Development of a Netball Specific Dynamic Balance Assessment

Daniel Lavipour

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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 qualification of any degree or diploma of a university or other institution of higher learning, except where due acknowledgement is made.

Signed…………………………………………………………..............

Daniel Lavipour

Date ....

Publications

The following three manuscripts are in preparation for submission for peer reviewed journal publication as a result of the work presented in this thesis.

Lavipour, D. G., Croft, J., and Cronin, J. (2009). Designing assessments of balance for strength and conditioning practice. (Target journal – Strength and Conditioning Journal)

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Intellectual Property Rights

Note to the Reader

Excluding chapters one and five, this thesis is presented as a series of chapters in publication submission format, which in some instances, due to the chosen submission format, may lead to some repetition. Furthermore there may be a difference in writing style between the chapters so as to make them appropriate for the specific targeted journal. This thesis fulfils the AUT University Masters of Philosophy guidelines by presenting three pieces of original research pertinent to the assessment of dynamic balance in netball. These pieces of research critique previous literature relevant to the topic and provide experimental application to the growing body of knowledge.

Abstract

The purpose of this study was to design a netball specific balance assessment. A literature review revealed a lack of suitable assessments for this athletic population. Existing tests failed to replicate sport specific movements, measured variables inappropriate for dynamic balance assessment, failed to indicate the origin of balance deficiencies, disregarded the quality of the movement being performed, failed to indicate the movement strategy used for balance corrections, gave no indication of segmental orientation, used equipment that is not accessible to many practitioners, only assessed static balance, used non sport specific conditions such as eyes closed and unstable surfaces or failed to report the reliability of the tests.

Prior to designing a netball specific balance assessment two elite level games of netball were analysed for the frequency of jump landings by jump direction, bi-lateral and uni-lateral landings, turns in the air, and jumps upon landing. Jump landings were chosen for analysis because previous research reported that jump landings and twisting on jump landings represented the greatest injury risk in netball (Otago, 2004; Powell & Barber-Foss, 2000). Forward jumps were performed most frequently (42%) followed by vertical (32%) and lateral jumps (26%). Uni-lateral landings (67%) were most common, as were jumps with no turn in the air (60%). It was less common to perform a second jump immediately upon landing (28%). There were marked differences between player positions in terms of jump direction and the number of jumps performed whereas whether a turn was performed in the air or whether the jump was landed on one or two limbs was more consistent between positions. In general, players could be split into end court and mid court by their landing profile. The exceptions were goal attack who had much in common with the mid court players and wing defence who had much in common with end court players.

Based on these findings and previous research on injury mechanisms, three movements were chosen for assessment: A single leg squat, a forward jump, and a forward jump with a turn in the air. The single leg squat was performed to a self selected depth whilst intensity of both jumps was standardised by controlling jump distance and jump height. Deviations from the line of gravity were calculated at the knee, hip and trunk as calculated from video footage using SiliconCoach to assess balance. Fourteen female netballers (16.8 ± 2.4 years) performed three successful trials of each movement on two separate testing occasions approximately one week apart. The reliability of the assessment was determined for within day and between days. The mean ICC values for each body segment, during each movement across the four variables ranged from 0.62 – 0.81 indicating 'moderate' (ICC > 0.61) test-retest reliability. The typical errors averaged across all body segments for the single leg squat, forward jump and jump with a turn were 1.1 cm (ICC = 0.71), 1.8 cm (ICC =0.72) and 2.6 cm (ICC = 0.62) respectively indicating 'moderate' reliability. The errors were considered too great for use in indicating the magnitude and origin of balance deficiencies and a more sensitive measure is required. The tests may be useful to give an indication of an athlete's movement competency prior to engaging in training for example knee movement in a single leg squat may indicate knee movement in a more dynamic forward jump.

Chapter One
Introduction

Chapter 1 – Introduction

Injury rates in netball are amongst the highest of all sports (Fong, Hong, Chan, Yung, & Chan, 2007). The majority of these injuries occur in the lower limbs (66%) with 26% at the ankle and 18% at the knee (McManus, Stevenson, & Finch, 2006). Injury mechanisms are thought to involve abrupt decelerations, which may be caused by the two step rule, twisting on jump landings, quick changes of direction, cutting and jumping (Otago, 2004; Powell & Barber-Foss, 2000). Balance, which is the ability to control the body's centre of mass over its base of support (Danis, Krebs, Gill-Body, & Sahrman, 1998; Pollock, Durward, & Rower, 2000), is important because it can affect the execution of these movement patterns and furthermore poor balance has been shown to be a risk factor for injury (Hrysomallis, 2007; Murphy, Connolly, & Beynnon, 2003; Wikstrom, Tillman, Schenker, & Borsa, 2008).

The strength and conditioning coach often tests various aspects of athletic performance to aid in programming. Common assessments include measures of strength, power, speed, endurance and anthropometry. However, assessments of balance, in-particular those that replicate sport specific movement patterns, are less common. Reasons for this include a failure of previous research to conclusively show a set of dependent variables and testing protocols appropriate for use by sporting populations. Consequently, at present balance performance in a sporting context is difficult to measure and interpret.

Currently balance can be assessed in a number of ways and these tests can be split into those tests which assess either *static* or *dynamic* balance. Static balance assessment such as Rhomberg's test (Khasnis & Gokula, 2003) usually involves timed double or single leg stances (Verhagen et al., 2005) during which performance is determined either from observations of stability, the balance time on a single leg or from measures derived from centre of pressure data from a force plate underfoot. Static assessments of this nature have previously been described as inappropriate for sporting populations due to the relative ease of the testing procedure and only suitable for impaired or elderly populations (Emery, 2003). Furthermore, it has also been shown that static balance performance is not related to balance performance under more dynamic conditions (Hrysomallis, McLaughlin, & Goodman, 2006). To make static assessments more difficult unstable surfaces have been used (Emery, Cassidy, Klassen, Rosychuk, & Rowe, 2005) and/or eyes closed conditions (Willems, Witrwouw, Delbaere, Maheui et al., 2005). Despite the increased difficulty even these conditions fail to make static balance assessments relevant to sporting populations as few sports require performance which involve these conditions (Hrysomallis et al., 2006). Advantages to static balance assessments are that they are relatively easy to administer and have several clear and established protocols (Eils & Rosenbaum, 2001; Verhagen et al., 2005). This however is not enough to validate their use for sporting populations for whom the sport specific challenge to balance goes beyond static conditions.

Dynamic balance assessment represents a more challenging approach to balance assessment because of the higher intensities and more complex movement patterns. Typically these assessments involve jumps and hops and are usually performed uni-laterally (Riemann, Caggiano, & Lephart, 1999). Dynamic balance assessments are less common but may be more relevant to sporting performance and injury because of the movement patterns and intensities involved (C. Brown, Ross, Mynark, & Guskiewicz, 2004; Myer, Ford, Brent, & Hewett, 2006; Riemann et al., 1999; Ross & Guskiewicz, 2003; Wikstrom, Tillman, Smith, & Borsa, 2005). Given the increased complexity of movement and greater number of factors involved in maintaining dynamic balance the identification of an appropriate set of variables has been problematic.

Commonly centre of pressure data, as in static balance assessment, is used to determine balance performance. However, at present it has yet to be shown how centre of pressure is appropriate as a measure of dynamic balance (Palmieri, Ingersoll, Stone, & Krause, 2002). There are several problems with using centre of pressure as indices of dynamic balance performance. Palmieri et al. (2002) highlighted that the same large deviations in the centre of pressure may represent poor postural control in some, and an effective means of achieving balance in others. More importantly analysing centre of pressure only gives an indication of an outcome with no indication of what is occurring at proximal body segments. Due to the risk of injury and implications for performance associated with the biomechanics of faulty movement (Murphy et al., 2003), the way someone attains balance may be more important than the degree to which balance is maintained. Consequently, an assessment of sport specific dynamic balance should seek to shed light on the origin of any deficiency in movement as well as the level to which balance is maintained. This will help in the development of appropriate individually specific conditioning strategies.

To better understand the process by which balance is maintained and as a means of quantifying balance it is possible that a videographic approach may be useful. Videography has been used previously to analyse movement sequences and several protocols exist which have been useful for describing movement deficiencies and have been subtle enough to detect changes in movement kinematics after training interventions (Noyes, Barber-Westin, Fleckenstein, Walsh, & West, 2005; Willson, Ireland, & Davis, 2006). A problem with these types of assessments is that they have tended to assess kinematics at isolated points in time such as at ground contact or maximal knee flexion (Noyes et al., 2005). Since movement is dynamic in nature, assessing movement in a static manner may not assess the balance strategies throughout the entire range of motion. Using videography, an adaption of how previous balance studies have measured ‘sway’ (such as in the measurement of centre of pressure) and how kinematic studies have measured segmental orientation may be beneficial in this regard. In practical terms this means an assessment which measures the relative position or 'sway' of specific segments around the base of support over time.

When it comes to designing a sport specific balance assessment and prior to selecting those variables of interest, a thorough understanding of the movement patterns specific to an activity or sport is desirable. With regards to netball, several studies have quantified activity patterns and highlighted anthropometric differences between player positions (Bale & Hunt, 1986; Otago, 1983; Steele & Chad, 1992) but no studies have quantified the movement patterns specific to the sport. A largely complete classification system for describing the frequency of different movements in sport exists (Bloomfield, Polman, & O'Donoghue, 2004). However given the large number of variables and time it takes to complete, a refined version which focuses on the main factors relevant to balance, injury and performance may be more appropriate for use. The main injury mechanisms in netball are thought to involve abrupt decelerations, in-particular twisting on jump landings, quick changes of direction, cutting and jumping (Otago, 2004; Powell & Barber-Foss, 2000). Therefore quantifying the types of movement in netball related to jump landings may represent an effective starting point for developing a battery of assessments relevant to the most high risk movements in netball.

This thesis will be presented as three separate chapters, written as individual studies prepared for peer reviewed journal submission. The first study (Chapter Two) reviews the literature and addresses the pros and cons of current balance assessments. This review includes a framework for designing future assessments and also includes the important variables to include when designing new sport specific balance assessments. In the second study (Chapter Three) a time motion analysis is performed examining the frequency of jump landings in elite netball. The data is presented specific to player position and the trends and differences between player positions are discussed. The results from this study are used to develop a netball specific dynamic balance assessment which is presented in the final study (Chapter Four). This study examines the reliability of the assessment procedure and discusses the validity of the battery in the context of current balance assessments.

Purpose Statement

The purpose of this thesis was to design a netball specific dynamic balance assessment that is suitable for use in the strength and conditioning facility.

Significance of the Study

Static balance assessments may fail to identify sport specific deficiencies due to the relative ease of the task and un-relatedness of the assessment procedure to the movements that occur in the sport. Dynamic balance assessments have greater sport specificity but fail to give an indication of segmental orientation which has been shown to be important for injury and functional human movement. Furthermore, dynamic balance assessments have tended to analyse variables more appropriate for static assessment. It is possible that a videographic assessment which measures segmental orientation may be useful in balance assessment as it could give an indication of movement strategies and the possible origin of any deficiency. This would aid in the programming of conditioning strategies for both injury prevention and performance development. Currently no such test exists in New Zealand and the assessment of injury risk in netball players of all age groups is limited to muscle balance assessments and questionnaires detailing injury history, medical history, current physical activity, and footwear (ACC & NetballSmart, 2009; NetballNZ, 2009). The addition of a sport specific dynamic balance assessment may assist in identifying deficiencies that are not highlighted using current screening procedures. The wider strength and conditioning fraternity will also benefit from such a test as current research has failed to conclusively demonstrate an assessment protocol with dependent variables relevant to injury and performance. Furthermore, few studies have performed a time motion analysis prior to designing assessments.

Study Limitations

- The results may not be applicable to other populations or sports.

Study Delimitations

- No subjects with a history of lower limb injury in the last three months were included in this study.
- All subjects were female netball players from one of the top ranked high school teams in New Zealand or from the local regional high performance centre. All participants were currently involved in competition and training and were between the ages of 14 and 21 years.

Chapter Two
Designing Assessments of Balance

Chapter 2 – Designing Assessments of Balance

Introduction

Balance training has gained popularity in recent years, particularly for its role in injury prevention (McGuine & Keene, 2006; McHugh, Tyler, Mirabella, Mullaney, & Nicholas, 2007; Olsen, Mykleburst, Engbretson, Holme, & Bahr, 2005). Although recent research has advanced our understanding of the best ways to train balance (Heitkamp, Horstmann, Mayer, Weller, & Dickhuth, 2001; Holm et al., 2004; Myer et al., 2006; Yaggie & Campbell, 2006), what is less clear is how to assess it. Currently a wide range of assessments exist but no field based assessments are suitable for athletic populations (Emery, 2003). This review discusses how balance is maintained and the benefits and limitations of current balance assessments. Based on this discussion recommendations will be made for developing new sport specific field based balance assessments, and the important variables to include in an assessment are presented.

What is Balance?

For the human body to maintain upright stance, its centre of mass (COM) must be located over its base of support. The ability to achieve stability in this respect is termed balance. Balance tasks are typically termed either *static* or *dynamic* depending on the nature of the motor task. For example, static balance involves stances during which movement is discouraged, such as standing still on one leg. On the other hand dynamic balance requires the athlete to maintain an upright stance whilst performing a motor task, such as performing a single leg squat. In terms of the maintenance of balance, it is the postural control system that regulates motor behaviour, and this system operates for the dual purposes of stability and orientation (Emery et al., 2005; Wedderkopp, Kaltoft, Holm, & Froberg, 2003). Occasionally a performer may choose to sacrifice balance for the purposes of orientation such as aligning body segments to make a catch which results in a fall. In other situations a performer may be prevented from making a play because they are primarily involved with maintaining upright stance. Whether stability is achieved or not, the orientation of body segments is governed by the postural control system and this process requires the integration of multiple processes, namely, sensory information (visual, vestibular and proprioceptive) to assess the position and motion of the body in space and the generation of appropriate forces to control body kinematics (Shumway-Cook & Woollacott, 2000).

Why is Balance Important?

Balance has been related to injury risk and those with poor balance tend to suffer more injuries (Hrysomallis, 2007; McGuine & Keene, 2006; Murphy et al., 2003). In recent years balance training has gained popularity for its role in reducing the number of sports injuries and is generally accepted as an effective means of doing so (Hrysomallis, 2007; McGuine & Keene, 2006; Murphy et al., 2003; Olsen et al., 2005). Balance also contributes to force production and developing balance can increase muscular strength and power and vice versa (Heitkamp et al., 2001; Myer et al., 2006; Willson et al., 2006; Yaggie & Campbell, 2006). In sport, balance should be maintained whilst performing sport specific movements and balance deficiencies have been shown to have a detrimental effect on the execution of these movements (Wikstrom et al., 2008). In some cases the strategies used to maintain balance are more important than the degree to which balance is maintained. Most balance assessments have tended to measure overall balance performance but not the kinematics of individual segments. Due to the risk of injury and implications for performance associated with the biomechanics of faulty movement, neglecting to observe movement strategy could be harmful. Consequently balance should not be studied in isolation and must be considered in a task specific context.

How is Balance Maintained?

Maintaining balance can be achieved through three main strategies; the ankle, hip and stepping strategies (Emery, 2003). The ankle strategy restores balance through movement primarily created at the ankle joint. This strategy has a primary role in recovering stability in static conditions (King & Zatsiorsky, 2002; Tropp & Odenrick, 1985) however under dynamic conditions its main function is to recover antero-posterior stability because of the limited medio-lateral movement possible at this joint. The ankle strategy is most commonly used in situations where the disturbance to balance is small and the support surface is firm and stable (Horak & Nashner, 1986; King & Zatsiorsky, 2002; Tropp & Odenrick, 1985).

The hip strategy restores balance by movement primarily created at the hip complex. This strategy is commonly used in both medio-lateral and antero-posterior instability when the disturbance to balance is large and fast or if the surface is unstable or smaller than the base of support (Horak & Nashner, 1986; Shumway-Cook & Woollacott, 2000; Tropp & Odenrick, 1985). Because of the limited ability of the ankle and knee to move medio-laterally the hip becomes the primary lower limb joint used when recovering balance in situations where larger corrections are required such as during high intensity jump landings and perturbations (Tropp & Odenrick, 1985). The trunk is also involved in medio-lateral stability and Allum et al. (1998) highlighted that under dynamic conditions on a moveable surface, it was proprioceptive input from the trunk and hip that were most important for triggering dynamic balance corrections. In a practical sense training exercises that are considered 'core training' may have the greatest implications for the execution of the hip strategy since the 'core' typically includes the hip complex with pelvic stability being particularly important (Lederman, 2010).

The stepping strategy can be used in the form of a step or a hop and is used when the ankle and hip strategies cannot maintain balance. It has been proposed that the stepping strategy is often used by untrained individuals when it would have been possible to recover balance by means of the stance strategies (McIlroy & Maki, 1993). The researchers found that giving the specific instruction of 'keep feet in place' was sufficient to decrease the frequency of those individuals who successfully maintained balance without the step strategy.

Assessments have shown that balance strategies change according to the task, the individual's movement strategies, and the various aspects of the environment (Bartlett, Wheat, & Robins, 2007). For example, Ross et al. (2004) found that during a step-down task, dominant and non-dominant limbs showed different landing strategies whilst demonstrating similar balance scores. Similarly the degree of stabilisation required for a task has been shown to affect the recruitment of muscle differently between individuals (Kornecki, Kebel, & Siemienski, 2001) and differences in joint angles during the same movement have been shown to alter muscle activation (Kasprisin & Grabiner, 2000). Other authors (Palmieri et al., 2002) have highlighted that when measuring centre of pressure deviations in balance tasks, that the same large deviations may represent poor postural control in some participants and an effective means of achieving balance in others. Furthermore, these differences in movement strategy may be advantageous to the individual in terms of injury prevention and maximising performance outcome variables (Bartlett et al., 2007). A problem for dynamic assessment, is that as the complexity of the task increases so too will the variation in movement strategy between individuals and even well trained individuals may use different movement strategies to perform the same task over repeated trials (Bartlett et al., 2007).

Balance Assessment

The strength and conditioning coach often tests various aspects of athletic performance to aid in programming. Common assessments include measures of strength, power, speed, endurance and anthropometry however, assessments of balance, in-particular those that replicate sport specific movement patterns, are less common. Reasons for this include a failure of previous research to conclusively show a set of dependent variables and testing protocols appropriate for use by sporting populations. Consequently balance performance is difficult to measure and interpret. The assessment of balance, in particular the degree to which it can be maintained and the movement strategies used to achieve it can provide a starting point for exercise prescription by highlighting the potential cause of any deficiency. Its usefulness also extends to describing trends and patterns within groups such as between sports or player positions.

Previous research has assessed how different postural control mechanisms affect balance during movements that include low level static stances to high intensity jump landings. After a thorough review of the current clinical balance tests, Emery (2003) concluded that none were appropriate for athletic populations and are only suitable for elderly and impaired populations. The subsequent sections will focus on reviewing information relevant to those practitioners who wish to develop new balance assessments suitable for the strength and conditioning facility. The benefits and limitations of various methods of assessing balance are discussed below, and a summary of these are included in Table 1.

Static Stance Balance Assessments

Several assessments have used periods of static stance on stable surfaces with eyes open to determine balance performance (Bernier & Perrin, 1998; Eils & Rosenbaum, 2001; Hoffman & Payne, 1995; Soderman, Werner, Pietila, Engstrom, & Alfredson, 2000; Verhagen et al., 2005; Willems, Witrwouw, Delbaere, Maheui et al., 2005; Willems, Witrwouw, Delbaere, Philipaerts et al., 2005). Typically subjects are required to stand on a force plate on a single leg for a fixed period of time. The positions of the non weight-bearing leg and arms may be controlled, for example subjects may be required to flex the non weight-bearing hip and knee to 90^{o}. Controlling for body position can help

Table 1: Benefits and limitations of current balance assessments

Type of Assessment	Benefits	Limitations
Static	• Quick and easy to administer • Can predict injury	• Do not reflect movements that occur in sports • Not challenging enough for sporting populations • Deficiencies in the static system do not necessarily predict deficiencies in the dynamic system • Often utilises advanced equipment that is not available to most practitioners • Limited sensitivity to changes in balance performance • Current assessments give no indication to the origin of any deficiency
Dynamic	• Relevant to the majority of functional movement • Represents a similar challenge to the postural control system that occurs during sports performance • Utilises fundamental movement patterns • Can predict injury	• Often utilises expensive and advanced equipment that is not available to most practitioners • Current dependent variables are often more suited to static balance assessments • Current assessments do not measure the movement strategies used to maintain balance • Current assessments give no indication to the origin of any deficiency
Videographic	• Can show changes in performance • Can predict injury • Most coaches have access to a video camera • Measures the movement strategies used to perform a task • 2D frontal plane knee motion analysis can provide reliable descriptors of the same variables from 3D analysis	• Current assessments are not true balance assessments as they give no measure of sway • Often disregard the base of support • 3D videography is expensive and advanced equipment not available to most practitioners • Often measure segmental orientation at isolated points in time rather through the full range of the movement
Qualitative	• Easy to administer • Requires minimal equipment • Movement strategy can be assessed provided specific criteria are in place	• Assumes competency on behalf of the assessor • Lack of reliability information on current qualitative movement assessments

standardise the testing procedure and make comparisons between individuals and across testing sessions less problematic. However, since individuals are able to maintain balance successfully through different movement strategies, preventing an individual from moving naturally may not reflect the way the individual maintains balance in a non-clinical setting. Measures of balance are most commonly calculated from displacements of the centre of pressure in the antero-posterior and medio-lateral directions (Bernier & Perrin, 1998) or from the maximum time for which balance is maintained on a single leg (Atwater, Crowe, Deitz, & Richardson, 1990).

Several researchers have commented that these static conditions may not be sufficiently difficult to reveal deficiencies in the postural control system among athletic populations (Emery, 2003; Hrysomallis et al., 2006; Riemann et al., 1999; Wikstrom et al., 2005). However, static stance tests can be made more difficult by disrupting the sensory or motor components. For example, the removal of vision demands that the subject makes greater use of sensory information from other sources such as plantar pressure and joint proprioception (Atwater et al., 1990; Bernier & Perrin, 1998; Beynnon, Renstrom, Alosa, Baumhauer, & Vacek, 2001; Emery et al., 2005; Verhagen et al., 2005; Watson, 1999; Willems, Witrwouw, Delbaere, Maheui et al., 2005). Furthermore, stance on a compliant or unstable surface reduces the subject's ability to sense pressure distribution and body orientation and reduces the effectiveness of corrective ankle torque (MacLellan & Patla, 2006; Perry, McIlroy, & Maki, 2000) and this approach has been used by various researchers (Atwater et al., 1990; Bernier & Perrin, 1998; Emery et al., 2005; Hrysomallis, McLaughlin, & Goodman, 2007; Kollmitzer, Ebenbichler, Sabo, Kerschan, & Bochdansky, 2000; McHugh, Tyler, Tetro, Mullaney, & Nicholas, 2006; Soderman et al., 2000; Willems, Witrwouw, Delbaere, Maheui et al., 2005; Yaggie & Campbell, 2006).

An example of an assessment which used eyes closed conditions is that by Watson (1999). Athletes were asked to stand on a single limb with the opposite hip and knee flexed to 90^{o}. The total amount of time the athlete could remain balanced was recorded as a measure of balance and any trial less than 15 seconds was deemed as abnormally poor balance. Although the removal of vision increases the difficulty of the balance tasks, sporting performance usually involves eyes open conditions and thus any findings from such as testing protocol may not be relevant to actual sporting performance.

An example of an assessment which used an unstable surfaces is reported by McHugh et al. (2006) which assessed balance using a tilt board that was instrumented with switches on each side to detect ground contacts (occurring at 10^{o} of tilt). The tilt board moved medio-laterally and subjects attempted to maintain balance while standing on a single limb (without shoes) for one minute with the arms folded across the chest. The total amount of time that the switches were activated represented the balance score. Some situations in sport result in landing on unstable surfaces such as an opponent's foot. Consequently unstable surface testing may be a valid balance assessment in this regard. However, most movements in sport are executed on stable surfaces with eyes open under dynamic conditions. As such, tests of balance for the athlete should replicate these conditions.

Currently the link between different types of balance performance such as static stance, eyes closed or unstable surface with sports performance is unclear. One study, (Hrysomallis et al., 2006) assessed balance among male Australian Footballers in a static and a semi-dynamic test. Subjects stood on a force plate on a single leg for 20 seconds with the knee of the non weight bearing limb flexed to 90^{o}. The displacements and maximal excursion of the centre of pressure in the medio-lateral direction were used as measures of balance. Dynamic balance was assessed by the same variables during a step onto a foam balance mat followed by a 20 second hold. Neither of the measures were correlated suggesting that performance in a static test was not reflective of more dynamic conditions. If static assessments are not reflective of dynamic conditions and given that most sports performance occurs under dynamic conditions, this would suggest that static balance assessments are not appropriate for providing an indication of balance ability specific to sports performance.

Although other studies (Heitkamp et al., 2001; Verhagen et al., 2005; Yaggie & Campbell, 2006) have assessed multiple measures of balance none have reported the correlation between the measures although this does not definitively imply no relationship exists. Holm et al. (2004) found that a training program which involved jumping, landing, cutting and wobble boards improved measures of dynamic balance but not static balance or proprioception. This suggests that static assessments are not appropriate for measuring improvements in dynamic balance and that the competencies may be somewhat different. A study comparing the effect of previous injury on balance measures (Ross & Guskiewicz, 2004) showed different responses to static and dynamic tests. The static balance measure, which involved a 20 second single leg stance on a force plate, could not differentiate between those participants with functional ankle instability and a control group. A dynamic balance measure, which involved performing a jump to 50-55% of their maximal vertical jump, landing on a single leg, stabilising and then remaining motionless for 20 seconds, was able to separate the two groups. The results from this study indicates that static balance assessment may not differentiate individuals with functional ankle instability, or dynamic balance assessments present similar conditions upon which individuals report to having recurrent ankle sprains. The authors recommended that when evaluating balance, assessments should involve single leg jump landings, not single leg stances in order to identify balance deficiencies related to functional ankle instability.

Since there may not be a strong relationship between static and dynamic balance, studies which only use one measure, especially a static balance measure, should do so with caution as important information could be missed (Hrysomallis et al., 2006). Despite this several studies have found that static assessments of balance may predict injury (Hrysomallis et al., 2007; Watson, 1999; Weyand, Strernlight, Bellizzi, & Wright, 2000; Willems, Witrwouw, Delbaere, Maheui et al., 2005; Zazulak, Hewett, Reeves, Goldberg, & Cholewicki, 2007) although others have found no correlation (Beynnon et al., 2001; McHugh et al., 2006; Soderman et al., 2000; Willems, Witrwouw, Delbaere, Philipaerts et al., 2005). It is not surprising that static balance deficiencies are able to predict injury since poor performance in these tests indicates a failure in the postural control system to limit excessive centre of mass movement. Given the ease of the testing procedures associated with static balance assessment, deficiencies in this low intensity task are likely to be magnified under higher intensity conditions, such as during sports performance. There is a lack of research in the area, and more is required to understand how static balance performance affects functional movement. Similarly more research is needed to understand how movement is affected by instability at a single joint, such as functional ankle instability. Future research would benefit from measuring if common faults in the postural control system occur along a continuum of movement tasks in each basic pattern, such as from a static single leg stance to a single leg squat and a single leg hop. Given the available information it is possible that balance deficiencies at lower levels may predict dynamic performance, however as discussed, static and dynamic balance should be interpreted as separate competencies. Within athletic populations static balance deficiencies are only likely to be found in the most impaired individuals, and amongst this group only, it is likely that static balance assessments are likely to lead to meaningful deficiencies in dynamic balance performance. Consequently static stance assessment may miss relevant information amongst sporting populations who may have reasonable levels of functionality and for whom dynamic movements represent the major injury risk.

Dynamic Balance Assessments

Dynamic tests are more relevant to sport because they represent similar challenges to the postural control system. Since dynamic movements such as jump landings are a major cause of injury dynamic assessments may have better prognostic value (Otago, 1983; Powell & Barber-Foss, 2000). In spite of this, research involving the assessment of dynamic balance is less common (Myer et al., 2006; Riemann et al., 1999; Ross & Guskiewicz, 2003; Wikstrom et al., 2005).

A variety of dynamic balance tests exist. Myer et al., (2006) had subjects balance on one leg before hopping forward 50 cm onto a force plate and maintaining balance on the same leg for 10 s. Deviations in the centre of pressure in medio-lateral and antero-posterior directions were analysed as well as maximal vertical ground reaction forces. Although this protocol is a dynamic balance task, the distance jumped is not indicative of the higher intensity jumps experienced during sport. Several other studies have developed more challenging protocols. Wikstrom et al. (2005), Ross and Guskiewicz (2003) and Brown *et al.* (2004) required subjects to jump 70 cm onto a force plate taking off with two legs and landing on one. During the jump subjects touched an overhead marker with a single arm of their choosing, which was placed at a position equivalent to 50% of the subject's maximum bilateral vertical jump height. The requirement to contact an overhead marker not only standardizes the vertical jump component but also may replicate a similar movement pattern to reaching up and catching / blocking a ball which is a component of several sports' jump patterns. On landing subjects were instructed to stabilize as quickly as possible and balance for 10 s with hands on hips, looking straight ahead. Time to stabilization was taken as a measure of balance and was calculated as the time for the vertical ground reaction forces to reduce to 5% of bodyweight after landing. Wikstrom et al. (2005) also included a *dynamic postural stability index* based on the magnitude of vertical ground reaction forces and centre of pressure deviations in the medio-lateral and antero-posterior directions.

Although these tests may highlight whether a postural control deficiency exists, they give no information on the origin of the deficiency due to a lack of information on segmental orientation. Centre of pressure change represents a summation of all the forces at proximal body segments and thus does not reveal what movements are occurring within the movement pattern being observed. This is particularly relevant as feedback of this nature would be useful for programming interventions and coaching correct movement patterns. Furthermore, specific biomechanical and kinematic deficiencies in movement task performance have different injury risks associated with them. For example movement issues at the hip often lead to injuries at the knee whilst issues at the feet may be more related to injuries at the ankle (Murphy et al., 2003).

Force plate analysis also requires the athlete to perform the movement successfully so as to achieve a clean centre of pressure trace and if an athlete has to use a stepping strategy to regain balance the trial is often repeated (Wikstrom et al., 2005). This is necessary for analysis of similar movement strategies in research studies but may overestimate balance ability in performance tests (Wikstrom et al., 2008). Consequently methodologies should be developed that accurately reflect balance performance.

Not all dynamic balance assessments have used force plates, and this approach may be attractive to the practitioner without access to such equipment or the expertise to use it. Riemann et al. (1999) used a sequence of ten jumps on a numbered floor pattern including forward, diagonal and lateral jumps as a measure of dynamic balance. Subjects jumped on a single leg with hands on hips and repeated the test on the opposite leg. A score of postural stability was given based on errors on landing (10 points) and during balance (3 points). Landing errors included not covering the landing mark, stumbling on landing, the landing foot not facing forwards within 10^o of inversion or eversion, and the hands coming off the hips. Balance errors included touching down with the free limb, touching the stance limb with the free limb, the free limb moving into excessive flexion, extension or abduction and the hands coming off the hips. The requirement of participants to maintain hands on hips standardises the movement so as to make comparisons between participants less problematic. The restriction of arm movement however does not necessarily limit the movement strategies possible and the increased difficulty of the task may have caused the participants to utilise an increased number of adaptive strategies to complete the task. Furthermore, it has been highlighted that individuals are likely to display different movement strategies between trials, even amongst experienced performers and that restricting an individual's normal movement pattern may lead to injury (Bartlett et al., 2007). The use of a scoring system for landing and balance errors in the study provides a useful method for quantifying the most common deficiencies. The criteria specified are useful for prescribing interventions as they indicate the type of landing and balance errors that occur. However the criteria makes no reference to the cause of any error which would be useful for programming.

Videographic Assessments

Several studies have used video to track joint position and body segment orientation and this type of analysis has contributed to a greater understanding of movement strategies during ground contacts, squat patterns, jump take-offs, running and jumping (Augustsson et al., 2006; Derrick, 2004; Hart, Garrison, Palmieri-Smith, Kerrigan, & Ingersoll, 2008; Noyes et al., 2005; Willson et al., 2006). Whilst these assessments do not measure sway around the base of support, the measurement of segmental orientation is related to balance and functional human movement.

Several authors have used multi camera systems to capture frontal plane knee angle during bilateral drop jumps (Ford, Myer, & Hewett, 2003) and during a single leg drop jump (Russell, Palmieri, Zinder, & Ingersoll, 2006), and lower limb joint moments during a single leg forward hop (Hart et al., 2008). Hart et al. (2008) used a ten camera motion analysis system to capture 3D lower body kinematics in a forward hop test. Subjects stood on a single leg one metre from the edge of a force plate and performed a hop to the centre of the plate landing on the same leg. Lower extremity kinematics were recorded from pre-take-off to after balance appeared to have been achieved. Trials were excluded if the subject was unable to balance which may have over-estimated true balance ability.

Russell et al*.* (2006) used 3D videography to measure segmental orientation at ground contact and deepest knee flexion in a single leg drop jump task. Frontal plane knee angles were recorded, which summarizes the relationship between the lower limb segments in the frontal plane. This measure differs from the Q-angle in defining the lower leg. Frontal plane knee angle uses a straight line through to the base of support as opposed to the direction of the quadriceps muscle force vector in the frontal plane (Schulthies, Francis, Fisher, & Van de Graaff, 1995) (see Figure 1). These measures are useful in that they can identify movement deficiencies such as knee varus and valgus which have been linked to incidence of lower limb injury (Hewett, Myer, & Ford, 2005, 2006). Ford *et al.* (2003) also used 3D videography to assess frontal plane variables but reported separations as opposed to angles. Separations are indirect measures of joint angles and can only be used with bi-lateral movements. The frontal plane distance between right and left lateral knee markers in a vertical bilateral drop jump was measured, normalized for height, although not hip width which may have been more appropriate since lateral not vertical separations were being measured. Since both Ford *et al.* (2003) and Russell *et al*. (2006) related frontal plane measurements derived from 3D measurements to determine gender differences in lower limb alignment on landing, practitioners can infer similar data by using a single frontal plane camera. This method was validated by McClean *et al.* (2005) who evaluated the potential of 2D analysis as a method for screening for frontal plane knee angles. Two dimensional analysis was compared to 3D data and it was found that a 2D frontal plane can provide reliable descriptions of frontal plane knee motion.

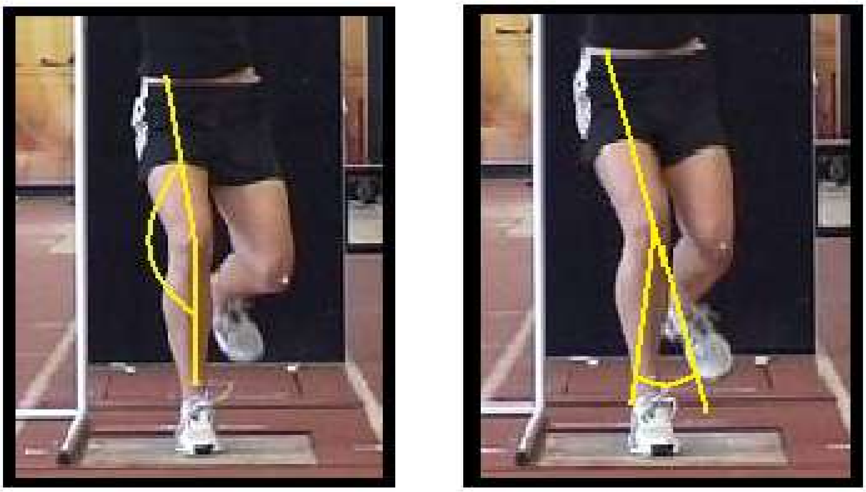


Figure 1: An example of a frontal plane knee angle (left picture) created by linking the anterior superior illiac spine, the middle of the patella and the most frontal and distal point of the tibia (which leads to the mid-point of the ankle mortise). This differs from the Q-angle (right picture) which is formed by linking the anterior superior iliac spine, the middle of the patella and the tibial tuberosity.

Noyes *et al.* (2005) used a similar approach in the drop jump screening test to capture frontal plane lower limb joint separations. Subjects were required to drop off a box, land bilaterally and immediately perform a maximal vertical jump. Using video footage, frontal plane bilateral knee and ankle separations were measured at ground contact, at deepest point, and take-off and normalised as a percentage of hip separation. High reliability was reported for test-re-test reliability (ICC = 0.94-0.96) and within-test reliability (ICC ≥ 0.90). The failure of the majority of research to report reliability is a major limitation in this area of study. Importantly the test was able to show improvements in lower body kinematics after a training intervention targeting the hip musculature, which validates its use as a sensitive enough measure capable of detecting the often small changes that occur with training.

Willson et al. (2006) also used a single camera to assess a frontal plane projection angle which linked the hip, knee and ankle. Subjects performed a single leg squat onto a seat at approximately 45^{o} knee flexion. The frontal plane projection angle was recorded at upright single leg stance and at the deepest point of knee flexion. Assessments such as this and by Noyes et al. (2005) are attractive to the practitioner in the field as they are easy to administer, require minimal equipment and give a result which has been shown to be responsive to training interventions.

Although a videographic approach is most useful, one common problem of some of these methodologies is that they have tended to assess joint position at specific points in time rather than throughout the movement. Since movement is dynamic in nature, the implications of assessing movement in a static manner, is that it may not assess the balance strategies throughout the entire range of motion. The assessment of balance also requires some measure of sway around the base of support over time since these variables define it. Although videographic assessments measure segmental orientation, few have included the position of the base of support in relation to superior body segments as part of the analysis. Even amongst studies of movement which do not measure balance, the recognition of the base of support may be useful as it is through this point that force is transmitted into the ground. A further problem with some of these movement assessments is that they are often bilateral, vertical, occur in a single plane of motion and do not replicate sport specific movement patterns. These movements are likely chosen to maximise the reliability of the assessment procedure. Sports performance can require unilateral force development, unilateral force absorption, multi-directional movement, and is not restricted to simple low intensity movement patterns. Finally, as highlighted previously, 3D videography systems are expensive, complicated to operate, time consuming to analyse and not accessible to every strength and conditioning coach. However single or dual camera analysis (e.g. frontal and sagittal) represents a realistic approach for many practitioners.

Qualitative Assessments

A qualitative approach to the assessment of balance may be of use to the assessor, particularly since a complete set of quantitative variables has yet to be established. A qualitative approach to the assessment of movement has been used previously and given the relationship balance shares with movement this method may be valid. Two tests have aimed to quantify movement dysfunction using descriptors of movement and rating scales. The *Movement Assessment Battery for Children (Version Two)* uses a three colour 'traffic light' scoring system to grade activities such as throwing, catching, walking, balancing and jumping (Henderson, Sugden, & Barnett, 2007). In this assessment, qualitative observations are used in conjunction with numerical scores of performance tests. Similarly the *Functional Movement Screen* uses a three point rating scale to grade key movement patterns. Qualitative observations of mechanics accompany specific criteria within each pattern which both contribute to the final score (Cook & Burton, 2009).

Two studies have used qualitative assessments of balance. Atwater et al. (1990) recorded the type of balance strategy used along with the duration of the stance but only went as far as highlighting whether a hip or ankle strategy was used which although profiles the athletes balance strategy does not necessarily add prognostic value. Riemann *et al.* (1999) also used qualitative descriptors of movement to assess balance in a multiple hop test, but did not assess the origin of any deficiency. It has been highlighted that because of the current lack of quantification in human movement and the absence of a complete set of dependant variables, qualitative assessments may represent good user-friendly utilities for the applied setting (T. Brown & Lalor, 2009).

Conclusion and Practical Applications

Based on this review it can be concluded that there is no single balance assessment suitable for use in an applied setting for sporting populations, indicated by the benefits and limitations of each type of assessment detailed in Table 1. Current assessments range from simple tests which may not represent the same challenges as during sports performance to others that have replicated sport specific movement patterns but have tended to assess variables more appropriate for static assessments. Few give any indication of the origin of any deficiency which majorly limits how the strength and conditioning coach can program appropriate interventions. Dynamic tests have sometimes relied on complicated, expensive and non-portable equipment which may not be available to every practitioner and also limits their use. Currently the coach and athlete cannot confidently use dynamic balance assessments to objectively determine: (1) if a balance deficiency exists; (2) what is the cause of any balance deficiency; (3) if treatment is needed; and (4) if a specific intervention has caused a meaningful change in balance.

It has been suggested that new measures of balance are required suitable for sporting populations and field based assessment (Emery, 2003). These assessments should consider the relationship of balance to functional human movement, measure appropriate variables for the movements in question, demonstrate reliability, and offer prognostic and/or diagnostic value. These types of assessment would be practically beneficial to strength and conditioning professionals and sports coaches.

Table 2 suggests a process for developing new tests of balance for specific sports. The first stage in this process is to gain an understanding of what the key injury risks and performance indicators are for the sport or individual in question. For example, in sports which involve jumping, knee valgus in squat patterns has been shown to limit vertical jump height and increase the risk of knee ligament injury (Chappell & Limpisvasti, 2008; Markolf et al., 1995). A list of the most common deficiencies is presented in Table 3. It would also be useful to gain an understanding of how each variable is affected by such factors as different movements, loads, and velocities as this will help the assessor manipulate each variable in the test.

Also of importance is an understanding of the mechanisms which control balance performance and how they are affected. For example, requiring participants to catch a ball during a movement task may disrupt some of the sensory information involved in postural control, namely the visual, vestibular and proprioceptive systems as well as the motor process involved. In terms of specificity this approach may be advantageous if this is a common movement pattern for the sport in question.

The next step in designing a balance assessment is to establish the required movement patterns for the sport and any differences specific to player position. This can be done using time motion analysis and a major limitation of previous research is a failure to perform this type of groundwork before choosing movements for an assessment. Time motion analysis has been used to quantify information on systems of play, patterns of play or information on the intensity of exertion of players (Bloomfield et al., 2004) by recording variables such as the distance covered during a game of soccer (Barros et al., 2007), the speed of movement prior to starting a sprint in rugby (Duthie, Pyne, Marsh, & Hooper, 2006), and game incidences in soccer such as the number of shots on goal (Hughes & Franks, 2005). Few studies have attempted to objectively record the different movement patterns which contribute to game-play despite the fact that this type of information would aid the development of effective conditioning strategies and assessment protocols. For example when designing an assessment it may be useful to determine if movements tend to exist in a particular plane of motion, movement pattern or sequence. When performing the time motion analysis it

Table 2: Framework for designing assessments of balance

Step	What to do	Why?	How?
1	Perform a review of the literature focusing on sport specific risk factors for injury, optimal movement strategies, balance mechanisms, the physical requirements of the sport and current assessment techniques.	When assessing balance and movement it is important to know the underlying mechanisms. Furthermore, knowledge of the common sport specific deficiencies will lead to the selection of the most appropriate dependent variables. Understanding and critiquing current assessment techniques will enable them to be used effectively or adapted appropriately to measure the desired performance qualities.	Search the peer-reviewed literature and coaching resources. Keywords can include: injury, movement, balance, dynamic stability, instability, assessment, lower limb, kinematics, lower limb alignment, biomechanics, landing, strength, knee, hip, and ankle.
2	Perform a movement analysis of the sport using elite players.	This process will help give a greater understanding of the most common movements involved and the sport specific challenges to the postural control system. By assuming elite players are less deficient than lower level players, using elite players will give a better picture of what is required for top level performance. However it may be the case that elite players do not perform all movements that could be used because of individual deficiencies.	Use performance analysis software to analyse frequency of movements including direction, intensity, unilateral vs bilateral, skills being executed during movement patterns (eg catching / twisting while lunging / squatting) and sequences of multiple movements (eg backward run followed by vertical jump).
3	Refine the movements observed in step 2, based on their frequency and importance to injury and performance, to a few key movements.	This will ensure that any deficiencies highlighted in the testing procedure are relevant to the sport being performed.	Standardize a set of movements observed in step 2 focusing on the risk factors highlighted in step 1. Be aware of previous methodologies from step 2 and their reliability and validity. Make allowances for individual differences in variables such as height, strength, power, movement and limb length.
4	Develop a method of scoring the chosen movements, which is quick and easy to perform, utilises minimal, inexpensive, and available equipment. The scoring method should be both prognostic and diagnostic.	This will enable performance to be monitored over time. The method should give insight into the origin of any deficiency. By using a simple methodology the assessment is more likely to be used regularly and effectively by practitioners who may have large numbers of athletes and limited access to more advanced equipment.	Review previous methodologies. Weight more important factors and include as many of the known factors that make up balance (see Table 3)
5	Assess the reliability of the test.	This will show the degree of reproducibility when the protocol is repeated under identical conditions.	Perform multiple trials of the test under test re-test conditions. Examine the effects of using different assessors.
6	Assess the sensitivity of the test to changes in performance and its predictive ability.	The ability of the assessment to reflect meaningful changes in the measure being tested enables the practitioner to track performance over time. The test's ability to predict factors such as injury will also validate its use as a screening tool.	Perform a balance training intervention. Assess performance pre and post training and measure if any meaningful changes were shown in the test. Track injury over a season and correlate this to performance in the assessment.

is also important to focus on the factors that are most relevant for injury and performance. For example, in netball two authors have highlighted that abrupt decelerations on jump landing and twisting on jump landing which may be caused by the two step rule are the major injury mechanism in the sport (Otago, 2004; Powell & Barber-Foss, 2000). Information on the types of jump landings will help design appropriate testing batteries.

From the movement frequency analysis, those movements that are most important for performance and represent the greatest injury risk should be used in the assessment battery. For greatest usability, particularly when working with large numbers of athletes, the battery should be refined to only the most important movements. Furthermore it may be possible to group movement patterns together in a sequence where appropriate. The movements should be performed at appropriate intensities specific to the sport.

From here a method must be developed for scoring the chosen movements. For the assessment to have the greatest impact on programming, the method must give insight into the origin of any deficiency. It is possible that qualitative measures that accompany more conventional quantitative measures such as forces and velocities will be useful in the absence of established variables. Likewise kinematic variables, which have not often been used in balance assessment, such as joint angles and separations may be useful as they give an indication of body position.

Once the assessment battery has been finalised and pilot work has been completed, the test must be validated in terms of reliability, to determine the reproducibility of the test and ensure any changes in performance cannot be attributed to errors or the variability associated with the procedure. Finally the ability of the assessment to predict injury and performance should be assessed and its usefulness in this regard will ultimately determine its validity.

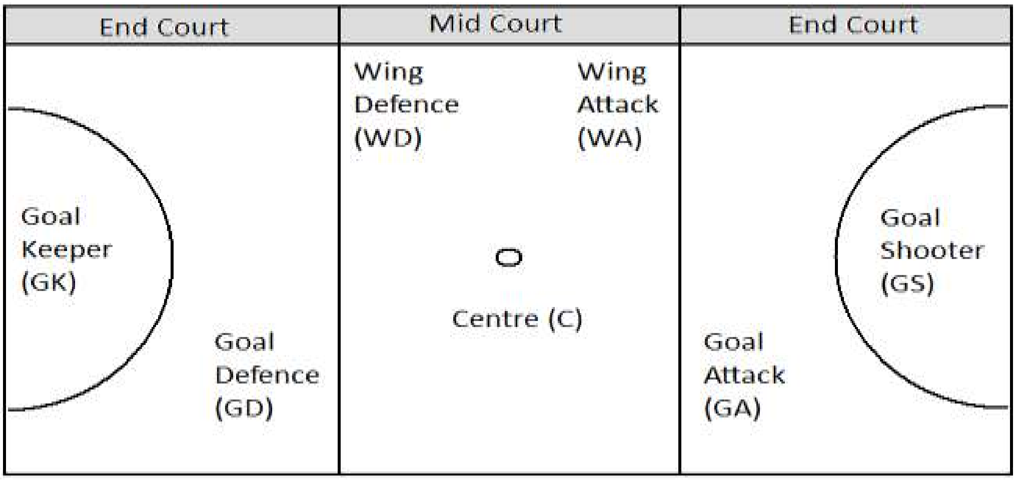
It is hoped that this review will contribute to a greater understanding of balance assessment and aid in the design of future protocols. The main findings of this review are that static and dynamic balance although related are different performance qualities. In order for the balance assessment to have real diagnostic and prognostic value, balance must be assessed in a sport specific context.

Table 3: Important variables to include in a balance screening tool

Variable	Why is it important?	Reference
The movement of body segments relative to the base of support	This is the main factor in the maintenance of an upright vertical orientation in stance and dynamic movement. It is also a predictor of lower limb injury.	(Hrysomallis, 2007; McGuine & Keene, 2006; Willems, Witrwouw, Delbaere, Philipaerts et al., 2005)
Knee control	Angular changes in the frontal plane such as valgus or varum especially under load are predictors of lower limb injury.	(Boden, Dean, Feagin, & Garrett, 2000; Hewett et al., 2005, 2006)
Hip control	Stability of the hip complex is required for movement above and below. A stable hip provides a foundation upon which to develop or resist force. Hip instability is also a predictor of lower limb injury	(Allum et al., 1998; Leetun, Ireland, Willson, Ballantyne, & Davis, 2004; Mykleburst et al., 2003)
Trunk control	Stability of the trunk is required for movement at the extremities as it provides a foundation upon which to develop or resist force.	(Allum et al., 1998; Leetun et al., 2004)
Ankle control and foot position	Deficits in ankle control are a predictor of lower limb injury. Increased ankle inversion / eversion is a risk factor for lower limb injury.	(Bellchamber & van den Bogert, 2000; Ford et al., 2003; Riemann et al., 1999)
Squat depth (in squat pattern assessments)	The risk of ACL injury increases with greater knee extension. A deep squat is also a measure of functionality and demonstrates effective synergistic muscle activity.	(Boden et al., 2000; McNair, Marshall, & Matheson, 1990)
Asymmetries	Side to side differences in performance are risk factors for lower limb injury.	(Baumhauer, Alosa, Renstrom, Trevino, & Beynnon, 1995; Ford et al., 2003)

Muscular strength / power	Deficits in strength and power limit the potential for the muscular protection of joints, ligaments and tendons.	(Hewett et al., 2006)
Muscular strength imbalance	The ability to balance muscular recruitment through positions of high load is a risk for lower limb injury.	(Baumhauer et al., 1995; Ford et al., 2003; Hewett et al., 2005; Soderman, Alfredson, Pietila, & Werner, 2001)
Kinematics of functional movement pattern	Faulty movement patterns represent a disruption to how muscles support and move joints.	(Cook & Burton, 2009; Kritz, Cronin, & Hume, 2009)
Failed trials	Several studies have omitted failed trials from their analysis of balance. The removal of failed trails may over-estimate balance ability.	(Wikstrom et al., 2008; Wikstrom et al., 2005)
Previous Injury	Previous injury is a major risk factor for injury and can be a cause of instability at the affected joint.	(Hewett et al., 2006; Murphy et al., 2003; Orchard, 2001)

Chapter Three
Frequency and Type of Landing Movements Among Elite Netball Players During Competition



Chapter 3 - Frequency and Type of Landing Movements Among Elite Netball Players During Competition

Introduction

When designing physical conditioning programmes and assessment batteries the strength and conditioning professional must be cognisant of the physical qualities required for the particular sport (Robinson & O'Donoghue, 2008) and any differences specific to player position (Di Salvo et al., 2007). Physical conditioning should prepare players for optimum performance and to avoid injuries. When designing physical preparation strategies, some type of time motion analyses is useful to quantify the occurrence of movement patterns, patterns of play or information on the intensity of exertion of players (Bloomfield et al., 2004). Performance analysis typically records variables such as the distance covered during a game of soccer (Barros et al., 2007), the speed of movement prior to starting a sprint in rugby (Duthie et al., 2006), and game incidences in soccer such as the number of shots on goal (Hughes & Franks, 2005). Few studies have attempted to objectively record the occurrence of different movement patterns of players during game play. Such information would aid the development of effective conditioning strategies.

The Bloomfield Movement Classification (Bloomfield et al., 2004) has gone some-way into exploring the frequency of movements which contribute to sports performance and perhaps represents the most comprehensive time-motion analysis method within field based team sports. Bloomfield *et al.* (2004) highlighted information that contained a large set of movement categories, directions, intensities, turns and playing activities needed to thoroughly understand and evaluate the necessary physical performance requirements of a sport. However, due to the large amount of time involved in such classification, few studies have adopted this approach and even this method omits specific movements that may be of interest to a trainer.

With regards to netball, early studies using time motion analysis highlighted differences in work to rest patterns between player positions (Otago, 1983; Steele & Chad, 1992). The differences observed were no doubt related to the rules of the game which restrict certain player positions from moving into particular court areas and the differences in game play across the court. The requirements of different positions has resulted in anthropometric specialisation (Bale & Hunt, 1986) with the end court players who tending to be taller contest the ball aerially than mid-court players. However, no research has systematically quantified movement patterns for each player position.

Several authors have highlighted that abrupt decelerations on jump landing and twisting on jump landing which may be caused by the two step rule are the major injury mechanism in netball (Otago, 2004; Powell & Barber-Foss, 2000). Consequently information on the types of jumps performed will aid strength and conditioning professionals and netball coaches develop conditioning strategies and performance assessment batteries for both injury prevention and monitoring performance. The purpose of this study therefore was to quantify the direction, turn and landing of jumps by elite netball players of different positions during match play.

Methods

Games Analysed

Two complete netball games, of New Zealand only teams, from the 'ANZ (Australia New Zealand) Netball Champsionship' were selected for time motion analysis. All on court players were investigated over the two games representing four teams, 28 players and seven different player positions (see Figure 2).

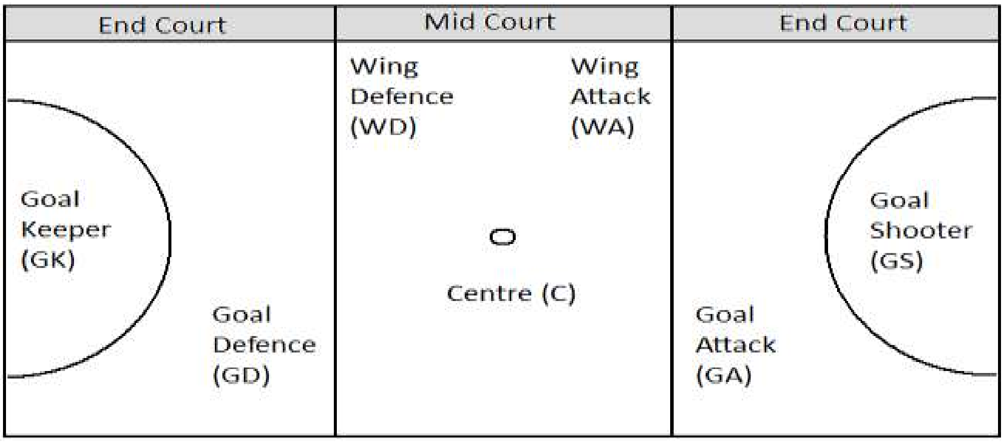


Figure 2: Representation of a netball court with player positions for a team attacking to the right

Analysis of Data

The footage was analysed using Sportscode software (Elite 6.5.3, Australia). A specifically created template was used to code the footage with a label assigned to each movement by position. Game footage was obtained from recorded televised footage. The videos were watched at 30% normal speed and a single investigator coded movements by entering movements in 'play' time or by pausing and re-winding the video if multiple actions were performed simultaneously. All movements were coded unless the athlete was in recovery (walking, easy jogging, easy back-tracking and low level movements), and if they matched the description of one of the movement classifications (see Figure 3).

JUMP	+	**VERTICAL** OR **FORWARD** OR **LATERAL**	+	**UNILATERAL LANDING** OR **BILATERAL LANDING**	+	**TURN IN THE AIR** OR **NO TURN IN THE AIR**
A JUMP IMMEDIATELY FOLLOWED BY A SECOND JUMP OR AN EXPLOSIVE CHANGE OF DIRECTION						

Figure 3: Movement classifications for game coding

In a vertical jump the direction was distinctly vertical and on landing any part of the performer's foot or feet contacted the ground within approximately a 50 cm radius of the take off point. A forward jump was landed within approximately 30^{o} to the left or right of the take-off direction (as indicated by the direction of the hips at take-off) with landing distance of greater than approximately 50 cm. A lateral jump was classified as any jump which was landed outside of approximately 30^{o} to the left or right of the take off direction (as indicated by the direction of the hips at take-off) with landing distance of greater than approximately 50 cm. A turn in the air occurred when the hips faced approximately 30^{o} or more to the left or right relative to take-off. Finally, if the player immediately performed a second jump or explosive change of direction upon landing that was recorded. These movements required the athlete to perform the second movement immediately after landing the first and therefore utilised their stretch shortening cycle as opposed to 'sticking' the landing with no immediate and subsequent movement.

Results

The average number of jumps recorded per position per game arranged in descending order were: C (82), WA (82), GA (70), GS (56), GD (46), WD (44), GK (38). In terms of jump direction, an average of 173 forward, 134 vertical, and 109 lateral jumps were recorded per game. The average percentage that each jump direction was performed per match per player position can be observed in Figure 4. There was a difference in the number of jumps performed by direction between different player positions. All mid court players performed forward jumps most frequently (WA=51%; WD=47%; C=43%). End court players performed vertical jumps were most frequently (GK=67%; GS=47%; GD=45%) with the exception of GA for whom forward jumps were most frequent (49%). Most players executed lateral jumps least frequently (GK=12%; GD=17%; WD=23%; GA=23%; GS=24%) with the exception of C (38%) and WA (32%).

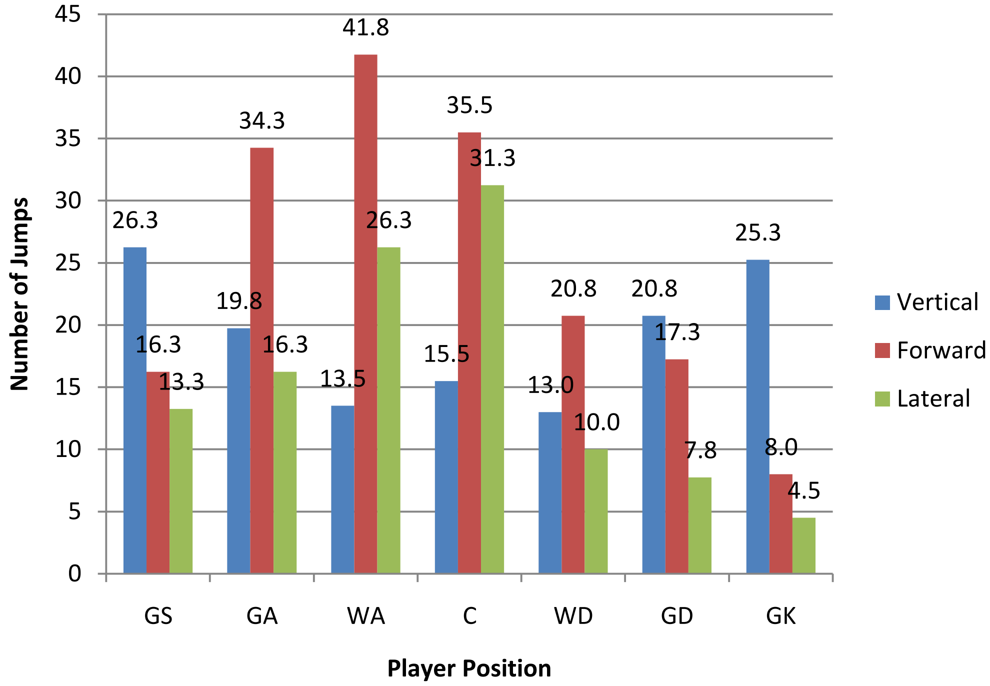


Figure 4: The average number of jumps performed in a vertical, forward and lateral direction per player position per game

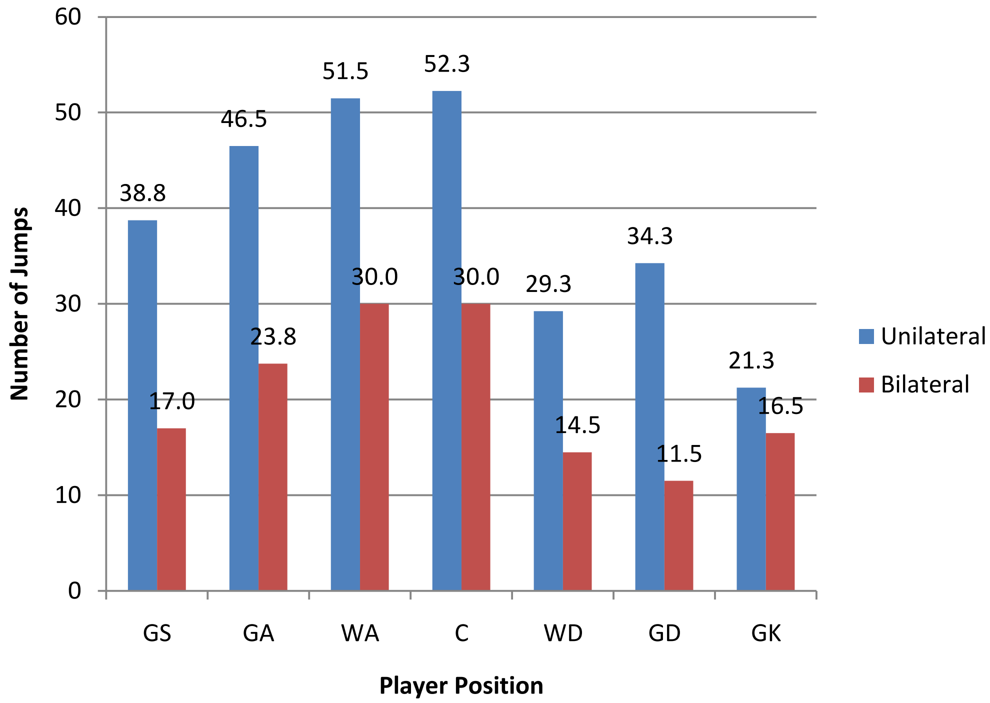


Figure 5: The average number of unilateral and bilateral jump landings performed per player position per game

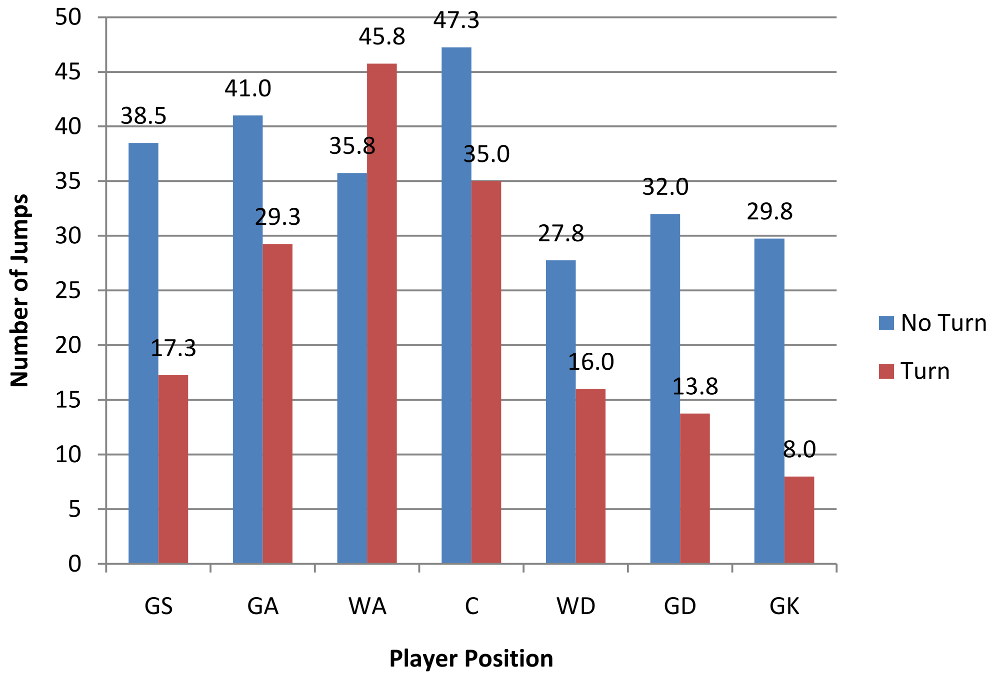


Figure 6: The average number of jumps performed with a turn in the air and no-turn in the air per single player position per game

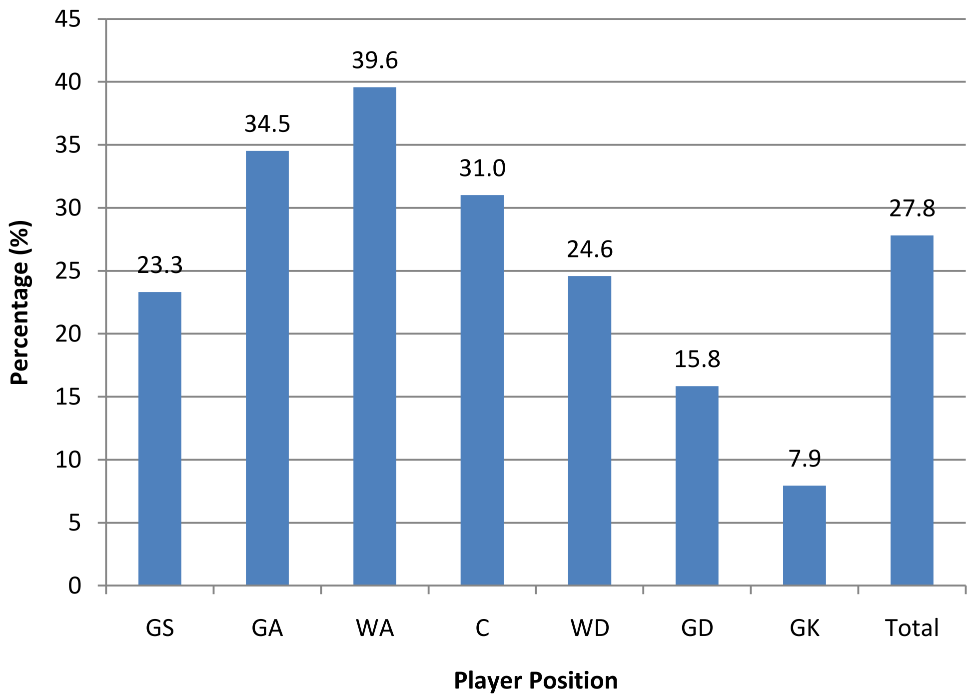


Figure 7: The average percentage of jump landings which were immediately followed by a second jump or explosive change of direction per single player position per game.

The average number of unilateral and bilateral jump landings for each player position per game are shown in Figure 5. Most player positions tended to perform approximately twice as many unilateral jump landings as bilateral landings (approximately 67% vs 33%). The exception was GK for whom there was only a 13% difference in the number of unilateral to bilateral landings.

The average number of jumps performed with a turn in the air compared to those jumps that were performed without a turn is shown in Figure 6. Most player positions performed a greater amount of jumps with no-turn in the air compared to a turn except for WA. Three end court players tended to favour jumps with no turn to a greater extent (GS=69%; GD=70%; GK=79%) than the four other player positions (WA=44%; C=57%; GA=58%; WD=63%).

The percentage of jump landings which were immediately followed by a second jump or explosive change of direction are shown in Figure 7. The average number of jumps that were landed and then immediately followed by a second jump or explosive change of direction was 28%. Three attacking positions had the most changes of direction or explosive jumps on landing (WA=40%; GA=35%; C=31%) compared to the remaining positions (GK=8%; GD=16%; GS=24%; WD=25%).

The average number of jumps landed unilaterally and bilaterally for each of the three jump directions are shown in Figure 8. For vertical jumps both unilateral and bilateral landings were approximately equally common (47% vs 53%). In comparison, unilateral landings were more prevalent during forward jumps (78%) and lateral jumps (68%).

The average number of jumps performed in a vertical, forward and lateral direction that had a turn or no turn in the air per game are shown in Figure 9. There was very little difference between the amount of forward jumps performed with a turn and no turn in the air (50%). However, during both vertical and lateral jumps, it was more common for no turn to be performed whilst jumping (65% and 75% respectively).

The average number of jumps landed on one or two legs performed with or without a turn in the air per game can be observed in Figure 10. For both jumps performed with a turn and without a turn in the air, approximately twice as many jumps are landed on one leg compared to two legs (64% and 67% respectively).

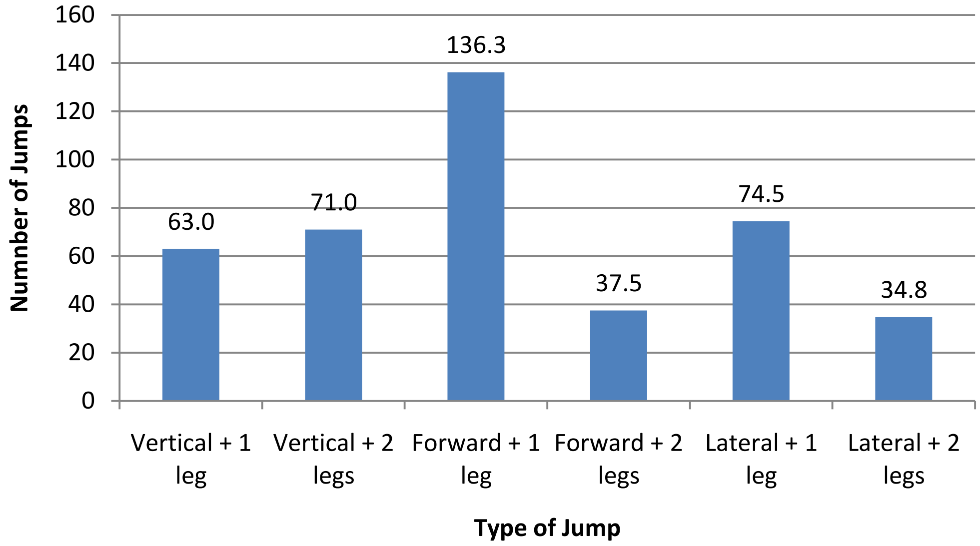


Figure 8: The average number of jumps landed unilaterally and bilaterally in each of the three jump directions

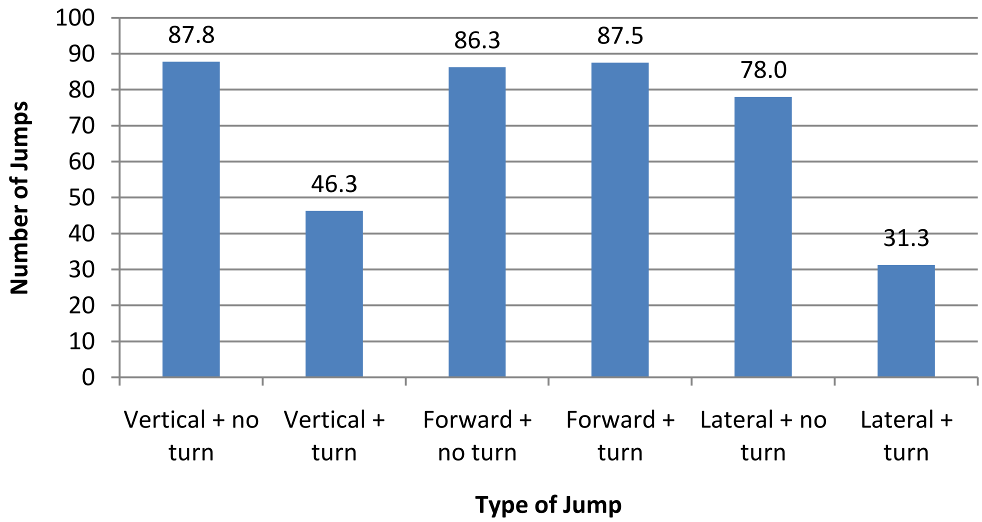


Figure 9: The average number of jumps performed in a vertical, forward and lateral direction with a turn or no-turn in the air per game

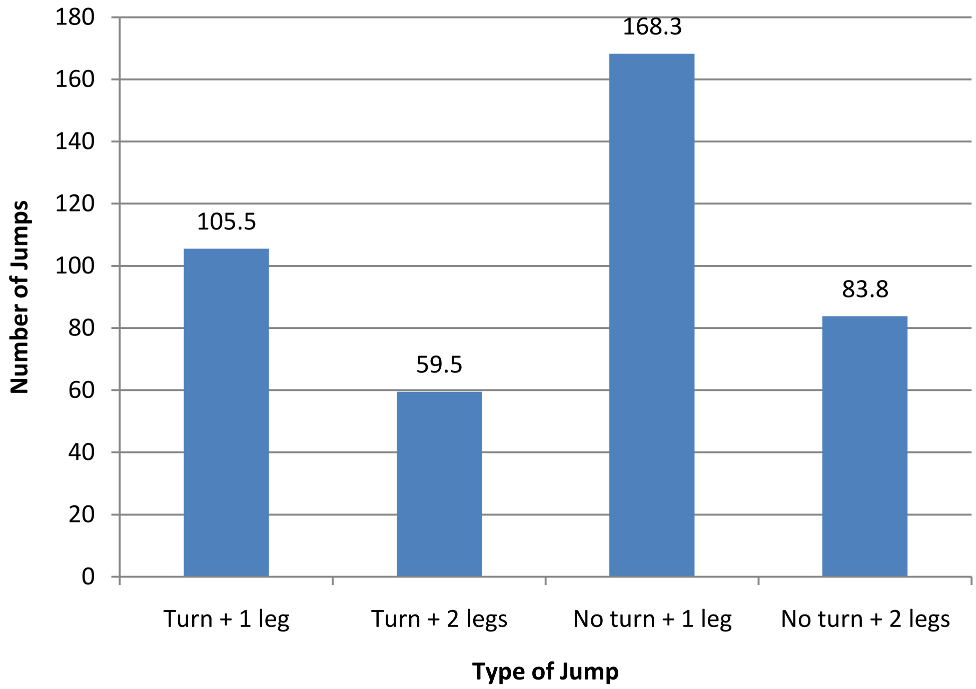


Figure 10: The average number of jumps landed on one or two legs performed with or without a turn in the air per game

Discussion

This study is the first to document the frequency of different types of jump landings in elite netball. Generally, of the three jump directions, forward jumps were performed most frequently by the mid court players (43%-51%) and vertical jumps were performed most frequently by end court players (45%-67%). However this was not the case for GA for whom forward jumps (49%) occurred most often. On the whole this reinforces the generally accepted notion that the ball is contested more aerially in the end courts but travels more horizontally and at chest height in the mid court. The difference between GA and GD in this regards cannot be attributed to the equivalent court area size and shape occupied but the two positions but instead likely within the difference between the roles. GA is often required to surge at speed from the mid-court into the shooting circle and so a high number of forward jumps are perhaps not surprising. Attacking play in netball is performed at higher velocities than defensive play (Davidson & Trewartha,

2008) and since forward jumps were more common among the attacking positions it may be the case that forward jumps are a characteristic of high speed attacking play.

Lateral jumps were the least favoured jump direction for all players except C and WA. Given that the ball is usually fed into the mid court by passing into space and at chest height, it is not surprising that these positions performed more lateral jumps than vertical jumps. Lateral jumps may be an effective means of innervating court space at speed to receive and intercept passes. As such, more lateral jumps were performed by GA (23%) and GS (24%) compared to GD (17%) and GK (12%). Since there was a trend for the attacking positions to perform a greater relative amount of lateral jumps, it may be the case that lateral movement, like forward movement is a characteristic of attacking rather than defensive play. We expected that lateral jumps would have been used more by defensive players to intercept passes but this was not supported by the data. It is important to highlight that the current research may not be generalizable to other populations and it may be that the defensive players studied chose not to perform lateral jumps because of individual deficiencies in movement or movement preferences. Lateral jumps may still be relevent for defensive positions and strength and conditioning professionals should aim to develop this movement ability in these player positions and assess if it carries over to game play.

Approximately twice as many jumps were landed unilaterally compared to bilaterally for all player positions except for GK. In general, vertical jumps were associated with two footed landings and since GK performed mostly vertical jumps the high number of two footed landings was not surprising. Unilateral jump landings appear to be a feature of forward and lateral jumps. This may be due to high horizontal velocities in these jumps which make bilateral landings a less efficient strategy requiring the absorption of greater landing forces and slowing of play. In comparison, vertical jumps are often likely performed from static stance or at low horizontal movement velocities and so bilateral landings may be preferable. Bilateral landings are more stable due to the larger base of support and greater musculature involved. This may be particularly useful in the shooting circle, where holding court position under the net is advantageous.

WA was the only position that twisted in the air more often than not. The mid court players and GA had less of a disparity between the amount of jumps performed with a twist and without. This highlights the more dynamic nature of these positions and the requirement for these players to have a ability to perform these movements. It may be the case that developing the remaining end court players' athleticism and capacity for rotation would lead to a greater number of these types of jumps. The player positions that performed the most second jumps or dynamic changes of direction immediately after landing an initial jump were WA (40%), GA (35%), and C (31%). Furthermore it is likely that this type of movement is a function of attacking play since GS (23%), GA (35%) and WA (40%) demonstrated a higher frequency of this type of movement than WD (25%), GD (16%), and GK (8%). Perhaps developing the eccentric strength and repeated jump ability of the athlete may lead to a greater number of these types of jumps. For both vertical and lateral jumps a greater number were performed without a turn in the air. In contrast, turning in the air and not-turning were equally common in forward jump. Turns in the air did not appear to affect whether a jump was landed on one or two legs.

Conclusion and practical applications

The findings of the current study may aid strength and conditioning professionals and netball coaches in the development of conditioning strategies and assessment batteries for both injury prevention and performance enhancement. The current study highlights differences in the frequencies of types of jumps between player positions. Implementing physical training programmes related to the frequencies of different movements per player position (see Table 4) may be an effective strategy for preparing athletes to handle the specific demands of their position. Prescribing resistance training and plyometric exercises based on the demands of each position may help prepare the athlete for the specific demands of their role and facilitate optimal performance.

Table 4: Jump landing requirements for each player position.

Position	Major Jump Direction	Jumps per Minute	Major Landing Style	Requirement for Turns in the Air	Requirement for 2nd Jump on Landing
GS	Vertical	0.9	Uni-lateral	Low	Moderate
GA	Forward	1.2	Uni-lateral	High	High
WA	Forward / Lateral	1.4	Uni-lateral	High	High
C	Forward / Lateral	1.4	Uni-lateral	High	High
WD	Forward	0.7	Uni-lateral	Moderate	Moderate
GD	Vertical / Forward	0.8	Uni-lateral	Moderate	Low
GK	Vertical	0.6	Bi-lateral	Low	Low

It is likely that the frequencies of jump landings observed are a characteristic of the specific population studied and caution should be made when generalising the findings to different groups. Furthermore, the jump strategies observed may be a reflection of the style of play, and the abilities or deficiencies of the athletes involved rather than what optimal netball performance involves. For example athletes may have preferred to perform more forward jumps compared to lateral jumps because they were unable to perform jumps in a lateral direction or that the coach had instructed them to do so. In these instances it is up to the strength and conditioning professional and netball coach to decide if the movements observed represent the type of athlete that is most effective and implement appropriate training strategies. When making programming decisions it may be more important to look at the type of jumps that are not being performed. For example, for all player positions less than 40% of all jump landings were followed by a second jump or change of direction. The coach may decide that this figure is too low and indicative of a slow style of play. The strength and conditioning professional could instigate a training phase focusing on developing multiple jump ability and by performing a similar movement frequency analysis of game play at the end of the phase determine if this carried over to performance. At present there is no research that the authors are aware of which has studied if developing one type of movement pattern in training will lead to its use in game play.

Further research is required to fully examine the movement patterns in netball and could include information on the intensities of jumps, the frequency of different movement patterns such as the squat, lunge, and twist as well as the variation in individual movement strategies used to complete the same task.

Chapter Four
The Reliability of a Netball Specific Dynamic Balance Assessment

Chapter 4 – The Reliability of a Netball Specific Dynamic Balance Assessment

Introduction

Netball is a sport that involves explosive jumps, high intensity landings and quick changes of direction and the injury rates in netball are amongst the highest of all sports (Fong et al., 2007). The majority of these injuries occur in the lower limbs (66%) with 26% at the ankle and 18% at the knee (McManus et al., 2006). Injury mechanisms are thought to involve abrupt decelerations, which may be caused by the two step rule, twisting on jump landings, quick changes of direction, cutting and jumping (Otago, 2004; Powell & Barber-Foss, 2000). In terms of minimising the effect of these injury mechanisms, balance is one component thought important because it can affect the execution and outcome of these movement patterns, and contribute to injury mechanisms (Wikstrom et al., 2008).

Balance is the ability to control the body's centre of mass over its base of support (Danis et al., 1998; Pollock et al., 2000) and has been correlated to injury (Hrysomallis, 2007; Murphy et al., 2003), muscular strength and power (Myer et al., 2006; Willson et al., 2006; Yaggie & Campbell, 2006). It makes sense that balance assessment should be part of the strength and conditioning coach's assessment battery, as the prevention of injury, improvement of movement efficiency and athletic performance are a major focus of programming. However, common strength and conditioning assessments usually include measures of strength, power, speed, endurance and anthropometry whilst assessments of balance and sport specific movement patterns are less common, possibly because they are more difficult to measure and interpret.

Previously balance has been assessed by a variety of non-specific, low intensity stances (Bernier & Perrin, 1998; Eils & Rosenbaum, 2001; Hoffman &

Payne, 1995; Soderman et al., 2000; Verhagen et al., 2005; Willems, Witrwouw, Delbaere, Maheui et al., 2005; Willems, Witrwouw, Delbaere, Philipaerts et al., 2005), using unstable surfaces (Atwater et al., 1990; Bernier & Perrin, 1998; Emery et al., 2005; Hrysomallis et al., 2007; Kollmitzer et al., 2000; McHugh et al., 2006; Soderman et al., 2000; Willems, Witrwouw, Delbaere, Maheui et al., 2005; Yaggie & Campbell, 2006) , and eyes closed conditions (Atwater et al., 1990; Bernier & Perrin, 1998; Beynnon et al., 2001; Emery et al., 2005; Verhagen et al., 2005; Watson, 1999; Willems, Witrwouw, Delbaere, Maheui et al., 2005). Several researchers have suggested that these tests, which are relatively static, are not sufficiently difficult and may fail to reveal deficiencies in balance relevant to sports performance and/or the skill level of the athletes being tested (Hrysomallis et al., 2006; Riemann et al., 1999; Wikstrom et al., 2005).

Dynamic assessments of balance are less common (C. Brown et al., 2004; Myer et al., 2006; Riemann et al., 1999; Ross & Guskiewicz, 2003; Wikstrom et al., 2005) but may be more relevant to sporting performance and injury because of the movement patterns involved (Otago, 1983; Powell & Barber-Foss, 2000). Typically these assessments involve jumps and hops and measure centre of pressure changes using force plate technology which summate all forces generated by the body and therefore do not provide information about individual body segments. This is particularly important to trainers as it is not possible to develop interventions aimed at correcting deficiencies within particular body segments without that information. Since force plate systems do not indicate the postural control mechanism involved in balance corrections there use in diagnosing the origin of a deficiency is limited (Palmieri et al., 2002). Palmieri (2002) also highlighted that patients with different diagnoses can have similar postural impairments resulting in similar deviations in the centre of pressure. Conversely patients with the same pathologies might display different changes in centre of pressure. Despite of its limitations centre of pressure may be appropriate for screening static balance ability where balance corrections most often take place at the ankle and involve small corrections. Another shortfall for strength and conditioning professionals is the availability and cost of force plate systems. Furthermore there is a lack of information on the movements that occur in sport and few studies have performed time motion analysis before constructing a movement assessment battery.

A preparatory time motion analysis in the current study was undertaken to determine the different types of jump landings in netball. The results from this investigation were used to determine the dynamic balance assessments. Jump landings were chosen for analysis because previous authors have highlighted that jump landings and twisting on jump landings are the major cause of injury in netball (Otago, 2004; Powell & Barber-Foss, 2000). The major findings of this preliminary analysis were: 1) forward jumps were the most prevelent (42%) followed by vertical jumps (32%) and lateral jumps (26%); 2) unilateral jump landings were most common compared to bilateral landings (67% vs 33%) and more jumps were performed without a turn in the air compared to with a turn ain the air (60% vs 40%); 3) only 28% of jump landings were followed immediately by a second jump. Previous assessments have tended to assess dynamic balance using only forward jumps (C. Brown et al., 2004; Hart et al., 2008; Myer et al., 2006; Ross & Guskiewicz, 2003; Wikstrom et al., 2005) however to be specific to netball a dynamic balance assessment should include jumps with horizontal, vertical and lateral components, focusing on unilateral landings and include jumps with a turn in the air.

Another limitation of the aforementioned dynamic assessments is that they fail to give an indication of segmental orientation which has been shown to be important for injury and functional human movement. For example, increased knee valgus and varum, an increased Q angle, and increased tibial varum, particularly under load have all been identified as risk factors for lower limb injury (Boden et al., 2000; Hewett et al., 2005, 2006; Murphy et al., 2003). Dynamic assessments have also tended to analyse variables more appropriate for static assessment such as single measures at a specific point of a movement rather than focusing on variability throughout the movement (Noyes et al., 2005; Willson et al., 2006). It is possible that videographic assessments which measure segmental orientation may be useful in balance assessment as they can give an indication of movement strategies and the origin of a deficiency, which would add prognostic value to the assessment battery and aid in programming (Augustsson et al., 2006; Derrick, 2004; Hart et al., 2008; Noyes et al., 2005; Willson et al., 2006). A field test that makes up for previously described shortcomings in that it is easy to administer, inexpensive, replicates sport specific movement patterns, suitable for teams and individual athletes, gives an indication of the origin of any deficiency, measures variables appropriate for dynamic balance, and adds both diagnostic and prognostic value to athlete assessment, would be of use to the strength and conditioning professional, clinician and sports coach.

Currently no such test exists and in New Zealand the assessment of injury risk in netball players of all age groups is limited to muscle balance assessments and questionnaires detailing injury history, medical history, current physical activity, and footwear (ACC & NetballSmart, 2009; NetballNZ, 2009). The addition of a sport specific balance assessment may assist in identifying deficiencies that are not highlighted using current screening procedures. In order for such a test to provide meaningful information, it is essential that the data collected under these conditions is reliable and valid. The current study aims to examine the inter-session and intra-session reliability of a videographic assessment of dynamic balance which utilises functional netball specific movement patterns.

Methodology

Experimental approach to the problem

This study used a repeated measures design to determine the reliability of a new test of balance which included a single leg squat, a single leg forward jump and a single leg jump with a turn in the air. During each trial the maximum displacements of the trunk, hip (landing leg) and knee (landing leg) were recorded relative to the line of gravity. The line of gravity was determined as the vertical line which originated from the base of support at approximately the head of the talus (see Figure 13). From these measures the following dependent variables were calculated for each of the body sites: total (medio-lateral) displacement range, the point of maximal lateral displacement, the point of maximal medial displacement, and the mid-point of the range. Frontal plane measurements were chosen for analysis as these have been highlighted as risk factors for injury (Hewett et al., 2005, 2006) and have been used previously to measure landing kinematics related to this risk (Ford et al., 2003; Hart et al., 2008; Russell et al., 2006). Furthermore frontal plane 2D analysis has been validated against 3D measurement as an appropriate tool for assessing joint angles related to injury. The rational for the expression of joint position in relation to the line of gravity was based on the concept that balance is attained when body segments are stabilised over the base of support in upright stance. Maximum squat depth was also recorded for each trial. Results were compared between three trials within a session and between two testing sessions approximately one week apart. Subjects reported to the indoor sports facility for testing and the order of testing is summarised in Table 5.

Table 5: Order of testing

Warm up	• 10mins • Jogging, dynamic stretching, progressive jumps and sprints
Maximal vertical jump (bilateral)	• Vertec vertical jump tester • Best of three trials
Maximal horizontal jump (bilateral)	• Best of three trials
Single leg squat	• Three successful trials • Or best three trials of a maximum of six attempts
Forward jump (unilateral)	• Three successful trials • Or best three trials of a maximum of six attempts
Jump with a turn in the air (unilateral)	• Three successful trials • Or best three trials of a maximum of six attempts

Subjects

Fourteen female netball players (16.8 ± 2.4 years, 175.4 ± 5.0 cm, 67.4 ± 6.8 kg) volunteered to participate in this study, which was approved by the AUT University Ethics Committee. All subjects either represented the top high school team in the country or a leading regional centre. All subjects were currently involved in netball training and competition under high performance programmes. No subjects had a history of lower limb or head injury in the three months prior to testing.

Maximal vertical jump testing

Maximal vertical jump height was assessed using a Vertec vertical jump tester (Sports Imports, Columbus, OH). Prior to the start of the assessment, subjects were instructed to stand next to the Vertec and reach up and touch the highest vane possible (2.2 cm increments) with one hand while maintaining a double leg stance. This height was recorded as the subject's standing reach height. Subjects were then instructed to perform a maximum vertical jump using a countermovement jump technique and touch the highest vane possible with one hand. Each subject performed three trials and the best of the three trials were recorded. The maximal vertical jump was determined as the difference between the maximum height reached during the jump and the standing reach height. The maximal vertical jump was used as a baseline measure for the sport specific jumps detailed later in this section.

Maximal horizontal jump testing

A 50 cm strip of tape was placed on the floor which represented the start line. Subjects were required to start with their toes on the start line and were instructed to perform a maximal bilateral forward jump. Each subject performed three trials and the best of the three trials was recorded. The maximal horizontal jump was determined as the distance between the start line and the closest heel of the subject to the start line. The maximal horizontal jump was used as a baseline measure for the sport specific jumps detailed later in this section.

Balance Assessments

For the three balance assessments subjects were instructed to wear fitted, dark shorts and V-neck sports tops as well as low cut gym shoes. Reflective markers were placed at the most proximal point of the sternum, the mid-point of the patella, and the anterior superior iliac spines (ASIS). The investigator demonstrated each movement, and subjects were given three trials to practice. The subjects were not provided with any verbal instructions regarding how to land or jump, except that they must attempt to stabilize upon landing and hold this position for five seconds. The decision not to standardise the jump or landing procedure was made so as to better reflect the subjects' individual movement strategies. A Sony Mini DV Camcorder sampling at 25 Hz placed on a camera tripod was used for recording the movements. The camera was positioned approximately 100 cm high and 10 m in front of the testing area so as to record movement in the frontal plane. The camera was positioned on an axis directly perpendicular to the landing mark and at a sufficient distance to minimise perspective and parallax error. A black back-drop was positioned behind the performer to increase the clarity of the reflective markers when viewed on the video.

For the three balance assessments subjects were given a maximum of six trials to complete three successful trials. A trial was deemed unsuccessful if the subject contacted the ground with the free limb, performed a hop with the stance limb, failed to take off and/or land on the correct marked points (jump assessments only), failed to contact the required vane of the Vertec (jump assessments only), or failed to land / squat with the foot facing forward within 10^{o}. If three trials were completed successfully the subject moved onto the next test. If the subject could not perform three trials successfully the investigator selected the best three trials of the six for data analysis.

For each movement pattern subjects completed all their trials on one side of the body before testing the opposite side, which minimized the moving of equipment. One minutes rest was given to subjects between each trial to minimize fatigue. No instruction was given to subjects about which limb to test first but once the first trial was started the subject started each of the subsequent movements with the same limb.

Single leg squat

Subjects were instructed to stand on a single leg on a marked point in front of the camera and stabilize themselves. Once stable, subjects performed a single leg squat to a self selected depth. Upon reaching their self selected squat depth the subject returned to the fully upright position whilst still maintaining a single leg stance. The subject performed three repetitions of the pattern without the non-weight-bearing limb touching the ground.

Forward jump

The forward jump protocol involved a unilateral jump in a forward direction preceded by a step (see Figure 11). The protocol was adapted from previous researchers (C. Brown et al., 2004; Ross & Guskiewicz, 2003; Wikstrom et al., 2005). Subjects started in a standing position on a marked line 55 cm from the take off line. The take off line was positioned at a distance of 70% the subject's maximal horizontal jump from the landing point. Subjects were required to step forward on to the take off line and immediately perform a forward jump landing on the opposite limb to the take off leg. During the jump subjects were required to touch a vane of the Vertec which was placed at a position equivalent to 30% of the subject's vertical leap with the same arm as the landing leg (see Figure 11). The Vertec was positioned at 50% of the horizontal jump distance and on the same side of the body as the arm which was required to touch it. Each subject was instructed to stabilise on landing and remain still in a self selected position for five seconds. We decided to place a greater emphasis on horizontal jump distance compared to vertical because the movement frequency analysis found that horizontal jumps (42% of all jumps) were more common than vertical jumps (32% of all jumps) in elite netball.

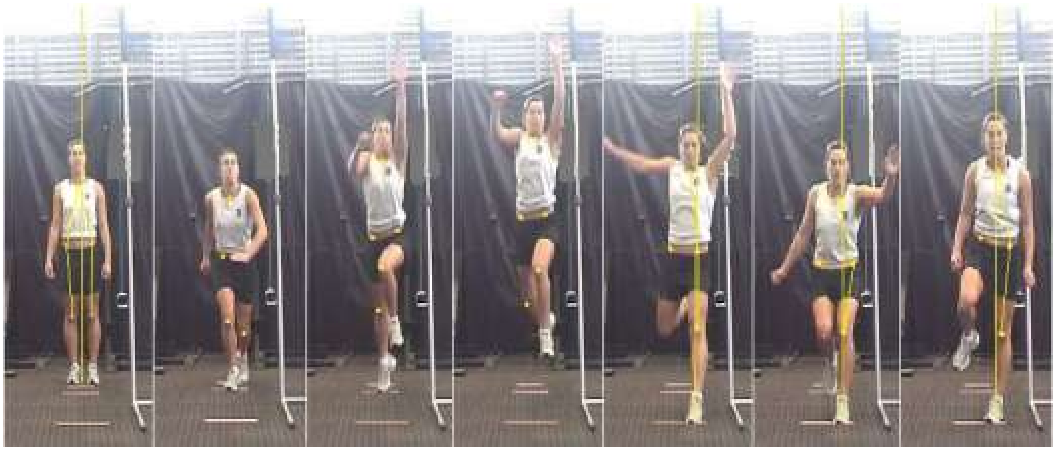


Figure 11: Forward jump movement sequence

Jump with a turn in the air

The jump with a turn in the air required a unilateral jump in a forward direction with landing at 90^{o} to the take off direction thus requiring the subject to control medio-lateral momentum (see Figure 12). The protocol was adapted from previous research (C. Brown et al., 2004; Ross & Guskiewicz, 2003; Wikstrom et al., 2005). Subjects started in a standing position on a line 55 cm from the take off line. The take off line was positioned at a distance of 70% the subject's maximal horizontal jump from a marked landing point at an angle of 90^{o}. Subjects were required to step forward on to the take off line and immediately perform a forward jump landing on the opposite limb (see Figure 12). During the jump subjects were required to touch a vane of the Vertec with the opposite arm as the take off leg. The Vertec was positioned at 50% of the distance to be jumped and on the same side of the body as the arm which was required to touch it at a height of 30% of the subject's vertical leap. Each subject was instructed to stabilise on landing and remain still in a self selected position for five seconds. We decided to include a turn in the air and have the subjects land laterally because a movement frequency analysis found that lateral jumps and jumps with turns in the air were an important part of netball game play (26% and 40% respectively).

Figure 12: Jump with a turn in the air movement sequence (right to left)

Data Analysis

The video data was analysed using siliconCoach Pro video analysis software (Version 6, Dunedin, NZ). A calibration procedure was performed by linking two known points on the screen which bisected the landing point. A vertical line was drawn representing the line of gravity (see Figure 13) through the base of support at approximately the head of the talus (Johnson, Leitl, & Waugh, 1980). The anatomical reference points were selected by clicking on each point at the point of maximal excursion from the line of gravity and were recorded in centimetres. Points recorded medially to the line of gravity were recorded as negative and points on the lateral side were recorded as a positive number. The total excursion of each anatomical reference point was calculated by measuring the distance between the maximal points of lateral and medial excursion. The midpoint of the sway was determined as the median value between the maximal lateral and medial displacements. The squat depth on landing was recorded for each of the three movements and was determined as the total distance between the ASIS at ground contact and the same mark at its deepest point. The procedure was repeated for both limbs. Maximal lateral displacement, maximal medial displacement, the displacement range and the midpoint of the range were calculated for each landmark. The depth of the squat on landing was also calculated.

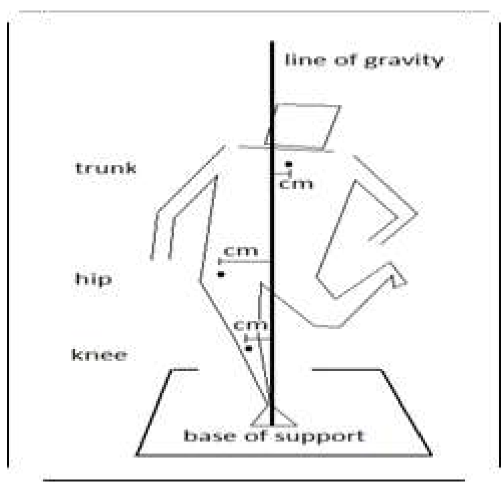


Figure 13: Representation of the method for calculating displacements

Statistical Analysis

The results were analysed with SPSS statistical software (Version: 15.0.1), a spreadsheet for calculating the standard error of the measurement (Hopkins, 2000) and a spreadsheet for calculating the clinical inference from a P value (Hopkins, 2007). Within trial data was compared using the standard error of measurement (SEM, or typical error) averaged across three trials as calculated by Hopkins (2000). The within trial typical errors (TE) from trial 1-2 and 2-3 were also calculated (Hopkins, 2000). Test-retest data was compared using the typical error (Hopkins, 2000), intraclass correlation coefficient (ICC), paired T-test and a qualitative inference based on a P value (Hopkins, 2007). Qualitative inferences on the differences between days were made by converting values to descriptors (Hopkins, 2002) according to the following schema: 1%, most unlikely; 1-5%, very unlikely; 5-25% unlikely; 25-75%, possibly; 75-95%, likely; 95-99% very likely; >99% almost certainly.

Results

The mean ICC values for the four variables (total medio-lateral displacement range, the point of maximal lateral displacement, the point of maximal medial displacement, and the mid-point of the range) for each body segment (trunk, hip and knee), during each movement were 0.62 – 0.81 indicating 'moderate' (ICC > 0.61) test-retest reliability (Shrout, 1998). Typical errors for each movement pattern averaged across all body segments for the single leg squat, forward jump and forward jump with a turn were 1.1 cm (ICC = 0.71), 1.8 cm (ICC =0.72) and 2.6 cm (ICC = 0.62) respectively indicating 'moderate' reliability.

The intra-session and inter-session reliability measures for the maximal lateral side displacements of the trunk, hip and knee for the three movements (single leg squat, forward jump, lateral jump) are shown in Error! Reference source not found. The typical error of the movements ranged from 0.7 cm – 10.0 cm (3.6 ± 2.4 cm). The ICCs of the movements ranged from 0.50 – 0.88

(0.64 ± 0.16). The smallest typical errors were associated with the single leg squat (1.4 ± 0.6 cm), followed by forward jump (3.3 ± 1.6 cm) and jump with a turn (6.1 ± 1.8 cm). The highest ICCs for each body segment were associated with the hip (0.71 ± 0.17), followed by the trunk (0.67 ± 0.12) and knee (0.66 ± 0.12). In contrast, the smallest typical errors (TEs) for each body segment were associated with the knee (1.51 ± 0.90 cm), followed by the hip (1.78 ± 1.01 cm) and the trunk (2.58 ±1.35 cm). However, when the typical errors were expressed as a percentage of the total displacement at each body segment the least variability was associated with the hip (13.9%), followed by the knee (14.5%) and the trunk (15.6%). Averaged across all movements the left side of the body demonstrated higher variability (ICC = 0.62 ± 0.12; TE = 2.16 ± 1.13 cm) compared to the right side (0.74 ± 0.12; TE = 1.76 ± 1.17 cm). The qualitative inference on the difference indicated that it was *most unlikely* that there was a difference between the majority of the mean lateral displacements between days indicating a consistency in the variability of measurement between testing occasions.

Within session and between session reliability measures for the maximal medial side displacements of the trunk, hip and knee for the three movements (single leg squat, forward jump, jump with a turn) are shown in Table 7. The typical error of maximum medial side displacement ranged from 0.8 cm to 7.6 cm (2.6 ± 1.4 cm). The smallest typical errors were associated with the single leg squat (1.7 ± 0.6 cm), followed by the jump with a turn (2.3 ± 0.4 cm) and the forward jump (3.6 ± 1.7 cm). The highest ICCs for each body segment were associated with the hip (0.81 ± 0.08), followed by the knee (0.77 ± 0.09) and the trunk (0.62 ± 0.14). In contrast, the smallest typical errors were associated with the knee (1.55 ± 0.29), followed by the hip (1.59 ± 0.76) and the trunk (2.24 ± 0.66). However when the typical errors were expressed as a percentage of the total sway at each body segment the least variability was associated with the hip (12.4%), followed by the trunk (13.5%) and the knee (14.9%). Averaged across all movements the left and right side of the body demonstrated similar variability (ICC = 0.72 ± 0.15 vs 0.75 ± 0.12; TE = 1.81 ± 0.63 cm vs 1.78 ± 0.71 cm respectively). The qualitative inference on the difference indicated that it was *most unlikely* that there was a difference between the majority of the mean medial displacements between sessions. The mean medial side displacement and the variability were different for each movement.

The intra-session and inter-session reliability measures for the total excursion of the trunk, hip and knee for the three movements (single leg squat, forward jump, jump with a turn) are shown in Table 8. The typical errors for the movements were 0.8 cm – 8.9 cm (3.6 ± 1.9 cm). The smallest typical errors were associated with the single leg squat (1.8 ± 0.8 cm), followed by forward jump (3.3 ± 1.1 cm) and jump with a turn (5.5 ± 1.6 cm). The means, standard deviations and typical errors were similar between days. The highest ICCs for each body segment were associated with the knee (0.77 ± 0.05), followed by the trunk (0.69 ± 0.19) and the hip (0.68 ± 0.17). In contrast the smallest typical errors were associated with the knee (1.60 ± 0.36 cm), followed by the hip (1.77 ± 1.08 cm) and the trunk (2.79 ± 1.61 cm). However when the typical errors were expressed as a percentage of the total sway at each body segment the least variability was associated with the hip (13.8%), followed by the knee (15.3%) and the trunk (16.8%). There was little difference between left and right lower limbs averaged across all movements (ICC = 0.73 ± 0.15 vs 0.70 ± .15; TE = 1.90 ± 0.82 cm vs 2.21 ± 1.53 cm respectively). The qualitative inference indicated that it was *most unlikely* that there was a difference in the total excursions between days. As expected, the maximum medio-lateral displacements were greater for the jump with a turn than the forward jump and single leg squat.

The intra-session and inter-session reliability measures for the midpoint of medial-lateral displacement of the trunk, hip and knee for the three movements (single leg squat, forward jump, jump with a turn) is shown in Table 9. The typical error for the movements ranged from 0.8 cm – 7.6 cm (2.6 ± 1.3 cm). The smallest typical errors were associated with the single leg squat (1.7 ± 0.8 cm), followed by jump with a turn (3.6 ± 1.7 cm) and forward jump (2.3 ± 0.4 cm). The highest ICCs for each body segment were associated with the hip (0.70 ± 0.17), followed by the trunk (0.65 ± 0.08) and the knee (0.63 ± 0.20). The smallest typical errors were associated with the knee (1.58 ± 0.72 cm), followed by the hip (1.78 ± 1.01 cm) and the trunk (1.96 ± 0.74 cm). However when the typical errors were expressed as a percentage of the total sway at each body segment the least variability was associated with the trunk (11.8%), followed by the hip (13.9%), and the knee (15.2%). Averaged across all movements the right side of the body demonstrated higher variability (ICC = 0.58 ± 0.15; TE = 1.91 ± 0.91 cm) compared to the left side (ICC = 0.74 ± 0.11; TE = 1.63 ± 0.70 cm). The qualitative inference on the difference indicated that it was *most unlikely* that there was a difference in the majority of mean medial displacements between days.

The intra-session and inter-session reliability measures for the depth of the squat on landing for the three movements (single leg squat, forward jump, jump with a turn) is shown in Table 10. The typical error for the movements ranged from 1.2 cm – 5.4 cm (2.5 ± 1.1 cm). The smallest typical errors were associated with the single leg squat (1.6 ± 0.3 cm), followed by forward jump (2.5 ± 0.2 cm) and jump with a turn (3.3 ± 1.4 cm). Averaged across all movements the right and left side of the body demonstrated equal variability (ICC = 0.90). The qualitative inference on the difference indicated that differences in the squat depth between sessions were *most unlikely* (Tables 6-9).

Table 6: Within test and test retest reliability data for the point of maximum lateral displacement

Variable				Within day reliability				Between day reliability		
				Day 1		Day 2				
				Mean ± SD	Typical error; ± 90% CI	Mean ± SD	Typical error; ± 90% CI	Typical error; ± 90% CI	ICC ± 90% CI	Qualitative Inference on Difference
Point of maximal lateral displacement	Single leg squat	Right	Trunk	6.6 ± 2.2	2.77; ±1.00	6.0 ± 1.7	2.11; ±0.77	1.16; ±0.42	0.82; ±0.19	Most Unlikely
			Hip	11.9 ± 0.5	0.66; ±0.24	12.0 ± 0.6	0.78; ±0.28	0.74; ±0.27	0.88; ±0.13	Most Unlikely
			Knee	4.6 ± 1.0	0.99; ±0.36	4.7 ± 1.4	1.64; ±0.60	0.73; ±0.27	0.61; ±0.44	Most Unlikely
		Left	Trunk	6.0 ± 1.8	1.80; ±0.65	5.9 ± 1.4	1.61; ±0.58	1.10; ±0.40	0.80; ±0.22	Most Unlikely
			Hip	11.6 ± 0.8	0.96; ±0.35	11.9 ± 0.8	0.88; ±0.32	0.89; ±0.48	0.84; ±0.18	Most Unlikely
			Knee	5.5 ± 1.0	1.07; ±0.39	5.2 ± 1.4	1.52; ±0.55	0.79; ±0.29	0.56; ±0.47	Most Unlikely
	Forward jump	Right	Trunk	6.9 ± 4.8	5.34; ±1.93	7.5 ± 5.4	6.98; ±2.53	2.82; ±1.02	0.65; ±0.39	Most Unlikely
			Hip	11.0 ± 1.7	2.12; ±0.77	11.7 ± 1.5	1.95; ±0.71	1.70; ±0.62	0.63; ±0.39	Most Unlikely
			Knee	3.7 ± 2.1	2.57; ±0.93	4.5 ± 1.9	3.03; ±1.15	1.14; ±0.42	0.77; ±0.25	Most Unlikely
		Left	Trunk	6.9 ± 4.6	4.64; ±1.68	6.9 ± 3.6	3.90; ±1.42	2.26; ±0.82	0.67; ±0.39	Most Unlikely
			Hip	11.1 ± 1.5	2.49; ±0.90	11.2 ± 1.5	1.78; ±0.65	1.99; ±0.72	0.54; ±0.54	Most Unlikely
			Knee	5.6 ± 2.1	2.77; ±1.00	5.5 ± 1.8	2.08; ±0.75	1.92; ±0.70	0.58; ±0.50	Most Unlikely
	Jump with a turn	Right	Trunk	8.1 ± 5.3	6.18; ±2.24	6.6 ± 7.1	10.02; ±3.62	4.38; ±1.59	0.58; ±0.46	Very Unlikely
			Hip	9.9 ± 3.9	7.01; ±2.54	9.6 ± 4.5	7.32; ±2.65	1.79; ±0.65	0.84; ±0.17	Most Unlikely
			Knee	3.2 ± 3.5	4.58; ±1.66	3.2 ± 3.7	5.29; ±1.91	1.35; ±0.49	0.84; ±0.18	Most Unlikely
		Left	Trunk	7.5 ± 7.5	8.30; ±3.00	7.6 ± 5.2	6.17; ±2.23	3.78; ±1.37	0.50; ±0.59	Most Unlikely
			Hip	11.1 ± 3.9	4.83; ±1.75	9.6 ± 4.5	3.83; ±1.39	3.57; ±1.29	0.51; ±0.56	Unlikely
			Knee	5.9 ± 4.4	5.73; ±2.07	4.7 ± 3.3	4.48; ±1.62	3.12; ±0.63	0.58; ±0.45	Most Unlikely

Table 7: Within test and test re-test reliability data for the point of maximum medial displacement

Variable				Within day reliability				Between day reliability		
				Day 1		Day 2				
				Mean ± SD	Typical error; ± 90% CI	Mean ± SD	Typical error; ± 90% CI	Typical error; ± 90% CI	ICC ± 90% CI	Qualitative Inference on Difference
Point of maximal medial displacement	Single leg squat	Right	Trunk	0.4 ± 2.2	3.63; ±1.32	0.9 ± 1.3	1.61; ±0.59	1.60; ±0.58	0.62; ±0.41	Most Unlikely
			Hip	9.7 ± 1.0	1.25; ±0.45	10.2 ± 0.6	0.79; ±0.29	0.82; ±0.30	0.80; ±0.21	Most Unlikely
			Knee	-2.7 ± 1.2	1.19; ±0.43	-1.8 ± 1.5	2.48; ±0.90	1.95; ±0.71	0.68; ±0.34	Most Unlikely
		Left	Trunk	0.4 ± 1.3	1.40; ±0.51	0.4 ± 1.3	2.79; ±1.01	1.35; ±0.49	0.76; ±0.26	Most Unlikely
			Hip	9.0 ± 0.9	0.95; ±0.35	9.6 ± 1.0	1.16; ±0.42	0.89; ±0.32	0.80; ±0.22	Most Unlikely
			Knee	-1.1 ± 1.3	1.63; ±0.59	-1.4 ± 1.3	1.71; ±0.62	1.43; ±0.52	0.64; ±0.08	Most Unlikely
	Forward jump	Right	Trunk	-2.6 ± 5.5	7.60; ±2.75	-2.6 ± 5.5	5.03; ±1.82	3.04; ±1.10	0.72; ±0.30	Most Unlikely
			Hip	5.2 ± 2.5	3.87; ±1.40	6.0 ± 2.5	3.34; ±1.21	1.40; ±0.51	0.90; ±0.11	Most Unlikely
			Knee	-3.3 ± 2.6	3.98; ±1.44	-2.4 ± 2.1	2.36; ±0.85	1.18; ±0.43	0.80; ±0.22	Most Unlikely
		Left	Trunk	-1.8 ± 3.8	3.83; ±1.39	-1.5 ± 3.5	5.02; ±1.82	2.15; ±0.78	0.69; ±0.36	Most Unlikely
			Hip	6.2 ± 1.9	2.22; ±0.80	6.5 ± 1.7	1.91; ±0.69	1.54; ±0.65	0.67; ±0.37	Most Unlikely
			Knee	-1.1 ± 1.6	1.80; ±0.65	-1.3 ± 2.0	2.49; ±0.90	1.66; ±0.60	0.81; ±1.25	Most Unlikely
	Jump with a turn	Right	Trunk	-28.0 ± 2.4	2.79; ±1.01	-27.5 ± 2.6	2.98; ±1.08	2.65; ±0.96	0.54; ±0.53	Most Unlikely
			Hip	-20.8 ± 1.9	2.33; ±0.85	-20.5 ± 1.8	2.34; ±0.85	2.03; ±0.74	0.83; ±0.19	Most Unlikely
			Knee	-13.7 ± 1.5	1.74; ±0.63	-13.9 ± 1.5	1.75; ±0.64	1.34; ±0.49	0.84; ±0.18	Most Unlikely
		Left	Trunk	-27.9 ± 2.6	2.87; ±1.04	-27.9 ± 2.4	2.55; ±0.93	2.64; ±0.96	0.38; ±0.69	Most Unlikely
			Hip	-20.5 ± 2.5	2.65; ±0.96	-20.5 ± 2.1	2.09; ±0.76	2.83; ±1.03	0.86; ±0.16	Most Unlikely
			Knee	-12.4 ± 1.8	2.08; ±0.75	-12.7 ± 1.6	2.00; ±0.72	1.76; ±0.64	0.86; ±0.16	Most Unlikely

Table 8: Within test and test re-test reliability data for total displacement range

Variable				Within day reliability				Between day reliability		
				Day 1		Day 2				
				Mean ± SD	Typical error; ± 90% CI	Mean ± SD	Typical error; ± 90% CI	Typical error; ± 90% CI	ICC ± 90% CI	Qualitative Inference on Difference
Total displacement range	Single leg squat	Right	Trunk	6.2 ± 2.5	3.08; ±1.12	5.1 ± 1.8	2.03; ±0.73	1.77; ±0.64	0.53; ±0.52	Most Unlikely
			Hip	2.2 ± 1.0	1.03; ±0.38	1.9 ± 0.7	0.76; ±0.27	0.57; ±0.21	0.57; ±0.48	Most Unlikely
			Knee	7.3 ± 1.4	1.44; ±0.52	6.5 ± 1.3	1.60; ±0.58	1.63; ±0.59	0.77; ±0.25	Most Unlikely
		Left	Trunk	5.6 ± 2.0	1.97; ±0.71	6.0 ± 2.8	3.48; ±1.26	1.17; ±0.43	0.92; ±0.09	Most Unlikely
			Hip	2.6 ± 1.0	0.98; ±0.36	2.3 ± 0.9	1.21; ±0.44	0.66; ±0.24	0.80; ±0.22	Most Unlikely
			Knee	6.6 ± 1.6	1.90; ±0.69	6.6 ± 1.8	2.16; ±0.79	1.47; ±0.53	0.70; ±0.33	Most Unlikely
	Forward jump	Right	Trunk	9.5 ± 4.7	5.42; ±1.96	9.1 ± 4.4	4.87; ±1.76	3.01; ±1.09	0.79; ±0.23	Most Unlikely
			Hip	5.8 ± 2.5	3.58; ±1.30	5.6 ± 2.3	2.83; ±1.03	1.47; ±0.54	0.73; ±0.31	Most Unlikely
			Knee	7.0 ± 2.4	3.34; ±1.21	6.9 ± 1.8	2.44; ±0.88	1.18; ±0.43	0.83; ±0.19	Most Unlikely
		Left	Trunk	8.7 ± 3.9	3.85; ±2.39	8.3 ± 3.4	4.06; ±1.47	2.08; ±0.76	0.64; ±0.39	Most Unlikely
			Hip	4.9 ± 1.8	2.50; ±0.91	4.7 ± 1.7	1.94; ±0.70	1.93; ±0.70	0.39; ±0.67	Most Unlikely
			Knee	6.7 ± 1.5	2.48; ±0.90	6.7 ± 2.2	2.75; ±1.00	1.39; ±0.50	0.71; ±0.22	Most Unlikely
	Jump with a turn	Right	Trunk	36.1 ± 4.5	5.04; ±1.83	34.1 ± 6.6	8.94; ±3.23	5.75; ±2.08	0.43; ±0.63	Unlikely
			Hip	30.2 ± 4.7	5.80; ±2.10	31.3 ± 3.4	6.98; ±2.53	2.83; ±1.02	0.84; ±0.18	Very Unlikely
			Knee	17.0 ± 3.4	4.19; ±1.52	17.1 ± 3.9	4.89; ±1.77	1.66; ±0.60	0.82; ±0.20	Most Unlikely
		Left	Trunk	35.3 ± 6.5	7.11; ±2.58	35.5 ± 5.6	6.48; ±2.34	2.97; ±1.08	0.82; ±0.20	Most Unlikely
			Hip	31.7 ± 3.6	4.01; ±1.45	31.3 ± 3.4	3.82; ±1.38	3.16; ±1.14	0.76; ±0.27	Most Unlikely
			Knee	18.3 ± 3.7	4.77; ±1.72	17.4 ± 3.3	4.10; ±1.49	2.24; ±0.81	0.79; ±0.23	Most Unlikely

Table 9: Within test and test re-test reliability data for the midpoint of the displacement range

		Variable		Within day reliability: Day 1 Mean ± SD	Day 1 Typical error; ± 90% CI	Day 2 Mean ± SD	Day 2 Typical error; ± 90% CI	Between day reliability: Typical error; ± 90% CI	ICC ± 90% CI	Qualitative Inference on Difference
Mid-point of the displacement range	Single leg squat	Right	Trunk	3.5 ± 1.9	2.84 ±1.03	3.5 ± 1.3	1.56; ±0.57	1.09; ±0.39	0.79; ±0.23	Most Unlikely
			Hip	10.8 ± 0.6	0.86 ±0.32	11.1 ± 0.6	0.69; ±0.25	0.74; ±0.27	0.88; ±0.13	Most Unlikely
			Knee	0.9 ± 0.8	0.83 ±0.30	1.4 ± 1.4	1.97; ±0.71	2.61; ±0.94	0.59; ±0.67	Most Unlikely
		Left	Trunk	3.2 ± 1.3	1.31 ±0.48	2.9 ± 1.2	1.46; ±0.53	1.10; ±0.40	0.57; ±0.47	Most Unlikely
			Hip	10.3 ± 0.7	0.82 ±0.30	10.7 ± 0.8	0.85; ±0.31	0.89; ±0.32	0.83; ±0.19	Most Unlikely
			Knee	2.2 ± 0.9	1.01 ±0.37	1.9 ± 1.0	1.20; ±0.44	0.89; ±0.32	0.55; ±0.50	Most Unlikely
	Forward jump	Right	Trunk	2.1 ± 4.9	5.87 ±2.12	2.9 ± 4.6	5.58; ±2.02	2.51; ±0.91	0.61; ±0.43	Most Unlikely
			Hip	8.1 ± 1.9	2.55 ±0.92	8.9 ± 1.9	2.35; ±0.85	1.70; ±0.62	0.63; ±0.41	Most Unlikely
			Knee	0.2 ± 2.2	2.91 ±1.05	1.0 ± 1.9	2.43; ±0.88	1.00; ±0.37	0.81; ±0.21	Most Unlikely
		Left	Trunk	2.6 ± 3.8	3.80 ±1.37	2.7 ± 3.2	4.02; ±1.46	1.95; ±0.71	0.66; ±0.37	Most Unlikely
			Hip	8.7 ±1.6	2.02 ±0.73	8.9 ± 1.4	1.51; ±0.55	1.99; ±0.72	0.52; ±0.53	Most Unlikely
			Knee	2.3 ± 1.7	1.99 ±0.72	2.1 ± 1.8	1.83; ±0.66	1.66; ±0.60	0.30; ±0.77	Most Unlikely
	Jump with a turn	Right	Trunk	-9.9 ± 3.3	4.08 ±1.48	-10.4 ± 4.2	5.88; ±2.13	2.20; ±0.80	0.68; ±0.36	Most Unlikely
			Hip	-5.5 ± 2.5	4.33 ±1.57	-5.5 ± 2.6	4.17; ±1.51	1.79; ±0.65	0.83; ±0.19	Most Unlikely
			Knee	-5.3 ± 2.3	2.76 ±1.00	-5.4 ± 2.2	3.10; ±1.12	1.06; ±0.39	0.84; ±0.18	Most Unlikely
		Left	Trunk	-10.2 ± 4.7	5.09 ±1.85	-10.1 ± 3.1	3.43; ±1.24	2.90; ±1.05	0.59; ±0.66	Most Unlikely
			Hip	-4.7 ± 3.0	3.34 ±1.21	-4.9 ± 1.9	2.44; ±0.89	3.57; ±1.29	0.50; ±0.55	Most Unlikely
			Knee	-3.3 ± 2.9	3.59 ±1.30	-4.0 ± 2.1	2.83; ±1.02	2.27; ±0.82	0.68; ±0.35	Most Unlikely

Table 10: Within test and test re-test reliability data for the depth of squat

Variable			Within day reliability				Between day reliability		
			Day 1		Day 2				
			Mean ± SD	Typical error; ± 90% CI	Mean ± SD	Typical error; ± 90% CI	Typical error; ± 90% CI	ICC ± 90% CI	Qualitative Inference on Difference
Squat depth	Single leg squat	Right	23.5 ± 1.7	1.87; ± 0.68	22.6 ± 1.7	1.84; ± 0.67	0.99; ± 0.36	0.98; ± 0.45	Most Unlikely
		Left	24.1 ± 1.1	1.36; ± 0.50	23.9 ± 1.3	1.22; ± 0.44	1.92; ± 0.75	0.93; ± 0.07	Most Unlikely
	Forward jump	Right	16.9 ± 2.6	2.85; ± 1.03	16.7 ± 2.1	2.27; ± 0.83	1.85; ± 0.67	0.91; ± 0.10	Most Unlikely
		Left	16.6 ± 2.3	2.43; ± 0.88	16.8 ± 2.5	2.59; ± 0.94	2.73; ± 0.99	0.84; ± 0.33	Most Unlikely
	Jump with a turn	Right	18.2 ± 3.8	5.37; ± 1.94	18.8 ± 2.5	2.56; ± 0.93	2.22; ± 0.81	0.80; ± 0.22	Most Unlikely
		Left	18.5 ± 2.6	3.22; ± 1.17	18.2 ± 1.8	2.22; ± 0.80	1.56; ± 0.57	0.94; ± 0.07	Most Unlikely

Discussion

The purpose of this investigation was to quantify the reliability of a new assessment for measuring dynamic balance in netball. The single leg squat was the least variable movement both within session and between sessions. Single leg squat was perhaps the least complex movement and was the only movement in which the foot remained in contact with the ground. The trend was for the more complicated patterns to demonstrate larger excursions at the trunk and hip. The trunk and hip appeared to have an increased role in medio-lateral balance corrections under more intense/complex movements demonstrated by an increased total displacement from the single leg squat to the forward jump (an increase of 3.2 cm and 3.0 cm for the trunk and hip respectively). Furthermore, it appeared that movement at the knee remained largely unaffected by movement at proximal body segments (a difference of 0.1 cm between single leg squat and forward jump). Therefore analysing knee movement in a single leg squat may predict knee movement in the more dynamic forward jump.

The stability of measures seemed to be similar irrespective of leg dominance (left leg -ICC = 0.74, TE = 1.7 cm vs. right leg – ICC = 0.74, TE = 1.6 cm) however we believe the 'moderate' reliability is insufficient to reveal side to side differences in balance performance with any real certainty. Furthermore this variability was not consistent between variables and did not follow a systematic trend.

The depth of the squat during each movement represented the most stable measure and is sufficiently reliable as a measure for comparisons to be made between testing occasions. The variability associated with the depth of the squat increased with the complexity of movement pattern and it is likely that the increased challenge to the postural control system affected the degree to which the subject could replicate a consistent squat depth on landing. The deepest squats were associated with the single leg squat (24 cm ± 1.5) whilst the squat depths in the forward jump were the shallowest (17 cm ± 2.5). The subjects were not instructed to land with a deep squat in the forward jump but this strategy may have been an effective technique for controlling poor body position in the air and vertical ground reaction forces on impact and therefore may represent a safer landing strategy. However, a shallow squat executed under control may be advantageous as it will be faster to perform and result in better athlete preparation for ensuing movement. Furthermore a shallow squat results in a reduced metabolic cost (Derrick, 2004).

One factor which affects the within subject reliability scores in a complex movement task is the individual variation associated with human movement. Balance can be maintained in different ways between individuals and assessments have shown that balance strategies will change according to the task, the individual's movement strategies, and various aspects of the environment (Bartlett et al., 2007). Furthermore, differences in movement strategies may help in preventing injuries and maximising performance (Bartlett et al., 2007). For example, differences in joint angles during the same movement alter muscle activation (Kasprisin & Grabiner, 2000) and the degree of stabilization required for a task has been shown to affect the recruitment of muscle between individuals (Kornecki et al., 2001). Ross *et al.* (2004) found that during a step-down task, the landing strategies of the dominant and non-dominant limbs were different whilst achieving similar balance scores. Similarly, Palmieri (2002) highlighted that when measuring centre of pressure deviations in balance tasks that equivalent large deviations in the centre of pressure may represent poor postural control in some, and an effective means of achieving balance in others. Furthermore, the unknown biological variability and measurement error associated with human movement make the development of a sufficiently difficult and reliable sport specific balance assessment challenging.

A number of balance assessments have been used by strength and conditioning coaches and clinicians but none are specific to situations that occur in netball. The movement patterns for the current test were determined by a time-motion analysis of competition play. Using movements that occur in the sport at similar intensities allows relevant inferences to be made from the test regarding the ability to execute netball specific movement patterns. This should enable better estimations of performance capability and injury risk, and assist in program design. Static balance may fail to highlight deficiencies in the postural control system because of the relative ease of the tests (Emery, 2003; Riemann et al., 1999; Wikstrom et al., 2005). Furthermore, deficiencies in static stance may not be related to dynamic balance which is more relevant to the high intensity movements that occur in sport (Hrysomallis et al., 2006). Previous dynamic assessments of balance have not adequately replicated sport specific movement patterns. For example, by requiring subjects to balance with hands on their hips, postural control mechanisms are isolated in the lower limbs which is not reflective of game situations (Riemann et al., 1999; Wikstrom et al., 2005). The movements and intensities chosen for the current test were the most challenging dynamic balance assessments to date and produced a range of responses across subjects. It would seem from the degree of variability that the movements were for the most part too challenging for these subjects. The more simple movements such as a single leg squat may offer the most reliable diagnostic information.

In terms of methodological considerations, it is important for a test to be easily administered, portable, affordable and easily understood (logical validity). The proposed methods required only a single frontal plane camera which is advantageous to the strength and conditioning professional and sports coach working in the field with many athletes and limited resources. A single frontal plane camera has been used in previous studies for describing lower limb alignment and changes in kinematics following training interventions (Noyes et al., 2005; Willson et al., 2006). However, the movements used in these analyses were simpler and therefore the resultant reliability was thought to be acceptable.

Finally, in terms of the reliability associated with the movements in this study, we analysed multiple indices of reliability, based on the recommendations of previous authors (Looney, 2000; Weir, 2005). The typical error is the absolute index of reliability and is expressed in the same unit as the measurement of interest (Weir, 2005). The intraclass correlation coefficient refers to the relative consistency of the measurement and is a unitless value which varies between zero (indicating no consistency) and one (indicating perfect consistency). On the whole the reliability of the measures presented here are comparable to previous medio-lateral stability measures (Flanagan, Ebben, & Jensen, 2008; Wikstrom et al., 2005). However, although the typical error and ICC values on the whole reflect 'moderate' reliability (Shrout, 1998) we believe are too low for determining balance performance. In addition to the individual variation, the variability may also be a result of measurement error such as marker movement and digital analysis.

Conclusions and Practical Applications

It is important when designing new assessment tools that they are valid and reliable. The movements have face validity because they were based on a time motion analysis of elite netball teams. However, the test did not present sufficient reliability for it to be used as an assessment of balance.

The depth of the squat upon landing was sufficiently similar within session and between sessions to be used by strength and conditioning coaches who wish to monitor changes in performance. Movement at the knee was similar between all movements and analysing medio-lateral knee motion in any one sequence may predict motion in another. It may be feasible to use knee motion in a single leg squat as an indicator of knee motion in a jump task. Since hip and trunk movement changed between tasks, the ability to stabilise these body segments appears to be task and intensity specific. Consequently hip and trunk movement must be assessed in a task specific context across a range of intensities. The different displacements of these body segments during different movements support the use of sport specific dynamic balance assessments.

Given the relationship between balance, functional movement and injury, there is no doubt a measure of dynamic balance should be developed for inclusion in an assessment battery. The assessment should indicate the size and origin of postural control deficiencies through the measurement of segmental displacements during a sport specific task. The movements included in this measure could be used as a sport specific movement assessment to give an indication of the ability of the athlete in a sport specific context. However, until a suitable method of scoring the test is developed and measurement error associated with videography and digitising reduced, the assessment can only serve as an indication of movement competency. Furthermore, it may be that measures other than the variables quantified in this study (i.e. medio-lateral displacement) better represent balance performance. The results of the present study highlight the individual variation associated with complex movement tasks, and further research is required to refine the utility of such assessments.

Chapter Five
Summary and Practical Applications

Chapter 5 - Summary and Practical applications

This thesis aimed to develop a practical assessment of dynamic balance suitable to assess netball players. Static balance assessments may fail to identify postural control deficiencies due to the relative ease of completing each task. Although dynamic balance assessments are more sport specific, previous tests have not given information on segmental orientation, the origin of any deficiency, or the movement strategy used for balance corrections. Information of this type may help predict injury, indicate movement competency and would be useful for programming training. Dynamic balance assessments have also tended to analyse variables more appropriate for static assessment. Furthermore, previous assessments were devised without an analysis of typical movements occurring during the specific sport. Therefore, it was proposed that a videographic assessment, based on sport specific movements, with measures of segmental orientation may be more useful to the trainer.

Since the aim was to create a sport-specific test we started by classifying landing movements performed in elite netball games. Jump landings were deemed important because abrupt decelerations and twisting on jump landings has been identified as a major cause of injury in netball. The results provided information which may aid strength and conditioning professionals and netball coaches develop conditioning strategies and assessment batteries for both injury prevention and performance enhancement. It was found that forward jumps were performed most frequently (42%) followed by vertical (32%) and lateral jumps (26%). Uni-lateral landings (67%) were most common, as were jumps without turn in the air (60%) and it was less common to perform a second jump immediately upon landing (28%). There were marked differences between player positions and players could generally be split into end court and mid court. However, goal attack had much in common with the other mid court players whilst wing defence had much in common with end court players. Implementing physical training programmes related to the frequencies of different movements per player position may be an effective strategy for preparing athletes to handle the specific demands of their position. However, the jump strategies observed may have been a reflection of the style of play, and the abilities or deficiencies of the athletes rather than optimal netball movements. Further research is required to fully examine the movement patterns in netball and could include information on the intensities of jumps, the frequency of different movement patterns that are commonly trained such as the squat, lunge, twist, bend, push and pull. Also of interest is the variation in individual movement strategies used to complete the same task. Studies should aim to quantify jump landing strategies employed by different teams from around the world and investigate their relationship with performance and injury.

Following the movement frequency analysis we devised an assessment battery using sport-specific movements which was not found to have sufficient reliability in order to make inferences on balance performance. The movements included a single leg squat, a forward jump, and a jump with a turn in the air. These movements were chosen based on the type of movements that are performed in netball. The study used frontal plane videographic techniques to measure segmental orientation as an indication of movement strategies and the origin of any deficiency. It was hoped that the current assessment could be used as a pre-screening tool, a readiness to return-to-play assessment, or as a tool to compare populations (e.g. elite vs. sub-elite, or previously injured vs. non-injured). However, because of the lack of reliability associated with the measure the assessment may be most useful as a movement assessment to give the coach an indication of each athlete's ability in this regards. The individual variation associated with complex movement tasks may be one reason for the failure of the assessment to demonstrate sufficient reliability scores as well as the error of the measurements involved. Future research should aim to develop reliable tests that consider the relationship between balance and functional movement and thereby give an indication of segmental orientation during the task. These tests will have implications for directing exercise prescription and predicting injury and performance.

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Participant Information Sheet

Date Information Sheet Produced:
26/06/08
Project Title
Assessing Injury Risk in Netball
An Invitation
I, Daniel Lavipour, am an MPhil candidate in sports science for AUT University in Auckland, working in conjunction with Netball New Zealand. You are invited to participate in a study that is expected to assist in the development of a test which will assess injury risk in netball players. Please understand that your participation is voluntary and you may withdraw at any time without any adverse consequences.
What is the purpose of this research?
This study aims to quantify those movement patterns and postural factors involved in injury risk.
How was I chosen for this invitation?
You represent an elite adult woman, an elite high school, or an elite school netballer.
What will happen in this research?
If you decide to participate in this research, you will be asked to complete a consent form prior to any data collection. Your age, height and weight will be recorded first. You will then be asked to warm-up as you would normally for a netball game or practice. You will be asked to complete 2 jump tests and 1 squat test. Your movements will be performed on a force plate and videotaped. You will be given time to familiarize yourself with each task before any data is collected. You will also be given up to 60s between each trial to recover. Please feel free to communicate any questions you have at any time during the session.
What are the discomforts and risks?
You are being asked to complete a series of jumps similar to those movements you use in netball where you will have to balance on one leg upon landing. There is a possibility of injuring yourself, however the probability of this occurring is no more likely than you injuring yourself in a

practice or a game. If at any time, you do not feel that you are able to complete the movements requested, please notify the researcher immediately. Additionally, please notify the researcher at this time if you have a current injury or have had an injury within the last four months that might affect your performance of these movements, or that might be worsened or aggravated by the required tasks. There will not be any adverse consequences if you need to withdraw for any reason, at any time.

How will these discomforts and risks be alleviated?

You have been asked to physically prepare yourself prior to the testing as well as 60 seconds between trials to recover. Please notify the researcher if you feel that you need more time to prepare or recover as we are interested in measuring your best performance.

What are the benefits?

By participating in this study, you are providing us with information about the movement patterns of netball players. The intention is to gain a better understanding of the movement patterns that are used in netball to land from jumps. Your participation will also assist in the development of the upcoming research studies focusing on the specific movement patterns that netball players use to successfully perform jumps and changes of direction in netball. This research will assist in the improvement of individual qualities of jump landings, giving you a competitive edge over your opposition.

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 identity and results of each participant will be kept confidential. Only the student researcher (Daniel Lavipour), the primary and secondary supervisor (James Croft and Assoc Prof. John Cronin) and the Netball NZ supervisor (Megan Crockett) will view the video footage collected. In the event that a video clip or still photo is used in a presentation, the head of the individual will be burred in an attempt to avoid identification. However, full confidentiality of the participants in clips or stills cannot be guaranteed. The summarised results from the study will be available to you upon completion of the study. These results will also be presented to Netball New Zealand as a means of developing the ensuing research studies.

What are the costs of participating in this research?

We acknowledge and respect the fact that the population of interest that this survey is being administered to is quite busy. We have attempted to keep the testing session brief. We estimate that your complete time commitment will be no more than 2 sessions of 30 minutes.

What opportunity do I have to consider this invitation?

After you have read through this form, you will have an opportunity to ask any questions you would like about the study. After your concerns have been satisfied, you will be given an opportunity to decide whether or not you would like to participate. Please feel free to take as much time as you feel is necessary to make this decision. If you would like to return at a later date or time, please notify the researcher and accommodations will be made without any adverse consequences.

How do I agree to participate in this research?

If you would like to participate in this study, please complete the attached consent form. If you would rather not participate, you are free to leave.

Will I receive feedback on the results of this research?

Yes, if you are interested in receiving the summarised results, please check the appropriate bubble on the consent form. We also ask that you provide your contact information so we can communicate the results to you. Your personal information will not be disclosed to anyone beyond the primary and secondary supervisor, the Netball NZ supervisor and the MPhil student.

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, Dr James Croft, james.croft@aut.ac.nz, 921 9999 ext 7685

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?

Please contact the student researcher, Daniel Lavipour 021 *** ***, daniel,lavipour@aut.ac.nz

Researcher Contact Details:
Daniel Lavipour. Email: daniel.lavipour@aut.ac.nz
Project Supervisor Contact Details:
Dr James Croft, james.croft@aut.ac.nz
Assoc. Prof. John Cronin, john.cronin@aut.ac.nz
Netball NZ Supervisor Contact Details:
Megan Crockett, meganc@netballnz.co.nz

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.