulae control	7; 10%	11; 15%	18; 22%
Trunk stability	9; 13%	4; 6%	13; 16%
Head alignment	4; 6%	8; 11%	12; 15%
Depth / Strength	6; 8%	4; 6%	10; 12%
Total responses	46; 57%	35; 43%	81; 100%
(Q.11) What movement(s) would best screen the upper body pull pattern?			
Chin-up	8; 14%	4; 7%	12; 21%
Bent over row	8; 14%	2; 3%	10; 17%
Supine pull up	3; 5%	7; 12%	10; 17%
Seated row	7; 12%	1; 2%	8; 14%
Romanian deadlift	5; 8%	0; 0%	5; 9%
Push up	2; 3%	2; 3%	4; 6%
Power clean	3; 5%	0; 0%	3; 5%
Bench row	2; 3%	1; 2%	3; 5%
Single arm dumbbell row	2; 3%	0; 0%	2; 3%
Lat pull down	2; 3%	0; 0%	2; 3%
Total responses	42; 71%	17; 29%	59; 100%
(Q.12) What issues do the movement(s) you selected to screen the athlete's pull pattern assess?			
Thoracic spine mobility	15; 15%	22; 19%	37; 30%
Scapulae control	12; 14%	18; 16%	30; 25%
Lumbar stability	10; 12%	17; 15%	27; 22%
Hamstring flexibility	9; 11%	10; 9%	19; 16%
Head alignment	4; 5%	5; 4%	9; 7%
Total responses	50; 41%	72; 59%	122; 100%

Survey 1 Questions	Strength & Conditioners (Number; %)	Physiotherapists (Number; %)	All raters (Number;%)
(Q.13) What movement(s) would best screen the trunk-bending pattern?			
Good morning / Standing forward bend	10; 18%	25; 45%	35; 63%
Deadlift	5; 9%	4; 7%	9; 16%
Barbell back squat	5; 9%	1; 2%	6; 11%
Romanian deadlift	4; 7%	0; 0%	4; 7%
Deep squat	1; 2%	1; 2%	2; 4%
Total responses	25; 45%	31; 55%	56; 100%
(Q.14) What issues do the movement(s) you selected to screen the athlete's trunk-bending pattern assess?			
Lumbo-pelvic rhythm	8; 15%	7; 13%	15; 27%
Trunk stability	4; 7%	8; 15%	12; 22%
Hip mobility	4; 7%	7; 13%	11; 20%
Posterior muscle strength	5; 9%	4; 7%	9; 16%
Hamstring flexibility	6; 11%	2; 4%	8; 15%
Total responses	27; 49%	28; 51%	55; 100%
(Q.15) What movement(s) would best screen the trunk-rotation pattern?			
Standing twist	17; 32%	10; 19%	27; 51%
Seated twist	10; 19%	16; 30%	26; 49%
Total responses	27; 51%	26; 49%	53; 100%
(Q.16) What issues do the movement(s) you selected to screen the athlete's trunk-rotation pattern assess?			
Where rotation occurs	18; 31%	20; 34%	28; 65%
Controlling lumbar rotation	11; 19%	10; 17%	21; 35%
Total responses	29; 50%	30; 51%	59; 100%
(Q.17) What movement(s) would best screen gait?			
Walking	16; 19%	18; 21%	34; 40%
Running	17; 20%	15; 18%	32; 38%
Single leg squat	6; 7%	3; 4%	9; 11%
Single leg stance	3; 4%	5; 6%	8; 9%
Hurdle step	1; 1%	1; 1%	1; 1%
Total responses	43; 51%	42; 49%	85; 100%
(Q.18) What issues do the movement(s) you selected to screen the athlete's gait assess?			
Hip alignment	7; 10%	12; 18%	19; 28%
Imbalances	12; 18%	7; 10%	19; 28%
Knee alignment	8; 12%	10; 15%	18; 27%

Strength	6; 9%	2; 3%	8; 12%
Pronation / Supination	1; 1%	2; 3%	3; 4%
Total responses	34; 51%	33; 49%	67; 100%

Table 12. Questions and response rates (number; %) for Survey 2 (n = 72).

Survey 2 questions	**Strength and Conditioners (n = 41)**	**Physiotherapists (n = 21)**	**Biomechanists (n = 10)**	**Total (n = 72)**
(Q.1) A movement screen for athletes should involve complex movements.				
Agree / Disagree	37; 51% / 4; 6%	20; 28% / 1; 1%	10; 14% / 0; 0%	*67; 93% / 5; 7%*
(Q.2) A movement screen for athletes should involve 5-10 movements.				
Agree / Disagree	37; 51% / 4; 6%	20; 28% / 1; 1%	10; 14% / 0; 0%	*67; 93% / 5; 7%*
(Q.3) A movement screen for athletes should involve both qualitative and quantitative analysis techniques.				
Agree / Disagree	40; 56% / 1; 1%	21; 29% / 0; 0%	10; 14% / 0; 0%	*71; 99%* / 1; 1%
(Q.4) A movement screen for athletes should involve two-dimensional video analysis.				
Agree / Disagree	40; 56% / 1; 1%	19; 26% / 2; 3%	10; 14% / 0; 0%	*69; 96% / 3; 4%*
(Q.5) The bodyweight squat will effectively screen an athlete's squat pattern.				
Agree / Disagree	39; 54% / 2; 3%	19; 26% / 2; 3%	10; 14% / 0; 0%	*64; 96% / 4; 4%*
(Q.6) The proposed screening criteria for the bodyweight squat.*				
Agree / Disagree	36; 50% / 5; 7%	15; 21% / 6; 8%	9; 13% / 1; 1%	*60; 84% / 12; 16%*
(Q.7) The bodyweight lunge and twist will effectively screen an athlete's lunge and trunk- rotation patterns.				
Agree / Disagree	39; 54% / 2; 3%	20; 28% / 1; 1%	10; 14% / 0; 0%	*69; 96% / 3; 3%*
(Q.8) The proposed screening criteria for the bodyweight lunge and twist.*				
Agree / Disagree	38; 53% / 3; 4%	19; 26% / 2; 3%	9; 13% / 1; 1%	*66; 92% / 6; 8%*
(Q.9) The standard push-up will effectively screen an athlete's upper body push pattern.				
Agree / Disagree	36; 50% / 5; 7%	20; 28% / 1; 1%	9; 13% / 1; 1%	*65; 91% / 7; 9%*
(Q.10) The proposed screening criteria for the standard push-up.*				
Agree / Disagree	37; 51% / 4; 6%	19; 26% / 2; 3%	10; 14% / 0; 0%	*56; 91% / 6; 9%*
(Q.11) The bodyweight bend and pull will effectively screen an athlete's trunk-bend and upper body pull patterns.				
Agree / Disagree	36; 50% / 5; 7%	18; 25% / 3; 4%	10; 14% / 0; 0%	*54; 89% / 8; 11%*

(Q.12) The proposed screening criteria for the bodyweight bend and pull.*				
Agree / Disagree	36; 50% / 5; 7%	20; 28% / 1; 1%	9; 13% / 1; 1%	*65; 91% / 7: 9%*
(Q.13) The bodyweight single leg squat will effectively screen an athlete's gait.				
Agree / Disagree	31; 43% / 10; 14%	17; 24% / 4; 5%	9; 13% / 1; 1%	*57; 80% / 15; 20%*
(Q.14) The proposed screening criteria for the bodyweight single leg squat.*				
Agree / Disagree	35; 49% / 6; 8%	18; 25% / 3; 4%	9; 13% / 1; 1%	*62; 86% / 10; 14%*
(Q.15) Standing posture should be included in a movement competency screen for athletes.				
Agree / Disagree	39; 54% / 2; 3%	20; 28% / 1; 1%	10; 14% / 0; 0%	*69; 96% / 3; 4%*
(Q.16) The proposed static posture screening criteria.*				
Agree / Disagree	38; 53% / 3; 4%	18; 25% / 3; 4%	10; 14% / 0; 0%	*66; 92% / 6; 8%*

*Criteria participants viewed are shown in Table 14

3.7 Discussion

The first MCS task validated by Survey 2 participants was a standing posture evaluation (96%) illustrated in Figure 28A. Static standing posture was included in the MCS based on Survey 1 participant comments that a MCS should involve a standing posture assessment. Researchers have maintained that an athlete's static standing posture can provide preliminary insight into the musculoskeletal structure of an individual. Issues such as muscle resting length and skeletal alignment have been suggested to offer insight into how the athlete may perform fundamental movement patterns (M. F. Kritz & Cronin, 2008; Watson, 2001; A. W. Watson & C. Mac Donncha, 2000).

The second MCS task validated by Survey 2 participants was the bodyweight squat (96%) illustrated in Figure 28B. A literature review identified the squat pattern to be a fundamental movement pattern in sport and sport specific training (M. Kritz et al., 2009a). The hand placement illustrated in Figure 28B was established to provide an opportunity to assess athletes' thoracic spine mobility during squatting (Butler et al., 2010). The ability to maintain an extended thoracic spine position during a traditionally loaded back squat exercise has been reported to be critical in the mechanics for health and safety (Dionisio et al., 2006). The athletes' ability to keep their elbows in line with their ears during the bodyweight squat movement may provide preliminary insight into the athletes' thoracic and shoulder function.

The third MCS task validated by Survey 2 participants was the lunge-and-twist (96%) featured in Figure 28C. The rationale for combining two fundamental movement patterns to make the complex lunge-and-twist movement was centred on the literature reviewed and Survey 1 participants' opinion to have the MCS comprised of complex movements. The literature has highlighted the benefits of using complex lunging tasks for assessing movement function related to certain lower limb injury mechanisms (Alkjaer et al., 2002; Hewett, Myer, Ford, et al., 2005; M. Kritz et al., 2009a; Loudon et al., 2002). Researchers have been particularly interested in the degree of frontal plane knee motion during lunging and other unilateral movement tasks (Chaudhari & Andriacchi, 2006; Claiborne et al., 2006; Imwalle, Myer, Ford, & Hewett, 2009). The frontal plane neuromuscular control of the knee is significantly challenged when the torso is required to rotate during a lower limb unilateral movement task (Imwalle et al., 2009; Myer, Chu, et al., 2008). It was therefore an intuitive decision by the authors to combine the forward lunge with a trunk rotation movement task.

The fourth MCS movement task validated by Survey 2 participants and illustrated in Figure 28D was the push-up (91%). The push-up was the preferred movement task by Survey 1 strength and conditioners (35%) and physiotherapists (36%) for assessing athletes' upper body push pattern movement competency. However, 19% of the Survey 1 strength and conditioning participants suggested the use of a loaded supine open chain pushing movement task (e.g. bench press) to assess upper body push pattern movement competency. However, as Survey 1 and 2 participants wanted to minimize the need for screening equipment to facilitate the MCS, the push-up was selected as the upper body push pattern movement task. In addition, the standard push-up performed on a flat surface requires an individual to push up to 69% of their body weight and can therefore be considered a loaded movement task (M. Kritz et al., 2010). Furthermore, it is difficult to observe shoulder stability and scapulothoracic rhythm during the bench press.

The fifth MCS movement task validated by Survey 2 participants and illustrated in Figure 28E was the bend-and-pull (89%). Like the MCS lunge-and-twist, the bend-and-pull is a complex movement. The rationale for combining the trunk-bend and upper body pull movement patterns was also based primarily on Survey 1 results and the literature reviewed. One of the popular upper body pulling movement tasks recommended by Survey 1 participants to screen upper body pulling movement competency was the traditional free weight pulling exercise, the bent over row (17%). The standing forward bend (63%) was the desired movement task recommended for assessing trunk-bending competency. Therefore, the decision to combine a bent over pulling task with a trunk-bending movement task appeared intuitive. The decision to make the MCS bend-and-pull a low threshold or unloaded movement task was based on two responses. Firstly, Survey 1 participants' opinion to minimize the need for screening equipment, and secondly, the reviewed literature that promoted the use of both loaded and unloaded movement tasks for screening upper body movement competency (M. Kritz et al., 2010).

The sixth MCS movement task validated by Survey 2 participants and illustrated in Figure 28F was the single leg squat (80%). The decision to use the single leg squat as the movement task for screening athletes' gait was multifactorial. Survey 1 participants recommended the single leg squat (11%) and a single leg stance (9%) as movement tasks that could be used to assess athletes' gait. Researchers have reported acceptable validity and reliability of the single leg squat and other unilateral movement tasks for evaluating gait (Alexander et al., 2008; Chaudhari, Hearn, & Andriacchi, 2005; K. M. O'Connor, Monteiro, & Hoelker, 2009; Whatman et al., 2011). Unilateral movement tasks like the single leg squat can challenge athletes' dynamic body alignment, which has been described as the ability to control excessive trunk lateral flexion, pelvic drop, hip adduction and internal rotation, knee abduction, tibial internal or external rotation and foot hyperpronation (Whatman et al., 2011). Athletes' dynamic body alignment is described in the single leg squat screening criteria that Survey 2 participants approved (86%). Dynamic body alignment has been reported to foster good running mechanics; intuitively, poor dynamic body alignment has been identified as an injury mechanism in runners (Whatman et al., 2011). The complexity of screening gait using either a walking or running movement task has well been documented (Krosshaug et al., 2007; Lord, Halligan, & Wade, 1998). In addition, because Survey 1 and 2 participants advocated the development of an efficient whole body functional screening tool, it was intuitive to the authors to have a MCS movement task that could be performed in a confined space that had the capacity to provide insight into an individual's gait competency.

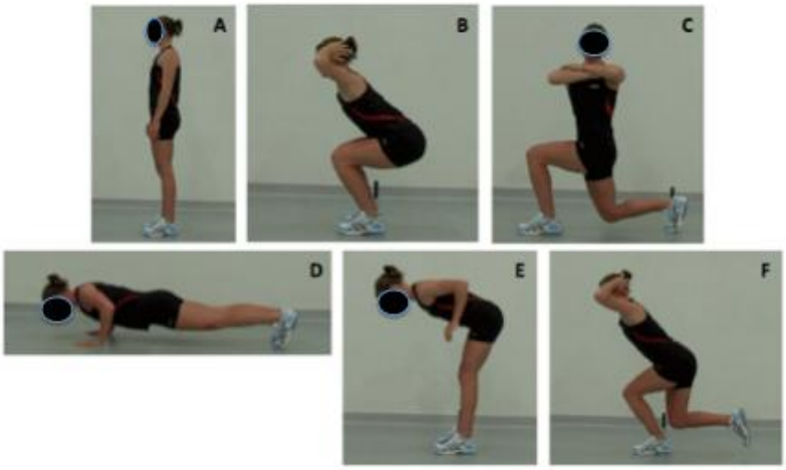


Figure 28. The Movement Competency Screen (MCS) tasks include (A) posture, (B) squat, (C) lunge-and-twist, (D) push-Up, (E) bend-and-pull, and (F) single leg squat.

3.8 Practical applications

The MCS may provide sport and health professionals with a better understanding of an athlete's movement ability and their awareness of what constitutes good movement competency. Important information may be gained simply by observing an athlete's kinesthetic awareness during the performance of the MCS movement tasks. An athlete's movement competency may provide insight into why athletes succeed (Bartlett, Wheat, & Robins, 2007), and it may also offer a mechanical rationale as to why certain athletes report increased rates of injury (Hewett, Lindenfeld, Riccobene, & Noyes, 1999). This information may prove valuable prior to exercise prescription for the purpose of enhancing the communication between sport and health professions to ensure that sport training programs accommodate athletes' movement ability, and that training adaptation contributes more to performance than the mechanisms of injury. The MCS developed and validated in this study may fulfil these objectives and may be effective at identifying a broad range of movement-related risk factors that would otherwise go unnoticed in traditional screening protocols. However, many of these contentions need further investigation.

CHAPTER 4. RELIABILITY OF THE MOVEMENT COMPETENCY SCREEN

This chapter was submitted for publication May 2012 and is under review.

4.1 Prelude

The previous chapter determined the content validity of the MCS. This chapter details the experimental study conducted to quantify the intrarater and interrater reliability of the MCS. Raters marked the movements against a template that provided criteria per body segment and per movement. It was agreed that the MCS consist of six tasks (squatting, lunging, upper body pushing, upper body pulling, trunk flexion, trunk rotation and unilateral lower limb function). These tasks challenge static postural alignment, and the fundamental movement patterns identified to exist in activities of daily living, sport and sport specific training. Although functional screening tests are advocated for athletes, the reliability of visually rating movement quality, especially of multiple body segments, has not been well defined. It is acknowledged that the utility of any assessment tool is dependent upon its validity and reliability. Therefore the purpose of this study was to establish the test-retest and interrater reliability of the MCS.

4.2 Overview

The purpose of this study was to quantify the reliability of the movement competency screen (MCS), a tool that involves a standing posture and five complex movement tasks designed to determine the movement competency of athletes. Raters marked the movements against a template that provided criteria per body segment and per movement. The intra-rater reliability (test-retest) of 12 raters, rating the three athletes' movements on video two times separated by at least seven days, was quantified using the Kappa coefficient. The inter-rater reliability analysis of 58 raters, rating the three athletes' movements on video, was quantified using average percentage agreement coefficients for all pair-wise comparisons of the 58 raters. Overall intra-rater test-retest reliability was almost perfect (Kappa = 0.93). Inter-rater reliability was substantial (79%). Given the good to excellent intra-rater and inter-rater reliability of the strength and conditioners ratings of three athletes' performing the MCS movement tasks, the MCS appears reliable across testing occasions and between raters.

4.3 Introduction

Sport and health professionals endeavour not only to develop and enhance an athlete's physical prowess but also minimize their training and competing time lost due to soft tissue injuries. This is evident by the research that has been devoted to investigating mechanisms of soft tissue injuries (Alentorn-Geli et al., 2009a, 2009b; S. McGill, 2010; Myer, Ford, Barber Foss, et al., 2010; Myer, Ford, & Hewett, 2010; Myer, Ford, Khoury, et al., 2010; Paterno et al., 2010). More recently efforts have been made to investigate the effectiveness of screening complex movements to assist with the understanding of how movement strategies, involving the kinetic chain, influence athletic performance and contribute chronically and/or acutely to the mechanisms of soft tissue injuries (Butler et al., 2010; Kiesel et al., 2009; Kiesel et al., 2007b; Minick et al., 2010). It is has been reported that traditional isolated muscle and joint assessments, common to many athlete pre-participation examinations and muscle balance assessments, fail to link how the kinetic chain responds to muscle weakness and joint instability during fundamental movement patterns (Quatman et al., 2009).

Although this information is considered valuable for identifying weakness and instability of specific muscle and joint complexes, the evidence is equivocal regarding the usefulness of this information on intervention strategies prescribed in athlete pre-habilitation and strength and conditioning programming (Watson, 2001). This is especially so when practitioners have expressed a need to better understand an athlete's movement competency related to the types of movement patterns commonly loaded in sport and strength and conditioning environments (Hewett, Myer, Ford, & Slauterbeck, 2006; Hewett, Snyder-Mackler, et al., 2007; McLean et al., 2005; Minick et al., 2010; Myer, Ford, Khoury, et al., 2010; Paterno et al., 2010). An assessment protocol that evaluates mobility, stability, and proprioceptive control utilizing fundamental movement patterns that challenge the kinetic chain has been recommended (Mottram & Comerford, 2008).

The movement competency screen (MCS) was developed for this purpose. The MCS consists of six tasks that challenge static postural alignment, and the fundamental movement patterns (squatting, lunging, upper body pushing, upper body pulling, trunk flexion, trunk rotation and unilateral lower limb function) identified to exist in activities of daily living, sport and sport specific training (Chek, 2000; Cook, 2003; M. Kritz et al., 2009a, 2010; Sahrmann, 2002). Although functional screening tests are advocated for athletes, the reliability of visually rating movement quality, especially of multiple body segments, has not been well defined. It is acknowledged that the utility of any assessment tool is dependent upon its validity and reliability. The purpose of this study therefore is to establish the test-retest and interrater reliability of the MCS.

4.4 Methods

4.4.1 Approach to the problem

This study required participants to complete the MCS for the purpose of establishing test-retest and interrater reliability of the MCS. Participants viewed and rated the video performance of three elite athletes of varying movement abilities (Athlete 1 = good movement competency, Athlete 2 = poor movement competency, Athlete 3 = fair movement competency) performing the MCS movement tasks for movement quality using the MCS dichotomous screening criteria. The MCS screening criteria utilises seven anatomical segments (head, shoulders, lumbar, hips, knees, and feet) and two movement abilities (range of motion and balance) to quantify the movement competency of athletes. The MCS videos and scoring sheet were made available to participants via a web-based platform. The degree of test-retest agreement of the 12 raters was quantified using the Kappa coefficient. The degree of interrater reliability was determined using the average percent agreement of all pairwise comparisons of 45 raters.

4.4.2 Subjects

Participants (n = 58) consisting of strength and conditioning (n = 41) and physiotherapy (n = 17) specialists were recruited for this study. They were asked to categorize their professional experience into one of two categories: 1-5 years (n = 26) and 6 – years and over (n = 32). AUT University Ethics Committee approved the study, and all participants received written information about the study and gave electronic informed consent.

4.4.3 Procedures

Video: The MCS tasks were recorded from the frontal and sagittal planes on digital video (Panasonic, USA) sampling at a rate of 60 Hz. The video camera was positioned on a tripod in front of the athletes, perpendicular to the frontal plane and at a height of 0.86 m and a distance of 5.5 m. The zoom function of the camera was used to allow the frame of view to capture the individual from hands stretched overhead to below the feet. Tape was placed on the floor to guide the athlete's transition from sagittal to frontal viewpoints for each movement task. The MCS video records were produced using iMovie™ video editing software with title screens used to identify the participant number and movement task. These videos were posted on the web for participants to view and rate at their discretion.

For the three videos that were used to determine test-retest and interrater reliability, an expert rater identified three elite, internationally competitive athletes who exhibited good, moderate and poor movement quality when performing the MCS movement tasks. The athletes in this study were male (n = 1) and female (n = 2) and wore form fitting athletic apparel that exposed the arms, legs and lumbar region. Each athlete was given standardized verbal instructions (see Table 13) prior to their screening, and the principal researcher demonstrated each movement task in a standardized manner. Each athlete was required to complete the MCS movement tasks within their pre-strength training warm-up routine four weeks prior to data collection to ensure substantial familiarization was achieved. The athletes performed six repetitions of each bilateral MCS task and 12 repetitions of each unilateral movement task (i.e. three facing the sagittal plane and three facing the frontal plane). The static posture assessment was performed for a five second count facing the sagittal plane and five seconds facing the frontal plane.

Assessment tool: For all MCS movement tasks raters visually assessed segment movement quality for the head, shoulders, lumbar, hips, knees, ankles and feet, as well as balance and depth. Segment ratings were based on a judgment as to whether participants achieved an acceptable segment position throughout the movement task based on MCS screening criteria (see Table 14). All ratings were recorded on a standardized rating sheet specifically designed for online collection.

Table 13. Verbal instruction for each MCS movement task.

MCS movement tasks	**Verbal instructions**
Posture	Please stand facing the camera with your hands by your side. (Hold athlete for three seconds.) Please turn to the side with your hands to the side. (Hold athlete for three seconds.)
Bodyweight squat	Perform a body weight squat with your fingertips on the side of your head and your elbows in line with your ears. Squat as low as you comfortably can at a comfortable speed.
Lunge-and-twist	Cross your arms and place your hands on your shoulders with your elbows pointing straight ahead. Perform a forward lunge then rotate toward the forward knee. Return to centre and then push back to return to the starting position. Alternate with each repetition.
Push-up	Perform a standard push up.
Bend-and-pull	Start with your arms stretched overhead. Bend forward allowing your arms to drop under your trunk. Pull your hands into your body as if you were holding onto a bar and performing a barbell rowing exercise. Return to the start position with your arms stretched overhead.
Single leg squat	Perform a single leg body weight squat with your fingertips on the side of your head and your elbows in line with your ears. Position the non-stance leg behind the body during the squat. Squat as low as you comfortable can at a comfortable speed.

Table 14. MCS screening criteria used by raters.

Body Region / Capacity	MCS Task 1 Posture	MCS Task 2 Squat	MCS Task 3 Lunge & Twist	MCS Task 4 Push-Up	MCS Task 5 Bend & Pull	MCS Task 6 Single Leg Squat
Head	Held in a neutral position appears centrally aligned.					
Shoulders	Held down away from ears. Slight flexion of thoracic spine OK.	Held down and away from ears. Elbows appear in line with ears.	Held down and away from ears. Rotation appears to occur through thoracic spine.	Held down and away from ears. Scapulae movement balanced and rhythmic and not excessively abducted during arm extension.	Held down and away from ears. Scapulae movement balanced and rhythmic. During arm flexion scapulae are retracted and are not excessively abducted during arm extension.	Held down and away from ears. Elbows appear in line with ears.
Lumbar	Held in neutral curve position.		Held in neutral curve position. Rotation and/ or lateral flexion does not occur during trunk twisting.	Held in neutral curve position.	Held in neutral curve position throughout trunk flexion.	Held in neutral curve position.
Hips	Appear to be horizontally aligned.	Horizontally aligned and mobile. Move back and down during flexion.	Mobile and stable to prohibit elevation and depression during rotation.	Held in line with the body during arm flexion and extension.	Facilitate trunk flexion.	Mobile to facilitate flexion and stable to minimize weight shift to over stance leg.
Knees	Knee caps pointing forward.	Aligned with hips and feet during flexion.	Aligned with hips and feet during flexion and do not	Extended.	Extended.	Aligned with hips and feet during flexion.

			move laterally during rotation.			
Ankles	NR.	Mobility allows adequate dorsi-flexion during knee and hip flexion.		NR.	NR.	Mobility allows adequate dorsi-flexion during knee and hip flexion.
Feet	Pointing straight.	Stable with heels grounded during lower limb flexion.	Heel of lead leg in contact with the floor, trail foot flexed and balanced on forefoot.	Feet straight, heels not falling in or out.	Pointing straight.	Stable with heels grounded during lower limb flexion.
Balance	Evenly distributed.		Maintained on each leg.	NR.	Maintained.	Maintained on each leg.
Depth	NR.	Top of thighs appear parallel with floor.	Lead thigh parallel with the floor.	Chest touches floor.	75-90 degrees of trunk flexion achieved.	Top of thigh appears parallel with floor.

Visual ratings: Two forms of reliability (test-retest and interrater) were quantified in this study. Test-retest reliability was determined utilizing 12 of the 58 study participants who were required to rate the three MCS videos twice over a ten-day period with at least seven days between ratings. Interrater reliability was determined utilizing all 58 participants. Raters were given 45 days to complete the visual rating and electronic scoring of each MCS video record. All participants were allowed to view each MCS video record for as long as they liked within the 45 days. Each rater was sent via email three Internet links to the three MCS scoring sheets. Each scoring sheet had an Internet link to the corresponding MCS video record. For scoring segment movement quality, raters were instructed to check the box associated with the segment that did not display the movement quality detailed in Table 14. Standardized instructions about how to view the video clips and use the MCS scoring sheet were given to all participants prior to them performing the visual ratings. However, once the participant submitted their scoring sheet, they were not permitted to make changes at a later date regardless of how early within the 45-day time frame they submitted them.

4.5 Statistical analyses

Test-retest reliability was established using the Kappa coefficient (SPSS 18). Interrater reliability was calculated using a web-based macro (Freelon, 2010), which calculated the average percent agreement from all pairwise comparisons of raters. Data were presented as a mean and standard deviation to indicate centrality and spread of agreement. Agreement coefficients were interpreted as < 0.00 – poor agreement, 0.01-0.20 – 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 (Landis & Koch, 1977).

4.6 Results

The test-retest reliability for the 12 raters ranged from 0.73 to 1.00 (see Table 15). The overall average Kappa = 0.93 indicated almost perfect agreement between raters. There were no clear trends within the data to explain why all raters did not achieve perfect agreement.

Interrater reliably for the fundamental patterns represented within the MCS movement tasks ranged from 0.70 to 0.85 (see Table 16); the average for all patterns was 0.79 indicating substantial agreement. Standing posture, squat (0.81), upper push (0.84), upper pull (0.84) and trunk-bend (0.85) patterns achieved greater agreement (≥ 0.80) than the lunge, trunk rotation and single leg movement patterns (0.70 to 0.76). There were no clear trends explaining why the aforementioned patterns had varying degrees of rater agreement. However, the agreement for Athletes 2 and 3 was worse than Athlete 1.

Interrater reliably for the body segments assessed using the MCS movement tasks ranged from 0.72 to 0.92 (see Table 17); the average for all patterns was 0.79 indicating substantial agreement. For the shoulders, lumbar, hips and knee segments the average rater agreement was lower (0.70 to 0.76) than the head, feet, balance and depth (> 0.80). Similarly, no clear trends were observed that explained the discrepancy in rater agreement other than the difference in the movement competency of the athletes in the videos. Greater overall rater agreement was observed for Athlete 1 as compared to Athletes 2 and/or 3.

Table 15. Test-retest reliability (Kappa coefficient) of 12 raters for all MCS movement tasks.

Rater 1	**Rater 2**	**Rater 3**	**Rater 4**	**Rater 5**	**Rater 6**	**Rater 7**	**Rater 8**	**Rater 9**	**Rater 10**	**Rater 11**	**Rater 12**	**Average**
1.00	1.00	1.00	1.00	1.00	0.73	0.87	0.87	0.93	0.85	0.92	0.94	0.93

Table 16. Interrater (n = 58) reliability (average pairwise percent agreement) for each fundamental movement pattern assessed within the MCS movement tasks.

Agreement by pattern with the MCS									
Athlete	Posture	Squat	Lunge	Twist	Push	Bend	Pull	Single	Total
1	0.91	0.86	0.90	0.84	0.94	0.91	0.94	0.77	0.88
2	0.74	0.75	0.67	0.63	0.74	0.76	0.78	0.70	0.72
3	0.75	0.82	0.70	0.64	0.84	0.84	0.84	0.65	0.76
Mean	0.80	0.81	0.76	0.70	0.84	0.84	0.85	0.71	0.79
SD	0.10	0.06	0.13	0.12	0.10	0.08	0.08	0.06	0.09

Table 17. Interrater (n = 58) reliability (average pairwise percent agreement) for the individual segments rated within each movement MCS movement task.

Agreement by segment									
Athlete	Head	Shoulders	Lumbar	Hips	Knees	Feet	Balance	Depth	Total
1	0.87	0.84	0.91	0.92	0.80	0.93	0.92	0.79	0.87
2	0.76	0.64	0.62	0.63	0.65	0.79	0.81	0.88	0.72
3	0.81	0.77	0.58	0.73	0.75	0.76	0.81	0.84	0.76
Mean	0.81	0.75	0.70	0.76	0.73	0.83	0.85	0.84	0.78
SD	0.06	0.10	0.18	0.15	0.08	0.09	0.06	0.05	0.09

4.7 Discussion

In terms of test-retest reliability, the Kappa coefficient was chosen to represent the stability of 12 raters in assessing three athletes on two testing occasions separated by seven days. Of the 12 raters, 95 % of the raters had almost perfect agreement (> 0.80), and 42% of the raters reproduced the exact same rating (1.00) between testing occasions. It would seem that for most of the raters the instructions and templates used to assess the MCS movement patterns allow for a high degree of reproducibility between testing occasions.

Visual rating of movement quality is used regularly as part of a screening process by both strength and conditioning and physiotherapy professionals to help identify the risk of injury. For this reason, it was important for the authors to establish the reliability of the MCS across multiple raters given the potential use of the MCS in both the strength and conditioning and physiotherapy environments. In addition, the authors were interested in better understanding if certain movement patterns and screening segments were easier to assess visually than others. Since standing posture, squat, push, pull, and bend movement tasks achieved higher agreement (> 0.80) than the lunge, twist and single leg patterns, sport and health practitioners need to be aware that certain movement patterns may be considered more difficult to visually assess. Similarly, the MCS criteria segment analysis established the variability between the rated segments (i.e. head, shoulders, lumbar, hips, knees, feet) and abilities (i.e. balance and depth). The shoulders, lumbar hips and knees achieved lower (< 0.76) percentage agreement than head, feet, balance and depth (> 0.80). Knudson (1999) suggested that a rating based on an overall impression of whole body motion during a task, like a vertical jump, was more reliable than ratings of individual segments. This notion may help to explain why the shoulder, lumbar, hip and knee segments achieved lower rater agreement.

In addition this study only captured video from the sagittal and frontal plane views, as this appears common in the literature and also practical for rating frontal plane control. It is possible that this 2D projection of a movement pattern may not be an adequate representation of movements in some planes. While we believe this is not uncommon practically, it is possible that other views could be used; a different perspective may have an effect on the level of agreement. To mimic professional practice, we allowed raters to view the MCS video records as many times as they wished within the 45 day period, which may have affected standardization to a degree. As a result, all agreements reported are not based on the same number of observations. However, it should be noted that this would be similar to actual practice i.e., the number of observations will differ amongst practitioners with different levels of expertise.

Lastly, in designing our study, we decided not to give detailed instructions or training to the raters on how to make ratings. This decision was intentional; we wanted to investigate the level of agreement that was likely to exist in current professional practice. It is possible that more explicit instructions or examples of what constituted each level of movement dysfunction would have increased agreement. Chmielewski (2007) concluded that rating scales should include stricter criteria with more explicit instructions to improve agreement between raters. As suggested by Chmielewski (2007), the main clinical concern in evaluating agreement during visual rating is to avoid ratings that would result in different clinical decisions. As visual observation of whole body functional movement is one of many assessments used in making a decision (e.g., strength and flexibility), we suggest the agreement reached was acceptable for practical use.

4.8 Practical applications

Strength and conditioners' and physiotherapists' visual rating of the MCS movement tasks via video resulted in almost perfect intrarater agreement and substantial interrater agreement. However, the reliability of the MCS can be improved with more explicit instructions and/or video examples of how the MCS is administered/scored. Such amendments to the MCS need to be considered in future iterations of the screen. Given acceptable reliability and validity, it is also important that users such as strength and conditioning coaches or physiotherapists provide feedback on the utility of the tool; as such critique may also refine future iterations and functionality of the tool.

CHAPTER 5. EFFECTIVENESS OF THE MOVEMENT COMPETENCY SCREEN: USER PERCEPTION

5.1 Prelude

Previous chapters have detailed the content validity and reliability of the MCS. Another important issue to consider when designing tools to be used by practitioners is the utility or efficacy of the tool. Many tools may have high reliability and/or validity but do little to influence diagnosis/prognosis and influence practice thereafter. In this regard it was important to know whether a screening tool such as the MCS is effective. Effectiveness in this study refers to whether the MCS users believe the use of the MCS has a positive influence on their daily professional practice and whether using the MCS enhances their understanding of movement competency in general. The purpose of this chapter therefore was to determine the effectiveness of the MCS from the perspective of its users (i.e. strength and conditioning and physiotherapy professionals).

5.2 Overview

The purpose of this study was to evaluate the effectiveness of the movement competency screen (MCS) from the perspective of strength and conditioning and physiotherapy professionals (MSC users). Effectiveness in this study refers to whether the MCS users believed the use of the MCS had a positive influence on their daily professional practice and whether using the MCS had enhanced their understanding of movement competency in general. Forty six strength and conditioning and physiotherapy professionals with an average of 12.4 ±7.7 years experience, of which 59% had used the MCS for over a year at the time the study was conducted, completed an online survey consisting of 16 questions. Seven-item Likert scales were used to rate responses on ten of the sixteen questions. MCS users strongly agreed that the MCS had enhanced their understanding of movement competency and had a positive influence on their daily professional practice.

5.3 Introduction

The use of movement-screening tools like the movement competency screen (MCS) by sport and health professionals to assess athletes' movement capability is now considered common practice (Mottram & Comerford, 2008). Screening is generally promoted as a risk assessment and performance enhancement strategy. The only empirical data reported in peer-reviewed journals for movement screens has been validity and/or reliability information. User opinion of the effectiveness of the screening tools and how the use of these tools influences professional practice is not documented.

It is understood that the mere act of screening athletes using a valid and reliable movement screen by itself will not reduce the incidence of injury or enhance the athletes' physical performance. The authors propose that the practitioner using the screening tool must understand the principles of kinesiology that underpin the movement screen. This knowledge will lead to the prescription of effective interventions, based on the results of the movement screen, in order to enhance athletes' movement competency and potentially reduce their incidence of soft tissue injury. If the goal is to develop a valid, reliable and effective movement-screening tool, then an understanding of how screeners perceive the movement screen and what knowledge the screener believes they gain from the screening process would be valuable development information.

The purpose of this study was to evaluate the effectiveness of the movement competency screen (MCS) from the perspective of strength and conditioning and physiotherapy professionals (MSC users). Effectiveness in this study refers to whether the MCS users believed the use of the MCS had a positive influence on their daily professional practice, and whether using the MCS had enhanced their understanding of movement competency in general.

5.4 Methods

5.4.1 Approach to the problem

This study required participants to complete an online survey designed to investigate participant opinion about the MCS for the purpose of establishing user perception of the effectiveness of the MCS. In addition, we were interested in whether MCS users had observed a decrease in the number of soft tissue injuries experienced by the individuals they screened as well as a general improvement in their physical prowess.

5.4.2 Subjects

Sport and health professionals (n = 46) recruited for this study included strength and conditioning (n = 28) and sport physiotherapy (n = 18) specialists; fifty nine percent of which had been using the MCS for over a year at the time the study was conducted. The average professional experience of strength and conditioning specialist participants was (10.6 ±6.7 y) and physiotherapy specialist participants was (15.2 ±8.5 y). AUT University Ethics Committee for Human Research approved the study, and all participants completed an informed consent prior to data collection.

5.4.3 Procedures

A survey was designed and made available to participants via a web-based platform to accommodate the international location of participants. Participants were sent an email request to participate in this study based on their involvement with previous MCS studies or their interest in receiving further information about the MCS after experiencing the screening tool at a workshop or conference. Participants were required to complete a web-based consent form. Once the consent form was submitted participants were sent a link to access the survey questions.

The majority of the survey questions were Likert items. A Likert item is a statement that the participant is asked to scale according to any subjective or objective criteria to which the level of agreement or disagreement may then be measured (Likert, 1932). A 7-point Likert scale was used to rate the responses to questions where 7 = Very Strongly Disagree, 6 = Strongly Disagree, 5 = Disagree, 4 = Neither Agree or Disagree, 3 = Agree, 2 = Strongly Agree, 1 = Very Strongly Agree.

5.4.4 Statistical analyses

Frequency analysis was performed for all survey questions. The mode and standard deviations were generated for all Likert responses to each question. Independent t-tests were used to determine if statistical differences existed between the physiotherapist's and strength conditioner's rating of the survey questions. Statistical significance was set at $p<0.05$.

5.5 Results

Participants' professional experience (12.4 ±7.7) and general use of the MCS can be seen in Table 18. The majority of participants reported they had used the MCS for over a year (59%). The most frequent use of the MCS was during a pre-participation (23%) and muscle balance assessment (28%). Interestingly, 15 (19%) of the strength and conditioning participants reported that they used the MCS when they first met an athlete or client as compared to 3 (2%) of the physiotherapists. Also 10 (13%) strength and conditioning and 8 (10%) physiotherapy participants reported that they used the MCS as part of a muscle balance assessment. Participants reported the bodyweight squat (24%) more often than the other MCS movement tasks as an effective movement task for measuring individuals' movement ability. However, 20% of the participants believed that all the MCS movement tasks were effective for measuring an individual's movement competency. All participants strongly agreed that their general understanding of human movement and fundamental patterns improved since using the MCS. Specifically though, participants reported that their understanding of hip mobility (22%), knee stability (19%) and thoracic spine mobility (18%) was enhanced the most as compared to the other functions measured by the MCS. Participants agreed that the MCS enhanced the way in which they prescribed resistance-training programs. Participants very strongly agreed that they used the MCS as part of their warm-up protocols. They strongly agreed that the individuals they train are more aware of what constitutes good movement competency since they started to perform the MCS movement tasks. Participants agreed that the individuals they train actually move better since using the MCS. They neither agreed nor disagreed when asked if they observed an increase in physical performance or a reduction in the incidence of soft tissue injuries of the individuals they have screened. Participants strongly agreed that using the MCS has enhanced the effectiveness of their communication with other sport and health professionals. Six (10%) strength and conditioning and six (10%) physiotherapy participants reported that they use the MCS to assist with designing an individuals' rehabilitation program. Overall all participants strongly agreed that the MCS was an effective tool to determine the movement competency of an individual.

The largest differences (>0.4) between physiotherapist and strength and conditioner ratings of the survey questions were observed for the following questions: whether the MCS had enhanced the way they prescribed resistance-training exercises (questions 9), whether since using the MCS to guide exercise and training load prescription their athletes / clients appeared to be moving better biomechanically (question 14) and whether the MCS was an effective tool to determine the movement competency of an individual (question 16). However, none of the between group differences were statistically significant.

A frequency analysis, mode and standard deviation of each Likert item used in this study is reported in Table 19. The mode for all Likert items for all participants was (6 ±0.9) inferring that overall participants strongly agreed that the MCS was an effective screening tool.

Table 18. Frequency analysis performed on participant responses of the effectiveness of the MCS.

		S & C (n = 28)	Physio (n = 18)	Total (n = 46)
Q1	Years in profession	10.57 ±6.66	15.22 ±8.50	12.39 ±7.70
Q2	Time using the MCS			
	Less than 6 months	6 (13%)	2 (4%)	8 (17%)
	7-12 months	4 (9%)	7 (15%)	11 (24%)
	Over a year	18 (39%)	9 (20%)	27 (59%)
Q3	How do you use the MCS?			
	When I first meet an athlete and/or client	15 (19%)	2 (3%)	17 (22%)
	Before each new strength training phase	7 (9%)	2 (3%)	9 (11%)
	Once per year as part of the athlete or clients performance profile	9 (11%)	3 (4%)	12 (15%)
	2-3 times per year as part of the athlete or clients performance profile	9 (11%)	2 (3%)	11 (14%)
	During the athlete's muscle balance assessment	10 (13%)	8 (10%)	18 (28%)
	After an athlete or client sustains an injury to help guide the rehabilitation process	6 (8%)	6 (8%)	12 (15%)
Q4	I have found the following MCS movements to be the most effective for measuring an athlete's movement ability.			
	Standing Posture	4 (4%)	2 (2%)	6 (6%)
	Bodyweight Squat	18 (17%)	6 (6%)	24 (23%)
	Lunge-and-Twist	13 (12%)	6 (6%)	19 (18%)
	Bend-and-Pull	5 (5%)	4 (4%)	9 (8%)
	Push-Up	10 (9%)	2 (2%)	12 (11%)
	Single Leg Squat	9 (8%)	7 (7%)	16 (15%)
	All MCS movement tasks	9 (8%)	11 (10%)	20 (19%)
Q5	My understanding of the following functions has been enhanced since using the MCS.			
	Shoulder stability	5 (5%)	0 (0%)	5 (5%)
	Thoracic spine mobility	11 (10%)	7 (6%)	18 (16%)
	Lumbar stability	7 (6%)	6 (5%)	13 (11%)
	Hip mobility	13 (12%)	9 (8%)	22 (20%)
	Knee stability	11 (10%)	8 (7%)	19 (17%)
	Ankle mobility	7 (6%)	7 (6%)	14 (12%)
	Foot stability	3 (3%)	2 (2%)	5 (5%)
	All of the above	6 (5%)	2 (2%)	8 (7%)
	None of the above	4 (4%)	3 (3%)	7 (7%)

Table 19. Likert items used to assess participant perception of MCS effectiveness.

		Very Strongly Agree	Strongly Agree	Agree	Neither Agree Or Disagree	Disagree	Strongly Disagree	Very Strongly Disagree	S&C Mode	Physio Mode	Total Mode
Q6	I find the MCS easy to use.	17	18	6	5	0	0	0	7 ±1	6 ±1.1	6 ±1
Q7	Using the MCS has enhanced my understanding of the general principles that govern human movement.	7	16	10	5	5	1	2	6 ±1.6	6 ±1.6	6 ±1.6
Q8	Using the MCS has enhanced my understanding of fundamental movement patterns.	9	21	8	3	0	3	2	6 ±1.5	6 ±1.7	6 ±1.6
Q9	The MCS has enhanced the way I prescribe resistance-training exercises.	12	13	15	5	0	0	1	7 ±1	5 ±1.4	5 ±1.2
Q10	Since using the MCS to guide exercise and training load prescription, I have observed a decrease in the number of soft tissue injuries experienced by my athletes / clients.	0	7	9	20	5	2	3	4 ±1.3	4 ±1.4	4 ±1.3
Q11	Since using the MCS to guide exercise and training load prescription, I have observed a decrease in the severity of soft tissue injuries experienced by my athletes / clients.	0	10	7	20	4	2	3	4 ±1.3	4 ±1.5	4 ±1.4
Q12	Since using the MCS I believe my athletes / clients are more aware of what constitutes good movement and the impact good movement has on physical performance and the incidence of injury.	13	17	12	3	0	1	0	6 ±1	6 ±1.3	6 ±1.1
Q13	I currently use the MCS in my program prescription as either warm-up or part of a battery of movement preparation exercises.	14	11	9	3	6	1	0	7 ±1.5	7 ±2	7 ±1.7
Q14	Since using the MCS to guide exercise and training load prescription my athletes / clients appear to be moving biomechanically better.	10	10	15	9	0	1	1	5 ±1.3	5 ±1.4	5 ±1.3

Q15	The MCS has improved my communication with the strength or health professional who also works with my athletes / clients.	8	15	11	7	1	3	1	5 ±1.4	6 ±1.7	6 ±1.5
Q16	The MCS is an effective tool to determine the movement competency of an individual.	14	21	8	1	2	0	0	6 ±1	6 ±1	6 ±1

5.6 Discussion

Given the goal was to develop a valid, reliable and effective movement-screening tool, an understanding of how screeners perceived the MCS and what knowledge the screeners believed they gained from the screening process was considered to be important development information. In this regard we surveyed strength and conditioners (S&C) and physiotherapists (Physios) with considerable experience (12.4 ±7.7 y). Given the knowledge and experience of the participants the results of this study are exciting. These participants could have easily been the toughest critiques of the MCS given the meritorious level of their professional practice. It was thought that the perception of the efficacy of the MCS may be different between S&C and Physios, hence the rationale for the inclusion of these two samples. However, this was not the case. Both S&C and Physio participants demonstrated surprising alignment regarding their perceptions of the effectiveness of the MCS. Question nine was the only question that provoked a noticeable difference in perception between the professional groups. Perhaps the Physio participants in this study generally did not prescribe resistance-training programs to the extent the S&C professionals in this study did and therefore did not feel the MCS impacted their professional practice in that manner. Given there was only one significant difference between S&C and Physio perception of the effectiveness of the MCS on professional practice, the subsequent discussion includes both S&C and Physio responses.

A principal objective of the MCS was that it provides a common language for S&C and Physio professionals to describe and guide interventions to develop and enhance athletes' movement competency. In this study participants strongly agreed that the MCS improved the effectiveness of their communication between other S&C and Physio professionals. Participants agreed that the MCS load levels assisted their program design and subsequent movement competency of their client or athlete. The MCS load levels were developed for a greater purpose than to categorise athletes' movement strategies via a number to enable quantification of their movement competency. Rather the load levels were developed to put athletes' movement competency into context as it relates to the modalities that may be used by S&C and Physio professionals to load athletes to challenge their physical prowess. The theory held by the authors is that prescribing loads that compliment athletes' movement competency instead of over-challenging it, provide athletes' an opportunity to develop movement strategies that will ultimately contribute to the mechanisms of performance and not the mechanisms of injury because they are being pushed beyond their capability and ultimately their soft tissue capacity.

The authors also proposed that using the MCS indirectly would educate the user about the fundamental principles that govern human movement related to the relationships throughout the kinetic chain between mobility and stability regions of the body. Participants strongly agreed that their understanding of fundamental movement patterns and the principles that govern human movement were enhanced with their use of the MCS. This is an important result of the development of the MCS that should not be overlooked. Experienced sport and health professionals have suggested that it would be difficult to achieve consensus between S&C and Physio professionals about the best way to enhance an athletes' physical prowess. The intention of this project was not to ultimately control how professionals write programs but to provide an objective method for identifying athlete's movement strategies so that the strength and conditioning plan developed for the athlete reflected the athlete's weaknesses as much as their strengths. It was encouraging for the authors to learn that the participants felt that the MCS made them more aware of what constitutes good movement. Therefore, the implication may be that participants' improved understanding of movement competency as a result of using the MCS may encourage the consistent development of a good movement foundation in the athletes. This may subsequently enable sport and health professionals to assertively explore new ways to physically challenge athletes, with confidence that their athletes' movement competency can support the challenges presented to them.

5.7 Practical applications

An understanding of user perception of the MCS was critical for the development of the MCS. We are not aware of any other studies that have reported user perception of a whole body movement-screening tool as part of the development of that tool. The results theoretically infer that the MCS screening criteria and scoring format are intuitive to users. An essential use of the MCS is when an S&C or Physio professional first meets an individual. The information gleaned from the MCS provides the S&C or Physio with an initial understanding of the strengths and weakness as it relates to the movements they intend to load in the gym and during conditioning. In addition, the results of this study support our premise that using the MCS as an educational tool helps inform and prompt users of the key principles that govern the execution of fundamental movement patterns. In addition, the MCS load levels may be used between S&C and Phyiso professionals to set a common language that may be used to administer how loads are programmed to develop, manage and enhance athletes' physical prowess. The next step in this journey is to better understand how the MCS affects physical performance and the incidence and magnitude of soft tissue injury. Do athletes that score higher on the MCS run faster and jump higher than athletes that score lower? Do athletes that score lower on the MCS experience a greater number of soft tissue injuries, and are those injuries considered more catastrophic than the injuries experienced by athletes who score higher on the MCS?

CHAPTER 6. EFFECTIVENESS OF THE MOVEMENT COMPETENCY SCREEN: INJURY VERSUS PERFORMANCE

6.1 Prelude

In the previous chapters the content validity, reliability and user perception of the MCS were established. Movement competency is of interest to strength and conditioning practitioners when considering an athlete's long-term athletic development and injury prevention. In this regard it is acknowledged that injury and performance are multi-factorial, however it may be that tools such as the MCS give some insights into predictors of injury and performance. The responses from the strength and conditioners and physiotherapists in the previous chapter were fairly neutral in terms of the utility of the MCS in these regards. The previous chapter outlined the next step in this journey was to better understand how the MCS affects physical performance and the incidence and magnitude of soft tissue injury. Do athletes that score higher on the MCS run faster and jump higher than athletes that score lower? Do athletes that score lower on the MCS experience a greater number of soft tissue injuries, and are those injuries considered more catastrophic than the injuries experienced by athletes who score higher on the MCS? To help answer these questions the aim of this study was to investigate whether the movement competency screening score could predict physical performance or injury.

6.2 Overview

This observational study allowed us to test whether descriptive movement competency screening (MCS) scores could predict physical performance or injury over one year. Data were gained from 91 New Zealand national level athletes. An on-line data collection system was used to record injuries sustained over one year. Physical performance was measured four times throughout the year (Sprint speed via electronic timing gates at 5-m, 10-m and 20-m; Body power via counter movement jumps, a standing static jump and a clap push-up on a force platform). Athletes were videoed from the front and side while performing five repetitions of the five MCS movements. One experienced rater rated each athlete's MCS movements using a rating sheet with MCS criteria. Regions/capabilities within each movement task that did not match the criteria were added to determine the load level for each movement. Individual MCS scores (1, 2 or 3; where 3 is highest competency) were added to give composites for upper body MCS (bend-and-pull, push up), lower body MCS (body weight squat, lunge-and-twist, single leg squat), trunk MCS (lunge-and-twist, bend-and-pull) and total MCS (all five movements). To test whether MCS scores could predict physical performance (speed or power) or injury (count or load), generalized mixed linear model models were derived in SAS. The only clear effect was for lower body MCS 2-3 score and lower body power for females (moderate effect -0.88; CL ±1.05) and for trunk MCS 2-3 score and trunk injury for all participants (very large effect 3.40; CL ×/÷ 3.19). Initial evidence indicated lower body MCS score may predict lower body power for females and trunk MCS score may predict trunk injury for all participants. MCS screening may have potential for use by strength and conditioning practitioners for predicting physical performance and injury risk in their athletes.

6.3 Introduction

Movement competency is the ability to move in a biomechanically efficient manner free of discomfort and pain (M. Kritz et al., 2009a). The way athletes move and activate their muscles influences joint loading and injury risk (Hewett et al., 2009; Myer et al., 2004), and can change the way metrics, such as strength and power, are expressed during the performance of sport specific tasks (Vanrenterghem et al., 2008). Movement competency and production of muscular power and speed is of concern for strength and conditioning practitioners when considering an athlete's long-term athletic development and injury prevention. Movement competency of athletes can affect athletic performance and the incidence of soft tissue injuries (Alentorn-Geli et al., 2009a, 2009b; Kiesel et al., 2007b; Myer, Chu, et al., 2008; Paterno et al., 2004).

Movement competency has been assessed with the Functional Movement Screen© (FMS) protocol developed by North American physiotherapists Gray Cook and Lee Burton, which uses specialized equipment and seven whole body movement tasks (Minick et al., 2010). The inter-rater reliability of the FMS measured via video ratings of 44 individuals performing the FMS movement tasks by one expert physiotherapist and one novice physiotherapist, showed excellent or substantial agreement (e.g. Squat 87.2% agreement, 0.80 Kappa) (Minick et al., 2010). The effectiveness of the FMS was examined with 46 National Football League athletes but predicted only 46 out of 100 injuries via the relationship between the athlete's FMS score and their incidence of injury (Kiesel et al., 2007b). The use of the FMS to guide exercise prescription and evaluate the effectiveness of training in 20 subjects (Frost et al., 2010) showed the FMS scores were not stable, so the influence of training on natural movement strategies could not be evaluated.

The objective of the MCS is to provide strength and conditioning professionals with insight into the movement competency of the athletes they coach prior to the prescription of a strength-training program. Excellent percentage agreement (80% to 97%) was achieved regarding the opinions of participants about the structure, movement tasks (i.e., six tasks that challenge seven fundamental movement patterns) and screening criteria (i.e., categorized into seven body regions and two capacities) for the MCS. Fundamental movement patterns include the body weight squat (M. Kritz et al., 2009a), the body weight lunge and twist (M. Kritz, Cronin, & Hume, 2009b), the push-up, the bodyweight bend and pull (M. Kritz et al., 2010) and the single leg squat. It has not yet been determined if MCS scores are associated with power and speed performance or injuries. Therefore the aim of this study was to investigate whether the movement competency screening score could predict physical performance or injury.

6.4 Methods

6.4.1 Approach to the problem

This observational study allowed us to test whether a baseline descriptive movement competency screening score (and composites for upper body, lower body and the trunk) could predict physical performance (speed or power) or injury (count or load) over one year.

6.4.2 Subjects

The 91 athletes (49 females: 25.9 ±4.7 yr; 171.2 ±12.0 m; 72.6 ±11.5 kg.; 42 males: 26.3 ±3.8 yr; 183.8 ±9.5 m; 84.9 ±10.2 kg) from the 2009-2010 New Zealand national hockey (31 males, 27 females), netball (22 females) and basketball (11 males) teams recruited for this study gave informed consent prior to data collection according to the protocols approved by AUT University Ethics Committee for Human Research where the study was conducted (AUTEC 11/109).

6.4.3 Procedures

An automated on-line data collection system was used to record injury over one year. Injury was defined as "any injury sustained during training or match that prevented a player from taking full part in all training activities planned for that day and/or match play for more than one day following the day of injury." For example, if a player had been injured in a match on Saturday and was not able to take part fully in training on Monday then this was recorded as an injury. This injury definition is consistent with the “time-loss” injury definition described by Fuller et al (Fuller et al., 2007). Injury severity was classified 1-3 as defined by: 1) slight modification to training and competition; 2) substantial modification to training and competition; and 3) no training or competition. Injury was derived as count (total number of injuries) and load (sum of the count and severity of injury) over one year.

Physical performance was measured four times throughout the year as stipulated within the athlete’s national performance plan. Speed tests consisted of a timed linear sprint using electronic timing gates set to record 5-m, 10-m and 20-m sprint times. Lower body power was measured from a dual limb counter movement jump, right limb counter movement jump, left limb counter movement jump and standing static jump. Upper body power was measured from a clap push-up. Upper and lower body power was measured on a force platform (Fitness Technologies, 400 Series, Adelaide, South Australia). Analysis was performed using the Ballistic Measurement System software (Fitness Technologies, 400 Series) collecting at 200 Hz. Reliability of the data for all movements assessed has been established to be ICC of $R > 0.98$ and a CV% of ~3%.

All performance test scores were added to give a total performance score with composite scores derived for sprint speed (5-m, 10-m, 20-m sprints), lower body power (dual limb counter movement jump, right limb counter movement jump, left limb counter movement jump and a standing jump) and upper body power (clap push-up).

All 91 athletes were videoed from the front and side while performing five repetitions of the five MCS movement tasks. The verbal instructions given to the athletes before each movement task was performed included:

- Body weight squat - Perform a body weight squat with your fingertips on the side of your head and your elbows held in line with your ears. Squat as low and as fast as you comfortably can.
- Lunge-and-twist - Cross your arms and place your hands on your shoulders with your elbows pointing straight ahead. Perform a forward lunge then rotate toward the forward knee. Return to center and then push back to return to the starting position. Alternate legs with each repetition.

- Bend-and-pull - Start with your arms stretched overhead. Bend forward allowing your arms to drop under your trunk. Pull your hands into your body as if you were holding onto a bar and performing a barbell rowing exercise. Return to the start position with your arms stretched overhead.
- Push up - Perform a standard push up.
- Single leg squat - Perform a single leg body weight squat with your fingertips on the side of your head and your elbows in line with your ears. Position the non-stance leg behind your body as you squat. Squat as low and as fast as you comfortable can.

One experienced rater rated each athlete's MCS movements using the rating sheet as outlined in Figure 29. Referring to the MCS criteria, the rater checked the primary or secondary region/capability that did not match the criteria. For example, if the individual's knees were not aligned during the squat, then the 'knees' region was checked on the scoring sheet. The scoring reflected the weakest side for all unilateral patterns. After completing the scoring of an individual's MCS, the checked regions/capabilities within each movement task were added to determine the load level for that pattern.

The individual movement competency screening scores (1, 2 or 3; where 3 is highest competency) were added to give composites for upper body MCS (bend-and-pull, push up), lower body MCS (body weight squat, lunge-and-twist, single leg squat), trunk MCS (lunge-and-twist, bend-and-pull) and total MCS (all five body weight squat, lunge-and-twist, bend-and-pull, push up and single leg squat movements).

MCS Score 18

PATTERN	PRIMARY	SECONDARY	LOAD LEVEL	COMMENTS
SQUAT	✓ SHOULDERS o LUMBAR o HIPS o ANKLES/FEET	o HEAD o KNEES ✓ DEPTH o BALANCE	1 2 **3**	Shoulders do not remain inline with ears and does not achieve desired depth. Shoulder issue may be due to muscle tightness or t-spine immobility. Safe to load with external mass.
LUNGE & TWIST (The Lunge)	o BALANCE o LUMBAR o HIPS o ANKLES/FEET	o HEAD o KNEES o DEPTH	1 2 **3**	
LUNGE & TWIST (The Twist)	o SHOULDERS ✓ LUMBAR o HIPS o ANKLES/FEET	o HEAD o KNEES o DEPTH o BALANCE	1 **2** 3	Does not limit lumbar rotation during rotation. Develop rotation mechanics awareness and strength before external loads are prescribed.
BEND & PULL (The Bend)	o SHOULDERS o LUMBAR o HIPS ✓ DEPTH	o HEAD o KNEES o ANKLES/FEET o BALANCE	1 **2** 3	Further assessment why depth is an issue is required by sports medicine. Hamstring strength and flexibility may be an issue. Load with bodyweight until better understood.
BEND & PULL (The Pull)	o SHOULDERS o LUMBAR o HIPS o DEPTH	o HEAD o KNEES o ANKLES/FEET o BALANCE	1 2 **3**	
PUSH UP	o HEAD o SHOULDERS o LUMBAR o DEPTH	o HIPS o KNEES o ANKLES / FEET o BALANCE	1 2 **3**	
SINGLE LEG SQUAT	✓ DEPTH o LUMBAR o HIPS o ANKLES / FEET	o HEAD ✓ SHOULDERS o KNEES ✓ BALANCE	1 **2** 3	Shoulders do not remain inline with ears and does not achieve desired depth. Shoulder issue may be due to muscle tightness or t-spine immobility. Safe to load with bodyweight until desired depth is achieved on a consistent basis.

SCORING INSTRUCTIONS

Load Level	Scoring rationale	Considerations
1 (Assisted)	2 or more primary regions checked	Pay close attention to the primary regions for each movement task. The primary regions will have the most meaningful impact on movement competency.
2 (Bodyweight)	1 primary region and 2 or more secondary regions	To score unilateral patterns the load level should reflect the poorest side. For example: If an athlete scores a 3 on their right leg and a 2 on their left leg, that athlete would score a 2 for their single leg squat pattern. Athletes' unilateral movement competency should be a reflection of their weakest side.
3 (External Load)	No primary and only 1 secondary regions	

Figure 29. An example of a scoring sheet for the movement competency screen (MCS)

6.4.4 Statistical analyses

The statistical approach to analyse the data was quantitative, and practical significance was reported using effect sizes and interpretation of the magnitudes of the estimates. As the study was conducted with elite athletes, there was no control group and there were low subject numbers.

To test whether the total movement competency screening score and composites for upper body and lower body could predict physical performance (speed or power) or injury (count or load), generalized mixed linear model models were derived in SAS. The performance comparisons of interest were total MCS score and total performance, lower body MCS scores and lower body power, lower body MCS scores and sprint speed, and upper body MCS scores and upper body power. The injury comparisons of interest were upper body MCS scores and upper body injury count, trunk MCS scores on trunk injury count and load, lower body MCS scores and lower body injury count, and total MCS scores and total injury count and load.

For the statistically savvy reader, the effect of the MCS score on physical performance was modelled with movement competency (fixed effect with three levels 1-3) interacted with the gender effect (two levels, male / female) and the random effects (estimated different residual variance for each of the six levels of gender by competency). The data were normalized and parsed into tertiles. Averaging the standard deviations of each predictor by gender and comparing the means across all predictor groups examined the effect of the tertiles on the dependant variables. Uncertainty in effects was expressed as 90% confidence limits, which were estimated using 5000 bootstrap samples. The effect of the MCS score on injury count and injury load was similarly modelled with a generalized mixed linear model by specifying an over dispersed Poisson distribution for the count and the load.

Outcomes were interpreted using probabilistic magnitude-based inferences (Hopkins, Marshall, Batterham, & Hanin, 2009). Standardized (Cohen) (difference in mean / SD) and unbiased effect sizes (ES) were used to assess magnitudes of differences between means of groups (<0.2, trivial; 0.20-0.59, small; 0.60-1.19, moderate; >1.20, large) (Hopkins et al., 2009).

6.5 Results

There were trivial to moderate effect sizes with large confidence limits for the comparisons between movement competency screen scores and the physical performance measures (lower limb power, running speed, upper limb power) for male and female participants (see data in Table 20). The only clear effect was for lower body MCS 2-3 score and lower body power for females (moderate effect -0.88; CL ±1.05).

Table 20. Comparison between movement competency screen scores 1 to 3 and physical performance measures (lower limb power, running speed, upper limb power) for male and female subjects.

	Estimates (90% CL)[a] for females			Estimates (90% CL)[a] for males		
	1-2	1-3	2-3	1-2	1-3	2-3
Upper body MCS score and upper body power	-0.04 (1.07)	-0.51 (0.84)	-0.47 (1.04)	-0.80 (1.29)	-1.30 (0.90)	-0.50 (1.21)
Lower body MCS scores and lower body power	0.59 (0.85)	-0.29 (1.14)	-0.88* (1.05)	-0.35 (1.04)	-0.08 (1.14)	0.28 (1.01)
Lower body MCS scores and sprint speed	0.33 (0.85)	0.03 (1.09)	-0.30 (1.01)	-0.01 (1.20)	-0.33 (1.16)	-0.31 (0.87)
Total MCS score and total performance	0.16 (0.87)	-0.45 (1.14)	-0.61 (1.05)	-0.22 (1.22)	-0.26 (1.25)	-0.04 (0.86)

[a]CL shown in ±. Effects considered <0.2, trivial; 0.20-0.59, small; 0.60-1.19, moderate; >1.20, large.
*Clear moderate effect.

There were small to large effect sizes with large confidence limits for the comparisons between movement competency screen scores and the injury counts and loads for all participants (see data in Table 21). The only clear effect was for trunk MCS 2-3 score and trunk injury for all participants (very large effect 3.40; CL ×⁄÷3.19).

Table 21. Comparison of movement competency screen scores for injury count and load for all subjects.

	Injury count estimates (90% CL)[a] for all subjects			Injury load estimates (90% CL)[a] for all subjects		
	1-2	1-3	2-3	1-2	1-3	2-3
Upper body MCS score and upper body injury	0.79 (2.13)	1.32 (2.33)	1.68 (2.46)	0.95 (2.30)	1.61 (2.56)	1.70 (2.80)
Trunk MCS score and trunk injury	0.65 (2.36)	2.22 (3.84)	3.40* (3.19)	0.50 (3.05)	1.78 (5.27)	3.55 (3.94)
Lower body MCS scores and lower body injury	0.95 (1.46)	0.82 (1.49)	0.87 (1.47)	1.08 (1.55)	0.80 (1.57)	0.74 (1.56)
Total MCS score and total injury	0.91 (1.43)	0.97 (1.50)	1.06 (1.46)	0.91 (1.49)	0.90 (1.55)	0.99 (1.50)

Scores greater than 1 equal higher competency while scores less than 1 equal lower competency. [a]CL shown in ×/÷ form. Effects considered <0.2, trivial; 0.20-0.59, small; 0.60-1.19, moderate; >1.20, large. *Clear very large effect.

6.6 Discussion

This pilot study aimed to determine whether the movement competency screening score could predict physical performance or injury. There was some initial evidence that a difference between a lower body MCS 2 and lower body MCS 3 score could predict lower body power for females, and that a difference between a trunk MCS 2 and trunk MCS 3 trunk score could predict trunk injury for all participants. However, the small sample sizes will have contributed to the unclear outcomes for the comparisons between movement competency screen scores and the physical performance measures or injury counts and loads. Outliers in the data from sampling variation may have contributed to clear outcomes. The results of this study are not unusual. Previous studies have attempted to establish a relationship between movement screening results and physical performance and the incident of injury with variable results. Kiesel et el.(Kiesel et al., 2007b) investigated the effectiveness of the FMS™ at predicting serious injury amongst American professional football players. FMS™ scores obtained prior to the start of the season and serious injury (membership on the injured reserve for at least 3 weeks) data were complied for one team (n = 46). Utilizing a receiver operator characteristic curve the FMS™ score was used to predict injury. A score of 14 or less on the FMS™ was positive to predict serious injury with specificity of 0.91 and sensitivity of 0.54. Although the results of this study were not particularly strong the authors claimed that fundamental movement (as measured by the FMS™) is an identifiable risk factor for injury in professional football players. Conversely, Plisky et el. (Plisky, Rauh, Kaminski, & Underwood, 2006) using the Star Excursion Balance Test (SEBT) with logistic regression models indicated that players with an anterior right/left reach distance difference greater than 4 cm were 2.5 times more likely to sustain a lower extremity injury ($P<.05$). Female participants with a composite reach distance less than 94.0% of their limb length were 6.5 times more likely to have a lower extremity injury ($P<.05$) (Plisky et al., 2006).

Having screening movements that can help predict performance or injury will enable strength and conditioners to monitor and prescribe exercises for athletes to enhance their performance and reduce their injury risk. Further work is required to investigate the MCS rating system to see if it is sensitive enough for predictive purposes. Prospective studies should be conducted to see how the MCS score components change with strength and conditioning interventions. The current study used only one baseline MCS screen and performance battery, and although injury was measured throughout the year, there was not enough body site-specific injury data to enable analyses of upper body movement competency by upper body injury count for example.

6.7 Practical applications

While this was a pilot study, the strength and conditioning practitioner may contemplate the results of these data in an applied way by considering how the MCS trunk score may be an indicator of trunk injury risk if poor trunk movement competency is aggressively loaded. In addition, our data seems to intimate that female athletes' lower body MCS scores may be a predictor for lower body power. Although the results of this study are modest at best the results are original in terms of making a link between movement competency and physical performance. The sport and health community now has a new assessment tool in the MCS that is valid and reliable with strong user support and modest evidence that the results of the MCS may be linked to performance and the incident of injury.

CHAPTER 7. GENERAL SUMMARY, LIMITATIONS, FUTURE RESEARCH AND RECOMMENDATIONS

7.1 General summary

A movement screen for sport and health professionals has not been empirically established prior to the studies conducted in this thesis. Therefore, the aim of this thesis was to use pragmatic methodologies to establish the validity, reliably and efficacy of whole body movement competency screening tool for sport and health professionals.

A review of the literature revealed several key methodological areas to be considered in the design of the experimental studies within this thesis. Principally at the time the research was conducted there had not been a movement competency screen for athletes developed using an evidenced based methodological approach. Initially literature was reviewed to determine what movements and criteria should constitute a movement screen. There were several studies that used a variety of movement tasks to challenge individuals' movement competency for the purpose of identifying mechanics of injury (Chaudhari & Andriacchi, 2006; Cibulka & Threlkeld-Watkins, 2005; Cools, Declercq, et al., 2007; Cowley, Ford, Myer, Kernozek, & Hewett, 2006; Ford et al., 2003; Forthomme et al., 2008). At the completion of the literature review a philosophy about what a movement screen for athletes should entail emerged. The authors' philosophy about the content of a movement screen was heavily influenced by the volume of research that has used lower limb complex movement tasks such as bilateral and unilateral squatting, lunging, stepping up and down, and vertical and horizontal jumping (Filipa, Byrnes, Paterno, Myer, & Hewett, 2010; Ford et al., 2003; Hewett, Snyder-Mackler, et al., 2007; M. Kritz et al., 2009a, 2010; Paterno et al., 2010; Whatman et al., 2011). It was evident that a consensus had not been explored regarding which movement tasks were believed to be the most prognostic for screening an athletes' movement competency.

Therefore, the first experimental study aimed to establish the content validity of a movement competency screen for athletes. To date there have been no studies that have investigated the opinions of sport and health professionals about which movements they believed to be the most suitable to use and why an athlete's movement capability should be screened. This study identified that sport and health professionals preferred the MCS for athletes involve between 5-10 complex movements challenging the kinetic chain and each of the fundamental movement patterns (squatting, lunging, upper body pushing, upper body pulling, trunk bending, trunk rotation, and single leg squatting). A combination of quantitative and qualitative analytic techniques were favoured for screening. In addition participants desired a screening tool that did not require extensive measuring equipment. In the end participants indicated that standing posture, a bodyweight squat, a lunge with trunk rotation, a trunk bend with a arm pulling motion, a standard push-up and a single leg squat were the movement tasks they wanted in a movement screen to assess athletes' movement competency.

The next step was to determine the reliability of the recommended MCS. Establishing the interrater and intrarater reliability of a visual rating tool had not been standardized. A variety of methodologies had been peer reviewed (Minick et al., 2010; Whatman et al., 2011). Nonetheless, it was important to the authors that the reliability of the MCS be ascertained for use via multiple raters considering multiple sport and health professionals may be working with the same athlete and may implement the MCS to inform exercise prescription. Intrarater reliability was established at Kappa = 0.93 indicating almost perfect agreement. Interrater reliability was 0.79 indicating substantial agreement. It was evident that there was greater variability amongst raters when rating an athlete who had poorer movement competency, which is not usual according to previous research (Whatman et al., 2011).

Upon the establishment of the content validity and reliability of the MCS, the authors were interested in gaining a greater understanding of the effectiveness of the MCS from a user perspective. Therefore, the third experimental study investigated strength and conditioning and sport physiotherapy practitioners' perceptions of the effectiveness of the MCS. To the authors' knowledge there has been no study previously reported that has captured the perception of the effectiveness of a movement-screening tool. Using a web platform participants were recruited from around the world. This study was successful in recruiting experienced participants who had been using the MCS for over a year to comment on its effectiveness. The results of this study indicated that overall participants strongly agreed that the MCS is an effective screening tool. This was an important discovery to further validate the content and the perception of the usefulness of the MCS, however, the final area of interest to the authors was whether the MCS could predict performance and/or the incident and magnitude of injury.

The final study of this thesis was a pilot study designed to investigate the relationship between scores achieved during a MCS and elite athlete physical performance and incidence and magnitude of soft tissue injury over a year. There was some initial evidence that a difference between participants that scored a MCS Level 2 versus a MCS Level 3 for lower body movement competency could predict lower body power for females, and that a difference between a MCS Level 2 versus a MCS Level 3 for trunk movement competency could predict trunk injury for all participants. This studies data is not surprising. Studies investigating the effectiveness of injury screening tools at predicting the incident of injury have reported varying results (Hewett, Snyder-Mackler, et al., 2007; Kiesel, Plisky, & Butler, 2011; Kiesel et al., 2007a; F. G. O'Connor et al., 2011). For example, the efficacy of the Functional Movement Screen (FMS™) at predicting the incident of injury has been reported in both elite athlete and military populations (Kiesel et al., 2007a; F. G. O'Connor et al., 2011). Within elite American football athletes the FMS™ was reported to predict four out of ten incidents of injury (Kiesel et al., 2007a). Within military populations the results multifactorial; A score of ≤14 on the FMS™ predicted any injury with a sensitivity of 0.45 and a specificity of 0.71 and serious injury with a sensitivity of 0.12 and a specificity of 0.94 (F. G. O'Connor et al., 2011). Neither of these studies investigated the efficacy of each FMS™ movement task and the incident of injury at specific anatomical regions. The authors of the aforementioned studies concluded that further work was needed to conclusively recommend the FMS™ as a tool capable of predicting soft tissue injury. We concur that more robust data collection procedures, specifically ensuring future studies investigating the efficacy of the MCS at predicting injury use only injury data considered a result of poor movement competency, rather than all injuries sustained within a certain time period. This may require future MCS efficacy studies to be prospective instead of retrospective.

Overall, the authors believe this thesis achieved the primary objective of developing a valid and reliable movement competency-screening tool. Yet, in the process of developing the MCS a movement competency paradigm (MCP) emerged that appears to effectively develop, manage and enhance the movement capability of an individual by matching their movement competency with specific training interventions. In addition, the MCP has provided a professional framework for efficient and effective communication between sport and health professionals during the management and rehabilitation of injury and has inspired new curricula focussing on the integration of assessment with programming in institutions of higher education throughout New Zealand, Australia and Malaysia.

7.2 Limitations

It is important to be cognizant of the following limitations when interpreting the results of this thesis. The empirical literature available that had investigated human movement competency and/or functional movement ability was limited. There were very few studies that had investigated the use of fundamental movement patterns to either determine individuals' movement ability or assist with identifying mechanisms of injury. There is a healthy amount of research that has used some of the fundamental movement patterns reported in this thesis as rehabilitation interventions. However, to date, injury research has not reported the subjects' movement competency before or after an intervention. This makes interpreting the outcomes of injury intervention research dubious because an individual's movement competency will influence how they are able to challenge the muscles that control their movement strategies. Furthermore, the systematic development of a screening tool to determine an individual's movement competency had not been previously reported; hence, this projects methodical design is mixed may be considered unique.

The participants used in study one were limited to strength and conditioning, sport physiotherapy and biomechanics specialists given their understanding of anatomy and kinesiology. However, due to the limited number of biomechanics professionals involved in this study, they were not used in subsequent studies. In addition, the sample size may have been affected by the methods used to recruit participants. Participants were asked to participate via email correspondence, which is effective for communicating over wide geographic ranges but may have limited the potential sample size due to the lack of personal participant contact. In addition, each participant's common knowledge and general experience screening movement may have been limited at the time of this study due to the inadequate amount of general research and public information about movement-screening protocols.

Only strength and conditioning and sport physiotherapy specialists were used in study two. The analysis used in study two to calculate agreement did not preserve complete independence of ratings, however we consider it unlikely this may have inflated the percent agreement values reported. Furthermore, only video from the sagittal and frontal plane views was utilized, as this appears common in the literature and is also practical for rating frontal plane control. It is possible that this 2D projection of a movement pattern may not be an adequate representation of movements in some planes or an ideal simulation of what occurs in real life. Furthermore, viewing of the transverse plane motions during some of the MCS movement tasks may have been difficult when presented with only frontal and sagittal viewpoints. While we believe this is not uncommon practically, it is possible that other views could be used, and this may have an effect on the level of agreement. Additionally, to mimic professional practice, we allowed raters to view the MCS video records as many times as they wished with the 45 day period, which may have sacrificed a level of the standardization. As a result, all agreements reported are not based on the same number of observations. Lastly, in designing our study we decided not to give detailed instructions or training to the raters on how to make ratings. This was intentional, as we wanted to investigate the level of agreement that was likely to exist in current professional practice. It is possible that more explicit instructions or examples of what constituted each level of movement dysfunction would have increased agreement.

The sample size in study three may have contributed to the non-normal distribution of the data. In addition, the participants were limited to strength and conditioning and sport physiotherapy specialists as these professional had the most experience with the MCS prior to the study. Furthermore, this study did not qualify the general human movement knowledge of each participant, and therefore the results should be interpreted with these limitations in mind.

Study four was a pilot study due to the limited number of elite athletes available at the time of data collection. Although few studies have reported using over ninety elite athletes, the athlete cohort was not homogenous and therefore from a statistical perspective, the sample size will have contributed to the unclear outcomes for the comparisons between movement competency screen scores and the physical performance measures or injury counts and loads. The participants' physiotherapist provided the injury counts data. The standardized form used to collate injury count and load was new to the physiotherapist and may have confounded the interpretation of the severity and magnitude of the injuries recorded.

Lastly, the load levels and training program detailed in chapter seven was not empirically investigated in this thesis due to time constraints and the fact that the original objective of this thesis was to develop a movement screen for strength and conditioning coaches.

7.3 Future research

This research project aimed to develop a tool to assist sport and health professionals with identifying how an individual performs fundamental movement patterns commonly loaded in activities of daily living, sport and sport specific training environments. In the process, several areas requiring further investigation have arisen.

It would be worth investigating if interviewing prospective participants in-person and providing them opportunities to explain their answers in greater detail would have influenced the MCS validity data. Also, it would be interesting to better understand how length of MCS use may affect the intrarater and interrater reliability. In addition, further investigation may be warranted to examine whether the length of exposure to the MCS affects users' perception of its effectiveness. The final study of this research project was a pilot study; therefore, a more robust study investigating the construct validity of the MCS and its movement tasks as they relate to physical performance and the incidence and magnitude of soft tissue injury is warranted. Finally, the effectiveness of the MCP and the MCS load levels at developing and enhancing an individual's movement competency versus conventional strength training and rehabilitation protocols would be an important next step toward solidifying the MCS as a industry standardized assessment tool.

7.4 Recommendations and practical applications

Although examining the MCS as it relates to performance and injury over an extensive time period may be considered the yardstick by which a movement screen like the MCS should be measured, we would maintain that this is only part of the big picture. The MCS is a tool that can be used to evaluate athletic development, therefore injury prediction and performance becomes a possible associated benefit and not the primary objective. As outlined above and although this has not been evaluated in the thesis it may be that the MCS on its own is not a performance or prediction tool, rather using the MCS enhances the training programs that a coach designs.

The MCS may be more meaningful at establishing guidelines for athletic competencies. Although movement-screening efforts may detect movement patterns that may make the athlete susceptible to injury, the primary purpose of the MCS is to grade an athlete's progress on increasing their physical prowess in a manner that will support optimal and safe power production. It is therefore, recommended that the MCS and MCP be used to assess movement competency and guide movement based intervention. Principally as an assessment tool the MCS can provide valuable information about how an individual performs fundamental movement patterns. This is very important to understand prior to prescribing exercises and loads when you consider the central tenant of soft tissue injury is that the internal and/or external demand experienced by the soft tissue exceeds its structural capacity (Bartlett et al., 2007; Chaudhari & Andriacchi, 2006; Hewett, Myer, Ford, et al., 2005; Neely, 1998). In addition, the MCS provides an opportunity to better understand the athlete's awareness of movement competency. How athletes perform the MCS movement tasks will give great insight into their training age and functional strength and weaknesses.

However, screening individuals' movement competency to better understand their movement capability prior to exercise prescription is only part of the paradigm to develop, manage and enhance movement competency and physical prowess. It is recommended that the information gained from the MCS be used to directly influence the exercises and loads prescribed, otherwise a resilient foundation of movement competency will not be prepared. Therefore, it would seem more appropriate for sport and health professionals to systematically load an individual based on their movement competency rather than their muscular strength. The strength training profession has well documented methods for progressively overloading muscle by manipulating 'how much' external mass is prescribed (Baechle, Earle, & Wathen, 2008; Christou et al., 2006; Harman, 2000; Kell & Asmundson, 2009), methods for progressing 'how' individuals are loaded based on their movement competency is comparatively unexplored. For this reason the MCP may be used to facilitate the results of the MCS informing program design (M. Kritz et al., 2009a, 2010). The MCP innovatively and systematically links a load modality (Table 22) to each MCS pattern score. The load modalities by themselves may be considered germane to sport and health professionals, yet how they are endorsed within the MCP is what makes the paradigm successful.

Table 24 illustrates the loading objective and exercise progressions for each MCP load level for each fundamental movement pattern challenged by the MCS. The key performance indicator to progress an individual to the next MCP load level is also provided. It is contraindicated to progress an individual to the next load level before their movement competency can support the internal and external demands required of the next level.

Level one assists a movement pattern utilizing strength bands (Figure 30) to attenuate the bodyweight force to enable the athlete to work through a full range of motion with proper mechanics. Illustrations of sample level one exercises are provided in Figure 31. Level two requires the individual to control and command their bodyweight load through the desired ranges of motion. Illustrations of sample level two exercises are provided in Figure 32. Level three introduces external mass in the form of traditional free weight modalities (e.g. barbells, dumbbells, medicine balls, etc.). Illustrations of sample level three exercises are provided in Figure 33. Level four focuses on the eccentric phase a movement pattern. It provides an opportunity for the individual to demonstrate proprioception, control and muscle strength at the point in a pattern's range of motion where the most joint forces have been recorded (Flanagan et al., 2004). Level five utilizes movement tasks performed at moderate to high force and velocities to provide individuals an opportunity to demonstrate their movement competency at various power outputs. Illustrations for level four and five have not been provided due to the fact that a still picture cannot properly illustrate the dynamic nature of eccentric and plyometric exercises.

Table 22. Movement competency paradigm load levels

MCP Load levels		
1	Assisted	Uses strength rubber bands to attenuate the bodyweight load to enable an individual to perform fundamental movement patterns at a load that does not exceed their biomechanical capacity.
2	Bodyweight	Uses natural bodyweight load to challenge the individual's movement competency.
3	External mass	Uses external mass (traditional free weights) to challenge an individual's movement competency.
4	Eccentric	Uses bodyweight load at high speeds with a purposeful and controlled stopping action at the end of the eccentric phase.
5	Plyometric	Uses bodyweight and if appropriate additional external mass at high accelerations and velocities through the eccentric and concentric phases of each fundamental movement pattern.

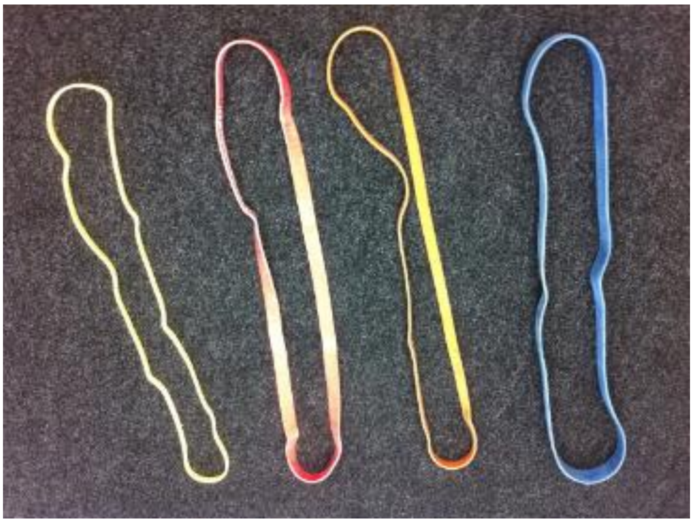


Figure 30. Illustration of 1-m strength rubber bands

Table 23. Sample exercise progressions

Load Level	*Squat*	*Lunge*	*Upper Push*	*Upper Pull*	*Trunk Bend*	*Trunk Rotation*	*Single Leg*
Level 1 – Assisted (Figure 30)	Bodyweight squat	Forward lunge, in place lunge	Push Up	Vertical pull-up, horizontal pull up	Good morning	Resisting rotation exercises (e.g. two point prone hold)	Single leg squat
KPI	Perform 100 repetitions in 3 sets or less of each pattern following the pattern technique detailed in Table 14.						
Level 2 – Bodyweight (Figure 31)	Bodyweight squat	Forward lunge, in place lunge	Push Up	Vertical pull-up, horizontal pull up	Good morning, sit ups	Standing and seated trunk twists	Single leg squat
KPI	Perform 100 repetitions in 3 sets or less of each pattern following the pattern technique detailed in Table 14.						
Level 3 – External Mass (Figure 32)	Back squats, front squats	Walking lunges, forward lunges	Weighted push up, shoulder press, bench press	Weighted pull up (vertical or horizontal)	Weighted good morning, weighted sit ups	Standing barbell rotations, cable wood chop	Bulgarian squats, step ups, Kettle bell pistols
KPI	Exercises performed at near maximal-to-maximal load capacity while maintaining the pattern technique detailed in Table 14.						
Level 4 – Eccentric	Drop and stick squat	Drop and stick lunge	Drop and stick push up	Pull up with and release and catch	Drop and stick good morning	Drop and stick lunge with rotation	Drop and stick single leg squat
KPI	50 repetitions of each exercise performed while maintaining the pattern technique detailed in Table 14.						
Level 5 – Plyometric	Jump squats, cleans, clean and jerk	Split jumps, split jerk	Explosive bench press, clap push ups	Snatch, pull up quick hands	Explosive sit ups	Explosive rotations	Bounding, single leg counter movement jumps
KPI	The technique detailed in Table 14 needs to be maintained during the performance of these exercises at all times.						

Figure 31. Illustrations of sample load level 1 exercises for each pattern (A – squat, B – In-place-lunge, C – push up, D – pull –up, E – good morning, F – two point prone hold, G – single leg squat).

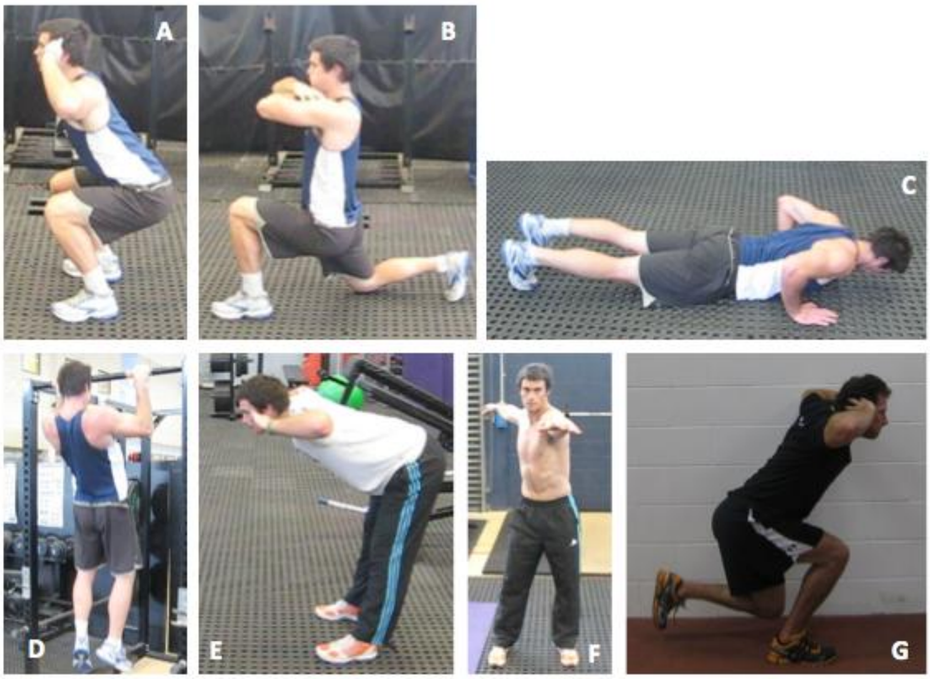


Figure 32. Illustrations of sample load level 2 exercises for each pattern (A – squat, B – forward lunge, C – push up, D – pull –up, E – good morning, F – standing arms out rotation, G – single leg squat).

Figure 33. Illustrations of sample load level 3 exercises for each pattern (A – back squat, B – forward lunge, C – push up, D – horizontal pull–up, E – good morning, F – standing bar rotation, G – Kettle bell pistol)

The key performance indicators detailed in Table 23 are important to endorse. It has been previously reported that loading an individual beyond what their movement competency can support will likely manifest into an injury mechanism. Therefore, careful consideration must be applied when sport and health professionals attempt to progress individuals' movement competency. One method used by development and elite sporting organizations in New Zealand and Malaysia to progress athletes movement competency is the MC 100 protocol. The MC 100 protocol detailed in Appendix 4 provides the athlete an opportunity to practice and perfect movement at a load that complements their movement competency. The MC 100 protocol uses high volume in the form of repetitions to progress an individual's movement competency from Level 1 to 2 to 3. The central tenant being that motor skills are best developed with repetition (Hewett et al., 1999). Progressing individuals from Level 3 to the more advanced movement tasks commonly associated with Levels 4 and 5 has not been robustly explored by the authors using the MC 100 protocol and are therefore not commented on in great detail. However, the authors believe the MC 100 could be used with MCP load levels 4 and 5 as a means of confirming athletes' capacity to tolerate high volumes of eccentric and plyometric loading before more aggressive stimulus is prescribed.

In conclusion, the MCS and MCP are strongly recommended to use any time strength training or rehabilitation exercises are prescribed to ensure the individual has the kinesthetic awareness and physical capacity to tolerate the prescribed loading, thus ensuring the loading prescribed contributes to the mechanisms of performance and not soft tissue injury.

APPENDIX 1 – ETHICS DOCUMENTATION

MEMORANDUM

Auckland University of Technology Ethics Committee

(AUTEC)

To: John Cronin

From: **Madeline Banda** Executive Secretary, AUTEC

Date: 23 June 2008

Subject: Ethics Application Number 08/61 **Movement Competency Screen (MCS): Development and Reliability.**

Dear John

Thank you for providing written evidence as requested. I am pleased to advise that the Chair of the Auckland University of Technology Ethics Committee (AUTEC) and I have approved your ethics application. This delegated approval is made in accordance with section 5.3.3 of AUTEC's *Applying for Ethics Approval: Guidelines and Procedures* and is subject to endorsement at AUTEC's meeting on 14 July 2008.

Your ethics application is approved for a period of three years until 23 June 2011.

I advise that as part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online through *http://www.aut.ac.nz/about/ethics*. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 23 June 2011;
- A brief report on the status of the project using form EA3, which is available online through *http://www.aut.ac.nz/about/ethics*. This report is to be submitted either when the approval expires on 23 June 2011 or on completion of the project, whichever comes sooner;

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

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

When communicating with us about this application, we ask that you use the application number and study title to enable us to provide you with prompt service. Should you have any further enquiries regarding this matter, you are welcome to contact Charles Grinter, Ethics Coordinator, by email at charles.grinter@aut.ac.nz or by telephone on 921 9999 at extension 8860.

On behalf of the AUTEC and myself, I wish you success with your research and look forward to reading about it in your reports.

Yours sincerely

Madeline Banda
Executive Secretary
Auckland University of Technology Ethics Committee
Cc:Mathew Kritz matthew.kritz@aut.ac.nz

Participant Information Sheet

Date Information Sheet Produced: 06, MAY 2008

Project Title

Movement Competency Screen (MCS): Development and reliability studies

An Invitation

You are invited to participate in this important research project. This project looks to develop a qualitative, video based assessment tool to assist strength and conditioning professionals in identifying faulty movement patters when an athlete performs movements that are fundamental to sport and sport specific training.

What is the purpose of this research?

It is the objective of this research project to investigate and develop a standardized assessment tool to identify faulty human movement when performing specific actions that are determined to be fundamental to sport and sport specific training.

How was I chosen for this invitation?

You have been invited to participate in this project because participants need to be well-trained athletes with a minimum training age of three years who are at least eighteen years old.

What will happen in this research?

You will be asked to perform bodyweight movements involving the following movement patterns: squat, lunge, upper body push, upper body pull, bend, twist, and single leg squat. Your performance will be recorded on video.

What are the discomforts and risks?

The discomfort is associated with performing nine repetitions of seven body weight movements. There will be a 2-minute recovery period between movements. The risks are associated with low intensity activity of a short duration.

How will these discomforts and risks be alleviated?

Given that the movements are not complex and only involve bodyweight for the external load the risks will be minimal, however, additional time between movements will be granted if necessary.

What are the benefits?

Your participation in this research project will enable the development of a valuable tool for strength and conditioning professionals. By identifying faulty movement patterns prior to the significant loading of muscles. There is a greater opportunity to enhance athletic performance while reducing the incidence of injury.

What compensation is available for injury or negligence?

In the unlikely event of a physical injury as a result of your participation in this study, rehabilitation and compensation for injury by accident may be available from the Accident Compensation Corporation, providing the incidence details satisfy the requirements of the law and the Corporation's regulations.

How will my privacy be protected?

The principle researcher and research supervisor will be the only persons viewing your personal information. All data collected (i.e. height, weight, age, name and video data of you performing the various movements) will be stored on the principle researchers computer that is password protected and secure at all times.

What are the costs of participating in this research?

The costs associated with this research project are related to time and cost of petrol. You will be required to participate in two video sessions taking approximately one hour each. The sessions will be separated by seven days.

How do I agree to participate in this research?

You will be required to sign a consent form after you finish reading this document.

Will I receive feedback on the results of this research?

You will receive feedback on the results and a report of your MCS score. Further consultation regarding your score may be provided upon request.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, *Associate Professor John Cronin,* **john.cronin@aut.ac.nz**, 64 9 921 9999 Ext. 7523. Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEC, Madeline Banda, *madeline.banda@aut.ac.nz*, 921 9999 ext 8044.

Whom do I contact for further information about this research?

Researcher Contact Details:

Matthew Kritz, matthew.krtiz@aut.ac.nz, 021 960 827

Project Supervisor Contact Details:

Associate Professor John Cronin, **john.cronin@aut.ac.nz**, 64 9 921 9999 Ext. 7523

Approved by the Auckland University of Technology Ethics Committee on *June 2008*, AUTEC Reference number *08/61.*

MEMORANDUM

Auckland University of Technology Ethics Committee

(AUTEC)

To:John Cronin

From:**Charles Grinter** Ethics Coordinator

Date:1 July 2011

Subject: Ethics Application Number 11/109, **Movement competency screen (MCS) efficacy study.**

Dear John

Thank you for providing written evidence as requested. I am pleased to advise that it satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC) at their meeting on 9 May 2011 and I have approved your ethics application. This delegated approval is made in accordance with section 5.3.2.3 of AUTEC's *Applying for Ethics Approval: Guidelines and Procedures* and is subject to endorsement at AUTEC's meeting on 25 July 2011.
Your ethics application is approved for a period of three years until 1 July 2014.

I advise that as part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online through http://www.aut.ac.nz/research/research-ethics/ethics. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 1 July 2014;
- A brief report on the status of the project using form EA3, which is available online through http://www.aut.ac.nz/research/research-ethics/ethics. This report is to be submitted either when the approval expires on 1 July 2014 or on completion of the project, whichever comes sooner;

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

Please note that AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to make the arrangements necessary to obtain this.

When communicating with us about this application, I ask that you use the application number and study title to enable us to provide you with prompt service. Should you have any further enquiries regarding this matter, you are welcome to contact me by email at ethics@aut.ac.nz or by telephone on 921 9999 at extension 8860.

On behalf of AUTEC, I wish you success with your research and look forward to reading about it in your reports.

Yours sincerely

Charles Grinter
On behalf of Dr Rosemary Godbold and Madeline Banda **Executive Secretary**
Auckland University of Technology Ethics Committee

Cc:Matthew Franklin Kritz mattk@nzazni.org.nz, Patria Hume

Participant Information Sheet

Date Information Sheet Produced:

06, MAY 2010

Project Title

Movement Competency Screen (MCS): Development and evaluation of kinematic procedures for valid and reliable estimation of faulty movement patterns in athletes.

An Invitation

You are invited to participate in this important research project. This project looks to develop a qualitative, video based assessment tool to assist strength and conditioning professionals in identifying faulty movement patters when an athlete performs movements that are fundamental to sport and sport specific training.

What is the purpose of this research?

It is the objective of this research project to investigate and develop a standardized assessment tool to identify faulty human movement when performing specific actions that are determined to be fundamental to sport and sport specific training.

How was I chosen for this invitation?

You have been invited to participate in this project because participants need to satisfy one or all of the following criteria.

Be involved in AUT's ---- paper which involvement in this study is required.

You are a strength and conditioning or fitness professional with three or more years experience writing strength training programs.

What will happen in this research?

You will be asked to view a video online and complete an MCS screening sheet based on whay you witness in the videos.

What are the discomforts and risks?

The discomfort is associated with operating and viewing information on a computer.

How will these discomforts and risks be alleviated?

You will be given 30 days to complete this study so that you may regulate the time required based on any discomforts experienced.

What are the benefits?

Your participation in this research project will enable the development of a valuable tool for strength and conditioning and fitness professionals. By identifying faulty movement patterns prior to the significant loading of muscles. There is a greater opportunity to physical performance while reducing the incident of injury.

What compensation is available for injury or negligence?

In the unlikely event of a physical injury as a result of your participation in this study, rehabilitation and compensation for injury by accident may be available from the Accident Compensation Corporation, providing the incident details satisfy the requirements of the law and the Corporation's regulations.

How will my privacy be protected?

The principle researcher and research supervisor will be the only individual viewing your personal information. All data collected will be stored on the principle researchers computer that is password protected and secure at all times.

What are the costs of participating in this research?

The costs associated with this research project are related to time. You will required to review three videos and score the participants using the MCS screening sheet, The process takes approximately 20 minutes per video.

How do I agree to participate in this research?

You will be required to check a box below associated with this online ethics form.

Will I receive feedback on the results of this research?

The results of this study will be made available to you upon your request.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, *Professor John Cronin,* **john.cronin@aut.ac.nz**, 64 9 921 9999 Ext. 7523. Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEC, Madeline Banda, *madeline.banda@aut.ac.nz* , 921 9999 ext 8044.

Whom do I contact for further information about this research?

Researcher Contact Details:

Matthew Kritz, mattk@nzasni.org.nz 021 960 827

Project Supervisor Contact Details:

Associate Professor John Cronin, **john.cronin@aut.ac.nz**, 64 9 921 9999 Ext. 7523

Approved by the Auckland University of Technology Ethics Committee on *type the date final ethics approval was granted*, AUTEC Reference number *type the reference number*.

Consent Form

Project title: **Movement Competency Screen Efficacy Study**

Project Supervisor: ***Professor John Cronin***

Researcher: ***Matthew Kritz***

- ○ I have read and understood the information provided about this research project in the Information Sheet dated August 2011.
- ○ I have had an opportunity to ask questions and to have them answered by email to Matthew Kritz.
- ○ I understand that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.
- ○ If I withdraw, I understand that all relevant information will be destroyed.
- ○ I agree to take part in this research.
- ○ I am aged 16 years or older.

Approved by the Auckland University of Technology Ethics Committee on 1 July 2011 AUTEC Reference number 11/109.

APPENDIX 2 – CHAPTER 11 SAS CODE

This SAS programme reads in the raw MCS data, codes it to create Allsegs, lower, middle and upper (1, 2, 3) movement competencies, and uses injury severity and injury counts to create load. Three combined tests are used (Jump Speed UppBody AllTests);

```
*LowerSegments=sum(squat,lunge,singleleg);
*MiddleSegments=sum(twist,bend);
*UpperSegments=sum(pull,push);

libname ss "D:\ \Matt Kritz 2009 to 2011\Matt Kritz visual rating SAS\Will SAS chapter 11
MCS 181011";
OPTIONS FORMCHAR="|----|+|---+=|-/\<>*";
options ls=90 ps=62 pageno=1;
*options nonotes nodate nonumber nostimer;
options notes nodate number stimer;
title;
/*
original spreadsheet:
```

Movement Competency Screen Pattern Load Level

Squat	Lunge	Twist	Bend	Pull	Push	Single Leg
2	2	2	2	3	2	1

Speed (s)					Power (w/kg)		
5 m	10 m	20 m	CMJ	SJ	CMJ Right	CMJ Left	Upper Body
1.04	1.79	3.07	70	64	35	35	16

Upper			Trunk			Lower		
Mild (1)	Moderate (2)	Severe (3)	Mild (1)	Moderate (2)	Severe (3)	Mild (1)	Moderate (2)	Severe (3)

```
*/

PROC IMPORT
  DATAFILE="D:\ \Matt Kritz 2009 to 2011\Matt Kritz visual rating SAS\Will SAS chapter
11 MCS 181011\Study 4 Data.XLSX"
  OUT=dat1
  DBMS=EXCEL replace;
GETNAMES=YES;
MIXED=YES;
attrib _character_ _numeric_ label="";
run;

*can also use DBMS=XLS replace, EXCEL works for xlsx;
*proc print data=dat1;run;

*injury data, with performance included as possible covariates;
data injury;
set dat1;
length Region $ 9;
if _n_>1;
Speed5m=5/Time5m;
Speed10m=10/Time10m;
Speed20m=20/Time20m;
array a Upper1--Lower3;
do over a;
  if a=. then a=0;
  end;
Region="Upper"; Severity="Mild    "; InjuryCount=Upper1; InjuryLoad=Upper1; output;
```

```
Region="Upper"; Severity="Moderate"; InjuryCount=Upper2; InjuryLoad=Upper2*2;
output;
Region="Upper"; Severity="Severe"; InjuryCount=Upper3;InjuryLoad=Upper3*3;  output;
Region="Upper"; Severity="All"; InjuryCount=Upper1+Upper2+Upper3;
InjuryLoad=Upper1+Upper2*2+Upper3*3; output;

Region="Trunk"; Severity="Mild    "; InjuryCount=Trunk1; InjuryLoad=Trunk1; output;
Region="Trunk"; Severity="Moderate"; InjuryCount=Trunk2; InjuryLoad=Trunk2*2; output;
Region="Trunk"; Severity="Severe"; InjuryCount=Trunk3;InjuryLoad=Trunk3*3;  output;
Region="Trunk"; Severity="All"; InjuryCount=Trunk1+Trunk2+Trunk3;
InjuryLoad=Trunk1+Trunk2*2+Trunk3*3; output;

Region="Lower"; Severity="Mild    "; InjuryCount=Lower1; InjuryLoad=Lower1; output;
Region="Lower"; Severity="Moderate"; InjuryCount=Lower2; InjuryLoad=Lower2*2;
output;
Region="Lower"; Severity="Severe"; InjuryCount=Lower3;InjuryLoad=Lower3*3;  output;
Region="Lower"; Severity="All"; InjuryCount=Lower1+Lower2+Lower3;
InjuryLoad=Lower1+Lower2*2+Lower3*3; output;

Region="WholeBody"; Severity="Mild"; InjuryCount=Upper1+Trunk1+Lower1;
  InjuryLoad=Upper1+Trunk1+Lower1; output;
Region="WholeBody"; Severity="Moderate"; InjuryCount=Upper2+Trunk2+Lower2;
  InjuryLoad=(Upper2+Trunk2+Lower2)*2; output;
Region="WholeBody"; Severity="Severe"; InjuryCount=Upper3+Trunk3+Lower3;
  InjuryLoad=(Upper3+Trunk3+Lower3)*3; output;
Region="WholeBody"; Severity="All";
  InjuryCount=Upper1+Upper2+Upper3+Trunk1+Trunk2+Trunk3+Lower1+Lower2+Lower3;

InjuryLoad=Upper1+Trunk1+Lower1+(Upper2+Trunk2+Lower2)*2+(Upper3+Trunk3+Low
er3)*3; output;
drop f1 Upper1--Lower3;

*proc print data=injury;run;

*performance data with injury processed to be possible covariates;
data perform;
set dat1;
if _n_>1;
Speed5m=5/Time5m;
Speed10m=10/Time10m;
Speed20m=20/Time20m;
array a Upper1--Lower3;
do over a;
  if a=. then a=0;
  end;
UpperInjuryCount=sum(of Upper1-Upper3);
UpperInjuryLoad=Upper1+Upper2*2+Upper3*3;
UpperInjurySeverity=UpperInjuryLoad/UpperInjuryCount;
TrunkInjuryCount=sum(of Trunk1-Trunk3);
TrunkInjuryLoad=Trunk1+Trunk2*2+Trunk3*3;
TrunkInjurySeverity=TrunkInjuryLoad/TrunkInjuryCount;
LowerInjuryCount=sum(of Lower1-Lower3);
LowerInjuryLoad=Lower1+Lower2*2+Lower3*3;
LowerInjurySeverity=LowerInjuryLoad/LowerInjuryCount;
TotalInjuryCount=UpperInjuryCount+TrunkInjuryCount+LowerInjuryCount;
TotalInjuryLoad=UpperInjuryLoad+TrunkInjuryLoad+LowerInjuryLoad;
TotalInjurySeverity=(UpperInjuryLoad+TrunkInjuryLoad+LowerInjuryLoad)/(UpperInjuryC
ount+TrunkInjuryCount+LowerInjuryCount);
array b UpperInjurySeverity TrunkInjurySeverity LowerInjurySeverity TotalInjurySeverity;
do over b;
  if b=. then b=0;
```

```
  end;
drop f1 Upper1--Lower3;

*proc print data=perform;run;

options pageno=1 ls=80;
title "Basic stats for movement competence";
proc freq data=perform;
tables squat--singleleg/nocum;
run;

proc freq data=perform;
tables (squat--singleleg)*sex/nopercent norow nocol;
run;

proc freq data=perform;
tables squat*lunge twist*bend pull*push/nopercent norow nocol;
run;

proc sort data=perform;
by sex;

*standardize fitness;
proc standard data=perform mean=0 std=1 out=stdscores;
var cmj--speed20m;
by sex;

data stdscores1;
set stdscores;
StdzdJump=mean(of cmj--cmjleft);
StdzdSpeed=mean(of speed5m--speed20m);
StdzdUpperBody=UpperBody;
StdzdAllTests=mean(of StdzdJump--StdzdSpeed);

*proc means n mean std min max maxdec=1 fw=7 data=stdscores1;
*var cmj--speed20m StdzdJump StdzdSpeed StdzdUpperBody StdzdAllTests;
run;

proc rank data=stdscores1 groups=3;
var StdzdJump--StdzdAllTests;
ranks Jump Speed UppBody AllTests;
by sex;

*proc print data=stdscores1; run;

data stdscores2;
set;
array a Jump--AllTests;
do over a;
  a=a+1;
  end;

proc sort;
by sex descending StdzdAllTests;

options ls=80;
title "Standardized scores and ranking into test competence, sorted by StdzdAllTests";
proc print;
*var sex Athlete StdzdJump--StdzdAllTests Jump--AllTests;
format  StdzdJump--StdzdAllTests 5.2;
run;
```

```
*merge test competence back into injury and perform data set;
proc sort data=stdscores2;
by Athlete;

proc sort data=injury;
by athlete;

data injury1;
merge injury stdscores2(keep=athlete StdzdJump--StdzdAllTests Jump--AllTests);
by athlete;
run;

proc sort data=perform;
by athlete;

data perform1;
merge perform stdscores2(keep=athlete StdzdJump--StdzdAllTests Jump--AllTests);
by athlete;
run;

*derive composite movement competence score by adding and ranking into three groups;
*and merge with perform1 and injury1 data sets;

data compcomp;
set perform1(keep=athlete sex squat--singleleg);
AllSegments=sum(of squat--singleleg);
LowerSegments=sum(squat,lunge,singleleg);
MiddleSegments=sum(twist,bend);
UpperSegments=sum(pull,push);
drop  squat--singleleg;

proc rank data=compcomp groups=3 out=compcomp1;
var AllSegments LowerSegments MiddleSegments UpperSegments;
ranks AllSegs LowerSegs MiddleSegs UpperSegs; *summed competence ranked into three groups;

proc sort data=compcomp1;
by sex AllSegments;

title "Composite movement competence";
proc print data=compcomp1;run;

proc sort data=compcomp1;
by athlete;

data compcomp2;
set compcomp1;
AllSegs=AllSegs+1; *now goes from 1 to 3;

data injury2;
merge injury1 compcomp2(drop=sex);
by athlete;
run;

data perform2;
merge perform1 compcomp2(drop=sex);
by athlete;
run;

*proc print data=injury2;run;
```

```
%macro basics;
Title1 “Basic stats for effect of &pred competence on &region &dep”;
*title2 "Crude stats for &trnvar.Smoothed for decay constant=&beta";
*title3 "The SD is used to estimate the effect of this covariate on injury";

proc means nonobs n nmiss mean std min max maxdec=1 fw=7 data=injury2;
var &dep;
class Severity &pred;
where Region="&region";
run;
%mend;

*first, effects of movement competence (allsegs) on injury;
options pageno=1;
%let dep=InjuryCount;

%let pred=Squat;
%let region=Lower;
%basics;

%let region=WholeBody;
%basics;

%let pred=Lunge;
%let region=Lower;
%basics;

%let region=WholeBody;
%basics;

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APPENDIX 3 – MCS DOCUMENTATION

MCS

HOW ATHLETES PRODUCE POWER IS MORE IMPORTANT THAN THE POWER THEY PRODUCE

The movement strategy a person uses to accomplish a movement task can be described as that person's movement competency. Good movement competency is considered movement strategies that are mechanically sound free of dysfunction and/or pain. Poor movement competency is considered movement strategies that are considered painful or dysfunctional that may contribute more to injury than performance. An individual's movement competency may be influenced by several variables, but what is important is that that the training prescribed does not exceed the person's movement and /or strength capability. The objective of the movement competency screen (MCS) is to identify which fundamental movement patterns can be aggressively loaded and which require developmental attention.

The fundamental movement patterns that exist in activities of daily living, sport and sport related training are; the squat pattern, lunge pattern, upper body push pattern, upper body pull pattern, trunk flexion or bend pattern, trunk rotation or twist pattern, and unilateral lower limb or single leg squat pattern.

The MCS is made up of five movement tasks that challenge each of the aforementioned fundamental movement patterns that provide the individual with an opportunity to demonstrate their movement competency.

The MCS movement tasks are the squat, lunge-and-twist, bend-and-pull, push up, and single leg squat. Visually watch or video-record an individual performing five repetitions of each of the MCS movement task from the front and to the side. Make sure the individual lead leg during side view trials is closest to the screener or video recorder. Below are the verbal instructions to give the individual before each movement task is performed.

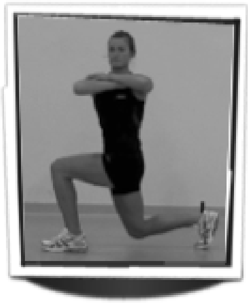
Referring to the MCS criteria simply check the region/capability that does not match the criteria. For example if the individual's knees are not aligned during the squat, then check the 'knees' region on the scoring sheet. After completing the scoring of an individual's MCS, add up the checked regions / capabilities within each movement task to determine the load level for that pattern.

The load level is recommended load that individual should use until their movement competency is enhanced. The load levels are based on the notion that an individuals' movement strategies are influenced by the load that is required to overcome. If a load is too great then an athlete will move in a manner that embraces their anatomical strengths, which may not be biomechanically correct or safe. The amount of time an individual should train at their movement competency load level would be determined by a successful MCS.

Verbal instructions for each movement tasks of the MCS

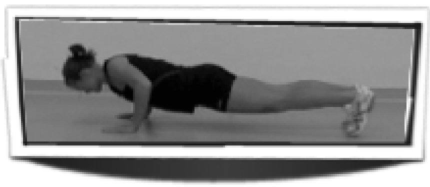
BODY WEIGHT SQUAT

Perform a body weight squat with your fingertips on the side of your head and your elbows held in line with your ears. Squat as low and as fast as you comfortably can.



LUNGE & TWIST

Cross your arms and place your hands on your shoulders with your elbows pointing straight ahead. Perform a forward lunge then rotate toward the forward knee. Return to center and then push back to return to the starting position. Alternate legs with each repetition.



PUSH UP

Perform a standard push up.

BEND & PULL

Start with your arms stretched overhead. Bend forward allowing your arms to drop under your trunk. Pull your hands into your body as if you were holding onto a bar and performing a barbell rowing exercise. Return to the start position with your arms stretched overhead.

SINGLE LEG SQUAT

Perform a single leg body weight squat with your fingertips on the side of your head your elbows in line with your ears. Position the non-stance leg behind your body as you squat. Squat as low and as fast as you comfortable can.

MCS SCORING SHEET

Athlete **Sport** **Date** **MCS Score**

SCREENING INSTRUCTIONS: Referring to the MCS criteria mark the PRIMARY or SECONDARY segments failed. The scoring sheet should reflect the weakest side for the unilateral patterns.

PATTERN	PRIMARY	SECONDARY	LOAD LEVEL	COMMENTS
SQUAT	○ SHOULDERS ○ LUMBAR ○ HIPS ○ ANKLES/FEET	○ HEAD ○ KNEES ○ DEPTH ○ BALANCE		
LUNGE & TWIST (The Lunge)	○ BALANCE ○ LUMBAR ○ HIPS ○ ANKLES/FEET	○ HEAD ○ KNEES ○ DEPTH		
LUNGE & TWIST (The Twist)	○ SHOULDERS ○ LUMBAR ○ HIPS ○ ANKLES/FEET	○ HEAD ○ KNEES ○ DEPTH ○ BALANCE		
BEND & PULL (The Bend)	○ SHOULDERS ○ LUMBAR ○ HIPS ○ DEPTH	○ HEAD ○ KNEES ○ ANKLES/FEET ○ BALANCE		
BEND & PULL (The Pull)	○ SHOULDERS ○ LUMBAR ○ HIPS ○ DEPTH	○ HEAD ○ KNEES ○ ANKLES/FEET ○ BALANCE		
PUSH UP	○ HEAD ○ SHOULDERS ○ LUMBAR ○ DEPTH	○ HIPS ○ KNEES ○ ANKLES / FEET ○ BALANCE		
SINGLE LEG SQUAT	○ DEPTH ○ LUMBAR ○ HIPS ○ ANKLES / FEET	○ HEAD ○ SHOULDERS ○ KNEES ○ BALANCE		

Load Level	Scoring Rationale	Considerations
1 (Assisted)	2 or more primary regions checked	Pay close attention to the primary regions for each movement task. The primary regions will have the most meaningful impact on movement competency. Athletes' unilateral movement competency should be a reflection of their weakest side. To score unilateral patterns the load level should reflect the poorest side. For example: If an athlete scores a 3 on their right single leg squat and a 2 on their left single leg squat, the athlete's single leg MC score would be a 2.
2 (Bodyweight)	1 primary region and 2 or more secondary regions	
3 (External Load)	No primary and only 1 secondary regions	
4 (Eccentric)	1 or more primary and secondary regions failed during explosive MCS	
5 (Plyometric)	No primary regions failed during explosive MCS	

Sample completed scoring sheet

PATTERN	PRIMARY	SECONDARY	LOAD LEVEL	COMMENTS
SQUAT	○ SHOULDERS ✓ LUMBAR ✓ HIPS ○ ANKLES/FEET	○ HEAD ○ KNEES ✓ DEPTH ○ BALANCE	1	Unable to maintain a neutral spine during squat. Does not initiate or finish the pattern with the hips.
LUNGE & TWIST (The Lunge)	✓ BALANCE ✓ LUMBAR ○ HIPS ○ ANKLES/FEET	○ HEAD ○ KNEES ○ DEPTH	1	Looses balance on left leg and extends lumbar to get into a proper lunge stance on both sides.
LUNGE & TWIST (The Twist)	✓ SHOULDERS ✓ LUMBAR ○ HIPS ○ ANKLES/FEET	○ HEAD ○ KNEES ○ DEPTH ○ BALANCE	1	Shoulders fail to maintain a level position during rotation. Appears to rotate through lumbar not t-spine.
BEND & PULL (The Bend)	○ SHOULDERS ✓ LUMBAR ✓ HIPS ✓ DEPTH	○ HEAD ○ KNEES ○ ANKLES/FEET ○ BALANCE	1	Bends through lumbar region, does not initiate bend or finish with hips. Does not achieve at least 75 degrees of trunk flexion.
BEND & PULL (The Pull)	✓ SHOULDERS ○ LUMBAR ○ HIPS ○ DEPTH	○ HEAD ○ KNEES ○ ANKLES/FEET ○ BALANCE	2	Shrugs shoulders during pull.
PUSH UP	○ HEAD ○ SHOULDERS ○ LUMBAR ✓ DEPTH	○ HIPS ○ KNEES ○ ANKLES / FEET ○ BALANCE	2	Does not achieve a chest to floor depth.
SINGLE LEG SQUAT	✓ DEPTH ○ LUMBAR ✓ HIPS ✓ ANKLES / FEET	○ HEAD ○ SHOULDERS ○ KNEES ○ BALANCE	1	Does not achieve desired depth, does not initiate movement with hip flexion, heel comes of the ground.

Load Level	Scoring Rationale	Considerations
1 (Assisted)	2 or more primary regions checked	Pay close attention to the primary regions for each movement task. The primary regions will have the most meaningful impact on movement competency. Athletes' unilateral movement competency should be a reflection of their weakest side. To score unilateral patterns the load level should reflect the poorest side. For example: If an athlete scores a 3 on their right single leg squat and a 2 on their left single leg squat, the athlete's single leg MC score would be a 2.
2 (Bodyweight)	1 primary region and 2 or more secondary regions	
3 (External load)	No primary and only 1 secondary regions	
4 (Eccentric)	1 or more primary and secondary regions failed during explosive MCS	
5 (Plyometric)	No primary regions failed during explosive MCS	

APPENDIX 4 – MC 100 PROTOCOL

Movement Competency 100 Protocol©

The objective of Movement Competency 100 Training© (MC 100 training) is to perform 100 repetitions of each pattern in one set with the MC pattern criteria maintain for every repetition. This will be difficult for individuals who have scored a level 1 or level 2. Therefore it is recommended that the 100 repetitions be broken into sets (e.g. 10 x 10) of repetitions that the individual can maintain the form detailed in the MC criteria for each pattern.

- Level 1 – Perform the 100 reps 3-4 times per week
- Level 2 – Perform the 100 reps 2-3 times per week

The rest per broken set is self-guided. However, the objective would be to move through the set of 100 as fast as possible with a large fluid ROM maintaining the technique indicative of good movement competency. Sample exercises are listed below and ordered from easiest to hardest. Video demonstrations of the exercises detailed below can be found on YouTube by searching the name of the exercises as they are written below.

Squat pattern x 100

(1) Assisted bodyweight squats
(2) Bodyweight squat
(3) Bodyweight squat hold band or dowel overhead

Pull pattern x 100

(1) Hanging Scapula retraction / protraction (Remember to keep your arms straight when you performing the hanging scapulae pulls)
(2) Assisted vertical or horizontal pull-ups
(3) Vertical or horizontal pull-ups

Single leg squat pattern x 100

(1) Assisted or bodyweight step ups (Start with a low step and gradually work up to a box that starts the stepping leg at 90 degrees)
(2) Assisted or bodyweight single leg box squat (Start with a high box. Work towards sitting on a bench that allows the quads to be parallel with the ground)
(3) Bodyweight single leg squat

Note: Alternating the single leg reps is recommended for poor MC individuals (i.e. 10 right leg, 10 left leg, etc)

Push pattern x 100

(1) Prone scapula retraction / protraction
(2) Assisted or incline push ups or hand release push ups
(3) Bodyweight push ups

Trunk bend x 100

(1) Assisted good morning
(2) Resisted good mornings

Trunk rotation x 100

(1) Bird dog
(2) Bird dog with internal elbow - knee touch
(3) Any other resistive rotation exercises

APPENDIX 5 – STUDY 1 SURVEY 1

Movement Competency Assessment Battery

A TOOL FOR LONG-TERM ATHLETIC DEVELOPMENT

Survey 1

Survey   Change Password   Log Out

INTRODUCTION

Thank you for agreeing to take part in this important research project. Your commitment involves three rounds of survey questions. The purpose of this survey format is to ascertain with greater reliability the opinion of respected sport science professionals regarding which movements should be involved in an assessment battery designed to investigate the faulty movement patterns of ***athletic*** individuals.

The primary objective of this research project is to develop a qualitative tool to enable strength and conditioning and sports medicine professionals to identify faulty movement patterns in athletes. It is the hypothesised that the information from the developed tool can then be used to more accurately develop a performance training protocol that addresses the specific needs of the athlete.

The questions below are designed to discover what movements you would use to identify faulty movement patterns when an athlete performs movements that are fundamental to athletics. The following movement patterns have been suggested as fundamental to sport and sport specific training: squat, lunge, push, pull, bend, twist, and gait. It is your responsibility to choose what specific squatting, lunging, pushing, pulling, bending, twisting and gait-like movements offer the greatest prognostic/diagnostic value. Remember the goal of this project is to develop a qualitative tool that measures an athletes fundamental movement ability as it relates to training. After identifying the movement you feel is the most prognostic please explain what that movement is specifically assessing. For example an overhead squat assesses mobility and stability of the major joints in the body. In addition adductor or abductor strength may be assessed by identifying if valgus or varus knee position occurs during squatting when viewed from the sagital plane. This is an important component of the survey, because I am interested to see how you as practioners understand these movements to be valuable for assessment and why. Then if you could explain how you would measure the issues identified (e.g. digital camera, plumb line, subjectively, etc).

Thank you for your time and energy I look forward to your input.

PARTICIPATION AGREEMENT

Thank you for agreeing to participate in this important study. You will be asked to complete a series of questions that will be disseminated over two to three surveys. Your honest answers are valued and appreciated. These surveys are secure and your answers will be anonymous. By clicking "I Agree" you agree to the following:

I agree to participate in the study entitled 'Study 1 Movement Competency – A tool for long term athletic development' and give my consent freely. I understand that the study will be carried out as described above. I realized that whether or not I decide to participate is my decision. I also realize that I can withdraw from the study at any time and that I do not have to give any reasons for withdrawing. I have had all questions answered to my satisfaction.

☐ I Agree

SECTION 1

Which types of movements would you choose?

○ Isolated ○ Complex

How many total movements would you select to represent the primal movements (squating, lunging, pushing, pulling, bending, twisting, and gait)?

What type of analysis techniques would you use?

◯ Qualitative ◯ Quantitative ◯ A combination of qualitative and quantitiative

Do you feel any specific equipment is required?

SECTION 2

What movement(s) would you choose to assess **squating** competency?

What issues does the movement(s) you have chosen address?

How would you measure those issues?

What movement(s) would you choose to assess **lunging** competency?

What issues does the movement(s) you have chosen address?

How would you measure those issues?

What movement(s) would you choose to assess **pushing** competency?

What issues does the movement(s) you have chosen address?

How would you measure those issues?

What movement(s) would you choose to assess **pulling** competency?

What issues does the movement(s) you have chosen address?

How would you measure those issues?

What movement(s) would you choose to assess **bending** competency?

What issues does the movement(s) you have chosen address?

How would you measure those issues?

What movement(s) would you choose to assess **twisting** competency?

What issues does the movement(s) you have chosen address?

How would you measure those issues?

What movement(s) would you choose to assess **gait** competency?

What issues does the movement(s) you have chosen address?

How would you measure those issues?

SECTION 3

Additional comments?

Click the button below to save your survey and complete it later.

Save Incomplete Survey

Click the button below when you have completed the survey.

Submit Completed Survey

PhD Research Project - Edith Cowan University & Auckland University of Technology

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