Biomechanical, anthropometrical and physical profile of the North-West University Club netball players and the relationship to musculoskeletal injuries

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SUMMARY

Keywords: Netball; biomechanics; anthropometry; agility; balance; explosive power; injuries.

Background: Netball is a physically demanding game and is associated with traumatic and overuse injuries, and it is therefore associated with high injury incidences (Hopper, 1986; Eggar, 1990). Literature indicates that deficiencies of certain parameters such as biomechanics, anthropometry and physical/motor abilities (agility, balance and explosive power) could influence a netball player's susceptibility to injury as well as the player's physical performance during a game (Arnheim & Prentice, 2000; Brukner & Khan, 2001; Bell-Jenje & Bourne, 2003; Kendall, McCeary & Provance, 1993; Fuller & Drawer, 2004; Rossouw & Rossouw, 2003; Whiting & Zernicke, 1998; Jones & Knapik, 1999; Murphy, Connoly & Beynnon, 2003; Trojian & McKeag, 2006; Moss 2002; Swanik & Swanik, 1999). Fortunately, effective conditioning exercises are available to improve biomechanical deviations, inadequate anthropometry or unacceptable physical/motor abilities (agility, balance and explosive power), and therefore it is essential to identify these shortcomings prior to the start of the netball season by means of assessment occasions (Junge *et al.*, 2004; Gabbet, 2004; Armsey & Hosey, 2004; Schwellnus & Derman, 2001).

Aims: The primary aim of this study was to determine the physical profiles of netball players from the North-West University (NWU) Netball Club aged between 18 and 23 years, with reference to the biomechanics, anthropometric measurements and physical/motor abilities (balance, agility and explosive power). The secondary aim was to identify shortcomings in the physical profiles (biomechanical variables, anthropometrical components and physical/motor abilities) of the netball players that could contribute to musculoskeletal injuries among these players.

Design: A descriptive study was made of the physical profiles of NWU Netball Club players.

Subjects: Female netball players from the first, second, third, fourth and the u/19 A and B teams of the North-West University Netball Club participated in this study. Forty players were tested during testing occasion one and 25 players were tested during testing occasion two.

Method: The players were tested pre-season in March 2007. The tests involved a thorough biomechanical analysis, anthropometrical measurements and the determining of physical/motor abilities, including agility, balance and explosive power. These tests were conducted by applying a recent approach that measures a combination of symmetry, dynamic mobility and local stability of the body for the biomechanical assessment (Hattingh, 2003). For the anthropometric measurements, three standardised variables were used: body fat percentage by means of 6 skin fold measurements, stature by means of a tape measure, and body mass by means of a calibrated scale (Ross & Marfell-Jones, 1991); the Illinois agility run test (Kirby, 1991 & www.brianmac.demon.co.uk/illinois.htm) for agility; the computerised balance test (Techno-Therapy, 1992) for balance, and the vertical jump for explosive power, measured by means of a tape-switch sensory mat connected to a Psion organiser (Boscosystem ErgoJump www.boscosystem.com). These tests were repeated end-season in August 2007. A clinic was held for injured players every Monday and this made it possible to monitor the injuries during the season. The clinic offered a diagnostic evaluation and advice, as well as a referral to a doctor or physiotherapist for treatment, if necessary.

A statistical analysis was done on all the data collected from the test batteries and injury clinics. Descriptive statistics (means, standard deviations, minimum and maximum values) were used as well as practically significant differences (d-values and p-values) (Ellis & Steyn, 2003).

Results: A profile of biomechanics, anthropometry and physical/motor abilities (agility, balance and explosive power) was compiled for the NWU Netball Club players. The data of the *total group of netball players* revealed numerous biomechanical deviations among the netball players during the first and second testing occasion.

With regard to anthropometry, the total group presented with an ideal body mass index (BMI) but with an above-average fat percentage (testing occasions one and two). The results of the first testing occasion showed that the performance of the total group was relatively acceptably regarding the agility and explosive power tests, but underperformed in the balancing test, according to the norm set for elite netball players. In the second testing occasion for the physical/motor tests, it was found that the netball club players performed relatively acceptably in the agility and balancing tests, but underperformed in the explosive power test.

The biomechanical assessment of the *juniors and seniors* indicated that the juniors presented with less biomechanical deviations than the seniors during both testing occasions. The anthropometrical assessment indicated that the BMI results of both groups (juniors and seniors) fell in the ideal category. The juniors as well as the seniors presented with above-average values for fat percentages. During the first tests the juniors performed better than the seniors on two (agility and balance) of the three physical/motor tests. The average agility scores for both groups fell in the average category, while the average value for the ability to balance was unacceptable. The seniors presented with a better average score for explosive power than the juniors, but the averages of both groups were considered acceptable. However, upon the second testing occasion the seniors outperformed the juniors in all three physical/motor tests. The averages for agility and balance were considered acceptable, but the averages for explosive power performances were unacceptable.

Among the *centre and goal players* the biomechanical data revealed that the goal players presented with less biomechanical deviations than the centre players during the first and second tests. The anthropometric assessment indicated that both groups presented with ideal BMI and with above-average fat percentages (testing occasions one and two). In all three physical/motor tests (agility, balance and explosive power) in the first and second testing occasions, the centre players performed better than the goal players. During the first testing occasion, both groups performed acceptably in the agility and explosive power test, but they underperformed in the balance test.

However, during the second testing occasion, the results of the centre players were acceptable for all three physical/motor tests, but the goal players underperformed in the explosive power test.

The data of the first and second testing occasion indicated that the *B-grade players* presented with better biomechanics than the *A-grade players* in most of the tests. For the anthropometric assessment, both groups (A- and B-grade players) presented with ideal BMI averages, but with above-average fat percentages. The physical/motor tests revealed that the A-grade players performed better than the B-grade players in all three physical/motor tests (agility, balance and explosive power). The averages of the A- and B-grade players were considered acceptable for all three physical/motor tests during the first testing occasion, but during the second testing occasion the B-grade players underperformed in the explosive power test.

A comparison of the results of the first and second testing occasion shows that the biomechanics and the anthropometrical status of the total group deteriorated through the season, although insignificantly so. The physical/motor abilities (agility and balance) of the total group improved significantly, with a significant decrease in performance on the explosive power test. The same tendencies were identified among the different groups (juniors and seniors; centre and goal players; A- and B-grade players), namely a deterioration in biomechanics and anthropometry, an improvement in agility and balance, and a decrease in explosive power abilities.

A netball epidemiological study was done on the data collected in the weekly injury clinics. The study recorded 46 injuries among the NWU Netball Club players during the season. The overall injury incidence (7.63 injuries/1000 player-hours) of the total group of netball players of this study was higher than the injury incidences for existing studies on netball (Ekstrand & Tropp, 1990). The seniors, centre players and A-grade players presented with higher injury incidences than the juniors, goal players and B-grade players respectively. The body part mostly affected by injuries was the ankle joint, with incorrect landing as the most common cause of injury.

Conclusion: A physical profile of every NWU Netball Club player (aged between 18 and 23 years) was documented, and included a thorough biomechanical analysis, an assessment of the player's anthropometrical status and performance in physical/motor ability tests, which consisted of an agility run, balancing and an explosive power test. Numerous biomechanical deviations, unacceptable anthropometry and average physical/motor abilities were identified among the netball players. These physical deficiencies could negatively influence a netball player's performance and could also contribute to musculoskeletal injuries. The injury incidence for the total group of netball players revealed a higher prevalence than previous studies on netball players. This could be ascribed to the numerous biomechanical deviations, unacceptable anthropometry and average physical/motor abilities which were identified among the netball players.

A comparison of the incidences of injury among the different groups (juniors and seniors; centre and goal players; and A- and B-grade players) indicated that the groups (seniors, centre players and A-grade players) which presented with more biomechanical stressors, presented with more injuries during the season (higher incidences of injury) than their counterparts (juniors, goal players and B-grade players), who performed better on the biomechanical assessments. Therefore, the conclusion could be made that netball players with more biomechanical deviations sustain more injuries than netball players with better biomechanical status.

OPSOMMING

Sleutelwoorde: Netbal; biomeganika; antropometrie; ratsheid; balans; plofkrag; beserings.

Agtergrond: Netbal is 'n veeleisende sport en word geassosieer met trauma- en oorgebruikbeserings, en daarom het dit 'n hoë beseringsyfer (Hopper, 1986; Eggar, 1990). Die literatuur beklemtoon dat sekere aspekte soos biomeganika, antropometrie en fisieke/motoriese vermoëns (ratsheid, balans en plofkrag) 'n netbalspeler se waarskynlikheid vir beserings asook die speler se prestasie tydens 'n wedstryd kan beïnvloed (Arnheim & Prentice, 2000; Brukner & Khan, 2001; Bell-Jenje & Bourne, 2003; Kendall, McCeary & Provance, 1993; Fuller & Drawer, 2004; Rossouw & Rossouw, 2003; Whiting & Zernicke, 1998; Jones & Knapik, 1999; Murphy, Connoly & Beynnon, 2003; Trojian & McKeag, 2006; Moss 2002; Swanik & Swanik, 1999). Die literatuur bevestig dat effektiewe kondisioneringsoefeninge geformuleer is om die biomeganiese afwykings, onvoldoende antropometrie of onaanvaarbare fisieke/motoriese vermoëns (ratsheid, balans en plofkrag) te verbeter, en daarom is dit belangrik om hierdie tekortkominge voorseisoen te identifiseer tydens toetsgeleenthede (Junge *et al.*, 2004; Gabbet, 2004; Armsey & Hosey, 2004; Schwellnus & Derman, 2001).

Doelwitte: Die primêre doelwit van hierdie studie was om die fisieke profiele van netbalklubspelers van die Noordwes-Universiteit tussen die ouderdomme 18 en 23 jaar te bepaal, deur te verwys na biomeganika, antropometrie en fisieke/motoriese vermoëns (ratsheid, balans en plofkrag). Die sekondêre doelwit was om die tekortkominge in die fisiese profiele (biomeganika, antropometrie en fisieke/motoriese vermoëns) van die netbalspelers te identifiseer wat kan bydra tot die voorkoms van muskuloskeletale beserings van hierdie spelers.

Ontwerp: 'n Beskrywende studie is gedoen van die fisieke profiele van NWU-Netbalklubspelers tussen die ouderdomme 18 en 23 jaar.

Deelnemers: Vroulike netbalspelers van die eerste, tweede, derde, vierde en die o/19 A- en B-spanne van die Noordwes-Universiteitnetbalklub het deelgeneem aan hierdie studie: 40 spelers is getoets gedurende die eerste toetsgeleentheid en 25 gedurende die tweede.

Metode: Die spelers is voorseisoen in Maart 2007 getoets. Die toetse het bestaan uit 'n deeglike biomeganiese evaluering, antropometriese metings en 'n bepaling van fisieke/motoriese vermoëns, wat ratsheid, balans en plofkrag ingesluit het. Die biomeganiese toetse is uitgevoer met behulp van 'n onlangse benadering wat die kombinasie van simmetrie, dinamiese mobiliteit en lokale stabiliteit van die liggaam bestudeer (Hattingh, 2003). Vir die antropometriese metings is drie gestandaardiseerde veranderlikes gebruik: liggaamsvetpersentasie deur die meting van 6 velvoue; lengte deur middel van 'n maatband; en liggaamsgewig deur middel van 'n gekalibreerde skaal. Die Illinois-ratsheidtoets (Kirby, 1991 & www.brianmac.demon.co.uk/illinois.htm) is gebruik om ratsheid te meet; 'n elektroniese balanstoets (Techno-Therapy, 1992) is gebruik vir balans; en die vertikale sprong vir plofkrag, gemeet deur 'n skakelsensoriese mat wat verbind is met 'n Psion-organiseerder (Boscosystem ErgoJump www.boscosystem.com). Hierdie toetse is weer naseisoen gedurende Augustus 2007 herhaal. 'n Kliniek waartydens die beserings deur die seisoen gemonitor is, is elke Maandag aangebied vir beseerde netbalspelers. Die kliniek het diagnostiese evaluering en advies gebied, en indien nodig ook 'n verwysing na 'n dokter of fisioterapeut vir behandeling.

Statistiese analises is uitgevoer op die data wat tydens die toetsprosedures en beseringsklinieke ingesamel is. Beskrywende statistieke (gemiddelde, standaard-afwykings, minimum en maksimum waardes) asook prakties betekenisvolle verskille (d-waardes en p-waardes) is gebruik (Ellis & Steyn, 2003).

Resultate: 'n Profiel van biomeganika, antropometrie en fisieke/motorieke vermoëns (ratsheid, balans en plofkrag) is opgestel vir die NWU-Netbalklubspelers. Met betrekking tot die data vir die *totale groep netbalspelers* is talle biomeganiese afwykings geïdentifiseer gedurende die eerste en tweede toetsgeleenthede.

Aangaande die antropometrie presenteer die totale groep met 'n ideale liggaamsmassa-indeks (LMI) maar met 'n bogemiddelde vetpersentasie (toets een en twee). Volgens die norm vir elite netbalspelers toon die eerste toetsgeleentheid relatief aanvaarbare resultate vir die ratsheid- en plofkragtoetse, maar onaanvaarbare resultate vir die balanstoets. Tydens die tweede toetsgeleentheid is aanvaarbare resultate behaal vir die ratsheid- en balanstoets, maar toon dat die totale groep onderpresteer het in die plofkragtoets.

Die biomeganiese evaluering van die *juniors en seniors* identifiseer minder biomeganiese afwykings by die juniors as die seniors (toetsgeleentheid 1 en 2). Die antropometriese evaluering toon dat die LMI-resultate van beide groepe (juniors en seniors) in die ideale kategorie val, met bogemiddelde vetpersentasies. Gedurende die eerste toetse het die juniors beter presteer as die seniors in twee (ratsheid en balans) van die drie fisieke/motoriese toetse. Die gemiddelde waardes vir ratsheid vir beide groepe val in die gemiddelde kategorie, met onaanvaarbare balansvermoëns. Die seniors het met 'n beter gemiddelde waarde vir plofkrag as die juniors presenteer, maar beide groepe se gemiddelde word as aanvaarbaar beskou. Met die tweede stel toetse het die seniors beter presteer as die juniors in al drie fisieke/motoriese toetse. Die gemiddelde vir die ratsheid en balans was aanvaarbaar, maar die gemiddelde waarde vir plofkrag was onaanvaarbaar.

Die biomeganiese data van die *senter- en doelspelers* toon dat die doelspelers met minder biomeganiese stressors as die senterspelers gedurende die eerste en tweede toetsgeleenthede gepresenteer het. Die antropometriese evaluering toon dat die gemiddelde van beide groepe in die ideale kategorie val, met bogemiddelde vetpersentasies (toetsgeleenthede een en twee). Met beide toetsgeleenthede het die senterspelers met beter fisieke/motoriee vermoëns (ratsheid, balans en plofkrag) presteer as die doelspelers. Beide groepe het tydens die eerste toetsgeleentheid aanvaarbare resultate getoon vir ratsheid en plofkrag, maar onaanvaarbare resultate vir balansvermoëns. Tydens die tweede toetsgeleentheid is aanvaarbare fisieke/motoriese resultate vir die senter spelers aangeteken, maar onaanvaarbare plofkragresultate vir die doelspelers.

Die data vir beide toetsgeleenthede toon dat die *B-graadspelers* met beter biomeganika gepresenteer het as die *A-graadspelers*. Die antropometriese evaluering vir albei groepe (A- en B-graadspelers) bevind ideale LMI, maar met bogemiddelde vetpersentasies. Die fisieke/motoriese toetse openbaar dat die A-graadspelers beter gepresteer het as die B-graadspelers in al drie fisieke/motoriese toetse (ratsheid, balans en plofkrag). Die gemiddeldes vir die A- en B-graadspelers is beskou as aanvaarbaar tydens die eerste toetsgeleentheid, maar tydens die tweede toetsgeleentheid het die B-graadspelers onderpresteer met die plofkragtoets.

Wanneer die eerste stel toetsresultate vergelyk word met die tweede stel toetsresultate is dit duidelik dat die biomeganika en die antropometrie van die totale groep verswak het gedurende die seisoen. Die fisieke/motoriese toetse toon dat die ratsheid en balans van die totale groep betekenisvol verbeter het, maar dat daar 'n afname in plofkrag was. Eenderse tendense het gepresenteer by die juniors en die seniors; senter- en doelspelers; asook by die A- en B-graadspelers, naamlik 'n verswakking van biomeganika en antropometrie, met 'n toename in ratsheid en balans en 'n afname in plofkrag.

'n Netbal- epidemiologiese studie is uitgevoer met die data wat ingesamel is tydens die weeklikse beseringsklinieke. Die studie het tydens die seisoen 46 beserings gerapporteer onder die NWU-Netbalklubspelers. Die algehele beseringstendens (7.63 beserings/1000 spelerure) vir die totale groep netbalspelers is hoër as die beseringstendense van vorige netbalstudies (Ekstrand & Tropp, 1990). Die seniors, senterspelers en A-graadspelers het met hoër beseringstendense gepresenteer as die juniors, doelspelers en die B-graadspelers onderskeidelik. Die liggaamsdeel wat die meeste geaffekteer is deur beserings was die enkelgewrig, met foutiewe landing as mees algemene oorsaak van besering.

Gevolgtrekking: 'n Fisieke profiel vir elke NWU-Netbalklubspeler (tussen 18 en 23 jaar) is opgestel. Dit het 'n volledige biomeganiese en antropometriese evaluering ingesluit asook 'n evaluering van fisieke/motoriese vermoëns, wat bestaan het uit ratsheid, balans en plofkrag.

Talle biomeganiese afwykings is geïdentifiseer by die netbalspelers met onaanvaarbare antropometrie en gemiddelde fisieke/motoriese vermoëns. Hierdie fisiese tekortkominge kan 'n netbalspeler se prestasie negatief beïnvloed en ook bydra tot muskuloskeletale beserings. Die beseringstendens van die totale groep netbalspelers toon 'n hoër waarskynlikheid tot besering as vorige studies oor netbalspelers. Hierdie hoë beseringstendens kan toegeskryf word aan die talle biomeganiese afwykings, onaanvaarbare antropometrie en gemiddelde fisieke/motoriese vermoëns wat geïdentifiseer is by die netbalspelers.

Die vergelyking van die beseringstendense van die verskillende groepe (juniors en seniors; senter- en doelspelers; en A- en B-graadspelers) toon dat die groepe (seniors, senterspelers, en A-graadspelers) wat gepresenteer het met meer biomeganiese afwykings 'n hoër beseringstendens getoon het as die groepe (juniors, doelspelers en B-graadspelers) met minder biomeganiese afwykings. Die gevolgtrekking kan gemaak word dat netbalspelers met meervoudige biomeganiese afwykings meer vatbaar is vir beserings tydens 'n netbalseisoen as die netbalspelers met 'n beter biomeganiese profiel.

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LIST OF ABBREVIATIONS

NWU	North-West University
m	meter
cm	centimetre
kg	kilogram
sec	seconds
e.g.	example
vs.	versus
ACL	Anterior cruciate ligament
ITB	Iliotibial band
SLR	Straight leg raise
PKB	Prone knee bend
PSIS	Posterior superior ileac spine
ASIS	Anterior superior ileac spine
Q-angle test	Quadriceps angle test
BMI	Body mass index
LMI	Liggaamsmassaindeks
VMO-L-comparison test	Vastus mediales obliquus – lateralis comparison test
C	Centre
WD	Wing defence
WA	Wing attack
G	Goal
GA	Goal attack
GK	Goal keeper
GD	Goal defence
NAIRS	National Athletic Injury Registration System
USA	United States of America
APA	Anticipatory postural adjustments

CHAPTER 1

PROBLEM STATEMENT AND RESEARCH AIMS OF THE STUDY

1.1. INTRODUCTION

1.1.1. History of netball

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CHAPTER 1

PROBLEM STATEMENTS AND RESEARCH AIMS OF THE STUDY

1.1. INTRODUCTION

1.1.1. History of netball

Netball is a team-based sport played in more than fifty countries worldwide. This popular game was created by James Naismith over a century ago, in 1891. Naismith derived netball from basketball, which is a combination of two ancient games played by the Greeks and the Romans respectively. The Greek word *Episskyros* defined a game which was excellent for dodging and marking in a confined space. The Romans invented *Trugon*, which was a game to improve ball-handling skills (Hopper, 1986). Naismith invented netball to accommodate women: because women's limited strength made it difficult for them to execute the long passes of basketball, Naismith was asked to develop a women's version of basketball, and the enjoyable game of netball was invented (All Australian Netball Association, 1983).

Netball has one of the largest numbers of participants in the Commonwealth, especially in Australia, New Zealand and the United Kingdom (Steele, 1990). Netball was brought to Australia in the early 1900's (Steele, 1990). Australia and New Zealand are the world's leading netball countries and between them they have won all the world titles that they have played for, thus far (All Australian Netball Association, 1983).

Hopper and Elliot (1993) report that netball is the most popular sport among women in Australia, enjoyed by approximately 800 000 players. According to these surveys and statistics, netball is one of the most popular sports among women, but despite the popularity of the game, a lack of published literature was identified during the literature review for this particular study.

1.1.2. Netball in South Africa

The primary aim of this study is to present the physical profiles of female netball players between the ages of 18 and 23 years at the Netball Club of the North-West University. The profiles will include each player's biomechanics, anthropometrical features and physical/motor abilities (agility, balance and explosive power). The researcher hypothesises that various biomechanical, anthropometrical and physical/motor abilities (agility, balance and explosive power) will contribute to musculoskeletal injuries in different body regions, especially in the lower limbs. The study will also identify possible areas which the players and coaches must attend to in terms of further conditioning and intervention. Participants could thus benefit from this study by acknowledging and addressing these areas, which in turn will result in improved performance and a decreased probability for injuries.

Venter *et al.* (2005) performed a similar study on the physical profiles of Boland provincial netball players. The secondary aim of that study was to compare the results with the profiles of Australian netball players. The outcome of this study was that top-level provincial players in South Africa are not on the same level as their Australian counterparts, with reference to the physical profiles of Boland netball players.

In 1994, the South African netball team participated in their first international tournament and currently they are ranked fifth in the world. Netball is played in South Africa on a daily basis in schools, clubs and at regional level. It has been reported that there are half a million players at school level and 9 700 adult players in South Africa (Venter *et al.*, 2005).

Upon re-admission of South Africa in international sport in 1994, it was apparent that South African sports teams lacked specialised coaching, sport-specific skills, essential physique and fitness skills that characterise elite sport (Venter *et al.*, 2005). Optimal performance in netball relies on the interaction of several factors, including physical conditioning and technique.

Venter *et al.* (2005) emphasise that more comprehensive studies must be conducted to obtain normative data. This study was the first attempt to provide normative data on provincial-level netball players in South Africa. Therefore, further research is not only essential to develop the game of netball at all levels in South Africa, but also to gain information in terms of injury rates and injury costs or financial implications.

1.2. PROBLEM STATEMENT

Netball is defined as a physical demanding game which is associated with traumatic- and overuse injuries (Venter *et al.,* 2005; Brukner & Khan, 2001). According to the literature injuries could be caused by biomechanical stressors, unacceptable anthropometry and poor physical/motor abilities (Brukner & Khan, 2001; Whiting & Zernicke, 1998). The key role biomechanics play in the performance and probability of injuries would be looked at first. Hass *et al.* (2005) found that *biomechanics* play a very important role in the probability of injury: the study of biomechanics will therefore be included in this research project. Hass *et al.* (2005) conducted a study on the biomechanics of the knee during landing, where lower-extremity skeletal malalignment contributed greatly to knee injuries. Structural malalignments related to the occurrence of injury include excessive Q-angle, thigh-foot angle, genu recurvatum, femoral anteversion, smaller intercondylar notch width, decreased notch width index and generalised joint laxity. The study compared the landing techniques of pre-pubescent females (8-11 years of age) to those of post-pubescent females (18-25 years of age). Hass *et al.* (2005) found that landing with a degree of knee flexion stabilises the knee, therefore decreasing the probability of a knee injury. Interestingly, this study found that post-pubescent females are more prone to lower-limb injuries than both pre-pubescent females and male athletes. Hass *et al.* (2005) concluded that this finding may be ascribed to the fact that post-pubescent females land with greater knee extension and adduction than pre-pubescent females and male athletes, therefore making post-pubescent players more susceptible to knee injuries.

Anthropometry would be discussed next. According to many research studies, anthropometry plays an important role in the probability of sporting injuries. Whiting and Zernicke (1998) write that anthropometric measures such as height, weight, body composition, muscle mass and shape (somatotype) are pivotal in assessing injuries. These anthropometric measures are also involved in determining body posture, biomechanics and flexibility (joint range of motion), which – either alone or in combination – can affect the risk of injury (Whiting & Zernicke, 1998). Arnheim and Prentice (2000) argue that anomalies in anatomical structures in body build (somatotype) may predispose an athlete to injuries, which corresponds with the findings of Whiting and Zernicke (1998). For these reasons, anthropometry will be investigated in this study.

The physical/motor abilities (agility, balance and explosive power) that could greatly influence the outcome of a netball game as well as affect a netball player susceptibility to injuries would be looked at lastly. Netball is a game that requires rapid acceleration, sudden changes in direction and elevated leaps to receive the ball, intercept a pass or catch a rebound from an attempted shot for a goal (Hopper & Elliot, 1993). Bloomfield, Ackland and Elliot (1994) describe netball as a physically demanding game where the player must be extremely agile and able to jump; therefore *agility* will be included in this particular study. Agility is defined as repeated sprints in different directions while maintaining balance and speed (Venter *et al.,* 2005). This ability to accelerate over a short distance is an extremely important performance parameter in netball and could greatly influence the outcome of a netball game (Venter *et al.*, 2005). Consequently, Venter *et al.* (2005) included agility in a study on the physical profiles of provincial Boland netball players. The primary aim of this study was to determine the profiles of 48 netball players, with the secondary aim to compare these results with the profiles of provincial Australian netball players. The researchers included tests for agility in this study, because agility is one of the major physical abilities required for playing netball (Ellis & Smith, 2003).

Previous research indicated that the Australian netball players exceeded the Boland netball players in the agility test (Venter *et al.*, 2005): thus, the agility of South African netball players must be determined and improved with specific exercises to promote netball in South Africa at all levels (school, club and provincial).

The next variable that will be determined in this extensive study is the ability to balance. Jordaan (2001) emphasises the essence of *balance* during the throwing and receiving actions in netball, especially when the player is standing on one leg. Venter *et al.* (2005) agree on the importance of balance when changing direction during a game, therefore balance directly influences a player's agility skills. The above-mentioned researchers conclude that balance is an indispensable skill for performing greater motor activities.

Netball is a physically demanding game that requires a player to possess high levels of strength and power. Venter *et al.* (2005) address the importance of explosive leg power, especially in a sport which requires jumping to intercept or catch a ball during a game. Vertical jump height is an indication of the power of the extensor muscles of the hips, knees and ankles. Evidently, *explosive power* is an important ability in a game like netball, and this ability therefore needs to be studied.

Hopper and Elliot (1993) did a study on the relations between lower limb and back injuries with perceived landing patterns and podiatric variables for injured and uninjured elite netball players. More than 25% of the 240 participants displayed overuse type injuries. These injuries consisted of retropatellar pain (24%) and shin pain (38%). Elphinston and Hardman (2006) conducted a study on the effect of an integrated functional stability programme on injury rates in an international netball squad and found a high rate of overuse and traumatic injuries among the netball players. The areas most involved were the lower back, ankle, knee and shoulder joint. Elphinston and Hardman (2006) identified the major causative factors as a reactive sports medicine system, poor player self-responsibility and inadequate player understanding of the anatomy and biomechanics of sound training, inadequate screening procedures and perceived conflict between sport science- and sports medicine personnel.

Evidently, literature reveals that netball places many demands on a player's technical and physical abilities and, as a result, injuries can and do occur. After Australia won the World Championship during 1991, netball in Australia attracted media coverage due to the increasing injury rate among netball players (Hopper & Elliot, 1993). Hopper and Elliot (1993) investigated the relation between injury profiles and participation in competitive netball. According to the literature approximately 11 228 netball players participated in an annual 14 week netball tournament held in Western Australia. During this 5 year period, 608 netball players received treatment in the first-aid room. The overall incidence rate was 5.4%, with the direct probability of a netball player's injury risk estimated at 0.054 per person per game. Despite the low injury rate in the above-mentioned study, Eggar (1990) reported that netball still has a higher injury rate than football, basketball, hockey and cricket in Australia. Therefore it is essential to incorporate preventative measures in each player's conditioning program. As literature reveals that netball is a sport associated with serious injuries with great financial implications, it is important to study the costs involved (Eggar, 1990). In 1990, Eggar investigated the causes, costs (injury related) and injury prevention programmes of eight major team sports in Australia. This report found that knee injuries accounted for 25% of all direct injury expenses, with an estimated cost of 100 million Australian dollars in 1990. These financial implications necessitate the incorporation of preventative programmes (Eggar, 1990).

Wilson (1993) agrees with Eggar (1990) that pre-season screening procedures are of utmost importance. These tests must be conducted by qualified personnel, who will analyse each player's physical profile, pre-season as well as during the season. These screening procedures must include parameters that are associated with the specific sport: for netball, the tests must for instance include a complete biomechanical analysis to identify potential musculo-skeletal problems, an anthropometry assessment and tests to determine physical/motor abilities, such as agility, balance and explosive power. All these parameters could contribute to the occurrence of netball injuries (Wilson, 1993).

In conclusion, netball is a physically demanding game and is associated with serious injuries with negative financial implications. Literature reveals that parameters such as biomechanics, anthropometry and physical/motor abilities (agility, balance and explosive power) play a key role in both a netball player's performance and susceptibility to injuries. The probability for injury could be reduced by incorporating a series of tests before and during the netball season to identify and address possible shortcomings in the netball player's physical profile.

1.3. RESEARCH AIMS

A dual aim was identified for this research, namely:

1. To determine the physical profiles of club netball players from the North-West University aged between 18 and 23 years, with reference to biomechanics, anthropometric measurements and physical/motor abilities (agility, balance and explosive power).

2. To identify biomechanical variables, anthropometrical components and physical/ motor abilities (agility, balance and explosive power) that could contribute to musculoskeletal injuries of netball players between the ages of 18 and 23 years at the Netball Club of the North-West University.

1.4. HYPOTHESIS

The study is based on the following hypothesis:

- Various biomechanical variables, anthropometrical components and physical/motor abilities (agility, balance and explosive power) of North-West University Netball Club netball players between the ages of 18 and 23 years may contribute to musculoskeletal injuries in different body regions, especially in the lower limbs.

1.5. RESEARCH METHOD

1.5.1. Literature review

The following media were used to find relevant literature on the subject:

- Internet
- EbscoHost (Academic Search Elite)
- Medline
- Pubmed
- Sportdiscus
- Journals.

A manual search was conducted in the library of the University of North West to find relevant books on the subject.

1.5.2. Test protocol

Female netball players from the first, second, third, fourth and the u/19 A and B teams of the North-West University Netball Club participated in this study; 40 players participated in the first testing occasion and 25 players in the second testing occasion.

Because Hass *et al.* (2005) point out that post-pubescent (18-25 years) female netball players are more prone to injury than other age groups, this study included netball players between the ages of 18 and 23 years. The sample group was not familiar with the proposed hypothesis of the study. The researcher measured the selected variables (biomechanics, anthropometrics and motor abilities) that are relevant to the study. Prior to the study, each player signed an informed consent form (Annexure A) and completed an injury questionnaire on current and previous injuries (Annexure B) for both testing occasions. The players were tested pre-season in March 2007 and post-season in August 2007.

Both testing occasions consisted of a thorough biomechanical analysis, anthropometrical measurements and a determination of physical/motor abilities, including balance, agility and explosive power. Every participant received the test results as well as an individual biomechanical rehabilitation programme after the performance of the second test procedure. A clinic was held for injured players every Monday and this made it possible to monitor the injuries during the season. The clinic offered a diagnostic evaluation, advice and if necessary a referral to a doctor or physiotherapist for treatment.

1.5.2.1. Battery of tests

(a) Biomechanical and postural components

The first protocol can be classified under the biomechanical and postural make-up of the players (Watson, 2001). For the biomechanical test battery, a recent approach that measures a combination of symmetry, dynamic mobility and local stability of the body was used (Hattingh, 2003). Two physiotherapists performed the biomechanical analysis of each subject. The biomechanical assessment was performed from the first lumbar vertebrae (L1) down to the subject's toes. The position of the cranium (head), cervical and thoracic area was included in the assessment of the sagital axis, because of the influence of these areas on the lumbar area.

This biomechanical and postural assessment protocol evaluated different zones, namely lumbo-pelvic region, hip girdle, lower limb (knee and foot complex) and neurodynamics. Since literature reveals that these areas are the most susceptible to injury in netball players, the researcher decided to focus on these areas (Hass *et al.,* 2005).

(b) Anthropometric variables

To calculate anthropometric body components, the protocol prescribed by the International Body of Kinanthropometrics was used in this study (Ross & Marfell-Jones, 1991).

For the anthropometric measurements, three standardised variables were used: body fat percentage by using 6 skinfolds (triceps skinfold, subscapular skinfold, supraspinal skinfold, abdominal skinfold, thigh skinfold and calf skinfold), stature by using a tape measure, and body mass by using a calibrated scale (Ross & Marfell-Jones, 1991).

(c) Physical/motor components

For motor evaluation three tests were used: the Illinois *agility* run (Kirby, 1991 & www.brianmac.demon.co.uk/illinois.htm), the computerised *balance* test (Techno-Therapy, 1992), and the vertical jump for *explosive power*, measured using a tape-switch sensory mat connected to a Psion organiser (Boscosystem ErgoJump www.boscosystem.com).

1.5.2.2. Statistical methods of data processing

The Statistica (StatSoft, 2004) and the SAS-computer programme (SAS Institute Inc., 2005) of the North West University, Potchefstroom campus were used for statistical data analysis. Statistical software was used for all the data analysis. Data was processed using the Statistica-7 for Windows program (StatSoft Inc., 2005). Descriptive statistics, repeated measures ANOVA, two-way frequency tables, and effect sizes (practical significance) were used (Thomas & Nelson, 2001; Ellis & Steyn, 2003).

1.6. STRUCTURE OF THESIS

This thesis consists of five chapters:

Chapter 1: Problem statement and research aims of the study
Chapter 2: Literature review
Chapter 3: Empirical investigation
Chapter 4: Results and discussion
Chapter 5: Summary, conclusions and recommendations

CHAPTER 2

LITERATURE REVIEW

2.1. INTRODUCTION

2.2. BIOMECHANICS

- **2.2.1. Definitions of biomechanics**
  - **2.2.1.1. Symmetry**
  - **2.2.1.2. Dynamic mobility**
  - **2.2.1.3. Core stability**
- **2.2.2. The value of correct biomechanics in sport performance**
- **2.2.3. The effect of incorrect biomechanics (pathomechanics) on an athlete's performance**
- **2.2.4. Sports injuries**
  - **2.2.4.1. Definitions of sports injuries**
  - **2.2.4.2. Definitions of traumatic sports injuries in netball**
  - **2.2.4.3. Definitions of overuse injuries in netball**
- **2.2.5. Injury incidence in various sports**
- **2.2.6. Prevention strategies for sport injuries**

2.3. ANTHROPOMETRY

- **2.3.1. Brief history of anthropometry**
- **2.3.2. Definitions of anthropometry**
- **2.3.3. The value of anthropometry in sport performance**

2.4. AGILITY

- **2.4.1. Definitions of agility**
- **2.4.2. The value of agility for netball players**

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2.5.1. Definitions of balance

2.5.2. The value of balance for athletes

2.6. EXPLOSIVE POWER

2.7. SUMMARY

CHAPTER 2

LITERATURE REVIEW

2.1. INTRODUCTION

Chapter two will discuss in depth the literature reviewed for this particular study. The existing definitions of biomechanics, as well as the value of correct biomechanics and the effect of incorrect biomechanics will be investigated. The literature which will be discussed in this chapter will reveal the key role of biomechanics in injuries in various sport types and injuries associated with netball in particular. Because these injuries negatively affect a club's competitive performance and finances, the prevention of these injuries is crucial. This chapter will also look at injury prevention strategies that could be incorporated in a sport club's training programme. The essential roles of anthropometry and motor abilities (agility, balance and explosive leg power) in the performance and probability for injuries of a netball player will be investigated. Literature reveals that these components are significant in the demanding game of netball and could affect the outcome of a netball game. Finally, this chapter includes a detailed discussion of the preferred parameters (biomechanics, anthropometry and physical/motor abilities) that must be included in a club's prevention programmes.

2.2. BIOMECHANICS

2.2.1. Definitions of biomechanics

Below, the important role which biomechanics play in the performance of an athlete as well as the role faulty biomechanics play in the aetiology of injuries will be discussed with reference to existing literature on the subject. First, this chapter will consider the different definitions of biomechanics.

Brukner and Khan (2001) explain the term *biomechanics* as the evaluation of sporting technique (e.g. running biomechanics). Biomechanics is also described as the subjective analysis of the interdependence of different body parts (Neely, 1998). Whiting and Zernicke (1998) define biomechanics as the area of science that studies the application of mechanical principles (forces) to biological problems. Topics as diverse as forces in biological structures, blood-flow dynamics, human gait, prosthetic design and biomaterials fall under the broad spectrum of biomechanics (Bartlett, 1999). Human biomechanics include only humans, while exercise and sport biomechanics can be defined as the study of forces and the effects on humans in exercise, sport and sports injuries (McGinnis, 2005).

It is essential to understand the concept of biomechanics prior to assessing an athlete and determining the possible cause of an injury. Neely (1998) refers to good biomechanics as *near symmetry, good dynamic mobility* and *core stability* of the human body. The section on biomechanics in this particular study will assess these key variables (symmetry, good dynamic mobility and core stability); therefore the definition designed by Neely (1998) is the most accurate and applicable for the purpose of this study. The subsections of this definition, namely symmetry, dynamic mobility and core stability, will be explained in the following paragraphs.

2.2.1.1. Symmetry

With symmetry, a neutral postural position is implied. According to Brukner and Khan (2001:45), the ideal (neutral) stance position of the lower limb is described as the position in which the joint alignments of the lower limbs and feet are symmetrical, with the weight-bearing line passing through the anterior superior iliac spine (ASIS), the patella and the second metatarsal of the foot. The examiner must be aware that each person has an own mechanical make-up due to structural characteristics and may never assume the ideal position. The ideal position occurs when the feet are symmetrical, with the subtalar (talocalcaneal) joint neither in pronation nor supination and the midtarsal joint (talocalcaneal and calcaneocuboid joints) in full pronation.

The feet are considered neutral when the forefoot is perpendicular to the bisection of the heel, with the ankle joint neither in plantarflexion nor dorsiflexion. The tibia must be perpendicular to the supporting surface, the knee in full extension and the hips neither in internally nor externally rotation (Brukner & Khan, 2001:45). The ASIS must be level bilaterally, with a slight anterior tilt of the pelvis and with the ideal discrepancy measured as = 2 cm but < 3 cm (difference in height between the ASIS and the posterior sacroiliac spine (PSIS)). In this position, the ligaments and capsule give minimal resistance (Panjabi, 1992). The neutral position is dependant on three interactive systems of movements, namely passive osteoligamentous, active fascia and muscles and neural control. These systems are interdependent and any injury to these systems may affect the postural position. Panjabi (1992) explains the result of injury as an abnormal increase in the size of the neutral postural position or lack of control of the neutral position. Instability normally presents, and consequently compensatory strategies are adopted, resulting in incorrect biomechanics and posture. If the individual is exposed to repetitive stress, a strain will occur. Therefore, any individual with a symmetry dysfunction must be educated to automatically assume the neutral (symmetrical) position to prevent injuries (Panjabi, 1992).

2.2.1.2. Dynamic mobility

Mottram and Comerford (2001) believe that good dynamic mobility is synonymous with good flexibility of the global mobilising muscles. The terms *flexibility* and *global mobilising muscles* will be explained and discussed in detail in the following paragraphs. Firstly, flexibility is defined as the ability of a muscle or joint to move without resistance through the joint's maximum range of motion (Arnheim & Prentice, 2000). Kendall *et al.* (1993:29) define flexibility as the ability to readily adapt to changes in position or alignment and may be expressed as normal, limited or excessive.

Nicholas (1997) argues that flexible muscles move through a greater range of motion and produces more power for extended periods of time; therefore adequate flexibility means more strength and power to an athlete.

Armstrong and McManus (1996) claim that flexibility is an essential, though neglected aspect of conditioning and therefore, according to Arnheim and Prentice (2000), it results in decreased performance, altered technique and uncoordinated movements, and it predisposes athletes to muscle strains and tears. Decreased musculotendinous unit (MTU) flexibility is commonly regarded as a cause of soft tissue injury (Hughes, 2007). This predisposition to injury due to decreased flexibility may be attributed to inflexible MTU reaching failure at a shorter length, not being able to absorb high contraction forces or inflexible scar tissue formation as a result of neglected previous injuries (Hughes, 2007).

Adequate muscle flexibility enables the muscles to absorb greater forces during the eccentric contraction (lengthening phase) and consequently generate more force during the concentric contraction. Increased flexibility also results in alleviation of delayed onset of muscle soreness (DOMS), as well as improvement of overall muscle function, such as skill and relaxation and regaining loss of range of motion when rehabilitating after an injury (Hughes, 2007). Inadequate flexibility could be due to a hereditary component but over-activity, inactivity or injury may contribute to this problem as well (Brukner & Khan, 2001). Growth could influence an athlete's flexibility significantly. During growth spurts, a loss of flexibility in children may occur when joints become progressively taut, and as a result the risk of injury increases (Armstrong & McManus, 1996). Kendall *et al.* (1993), Williford *et al.* (1994) claim that age and body composition is two major factors that could influence an athlete's flexibility. These researchers studied the forward-bending test which assesses the length of the posterior muscles (back muscles, hamstring muscle) of persons in different age groups. The forward-bending test is also known as the sit-and-reach test. This test is performed with the subject sitting with legs extended (long-sitting) with feet at a right angle. Next, the subject must reach forward, trying to touch the base of the big toe, or beyond, with finger tips, reaching as far as range of muscle lengths permits. The ability to touch the toes with finger tips is considered normal for young children and adults (Kendall *et al.*, 1993).

However, many individuals between the ages of 11 and 14 years, who show no signs of muscle or joint tightness, are unable to touch their toes. The reason seems to be that the proportionate length of the trunk and lower extremities in individuals of this age group is different from that of younger and older age groups. Thus, the legs of individuals in the age group 11 to 14 years become proportionally longer in relation to their trunk (Kendall *et al.,* 1993).

Most sports therapists believe that maintaining good flexibility is important in the prevention of injuries to the musculotendinous unit, and consequently include stretching exercises in the warm-up before engaging in strenuous activity (Prentice, 1999). Karstens (2002) mentions that flexibility, like any other physical or motor ability, has to be maintained through training. One must remember that excessive flexibility may lead to hypermobile joints and that it may predispose the athlete to injury as well, due to the decreased joint stability (Jones & Knapik, 1999). Good body mechanics depend on adequate, not excessive, range of joint motion; therefore normal flexibility is a positive attribute, whereas excessive flexibility is not (Kendall *et al.,* 1993).

Kendall *et al.* (1993:3) refer to a basic principle regarding joint movements that claims that "the more flexibility, the less stability; the more stability, the less flexibility". However, a problem arises with this principle because skilled performance in a variety of sports such as dance and acrobatic activities requires excessive flexibility and muscle length. Although "the more the better" may apply to improving the skill of performance, it may adversely affect the well-being of the performer. The ideal range of movement of joints, which indicates the amount of flexibility, will be included in chapter three under biomechanics. These criteria for adequate flexibility and range of motion are accepted as a norm to work with when assessing an athlete's flexibility (Hattingh, 2003).

Secondly, global muscles are defined as the large outer units of the body, which generate torque to produce movement and spinal orientation and balance external loads (Mottram & Comerford, 2001). Brukner and Khan (2001) describe these muscles as the dynamic or phasic group which are the large, torque-producing muscles.

In the lumbo-pelvic area the largest global muscles are rectus abdominis, external oblique and the thoracic part of lumbar iliocostalis, which link the pelvis to the thoracic cage and provide general trunk stabilisation as well as movement. In conclusion, global muscles fulfil the primary function of load transfer and tend to tighten and shorten if overused and must be assessed and mobilised (stretched) when needed (Mottram & Comerford, 2001).

2.2.1.3. Core stability

The *definitions of core stability*, *the muscle involved in the core* and the *value of core stability* will be discussed in the following paragraphs. Core stability is the last component of the definition of good biomechanics. Kibler, Press and Sciascia (2006:190) define core stability as "the ability to control the position and motion of the trunk over the pelvis and legs to allow optimum production, transfer and control of force and motion to the terminal segment in integrated kinetic chain activities". The core is central to almost all kinetic chains of sports activities; therefore the control of core strength, balance and motion will maximise all kinetic chains of upper and lower extremity function (Kibler *et al.,* 2006). The core acts as an anatomical base for motion of the distal segments. Kibler *et al.* (2006:190) summarise this function of the core as "proximal stability for distal mobility" for throwing, kicking and running activities.

Physiological activation of the core muscles results in several biomechanical effects that allow efficient local and distal function of joints. The pre-programmed muscle activation result in anticipatory postural adjustments (APA), which position the body to withstand the perturbations to balance created by the forces of activities, such as kicking, throwing or running. These activations of the core muscles also create interactive moments that develop and control forces and loads at joints. The muscles in the central core create a large rigid cylinder and a large moment of inertia against body perturbation while still allowing a stable base for distal mobility (Kibler *et al.,* 2006).

The APA that create the proximal stability for distal mobility, are developed in the central body segments and are essential for developing proper force at distal joints and for creating relative bony positions that minimise internal loads at the joints (Kibler *et al.*, 2006). Function is most often produced by the kinetic chain, which is the coordinated, sequenced activation of body segments that places the distal segment in the optimum position at the optimum velocity with the optimum timing to produce the desired athletic activity (Kibler *et al.*, 2006).

The *muscles* responsible for core stability are the small, intrinsic muscles of the body, known as the local stabilisers (Mottram & Comerford, 2001). Kibler *et al.* (2006) indicate that the core muscle complex consists of numerous muscles, of which some are small and short with small lever arms to span single joints. These muscles are activated in "length-dependent" muscle activation patterns (Mottram & Comerford, 2001). Multifidi is an example of short muscles that provide single-joint segmental stabilisation that allow the longer, multi-joint muscles to work more efficiently to control spine motion. The core complex also consists of muscles which span numerous spinal segments and function as prime mover muscles to integrate several joints and to produce force. These muscles are activated in "force-dependent" activation patterns (Mottram & Comerford, 2001).

The core stabilising complex consists of the following muscles: lumbar multifidus, psoas major, quadratus lumborum, the lumbar parts of iliocostalis and longissimus, transversus abdominis, the diaphragm and the posterior fibres of internal oblique (Brukner & Khan, 2001). These muscles attach directly to the lumbar vertebrae and are responsible for providing segmental stability and control movements at the lumbar spine by increasing muscle tone when the body is subjected to load (Brukner & Khan, 2001 and Mottram & Comerford, 2001). Contracting the transverse abdominus increases intra-abdominal pressure and tensions the thoracolumbar fascia, which creates a rigid cylinder and enhances stiffness (stabilisation) of the lumbar spine during activity.

Research shows that contraction of the abdominal muscles provides postural support before limb movement, such as throwing, and therefore the spine and core of the body are stabilised before limb movements occur. This muscle activation allows the limbs to have a stable base for motion and muscle activation (Jensen, Laursen & Sjogaard, 2000). Clinical tests show that only a slight increase in activation of the multifidi and abdominal muscles is required to stiffen (stabilise) the spinal segment; 5% of maximal voluntary contraction is required for daily activities and 10% of maximal voluntary contraction is required for vigorous activity, such as sporting activities. Thus, it is clear that transverses abdominus plays a critical role in the stabilisation of the lumbar spine.

The *value of core stability* will be discussed in the following paragraphs. According to literature, the core muscles assist in creating the neutral zone. In this position (neutral zone) the ligaments are exposed to minimum tension and load. Panjabi (1992) defines the neutral zone as the range within spinal motion which is produced with limited internal resistance by passive spinal restraints. Brukner and Khan (2001) describe the core muscles as the postural and tonic muscles, which pre-anticipate movement and give stability around the neutral zone (Bell-Jenje & Bourne, 2003). The neutral position, which originates from the neutral zone, is the posture in which the overall internal stresses and muscular effort to maintain this position are minimal, making this the ideal posture to function in. Posture is defined as the relative arrangement of a person's body parts (Kendall *et al.,* 1993).

Kendall *et al.* (1993) refer to good posture as "the state of muscular and skeletal balance which protects the supporting structures of the body against injury or progressive deformity irrespective of the attitude in which these structures are working or resting in. In this position the muscles will function most efficiently and optimum positions are afforded for the thoracic- and abdominal organs." Kendall *et al.* (1993) describe poor posture as a faulty relationship of various body parts, which produces increased strain on the supporting structures. Poor posture causes insufficient balance of the body over its base of support (Kendall *et al.,* 1993).

Literature makes it clear that the core provides local strength and balance, and therefore maximises efficient athletic function and decreases the probability for injuries (Kibler *et al.,* 2006). Research shows a correlation between poor core stability and various injuries, especially back and knee injuries (Kibler *et al.,* 2006). Evidence shows that the function of two major local stabilisers, lumbar multifidus and transversus abdominis, is usually impaired in patients with low back pain. The activation of transverses abdominus has shown to be delayed in sufferers of chronic low back pain compared to individuals who have never experienced back pain before (Hodges & Richardson, 1998). Up to 70% of the population (including athletes) suffer from low back pain at some stage in their lives (Brukner & Khan, 2001).

According to Kibler *et al.* (2006) most of the prime mover muscles for the distal segments (arms and legs), such as latissimus dorsi, pectoralis major, hamstrings, quadriceps and iliopsoas, attach to the core of the pelvis and the spine. The major stabilising muscles for the extremities (upper and lower trapezius, hip rotators and glutei) also attach to the core; therefore weak hip muscles which result in the alteration of hip and trunk positions are a common finding associated with knee injuries. Weak hip abductors and tight hip flexors are associated with anterior knee pain and chondromalacia patellae (McConnell, 2002). Alterations in hip muscle activity are associated with an increase in hip varus, hip flexion and knee valgus in squatting or landing activities, and therefore increases load on the anterior cruciate ligament (ACL) leading to ACL injuries (McConnell, 2002). Leetun, Ireland and Wilson (2004) found that weak hip external rotators are correlated with knee injuries. Based on these associations, most rehabilitation and conditioning programmes for the knee now emphasise core stability and hip strengthening exercises (Malone, Davies & Walsh, 2002).

To accentuate the key role core stability plays in multiple injury rehabilitation, Brukner and Khan (2001) explain the essence of core strength and stability of the pelvic complex in hamstring injury rehabilitation.

Brukner and Khan (2001) conclude that excessive movement of the pelvis in sprinting increases the loading on the hamstrings and this can lead to the occurrence of a hamstring tear. A core rehabilitation programme usually consists of low load exercises, but the inclusion of running sessions (3-6 km, once a week), performed with good pelvic control is of utmost importance. The aim of this combination is to maintain basic trunk stability that will contribute towards preventing the recurrence of a hamstring injury (Brukner & Khan, 2001). Literature stresses the necessity for these muscles to be strengthened through motor learning exercise protocols, which focus on stability training and practising of correct recruitment sequencing. These protocols could teach athletes to isolate and condition these stabilising muscles (Jull & Richardson, 2000). In terms of sport, this means that athletes will become stable and less likely to experience injuries, especially of the lower back and lower limbs (Luger & Pook, 2004).

To summarise, various definitions for biomechanics have been applied in different research studies on sport-specific issues. Neely's (1998) definition of biomechanics is the most appropriate and specific definition in existing literature. It describes biomechanics as a complex, integrated parameter that must be investigated thoroughly and for which all aspects – namely symmetry, good dynamic mobility and core stability – must be taken into consideration. These aspects must be included in the athlete's assessment and in his conditioning programme.

2.2.2. The value of correct biomechanics in sport performance

In the medical world it is becoming increasingly aware that correct biomechanics play a key role in an athlete's performance as well as in minimising the athlete's probability for injury. Researchers believe that humans with good biomechanics experience less energy expenditure, along with increased muscle efficiency, resulting in decreased stress and fatigue (increased performance and decreased injuries) (Neely, 1998).

These biomechanical principles can be used to provide the basis for alterations in technique, equipment, posture or training, to prevent or rehabilitate injuries (McGinnis, 2005). Brukner and Khan (2001) have found that correct biomechanics reduce the risk of injury by providing efficient joint movement. Similar findings were made by Cook *et al.* (2000), in their investigation of the way in which correct biomechanics in landing techniques affected the lower limb. Although there are various definitions of biomechanics, in the above context it refers to the technique of landing. Cook *et al.* (2000) found that landing from a vertical jump with the correct biomechanics can reduce the vertical ground reaction force on the lower limb with 25%, therefore minimising the risk for injury. The study concluded that flat foot landing combined with a larger range of knee- and hip flexion, rather than forefoot landing, reduces the ground reaction forces. This is an essential biomechanical adjustment due because approximately 40% of the landing energy is absorbed through the ankle joint and calf muscles, which are then transmitted to the knee. Thus, the calf complex must function well to fulfil this shock absorbing role (Cook *et al.,* 2000). Richards, Ajeman and Wiley (1996) found that with patellar tendonitis, the correct biomechanics improve the energy-absorbing capacity of the limb both at the affected musculoskeletal junction as well as at the hip and ankle joints.

The findings of the above-mentioned study are supported by research conducted by Hass *et al.* (2005) on the biomechanics of the knee during landing. Hass *et al.* (2005) emphasised that lower-extremity skeletal malalignment contributes to knee injuries, especially during strenuous activities like jumping and landing. Structural malalignments, related to the occurrence of injury, include excessive Q-angle, thigh-foot angle, genu recurvatum, femoral anteversion, decreased intercondylar notch width, decreased notch width index and generalised joint laxity (Hass *et al.,* 2005). The study compared the landing techniques of prepubescent females (8-11 years of age) with those of postpubescent females (18-25 years of age). Hass *et al.* (2005) found that landing with a degree of knee flexion stabilises the knee, therefore decreasing the probability of knee injuries. Interestingly, this study found that postpubescent females are more prone to lower-limb injuries than both prepubescent females and male athletes.

Hass *et al.* (2005) concluded that this finding may be ascribed to the fact that postpubescent females land with greater knee extension and adduction than prepubescent females and male athletes, therefore making postpubescent players more susceptible to knee injuries. According to Steele (1990), players must adopt the following technique modifications to decrease the occurrence of ankle and knee injuries:

- Land with the foot neutrally aligned to eliminate excessive ankle adduction-abduction, internal rotation or dorsiflexion;
- ensure adequate hip flexion (approximately 33° at foot-ground contact and 45° at peak resultant force) and adequate knee flexion (approximately 17° at foot-ground contact and 40° at peak resultant force);
- reduce the foot-hip displacement by eliminating an exaggerated "striding out" position often adopted at landing by netball players.

Evidently, correct biomechanics are beneficial to an athlete due to the direct effect correct biomechanics has on an athlete's performance. Neely (1998) indicates that humans with good biomechanics experience less energy expenditure along with increased muscle efficiency, with resultant decreased stress and fatigue. Therefore, correct biomechanics ensure increased performance with decreased injuries.

2.2.3. The effect of incorrect biomechanics (pathomechanics) on an athlete's performance

Many studies on various sport types concluded that incorrect biomechanics influence an athlete's ability to perform, and increase the athlete's risk for injury. Below, literature on the effects of incorrect biomechanics and injuries associated with faulty biomechanics in various sport types will be discussed.

Brukner and Khan (2001: 43) discuss the negative effect incorrect biomechanics could have on an athlete's performance with reference to javelin as a sport: "A javelin thrower with incorrect biomechanics will not only have a shorter throw than he or she could have but is also more prone to injury." Incorrect biomechanics, also known as pathomechanics, refers to mechanical forces that affect the body due to a structural body deviation, which may lead to faulty alignment; therefore pathomechanics may precede an injury (Brukner & Khan, 2001). According to literature, the lower limbs (knee and ankle joints) are more prone to injury than any other joints, in various sports types. One of the multiple causes of these injuries are incorrect biomechanics (Brukner & Khan, 2001).

Murphy *et al.* (2003) point out that according to the National Collegiate Athletic Association injury surveillance system for 2000-2001, done in the United States of America, the ankle, knee and lower leg are the most common sites susceptible to injury. Many studies conducted on rugby injuries show that the most common site of injury is the lower limb (Babic *et al.*, 2001). Babic *et al.* (2001) found that 47.62% of injuries in the Croatian-Slovenian rugby first league in the 1996/97 season were of the lower limb. The prevalence of lower limb injuries were found to be 51.7% amongst elite Australian rugby union players who represented Australia in the Wallaby team between 1994 and 2000 (Bathgate *et al.*, 2002).

A study conducted by Erasmus (2006) on the effect of a prevention programme on the rugby injuries of 15- and 16-year old schoolboys, reported that the anatomical site most commonly injured among all participants were the lower limb, at 57.91% for the 15-year old experimental group, 59.99% for the 15-year old control group, 70% for the 16-year old experimental group and 50% for the 16-year old control group. These results were compliant with the recent findings of Hattingh (2003:150, 154) for lower limb injuries among 15-year old players (55.42%), 18-year olds (56.67%), 19-year olds (72.72%) and 20-year olds (66.65%). Hass *et al.* (2005) found that lower limb injuries are the most common injuries among netball players as well; therefore this study will focus primarily on the lower limbs and injuries occurring at these areas (ankle, knee joints and lower leg) (Hass *et al.,* 2005).

The following table summarises the most familiar non-traumatic (overuse) lower limb injuries and the biomechanical abnormalities usually detected with these injuries (Brukner & Khan, 2001:54):

Table 2.1 Lower limb injuries and associated biomechanical abnormalities

Overuse Injuries	*Associated biomechanical abnormalities*
Sesamoiditis	• Pronated foot • Abducted gait
Plantar fasciitis	• Pronated foot/high arched foot • Abducted gait • Ankle equines
Achilles tendinopathy	• Pronated foot • Ankle equines
Peroneal tendinopathy	• Pronated foot at toe-off
Patellar tendinopathy	• Pronated foot • Tight quadriceps, hamstring, calves • Anterior pelvic tilt • Varus alignment
Patellofemoral syndrome	• Pronated foot • Anterior pelvic tilt • Varus alignment • Abducted gait
Iliotibial band friction syndrome	• Lateral pelvic tilt • Varus alignment
Hamstring strain	• Anterior pelvic tilt
Metatarsal stress fracture	• Pronated foot • Supinated foot
Navicular stress fracture	• Pronated foot • Varus alignment

Overuse Injuries	*Associated biomechanical abnormalities*
Fibular stress fracture	• Supinated foot • Pronated foot • Varus alignment

The following overuse injuries in the previous table are mostly associated with netball players (Brukner & Khan, 2001):

Table 2.2 Overuse injuries associated with netball

Patellar tendinopathy	• Pronated foot • Tight quadriceps, hamstring, calves • Anterior pelvic tilt • Varus alignment
Medial shin pain	• Pronated foot • Ankle equines • Varus alignment • Abducted gait
Patellofemoral syndrome	• Pronated foot • Anterior pelvic tilt • Varus alignment • Abducted gait

Two types of abnormalities are considered as the cause of pathomechanics. Firstly, anatomical (static) abnormalities include leg length discrepancies and knee joint malalignment (Brukner & Khan, 2001). Leg length discrepancies and knee joint malalignment are examples of intrinsic factors that could contribute to injuries.

These abnormalities cannot be altered but the secondary effects can be minimised by compensatory devices such as a shoe build-up in the case of leg length discrepancy or an orthotic in the case of genu valgum (Brukner & Khan, 2001). Secondly, functional (secondary) defaults that are abnormalities which may occur following an injury or due to incorrect technique, for example, a ligament sprain, may result in joint laxity, while a lengthy period of immobilisation may lead to muscle imbalances (Brukner & Khan, 2001). Poor technique can cause abnormal biomechanics and contribute to subsequent injury, traumatic or non-traumatic (overuse) injuries.

The following table will reveal different technique faults and possible associated overuse injuries in different sports caused by incorrect biomechanics (Brukner & Khan, 2001: 44):

Table 2.3 Correlation of technique faults with injury

Sport	*Technique*	*Overuse Injury*
Tennis	• Excessive wrist action with backhand	• Extensor tendinopathy
	• Service contact made too far back	• Flexor tendinopathy
Swimming	• Insufficient body roll	• Rotator cuff tendinopathy
	• Low elbow on recovery	• Rotator cuff tendinopathy
	• Insufficient external rotation of the shoulder	• Rotator cuff tendinopathy
Diving	• Shooting at the water too early	• Lumbar spine injuries
Cycling	• Incorrect handlebar and saddle height	• Thoracic/lumbar spine injuries
	• Toe in / toe out on cleats	• Iliotibial band / patellofemoral syndrome
Javelin	• Elbow "dropped"	• Medial elbow pain
	• Poor hip drive	• Thoracic/lumbar spine

Sport	*Technique*	*Overuse Injury*
		dysfunction
Triple jump	• “Blocking” on step phase	• Sacroiliac/lumbar spine injuries, patellar tendinopathy, sinus tarsi syndrome
High jump	• Incorrect foot plant	• Patellar tendinopathy, sinus tarsi syndrome, fibular stress fracture
Running	• Anterior pelvic tilt	• Hamstring injuries
	• Poor lateral pelvic control	• Iliotibial band friction syndrome
Baseball pitching	• Opening too soon	• Anterior shoulder instability, medial collateral ligament sprains of the elbow, osteochondritis radiocapitellar joint
	• Dropped elbow ‘hanging’	• Rotator cuff tendinopathy
Gymnastics	• Excessive hyperextension on landing	• Stress fracture pars interarticularis
	• Tumble too short (not enough rotation)	• Anterior ankle impingement
Rowing	• Change from bow side to stroke side	• Stress fracture ribs
Ballet	• Poor turnout	• Hip injuries, medial knee pain, stress fracture second metatarsal

In the table, it is evident that pathomechanics usually lies at the root of overuse injuries (Arnheim & Prentice, 2000). The main objective of the examiner must be to detect the cause of the overuse injury immediately.

The cause may be evident or subtle: more evident causes are a sudden increase in training quantity, poor footwear or a biomechanical abnormality, while more subtle causes include running on a cambered surface, leg length discrepancies or muscle imbalances. Muscle imbalances are an example of pathomechanics.

The occurrence of muscle imbalances in the biomechanical system may lead to joint dysfunction, postural imbalances and ultimately injury (Bell-Jenje & Bourne, 2003). According to Kendall *et al.* (1993), muscle imbalances have negative effects on the alignment and the function of the human body. Muscle imbalances distort joint alignment, thus placing the joints, ligaments and muscles under excessive stresses and strains.

The causes of overuse injuries are usually divided into extrinsic factors and intrinsic factors (Rossouw & Rossouw, 2003). Both types of risk factors can modify the occurrence of a participant's sustaining an injury and/or the severity of the possible injury (Fuller & Drawer, 2004). The following table will give a more thorough explanation of these factors (Jones & Knapik, 1999):

Table 2.4 Overuse injuries: predisposing causes

1. Extrinsic factors	*Causes*
a. Training errors	• Excessive volume
	• Excessive intensity
	• Rapid increase
	• Sudden change in type of exercise
	• Excessive fatigue
	• Inadequate recovery
	• Faulty technique
b. Venue	• State of floor or ground
	• Lighting
	• Safety measures

1. Extrinsic factors	*Causes*
c. Shoes	• Inappropriate
	• Worn out
d. Equipment	• Inappropriate tools e.g. racket
	• Risk acceptance
f. Weather conditions	• Relative humidity
	• Wind
g. Trainer	• Conduct of matches
	• Rules
	• Referee's application of rules
h. Inadequate nutrition	
2. Intrinsic factors	*Causes*
a. Malalignment	Pes planus
	Pes cavus
	Rear foot varus
	Tibia vara
	Tibia valgum
	Tibia varum
	Restricted joint range of motion
b. Physical fitness	Muscle endurance
	Aerobic endurance
	Strength
	Speed
	Flexibility of muscles
c. Psychological factors	Self-concept
	Locus of control
c. Sex, size, body composition	
d. Other	Genetic factors, endocrine factors, metabolic conditions

Posture analysis is a subdivision of the biomechanical assessment. Kendall *et al.* (1993:4) argue that: "faulty posture places constant and repetitive small stresses on the human body and could cause the same kind of difficulties, over an extended period, as a sudden severe stress or trauma". Arnheim and Prentice (2000) report that postural deviations in athletes could lead to sports injuries. The origin of postural malalignment may be due to unilateral muscle and soft-tissue asymmetries or bony asymmetries. These asymmetries could be the result of many sports activities, such as cricket and tennis, which are unilateral, thus causing asymmetries in body development (Brukner & Khan, 2001). As a result, the athlete engages in poor mechanics of movement (pathomechanics). The resulting imbalances are manifested by a postural deviation as the body seeks to re-establish itself in relation to its centre of gravity. Often, such deviations are the primary cause of overuse injury. For example, a consistent pattern of knee injury may be related to asymmetries within the pelvis and the legs (short-leg syndrome), therefore resulting in incorrect biomechanics. Literature indicates that incorrect biomechanics are considered as a potential cause of non-traumatic sporting injuries (overuse injuries) (Brukner & Khan, 2001).

According to Brukner and Khan (2001), incorrect biomechanics, such as faulty technique, could also contribute to the occurrence of injuries (traumatic injuries). Incorrect landing could overload the ankle and knee joint and evidently lead to ligamentous strains. According to Hopper and Elliot (1993), most injuries in netball occur when landing from a jump, with the ankle and subtalar joints in a position of plantar flexion and inversion respectively. The position of the foot at the time of landing influences the magnitude of the vertical ground reaction forces. Subjects normally adopt one of two landing techniques: some land on the forefoot, while others land relatively flat-footed. Flat-foot landing increases the ground reaction forces because there is less time to decrease the velocity of the heel after foot strike (Hopper & Elliot, 1993). Neal and Sydney-Smith (1992) maintain that receiving a pass when jumping can influence the player's foot position at landing, while Steele and Milburn (1989) have found that when receiving a pass from chest height, the subjects tend to land on the heel, whereas higher passes tend to lead to forefoot landing.

Although landing on the forefoot may therefore be the recommended landing technique to decrease ground reaction forces, there is evidence that this technique increases stresses in certain structures. In jogging, for instance, the initial ground reaction forces were significantly higher than those during forefoot jogging, but 20% higher forces were generated in the Achilles tendon and ankle joints during forefoot running (Denoth, 1986). Therefore, it is apparent that muscle activity and movement at the lower limb joints influence the magnitude of impact forces and resultant joint loadings. If the neuromuscular system is unable to control joint motion at that time, inevitably the lateral ligament complex is exposed to increased stress, and injury may occur (Hopper *et al.*, 1999).

To summarise, intrinsic and extrinsic factors could contribute to an injury (Rossouw & Rossouw, 2003). Incorrect biomechanics (static and functional) are an example of an intrinsic factor which could contribute greatly to the occurrence of sports injuries, especially in a physically demanding game as netball. Interventions can be applied to decrease the effect of incorrect biomechanics on athletes: in the case of static abnormalities, compensatory devices could be incorporated and the correct technique could be developed where functional deviations are detected as the cause of the injury (Derman & Schwellnus, 2001).

2.2.4. Sports injuries

Various definitions and grading of sports injuries will be discussed in this section. Injuries will be categorised into injuries caused by trauma on the sports field and non-traumatic sports injuries known as overuse injuries. The definition and grading of the severity of an injury that will be used in this particular study for netball injuries will be stipulated.

2.2.4.1. Definitions of sports injuries

According to Neely (1998), when studying injuries one must consider the definitions and population concerned. There are still inconsistencies regarding definitions of injury, severity of injury and when an injury is regarded as "significant". Lysens, De Weerdt and Nieuwboer (1991) define "sports injury" as all types of injuries sustained while participating in sports activities, while "injury" is the damage caused by physical trauma to structures of the body (Whiting & Zernicke, 1998).

Many different definitions of injury have been used in various studies on strength, flexibility and sports injuries (Knapik *et al.*, 1992). Different operational definitions of injury exist, even within a specific sport, such as rugby or netball. Below, definitions of rugby injuries are discussed first.

The two most specific definitions of injuries sustained while playing rugby are those by Lee, Garraway and Arneil (2001), and by Garraway and Macleod (1995). Lee *et al.* (2001:412) define a rugby injury as "an injury sustained on the field during a competitive match or during training, which prevented the player from playing or training from the time of injury or from the end of the match or training session in which the injury was sustained". Garraway and Macleod (1995:1485) define a rugby injury as "an injury sustained on the field during a competitive match or during training, *or during other training actively directly associated with rugby,* which prevented the player from playing or training from the time of injury or from the end of the match or training session in which the injury was sustained". Many South African studies use this definition to code the severity of an injury.

The second important aspect that must be considered when investigating an injury is the severity of that injury. According Armsey and Hosey (2004), the severity of sports injuries can be described on the basis of the following criteria:

- The nature of the sports injury;
- duration and nature of the necessary treatment;
- amount of sporting time lost;
- days needed to recover;
- working time (participating time) lost;
- permanent damage; and
- costs involved (treatment costs).

There are different classification systems to describe the severity of sports injuries, based on the type of tissue (e.g. bone vs. ligament) and body regions (e.g. head vs. leg) which are involved (Whiting & Zernicke, 1998). The more damage to the tissue, the more severe the injury. The grade of severity could be described as mild, moderate or severe, depending on the corresponding performance deficit or functional limitation of the athlete.

The National Athletic Injury Registration System (NAIRS) in the United States of America (USA) grades injuries according to the duration of the time that the athlete is unable to return to the specific sport: 1 to 7 days of incapacitation is graded as "minor", 8 to 21 days as "moderately serious", and over 21 days or permanent damage as "serious" (Van Mechelen, Hlobil & Kemper, 1992:85). Injuries which allowed a player to return to rugby practice within seven days of its occurrence are graded as transient (Lee *et al.*, 2001). Armsey and Hosey, (2004) point out that most definitions agree that injuries are graded as significant if the athlete is incapacitated for 7 days or more.

Secondly, the definitions and grading of netball injuries will be studied. Literature on netball does not define the term "injury" adequately. Hopper, Elliot and Lalor, (1995) describe an injury as a situation when a player requires immediate treatment or where a body part presents with some degree of disability. These criteria for an injury were used again in other two surveys conducted by Hopper: the one survey was conducted with Jones (1983) on netball injuries at Matthews Netball Centre in Western Australia and the second survey, in 1986, was on netball and conditions related to netball injuries.

In 1993 Hopper and Elliot studied lower limb and back injury patterns of elite netball players. From the 240 players that participated in this study, 23% sustained an injury. Most of the injuries were ligamentous (40.5%), with some overuse tendinitis (11.5%). For this study the working definition for an injury was considered as a disability that caused pain and some degree of dysfunction (Hopper & Elliot, 1993).

The researcher considers the definitions on an injury sustained while playing netball to be inadequate and non-specific; therefore the definition incorporated by Garraway and Macleod (1995:1485) for rugby injuries will be applied in this particular study. Thus, for the purpose of this research, the following definition of a netball injury will be used: "an injury sustained on the field during a competitive match or during training, or during other active training directly associated with netball, which prevented the player from playing or training from the time of injury or from the end of the match or training session in which the injury was sustained". The severity of injuries has to be determined when injuries in a specific sport are investigated. Hopper and Elliot (1993:151) used the following classification of the severity of an ankle injury in a study on lower limb and back injury patterns of elite netball players:

- *Grade 1:* 4% to 10% deformation, with only a few fibres torn, capsule intact and a stable joint;
- *Grade 2:* 10% to 20% deformation, with more than 50% of fibres torn, capsule possibly torn and the joint unstable; and
- *Grade 3:* avulsion fracture, fracture or a complete rupture of the structures.

Because this grading is only applicable to ankle injuries and cannot be applied to injuries of other body parts, this grading system is inadequate. The definition of the severity of injuries formulated by NAIRS will be applied in this study: 1 to 7 days of incapacitation is graded as "minor", 8 to 21 days as "moderately serious", and over 21 days or permanent damage as "serious" (Van Mechelen *et al.,* 1992:85).

To summarise, there are many inconsistencies in the definition of a significant sports injury and the severity of an injury. In the sport of netball the available definitions are inadequate and out-dated; therefore the definition derived from Garraway and Macleod (1995:1458) will be used, while the severity of injury will be graded according to the definition of the NAIRS (Van Mechelen *et al.*, 1992:85).

2.2.4.2. Definitions of traumatic sports injuries in netball

Brukner and Khan (2001) define a traumatic sports injury as the occurrence of a soft tissue and/or a bone lesion after a specific physical incident. In netball this incident is usually described as a slip, a fall or a collision with another player (Hopper, 1986). According to literature, the joints mostly affected by traumatic injuries in netball are the ankle and knee joint. In a study conducted by Hopper (1986), the incidence of injury revealed that 58.2% of injuries occurred at the ankle; 15.2% at the knee; 13.3% at the hand and 13.3% at other parts of the body. Incorrect landing (73.8%), a slip or a fall (74.2%) was the main causes of these injuries.

A study on lower limb and back injury patterns of elite netball players reported 30.2% ankle injuries, followed by 15.9% shin/calf injuries. A similar incidence of perceived reason for injury was recorded for contact with another player (29%), and incorrect landing (29%), followed by a slip, trip or sudden stop (21%) (Hopper *et al.,* 1995). These findings were similar to the results from a one day veterans' netball tournament, where 29.6% of players presented with ankle injuries and 13.6% complained of leg/calf problems (Steele, 1990). According to Hopper and Jones (1983), the ankle, knee and hand are the most common sites to be injured.

Many studies conclude that statistically the ankle and knee joints are the most susceptible to injury. Literature points out that the position of the foot (forefoot/flatfoot) (Hopper *et al.,* 1999) and the position of the knee (amount of knee flexion) (Hass *et al.,* 2005) could influence the probability of injuries at these joints.

2.2.4.3. Definitions of overuse injuries in netball

Overuse injuries are defined as injuries to a body part of an athlete or individual where no trauma was involved (Brukner & Khan, 2001). According to Kendall *et al.* (1993), overuse injuries could be caused by faulty posture which places constant and repetitive small stresses on the human body and could, over an extended period, cause the same kind of difficulties as a sudden severe stress or trauma. Brukner and Khan (2001) consider incorrect biomechanics as a potential cause of non-traumatic sporting injuries (overuse injuries). Literature proves that incorrect biomechanics, static (Table 2.1) and functional abnormalities (Table 2.2), as well as extrinsic factors (Table 2.3) may lead to overuse injuries.

Specific overuse injuries associated with netball will be discussed in the following paragraphs. It is clear that incorrect biomechanics are associated with overuse injuries in various sport types. Literature makes it clear that netball is mostly associated with four overuse injuries, namely *patellar tendonitis, retropatellar pain, shin splints* and *fatpad impingement* (Brukner & Khan, 2001).

Firstly, the possible causes of *patellar tendinitis*, as identified in literature, will be discussed. The repeated jumping and landing activities of netball overload the patellar tendon, and thereby contribute excessively to overuse injuries (Brukner & Khan, 2001). Numerous functional biomechanical abnormalities are associated with patellar tendonitis, e.g. inflexibility of musculus (m) hamstrings, iliotibial band and calf muscles, combined with restricted knee and ankle range of motion. Weakness of the gluteal, lower abdominal, quadriceps and calf muscles leads to fatigue and aberrant movement patterns, therefore altering forces acting on the knee and restricting range of motion during an activity, which could contribute to the occurrence of injuries (Brukner & Khan, 2001). These deviations overload the patellar tendon and could cause tendinitis.

A study conducted by Hopper and Elliot (1993) obtained the same results. Hopper and Elliot (1993) did a study on the relations between lower limb and back injuries with perceived landing patterns and podiatric variables for injured and uninjured elite netball players. More than 25% of the 240 participants had overuse type injuries, which consisted of *retropatellar pain* (24%) and *shin pain* (38%) (Hopper & Elliot, 1993). Ninety two percent of the 228 participants were given a podiatric assessment.

The study found that 22.5% of the players were cleared as "normal", while an astonishing 42.1% of the players presented with rear foot varus with compensating subtalar pronation. Excessive pronation may produce an unstable forefoot, making the netball player susceptible to an ankle sprain (Donatelli, 1990). Brukner and Khan (2001) reported that the following biomechanical abnormalities have been associated with patellofemoral pain: internal femoral rotation, increased Q angle, and excessive subtalar pronation. The above-mentioned biomechanical deviations could be accompanied by decreased flexibility in the following muscles: gastrocnemius, hamstring, rectus femoris, vastus lateralis, and tightness of the iliotibial band and lateral retinaculum. The cause of stress fractures, periostitis and compartment syndrome could be excessive subtalar pronation, which requires the muscles of the lower leg to contract harder and longer, therefore causing fatigue (Brukner & Khan, 2001). With fatigue, the muscles fail to provide the normal degree of shock absorption. This mechanism may lead to the development of these injuries. The occurrence of fatpad impingement is associated with biomechanical deviations, namely hyperextension of the knees and increased anterior pelvis tilt (Brukner & Khan, 2001).

Injuries may have permanent negative effects, such as arthritis, on an athlete's body, therefore the incidence of injuries must be minimised. Injuries have a definite influence on players' subsequent lifestyles: the impact of sport-related lower limb injuries, for example, could have a life-long negative effect on an athlete's quality of life, as there is evidence that knee and ankle injuries could result in an increased risk of osteoarthritis in later life (Emery *et al.*, 2005). Therefore, it is of utmost importance to develop injury prevention programmes to minimise the risk and probability of injuries in all sport types.

In conclusion, overuse injuries occur in the absence of trauma and are caused by faulty biomechanics. Incorrect biomechanics are categorised as static (joint alignment) and functional (incorrect technique) abnormalities. Overuse injuries such as patellar tendonitis, retropatellar pain, shin splints and fatpad impingement are greatly associated with the sport of netball.

2.2.5. Injury incidence in various sports

Below, the incidence of injuries in various sports will be studied firstly, and thereafter the incidence of injuries in netball will be investigated. *Injury incidence* is defined as the number of new injuries in a fixed time period divided by the number of people at risk (Whiting & Zernicke, 1998). The injury incidence can also be expressed in terms of injury rate, which is the number of injuries in a population divided by a reference number (Whiting & Zernicke, 1998), where a reference measure can be the number of hours of exposure, the number of kilometres run or the number of games played. Examples of injury rates include the number of injuries per year, injuries per match, injuries per season, injuries per 1000 players or injuries per 1000 hours of participation (Whiting & Zernicke, 1998).

Van Mechelen *et al.* (1992) propose that sports injury incidence should preferably be expressed as number of injuries per exposure time, therefore the number of injuries per 1000 hours of participation. Incidence values are useful to estimate and evaluate the level of risk for participants in a specific sport (Fuller & Drawer, 2004). Burt and Overpeck (2001) estimate that an average of 2.6 million emergency department visits occur due to sports participation per year in the USA for individuals aged between 5 and 24 years. The highest average annual sports and recreation related injury episode rates are for children aged between 5 and 14 years (59.3 per 1000 participants) followed by persons aged between 15 and 24 years (56.4 per 1000 participants).

Backx *et al.* (1989) did a survey in the USA on 7468 children aged between 8 and 17 years and reported twice as many injuries in the group of females aged between 13 and 16 years than in the females aged between 8 and 12 years. Thus the risk ratio for injury was greater for the older group (2.07) than for the younger group (1.17) (Backx *et al.*, 1989). Similarly, DeHaven and Linter (1986) evaluated 3431 cases of athletic injuries in the USA. The purpose of the study was to determine differences among gender, sport and age groups regarding sports injuries.

The authors reported that for ages 13-25 years, the incidence of patellofemoral pain, internal knee derangement and ligamentous sprains of the knee increased with increasing age. DeHaven and Linter (1986) also reported that injuries were more concentrated at the knee joint in female participants than in male athletes.

Hopper, McNair and Elliott (1999) did a study on the effects of taping and bracing at the ankle joint of netball players. The lateral ligaments of the ankle are the most common site of injury in netball (Hopper *et al.*, 1995). The incidence of ankle injuries of netball players in Australia and New Zealand has been reported to be 3.3 injuries per 1000 hours of participation, which is higher than that reported for soccer (1.7-2.0 injuries per 1000 hours) (Ekstrand & Tropp, 1990), volleyball (2.6 injuries per 1000 hours) (Bahr, Karlson & Overbo, 1994) and rugby union (2.34/1000 player hours) (Roux *et al.*, 1987), but lower than that of basketball (5.5 injuries per 1000 hours) (Leanderson & Wredmark, 1995). On the other hand, a study conducted by Serfontein (2006) on rugby players reveal an injury incidence of 4.96/1000 player hours, therefore higher than the injury incidence of netball players. A study conducted by Eggar (1990) reported that netball has a higher injury rate than football, hockey, cricket and basketball in Australia.

A survey conducted in Western Australia on netball injuries and conditions related to these injuries, reported a total of 158 injuries in a population of 3108 participants; therefore 5.2% of the total population sustained an injury (Hopper, 1986). Most of the injured players (113) were seniors players, aged between 16 and 22 years, while 45 junior players (12-15 years) presented with an injury (Hopper, 1986).

The study revealed that 35.3% of the injuries occurred in the highest grade (A grade) players, while only 3.5% occurred in the lowest grade (G grade). Thus, a higher injury rate was reported among the more skilful players (grade A), because these players were more determined and focused on winning and consequently took greater risks during play, which made them more vulnerable to injury (Hopper, 1986).

Hopper *et al.* (1995) completed a descriptive epidemiology of netball injuries during competitive tournaments in Western Australia. The study was conducted over a five year period (1985-1989), during which 608 players of the 11228 participants presented with an injury, bringing the overall incidence rate of injury 5.4%. Ankle injuries (84%) were most frequent, and 67% of these injuries were diagnosed as lateral ligament sprains while 10% of the injuries involved a fracture to the foot or ankle. Knee injuries represented 8.3% of the total number of injuries. The overall incidence rate was 5.4%, with the direct probability of a netball player's injury risk estimated at 0.054 per person per game; therefore netball is a relatively safe game to participate in.

In conclusion, netball is considered a safe sport, but despite the low injury rates, studies reported that netball still has a higher injury rate than Australian football, basketball, hockey, cricket (Eggar, 1990), soccer (Ekstrand & Tropp, 1990) and volleyball (Bahr *et al.,* 1994) in Australia. For that reason it is essential to incorporate preventative measures in each player's conditioning programme.

2.2.6. Prevention strategies for sports injuries

According to literature, injuries are a common phenomenon in the world of sports, with a direct effect on the performance and success of an athlete. The negative financial implications for the athlete or club must be taken into consideration as well, due to the costs involved in the medical interventions and rehabilitation associated with sports injuries. Because prevention is better than cure, sports management must focus on prevention strategies to reduce the rate of injuries among athletes.

Some believe that the primary aim of exercise and sports biomechanics should be "injury prevention and rehabilitation" (McGinnis, 2005). The following section will give an overview of the shortcomings of injury prevention as well as the interventions that could make a positive contribution towards preventing injuries.

Brukner and Khan (2001) argue that injury prevention remains largely neglected in the world of sport. Prevention could be categorised as "primary", "secondary" and "tertiary" prevention (Brukner & Khan, 2001). These are described as:

- Primary prevention – to promote health and prevent diseases.
- Secondary prevention – the diagnosis and treatment of a condition to limit the development of a disability.
- Tertiary prevention – the rehabilitation of the condition to reduce or correct the existing disability.

Junge *et al.* (2004) recommend the development and implementation of preventative interventions to reduce the severity and rate of injury. Gabbet (2004:856) stresses that the implementation and evaluation of effective injury prevention strategies depend on the identification of injury risk factors. Engebretsen and Bahr (2005:312) justify the need for research into the new field of prevention of sports injuries with three important points:

- It should firstly ask important questions not answered by others.
- This new field should potentially create truly new knowledge and lead to new ways of thinking and improving the health of patients.
- Lastly, results from this research should be publishable in respected peer-reviewed journals and presented at high quality meetings.

Many researchers agree on the importance of early detection of possible aspects that could lead to an injury. Armsey and Hosey (2004) point out that a clinical examination (biomechanical analysis) that concentrates on the detection of musculo-skeletal defects could be useful in the prediction of future injuries.

A biomechanical analysis focuses on the athlete's musculo-skeletal integrity. Armsey and Hosey (2004) report that, fortunately, sport pre-participation physical examination has become an annual undertaking in the sports-medicine community. The aims of pre-participation assessment are to examine an athlete for an existing injury, and secondly to screen for identifiable underlying injury risk factors (Schwellnus & Derman, 2001). Kendall *et al.* (1993) indicate that physical examinations must consist of muscle tests, postural examinations, assessments of objective findings, musculoskeletal evaluations and treatment in the prevention of injuries. These evaluations (biomechanical analyses) must be designed to detect potential problem areas, including muscle imbalances, weakness of joint stabilisers, joint function and lack of full recovery from previous injuries (Koester & Amunson, 2003). Manual muscle testing is the tool of choice to determine the extent of muscle imbalances (Kendall *et al.*, 2001).

According to Wilson (1993), the ideal is for a professional to analyse each player's biomechanical profile, pre-season as well as during the season, to identify potential musculo-skeletal problems that make the player more susceptible to overuse injuries. This biomechanical deviation may be due to a structural abnormality, e.g. genu valgum, or secondary it may be the result of muscle weakness, muscle imbalances or inco-ordinate muscle action. When an abnormality is detected the examiner must incorporate the necessary interventions. This intervention must include an individualistic conditioning program formulated according to the athlete's biomechanical profile. The conditioning team must understand the mechanics of the body and its response to stresses and strains sustained, prior to the implementation of an exercise programme to prevent overuse injuries (Venter *et al.,* 2005).

To develop the prescribing therapeutic exercises, one must determine the flexibility and strength of specific muscles because most of these exercises are designed either to stretch shortened muscles or to strengthen weakened muscles (Kendall *et al.,* 1993). The conditioning programme must include muscle stretching and strengthening exercises, motor re-education, taping, padding, shoe modifications and orthoses.

McGinnis (2005) maintains that biomechanical principles must be incorporated to provide the basis for alterations in technique, equipment, posture and training to prevent- or rehabilitate injuries. Pre-participation physical examinations contribute to decreasing sports injuries (McGinnis, 2005; Junge *et al.,* 2004; Gabbet, 2004; Armsey & Hosey, 2004). Other factors that may assist in injury prevention in the milieu of sport are the following (Brukner & Khan, 2001):

- adequate warm-up;
- stretching;
- taping and bracing;
- protective equipment;
- suitable equipment;
- appropriate surfaces;
- appropriate training;
- adequate recovery after an injury;
- psychology; and
- nutrition.

Erasmus (2006) studied the effect of a prevention programme on rugby injuries of 15- and 16- year old schoolboys. The following paragraphs will discuss the study method as well as the results of that study with regard to the injury rates of participating teams. The primary aim of the study was to determine the effect of an approved injury prevention programme on the incidence of rugby players between the ages of 15 and 16 years, over a two-year period (Erasmus, 2006). The secondary aim was to measure the effect of an approved injury prevention programme on the selected anthropometrical, physical, motor, biomechanical and postural variables of all the groups involved in this study over a period of two years. Following from these aims, a sub-aim of that study was to use information from the study to provide modifications – if necessary – to the current prevention programme in order for it to be effectively applied at high school rugby level (Erasmus, 2006).

The methodology of the study involved three testing occasions over a two year period. These tests determined the anthropometrical, physical, motor, biomechanical and postural status of the participants (Erasmus, 2006). At the end of every evaluation, deficits were identified in the performance of all players in the experimental group and the prevention programmes were planned accordingly. Players in the experimental group received exercises to address the specific deficits identified (Erasmus, 2006). The results of the study concluded that the implemented programme did not have a significant effect on the anthropometric, physical and motor components of the participants. The programme did, however, improve the biomechanical and postural variables over a period of two years. These improvements could explain the significant decrease in the injury incidence in both experimental age groups. Considering intrinsic injury incidence, the results report that from the first season to the second season, a highly practically significant reduction was visible in the intrinsic injury incidence of the 15-year old (d=1.45) as well as the 16-year old (d=1.04) experimental groups (Erasmus, 2006).

Elphinston and Hardman (2006) performed a similar study as Erasmus (2006) on netball players. The thesis studied the effects of an integrated functional stability programme on injury rates of the Welsh national netball squad. The following paragraphs will discuss the procedure of the study and the positive effect the incorporation of an integrated training programme had on the players' injury rates. According to Elphinston and Hardman (2006), the efficacy of athlete profiling and injury prevention programmes is influenced by procedural clarity; the philosophy of athlete development within the sporting body and the dynamics within the multidisciplinary team. These factors contribute to the cost- and time effectiveness of these programmes (Elphinston & Hardman, 2006). The main objective of this study was to implement a programme designed to address injury rates and support sports performance development in the Welsh netball squad.

A conditioning programme was established first, as the squad did not participate in a structured training programme before (Elphinston & Hardman, 2006). Prior to the implementation of this conditioning programme, a functional profiling of the players was conducted. The objectives for the profiling were to (Elphinston & Hardman, 2006:170):

- identify individual structural and functional limitations;
- assess the players' ability to produce and control forces at varying speeds, in varying planes, and under different coordination, perturbation and contextual interference conditions;
- assess players' understanding of their own anatomy, mechanics and the purpose of specific aspects of their training; and
- to educate the players regarding self-awareness and self-evaluation to facilitate personal engagement with the testing procedure and the training programme.

By assessing the squad in this way, it was possible to illustrate clearly to both players and the multidisciplinary team members (coach, physiologist, physiotherapist, conditioning coach) why injuries were occurring and how the training programme could be modified to ensure continued progression rather than reaching a plateau in training and performance (Elphinston & Hardman, 2006). The training programme was revised according to a "flexible periodisation" in which individual athlete requirements were met according to physical condition, training status, playing position and the overall aim of the squad in a particular phase of the netball season (Elphinston & Hardman, 2006). The programme's main objectives were to address the squad's shortcomings by improving flexibility, joint stability and motor abilities such as balance, propioception and agility. The initial foundation programme was incorporated over a seven week period in July 2000.

The results reported a significant decrease in injury rate. Prior to the implementation of the functional stability programme, a high rate of overuse and traumatic injuries occurred among the players. These injuries included lower back, ankle, knee and shoulder incidents.

During the netball season in 2001, twenty two injuries occurred, while only four injuries were recorded in 2002, indicating that the implementation of this functional stability programme had a dramatic effect on the injury rates of the netball players (Elphinston & Hardman, 2006). The multidisciplinary team must consider the following practical implications when initiating a training programme in a squad (Elphinston & Hardman, 2006):

- To have a positive impact on injury rates within a squad, the cooperation and integration of the multidisciplinary team are essential and will sometimes require a significant restructuring of the existing plan.
- Well-designed profiling procedures can yield relevant information for both performance and prevention, and the revised programme must respond to the results of the profiling procedures.
- The choice of tests must be relevant and applicable to the specific sport to ensure player compliance.
- Finally, a functional profiling procedure can be used to examine not only the players' physical control but also their self-awareness, level of understanding and ability to evaluate themselves and others on common training movements.

The above-mentioned measures to prevent injuries are applicable to all sports, including netball. The most important factor in prevention strategies are the pre-season evaluating sessions. These sessions must include parameters that play an essential role in the game of netball, such as biomechanics, anthropometry and motor abilities including agility, balance, speed, acceleration, endurance and explosive power (Venter *et al.,* 2005). These tests could be repeated during and at the end of the season to determine the profile of every netball player during different stages of the netball season.

Finally, based on the tests results, an adequate and need-specific conditioning programme must then be developed by the conditioning team (physiotherapist, biokineticist and sports scientist), which addresses the shortcomings of every player.

This particular study will only focus on biomechanics, anthropometry and physical/motor abilities including agility, balance, and explosive power.

2.3. ANTHROPOMETRY

The second parameter this study will investigate is the role of anthropometry in the performance of an athlete and its potential contribution towards the occurrence of sports injuries. The history, definitions and value of anthropometry will be discussed.

2.3.1. Brief history of anthropometry

Kinanthropometry is the modern term used for knowledge on anthropometry and is derived from three Greek words *Kineo,* which means "to move"; *Anthropos*, the Greek word for "human"; and *Metrein*, which means "to measure" (De Ridder, 1993). Quetelet created the term "anthropometry" in 1835 and wrote four volumes on "man and the development of his faculties", which studied the physical features of humans as well as the birth, death, power, length, agility, and many more aspects of the human life (Barrow & McGee, 1979). The Indians referred to their document on anthropometry as the "Silphi Sastri", and this study focused on the silhouettes of the human body and divided the body into 480 regions (Barrow *et al.*, 1979). The Egyptians divided the human body into nineteen segments. Each segment was measured according to the length of the high priest's middle finger: for example, the length of five fingers measured the distance from the floor to a person's knee, ten to the arch of the pubis and nineteen to the vertex of the skull (Barrow *et al.*, 1979).

2.3.2. Definitions of anthropometry

According to Whiting and Zernicke (1998), the domain of anthropometry is the analysis of the human body's structural variability. The definition by Ross *et al.* (1987) is the most detailed and most relevant definition for this study, and will therefore be used here.

Ross *et al.* (1978) describes anthropometry as the study of a human's size, physique (somatotype), proportion, composition, puberty and motor function to comprehend the growth, training, performance and nutrition of humans which has direct effects on medicine, education and the authorities. These studies must be executed with respect to the individual's rights and in service to humanity. De Ridder (1993) defines an anthropometric investigation as the measurements of the morphological components of humans in motion. Morphology is defined as the physique, form and composition of a human being.

Anthropometric measurements include osteometry (measurement of the dimensions of the skeletal system), craniotomy (measurement of the bones of the skull), skinfold measurements to determine body composition and measurements of height and weight (Arnheim & Prentice, 2000). To simplify the procedure to determine every player's body fat percentage, this study will only include the measurements of six skinfolds, body height and body weight. These calculations will deliver adequate and accurate data on the anthropometry of the netball players.

2.3.3. The value of anthropometry on sport performance

Hippokrates was one of the first philosophers to differentiate between two physiques (somatotypes): *phthisic habitus* (tall and slender) and *apoplectic habitus* (short and fat) (Phillips & Hornak, 1979). Duquet and Carter (2001:48) define somatotype as "a qualified expression or description of the present physique (morphological conformation) of a person". According to De Ridder (2002), somatotypes deliver a quantitative summary of an athlete's physique. An athlete can be divided into one of three categories according to physique (shape) – this is known as somatotyping. De Ridder (2002) describes the three different somatotypes as mesomorphic, which is categorised as excessive muscle tissue relative to body height; endomorphic, which is defined as relatively more fat than lean muscle tissue; and ectomorphic, a relatively tall and slender physique.

An individual's somatotype would greatly influence the sport they participate in. Jordaan (2001) has found that the heavier a person is, the slower their acceleration; thus there is a direct correlation between acceleration and body weight. Similarly, Nicholas (1997) points out that the speed and agility of elite rugby players can be negatively influenced by excess body fat. Bloomfield *et al.* (1994) explain that someone with a small physique, a mesomorph, would rather participate in a sport which requires repeated changes in direction, while an athlete with a larger physique, an endomorph, would perform better in a contact sport. In netball, the work profile of the centre players (centre, wing attack, wing defence) involve more running, jumping and changing direction than that of the goal shooters (goal shooter, goal attack) and defenders (goal keeper, goal defence). As a result, centre players would tend to have a mesomorphic physique while goal shooters and defenders would be divided into the ectomorphic category (Jordaan, 2001).

As early as the fourth century, Greek scientists believed that an athlete's performance is dependent on his morphology (physique, form and composition), and the Greeks accordingly identified certain morphological characteristics an athlete had to comply with to be successful in a specific sport. Likewise, Tanner (1964), as a representative of modern science, remarked: "Physique is a factor in the sort of success that may lead to inclusion in an Olympic team: or, more negatively, that lack of the proper physique may make it almost impossible for an athlete to reach that degree of success." (Tanner, 1964:14, as quoted by De Ridder, 2002).

Norton *et al.* (1996), as quoted by De Ridder (2002), support the above-mentioned theory, through research that proves that specific types of sports have particular morphological criteria an athlete has to comply with to be successful. Literature shows that athletes who perform best at a specific sport have the correct "sport-specific" physique. The morphological information detected from top athletes would therefore reveal the correlation between the morphology of an athlete and the specific sport in which that athlete performs (De Ridder, 2002). This information could be used to prescribe the necessary exercises to athletes to adjust and improve their physique according to the criteria of the profiles of elite athletes.

Morphology plays a major role in the performance of an athlete, but is only one of many factors that could determine an athlete's performance in sport. Others factors are ball skills, coordination, physiology, psychology and biomechanics (De Ridder, 2002).

The average body fat composition of the female is approximately 23%, compared with 15% of the male of (De Ridder, 2002). The female has a lower lean body mass, indicating less muscle mass and more body fat. The increased body fat is due to the hormone estrogen, which plays an important role during pregnancy. Athletes need a certain amount of body fat for normal physiological functioning of the central nervous system (Vander, Sherman & Luciano, 1998): the minimum for female athletes is 10% and for male athletes 6% (De Ridder, 2002). This stored fat also serves as energy reserves and protection of internal organs against injury (De Ridder, 1993). De Ridder (1993) points out that when the body fat of athletes is below the optimum, secondary amenorrhoea (in females), kidney dysfunction and a drop in performance may occur. The amount of body fat content also gives an indication of the state of a player's fitness, since fat content drops with increasing levels of fitness and increases during the off-season (Noakes & Du Plessis, 1996).

According to various research reports, anthropometric measures such as height, weight, body composition, muscle mass and shape (somatotype) play a central role in assessing injuries (Whiting & Zernicke, 1998). According to Jones and Knapik (1999) anthropometry (body composition) is classified as an intrinsic factor that could contribute significantly to overuse injuries.

These anthropometric measures are also involved in determining body posture, biomechanics and flexibility (joint range of motion), which – either alone or in combination – can affect the risk of injury (Whiting & Zernicke, 1998). Arnheim and Prentice (2000) report that anomalies in anatomical structures in body build (somatotype) may predispose an athlete to injuries. According to literature, anthropometry has a direct effect on the probability of injuries, the athlete's performance and an athlete's biomechanics and motor skills.

Hence, this parameter must be included in a team's physical assessments. Ellis and Smith (2000) also recommended the inclusion of anthropometrical measurements in a study on the physical profiles of Boland netball players.

2.4. AGILITY

Agility is the first motor ability that will be investigated. The following section will discuss various definitions of this essential ability as well as the value of agility for athletes, including netball players, in sport performance. Different tests to determine agility will be included in this section as well.

2.4.1. Definitions of agility

Agility is defined as repeated sprints in different directions while maintaining balance and speed (Venter *et al.,* 2005). Van Gent (2003) defines agility as the ability to make sudden, effective changes in direction without losing much speed. Ellis, Gaston and Lawrence (2000) define agility as basic movements requiring the player to perform sudden changes in body direction in combination with rapid movement of the limbs.
The national Australian protocol for the assessment of agility performance suggests that the ability to use these manoeuvres successfully in the actual game will depend on other factors, such as visual processing, timing, reaction time, perception and anticipation (Ellis & Smith, 2000).

Malina and Bouchard (1991) observe that good agility is dependent on different qualities, such as speed, power, rhythm, timing, body control and balance. This ability to accelerate over a short distance is an extremely important performance parameter in netball and could greatly influence the outcome of a netball game (Venter *et al.,* 2005).

2.4.2. The value of agility for netball players

Ellis and Smith (2000) consider agility as one of the major physical and motor abilities required for playing netball. Netball is a game that requires rapid acceleration, sudden changes in direction and elevated leaps to receive the ball, intercept a pass or catch a rebound from an attempted shot for a goal (Hopper & Elliot, 1993). Bloomfield, Ackland and Elliot (1994) describe netball as a physically demanding game where the player must be extremely agile and able to jump. Ellis and Smith (2000) also describe agility as one of the major physical abilities required for playing netball. The inclusion of agility in the recommended battery of tests is thus essential in a netball team's assessment procedures at the beginning of the season as well as during the season.

Ellis and Smith (2000) remark that most agility tests simply measures a netball player's ability to rapidly change body direction and position in the horizontal plane after reaching a high speed. Young, James and Montgomery (2002), however, created a model that includes change in direction speed and perceptual skill, these two aspects were identified as the two pivotal components of agility. Change of direction speed is defined as the player's physical ability to undertake a planned movement requiring at least one change of direction, while perceptual skill reflects a netball player's ability to interpret and react to a stimulus and to make at least one change of direction (Young *et al.,* 2002). The primary aim of that study was to present a new methodology for the measurement of agility for netball that is considered more ecologically valid than previous agility tests (Farrow, Young & Bruce, 2005). The agility performance of three groups of different level of skills (highly, moderately and lesser skilled) were recorded when responding to a life-size, interactive video display of a netball player initiating a pass.

These results were compared to a traditional, pre-planned agility test where no external stimulus was present (Farrow *et al.,* 2005). The study concluded that a planned agility test which excludes a perceptual external stimulus, was completed faster than the reactive test. Farrow *et al.* (2005) recommend the inclusion of a sport-specific perceptual stimulus when developing future agility tests in team sports.

This addition will provide coaches and scientists with more complete and accurate feedback on the status of the athletes' agility abilities (Farrow *et al.,* 2005).

Venter *et al.* (2005) made a study of the physical profiles of provincial Boland netball players. The primary aim of that study was to determine the profiles of 48 netball players, with the secondary aim to compare the results with the profiles of provincial Australian netball players. The researchers included tests for agility (the 505 agility test), as agility is one of the major physical abilities required for playing netball (Ellis & Smith, 2000). The results showed that Australian netball players exceeded Boland netball players in the agility test (Venter *et al.,* 2005).

Various tests are available to determine an athlete's agility, for instance the Illinois-agility-test, T-test for agility, 505-agility-test and Herzberg agility test (Hattingh, 2003). Any agility test, however, should include changes of direction; acceleration and deceleration; and quick starts and stops (Prentice, 1999). The lack of a universal agility test and the fact that agility is sport-specific, make it difficult to compare results of different studies. The test used most often to evaluate an athlete's agility skills is the Illinois agility test (Hattingh, 2003).

Literature emphasises the essence of agility in a sport associated with changing direction without losing speed, such as netball (Venter *et al.,* 2005). Since players' agility could determine the outcome of the game, all team members' agility must be determined, to give feedback to the conditioning coaches and, if necessary, it must be followed by the correct exercises to improve every player's agility.

2.5. BALANCE

Balance is the second motor ability that will be studied. The essence of balance in different sport types, including netball, will be discussed in the following section. Literature indicates that the development of balance can improve an athlete's ability to balance and it reduces the risk of injury, thus affecting an athlete's performance.

Firstly, the definitions of balance will be presented, and secondly the value of balance for athletes to perform will be explored.

2.5.1. Definitions of balance

Gallahue and Ozmun (1989) define balance as the ability of the body to remain in equilibrium when the body occupies different positions. Blackburn and Voight (2001) define balance as the process through which the body's centre of mass is controlled, with respect to the base of support, whether it is stationary or moving. The definition of balance could be divided into three components: the ability to maintain a position, the ability to move voluntarily and the ability to react to a perturbation. All three components are important to maintain an upright posture (Blackburn & Voight, 2001).

Although balance is often considered a static process, it is actually a highly integrative dynamic process involving multiple neurological pathways (Guskiewicz, 1999). The broader term used for balance is *postural equilibrium.* Postural equilibrium refers to the alignment of joint segments in the effort to maintain the centre of gravity within an optimal range (Guskiewicz, 1999). Blackburn and Voight (2001) differentiate between static and dynamic balance: static balance refers to an individual's ability to maintain a stable antigravity position while at rest by maintaining the centre of mass within the available base of support, while dynamic balance involves automatic postural responses to the disruption of the centre of mass position (Blackburn & Voight, 2001). Static balance develops between the ages of 2 and 12 years and reaches a peak at the age of 8 years (DeOreo, 1971). Dynamic balance develops mostly between the ages of 9 and 12 years; thus slower than static balance.

Cratty (1970) found that a person's balance with closed eyes is the weakest at the age of seven years. Jordaan (2001) suggests that the ability to balance increases until the age of 11 years, after which a person reaches a plateau due to growth elements.

The postural control system functions as a feedback circuit between the brain and the musculoskeletal system. Involvement of the central nervous system in maintaining an upright posture can be divided into two aspects. The first is the sensory organisation which involves the processes that determine the timing, direction and amplitude of corrective postural actions based on information obtained from the vestibular, visual and propioceptive inputs. The second component is muscle coordination, which is the collection of processes that determine the temporal sequencing and distribution of contractile activity among the muscles of the legs and trunk. This muscle coordination generates supportive reactions for maintaining balance (Guskiewicz, 1999).

The body is equipped with three systems to maintain an upright position against gravity. The vestibular system, which is enhanced by vision, is centred in the inner ear, and is the mainstay of the balance mechanism. It is assisted by information from the mechanoreceptors. Injury damages these receptors, resulting in diminished ability to know where the joint is in space (propioception), and a diminished inability to detect motion. This directly affects skilled movements and indirectly affects the ability to balance (Blackburn & Voight, 2001).

Adequate propioception is required to retain one's balance. Propioception is described by Brukner and Khan (2001) as nerve impulses originating from joints, muscles, tendons and associated deep tissues, which are then processed in the central nervous system to provide information about joint position, motion, vibration and pressure. These nerve impulses are conducted by nerve endings and nerve pathways. Acute or overuse soft tissue damages these nerve endings and pathways, and as a result impaired segmental transmission of nerve impulses in a reflex action occurs. This may result in impaired balance and decreased co-ordination, diminished joint position sense, tendency for joints to give way and altered reflexes when performing specific or general movements. Since this impairment may lead to more extensive lower limb injuries, it is of the utmost importance to include early and comprehensive proprioceptive training in the rehabilitation programme after an injury (Brukner & Khan, 2001).

In conclusion, various definitions exist for the ability among athletes to balance. For the purpose of this study, the definition by Blackburn and Voight (2001) will be adopted. Blackburn and Voight (2001) define balance as the process through which the body's centre of mass is controlled, with respect to the base of support, whether it is stationary or moving. Literature describes balance as an integral and complex ability which consists of three systems (vestibular system, visual system, mechanoreceptors), which directly interact with one another. When one of these systems is altered by injury or trauma, the athlete's ability to balance is consequently affected. This interaction between the three systems accentuates the importance of adequate rehabilitation after an injury.

2.5.2. The value of balance for athletes

Existing studies on balance indicate that balance is an essential component of various sport types and that a correlation exists between inadequate balance and the occurrence of lower limb injuries. Research has also shown that programmes to improve athletes' balance are very effective and achieve significant results. Studies were, for instance, conducted on athletes who participated in different sports, such as football, volleyball, soccer and netball. Murphy *et al.* (2003) observe that an athlete's ability to maintain the position of gravity could be a potential risk factor for lower extremity injury due to increased variation in postural stability, which is associated with an altered neuromuscular control strategy; increased intersegmental joint forces and corresponding increased forces developed about articular, ligamentous and muscular structures.

Several studies have found a correlation between ankle propioception and balance, and ankle injuries (Stasinopoulos, 2004; Verhagen *et al.*, 2004; Baltaci & Kohl, 2003) as well as lower limb injuries (Murphy *et al.,* 2003; Baltaci & Kohl, 2003). Trojian and Mckeag (2006) detected a significant correlation between a positive single-leg balance test and ankle sprains, during pre-season testing of high school and collegiate athletes. Two hundred and thirty athletes from men's American Football, men's and women's soccer and women's volleyball, participated in this study.

The athletes with a positive test imposed an increased risk of ankle sprains. A test is classified as positive when the athlete needs to use his arms or moves his weight bearing foot to regain his balance (Trojian & Mckeag, 2006). No additional interventions (braces or taping) were used to stabilise the athletes' ankles. The study proposed that the single leg balance test is a reliable and valid test for predicting the occurrence of ankle sprains (Trojian & Mckeag, 2006).

Baltaci and Kohl (2003) did a literature review on the influence of proprioceptive and balance training on ankle and knee injuries. Baltaci and Kohl (2003) argue that ankle proprioceptive training has decreased functional instability, which is associated with an increased risk of injury in ankles and which decreased the incidence of re-occurrence of an ankle injury. Proprioceptive training decreased postural sway and the risk of injury in sports and everyday activities. Verhagen *et al.* (2004), in their study on 288 volleyball players, found that the intervention group that performed a proprioceptive balance board programme had a lower incidence of ankle injuries than a control group. Although this lower incidence was limited to participants with previous ankle injuries, it nevertheless shows the preventative potential of balance board programmes on ankle injuries.

A study conducted by Stasinopolous (2004) to compare the efficiency of preventative taping, technical training and proprioceptive training in the reduction of ankle sprains, proved that proprioceptive training was most effective in decreasing further ankle sprains. Rozzi *et al.* (1999) conducted a research study on the effect of a 4-week balance training programme on single-leg stance. This study included subjects with functional unstable ankles as well as subjects with non-impaired ankles. After the 4-week training period, the balance results of both groups revealed significant improvements in balance ability. Rozzi *et al.* (1999) concluded that balance training is an effective means of improving joint proprioception and single-leg standing ability in subjects with unstable and non-impaired ankles.

Clark and Burden (2005) used 19 male participants with functionally unstable ankles to investigate the effects of wobble-board training on the onset of muscle activity and perception of stability. After completing the programme, the group showed a significant reduction in muscle onset latency and an improvement in perception of functional stability. This study proved that wobble board exercises reduce the risk for further sprains in individuals with unstable ankles.

Literature points out the positive effect of balance and proprioceptive training on an athlete's ability to balance. According to Jordaan (2001), Venter *et al.* (2005) and Elphinston and Hardman (2006), the ability to balance is an essential parameter in the game of netball. Accordingly, balance and proprioceptive training has to be included in a netball team's preparation during the netball season. Jordaan (2001) also emphasises the essence of balance in the throwing and receiving actions of netball, especially when the player is standing on one leg. Venter *et al.* (2005) agree with the importance of balance when changing direction during a game, as balance directly influences a player's agility skills. The above-mentioned research concludes that balance is an indispensable skill while executing greater motor activities. Elphinston and Hardman (2006) agree with the importance of adequate balancing skills of netball players as well and included tests on balance and propioception in a study on the effect of an integrated functional stability programme on injury rates in a Welsh international netball squad. During the study, a significant difference in balance and propioception between left and right side stance as well as a lack of fundamental control problems and diminished confidence to move in both directions and of either foot, were detected. Therefore, performance and injury implications became clear very early in the study procedure, which revealed a correlation between inadequate balance and propioception and the occurrence of injuries.

Evidently, balance is a complex function essential for an athlete participating in a physically demanding sport, such as netball. Literature stresses that the ability to balance is a vital parameter in the game of netball. Studies proved that athletes with insufficient balance are more prone to injuries, especially ankle injuries.

However, intervention programmes showed that an athlete's ability to balance could be improved with specific exercises.

2.6. EXPLOSIVE POWER

The final motor ability to be considered is explosive power. The description of explosive power as well as the essence and enhancement with specific exercises of this ability in athletes will be discussed in the following paragraphs. Venter *et al.* (2005) address the importance of explosive leg power, especially in a sport such as netball or basketball, which requires jumping to intercept or catch a ball during a game. The activity of jumping is categorised as a form of plyometric training. The term *plyometrics* is defined as a type of exercise that enables a muscle to reach a maximal strength in the shortest time possible. Plyometrics is derived from the Latin words "ply", which means increase, and "metrics", which means "measure". Thus, the combination means "measurable increase" (Allerheiligen, 1994: 319).

The aim of plyometric training is to reduce the time required between the yielding of eccentric (lengthened muscle state) muscle contraction and the initiation of the overcoming concentric (shortened muscle state) contraction. In eccentric contractions the muscles undergo tension and stretch; in concentric contractions the muscles undergo tension and shorten. Normal physiological movement is preceded by an eccentric pre-stretch that loads the muscle and prepares it for the ensuing concentric contraction. The coupling of the eccentric-concentric muscle contraction is known as the stretch-shortening cycle. The cycle consists of two components: propioceptive reflexes and the elastic properties of muscle fibres. These components work together to create a response (Voight & Tippett, 1999). When an eccentric contraction occurs, the muscle lengthens like a spring.

With the lengthening of the muscle, the series elastic component is stretched and contributes to the overall force production. Literature reveals that significant increases in concentric muscle force production occurs when preceded by an eccentric contraction. However, the preceded eccentric contraction has to be performed quickly and without delay (Voight & Tippett, 1999). This rapid eccentric movement evokes the stretch-shortening cycle, which results in greater concentric contraction of the same muscles. Plyometric activities also stimulate propioceptive feedback to improve the muscle activity patterns.

A team's conditioning schedule must include plyometric exercises, to improve these stretch-shortening sequences that are part of the normal force dependent patterns required of an athlete, especially in a sport marked by jumping activities. Literature emphasises the importance of tests to determine a player's explosive leg power and of improving these results with specific exercises. Ellis and Smith (2000), for example, stress the essence of including tests for explosive leg power in a team's pre-season testing, due to the integral part jumping plays in a netball game.

Many sports activities subject the lower limb to plyometric types of activities, such as jumping. These activities may be partially responsible for enhanced proprioception when considering the effects of muscle contraction and chronic neural adaptation on proprioception. Propioception is increased when muscles are voluntarily contracted. These preparatory muscle contractions, which are needed for plyometric activities, protect the joint and improve feedback to the central nervous system. Therefore, the inclusion of plyometric exercises during rehabilitation will improve an athlete's ability to protect him-/herself against joint positions where he/she is vulnerable to injury (Swanik & Swanik, 1999).

Before returning to a sport after an injury, an athlete must have adequate power. Brukner and Khan (2001) maintain that power is an important component of many sporting activities. Power is the rate of doing work and as such it has a time component. Usually, this time component is relatively rapid.

As a result, an athlete must have the ability to generate power by producing a stretch-shortening cycle in which the muscle is eccentrically stretched and slowly loaded.
This pretensioning phase is followed by a rapid concentric contraction to develop a large amount of momentum and force (Brukner & Khan, 2001). Power is an essential component that is necessary to return to activity, otherwise inadequate power may lead to poor performance and the re-occurrence of an injury. An excellent way to develop power and prevent re-injury or any injury is plyometric training (Moss, 2002). Sprinting and jumping activities are two forms of plyometric exercises that could be included it a team's training programme (Marginson *et al.,* 2005).

Plyometric training enables the neuromuscular system to accept increased strength loads more quickly, thus preparing the body to accept stresses to which it is exposed during sport activities. These training techniques will help to reduce future injuries (Voight & Tippett, 1999).

Adequate power is an essential parameter in netball. Netball is a physically demanding game that requires a player to possess high levels of strength and power. Venter *et al.* (2005) addresses the importance of explosive leg power, especially in a sport which requires jumping to intercept or catch a ball during a game. Vertical jump height is an indication of the power of the extensor muscles of the hips, knees and ankles. Venter *et al.* (2005) used the vertical jump test in a research study on the physical profiles of provincial Boland netball players. The results were then also compared with those of provincial Australian netball players. A significant difference in vertical jump height was found between the two groups: on average, the Australians jumped 12 cm higher than their Boland counterparts.

To conclude, explosive leg power plays a key role in sport, especially in sports involving powerful jumping activities. Explosive power is physiologically repeated sequences of stretch-shortening phases, which could be enhanced with specific exercises, such as plyometric exercises (Voight & Tippett, 1999).

An athlete's performance and injury incidence could improve when including plyometric exercises in the conditioning programme (Swanik & Swanik, 1999).

2.7. SUMMARY

The primary aim of this particular study was to determine the physical profiles of club netball players between the ages of 18 and 23 years from the North-West University, with reference to the biomechanics, anthropometric measurements and motor abilities (balance, agility and explosive power). The secondary aim was to identify potential aspects of the netball players' physical profiles (biomechanical variables, anthropometrical components and physical/motor abilities) that could contribute to musculoskeletal injuries. These components (biomechanics, anthropometric measurements and physical/motor abilities) are considered to be essential parameters in the game of netball (Venter *et al.,* 2005), and are therefore investigated in this study. Furthermore, as very few studies have been conducted on netball players in particular, this research aims to make a contribution in that area.

In the available literature, different definitions are used for the same terms. This is, for instance, the case with *biomechanics*, *anthropometry*, *physical/motor abilities* (*agility*, *balance* and *explosive power*), and *injuries*. Yet, regardless of the specific definition, it is clear that these components play a key role in the performance and injury incidence of various sports, including netball (Brukner & Khan, 2001). Deviations or lack of ability of any of these components (biomechanics, anthropometry and physical/motor abilities) could contribute significantly to the occurrence of overuse as well as traumatic injuries.

Biomechanics was discussed in 2.2. The definition of biomechanics formulated by Neely (1998) was adopted. Neely (1998) describes good biomechanics as near symmetry, good dynamic mobility and core stability of the human body.

When deviations occur in any of these components (near symmetry, good dynamic mobility and core stability), a netball player's performance could be altered and this could result in overuse injuries such as patellar tendinopathy, medial shin pain and patellofemoral syndromes (Hopper & Elliot, 1993; Brukner & Khan, 2001).

These biomechanical abnormalities should preferably be detected before the start of the netball season and the necessary exercises should be prescribed accordingly (Koester & Amunson, 2003; Gabbet, 2004; Armsey & Hosey, 2004). Fortunately, these individualistic rehabilitation programmes are very effective and can correct these biomechanical deviations (Erasmus, 2006; Elphinston & Hardman, 2006).

The second parameter to be discussed was anthropometry. The definition of anthropometry offered by Ross *et al.* (1987) is used here, namely that anthropometry is the study of a human's size, physique, proportion, composition, puberty, and motor function to comprehend the growth, training, performance, and nutrition of humans, which has direct effects on medicine, education and the authorities. These studies must be executed with respect to the individual's rights and in service to humanity.

An athlete's anthropometry could influence his/her choice of a specific sport, as well as his/her playing position in that sport (De Ridder, 2002). Jordaan (2001) concluded that in netball, centre players, such as the centre, wing attack and wing defence, would tend to have a mesomorphic physique while goal shooters and defenders would have an ectomorphic physique. Anthropometry has a direct effect on the probability of injuries, the athlete's performance and the athlete's biomechanics (body posture and flexibility) and motor skills (Whiting & Zernicke, 1998; Jones & Knapik, 1999; Arnheim & Prentice, 2000).

Agility is the first motor ability that was discussed. Because various authors describe this ability as an essential parameter required for playing netball (Bloomfield *et al.,* 1994; Ellis & Smith, 2000; Venter *et al.,* 2005), it is investigated in this study.

The definition by Van Gent (2003) was adopted here: agility is the ability to make sudden, effective changes in direction without losing much speed. As a netball game's outcome is determined by the players' ability to rapidly change body direction and position in the horizontal plane after reaching a high speed, this ability (agility) is essential during a netball game (Ellis & Smith, 2000; Venter *et al.,* 2005).

Another essential parameter required to play netball is the ability to balance. Many authors accentuate the important role of balance in the game of netball, especially when the player is standing on one leg during throwing and receiving actions (Jordaan, 2001; Venter *et al.,* 2005). For the purpose of this study, balance is defined as the ability to maintain a position, to voluntarily move and to react to a perturbation (Blackburn & Voight, 2001). Literature indicates a significant correlation between inadequate balance and the occurrence of lower limb injuries in various sports, especially netball (Baltaci & Kohl, 2003; Murphy *et al.,* 2003; Stasinopoulos, 2004; Verhagen *et al.,* 2004). Fortunately, programmes to improve netball players' ability to balance can be applied with very good results (Stasinopoulos, 2004).

Explosive power was the final motor ability to be discusses in this chapter. Explosive power is essential in sports associated with jumping activities, such as netball (Swanik & Swanik, 1999; Venter *et al.,* 2005). Power is an important aspect of explosive power. It is the rate of doing work and has a time component; therefore an athlete must have the ability to generate power by producing a stretch-shortening cycle in which the muscle is eccentrically stretched and slowly loaded. This pretensioning phase is followed by a rapid concentric contraction to develop a large amount of momentum and force (Voight & Tippett, 1999; Brukner & Khan, 2001). The inclusion of plyometric exercises to improve a netball player's explosive power is essential to increase performance and also to rehabilitate a player after an injury (Swanik & Swanik, 1999; Moss, 2002).

This chapter explained the significant role of components such as biomechanics, anthropometry and physical/motor abilities (agility, balance and explosive power) in a netball player's performance and in the probability of injury. The next chapter, chapter 3, will discuss the empirical investigation of this study.

CHAPTER 3

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CHAPTER 3

EMPIRICAL INVESTIGATION

3.1. INTRODUCTION

From the previous chapters it is evident that netball is a sport associated with serious injuries, especially to the ankle- and knee joint. These injuries require medical attention, physiotherapy, rehabilitation and therefore have extensive financial implications on the club or province. The literature reveals that overuse injuries is prominent under netball players. Overuse injuries can also lead to the exclusion of a player in a team, due to the severity of the injury, for up to six weeks, and therefore affects the team's performance as well. According to the literature pathomechanics (biomechanical deviations) plays a key role in the cause of overuse injuries. Other factors that may contribute to overuse injuries are anthropometrical components and lack of specific physical/motor abilities (agility, balance and explosive power).

The secondary aim of this study is to identify biomechanical variables, anthropometrical components and physical/motor abilities (agility, balance and explosive power) that could contribute to potential musculoskeletal injuries of netball players between the ages of 18 – 23 years at the netball club of the North-West University in Potchefstroom.

The contents of this chapter will include the variables that were recessing to do the empirical analysis of the study. The following divisions will be discussed: choice of subjects; questionnaires and survey forms; procedures and methods of data collection; and the test battery (biomechanical status, anthropometrical components and physical/motor abilities).

3.2. CHOICE OF SUBJECTS

Forty female netball players, during the first tests, and twenty five, during the second tests from the first, second, third, fourth and the u/19 A and B teams of the North-West University netball club participated in this study. The ages of the players ranged from 18 – 23 years. Ten members of the netball club could not participate in the first tests and fifteen couldn't take part in the second tests due to personal reasons and injuries. All participants were currently training at the netball club.

3.3. QUESTIONNAIRES / SURVEY FORMS

All informed consent forms, injury questionnaires, injury report forms and evaluation sheets were designed by the researcher excluding the biomechanical assessment form that was implemented by Hattingh (2003). These forms consisted of the following:

- Informed consent form
- Injury questionnaire
- Injury report form
- Biomechanical assessment form
- Netball data sheet included anthropometry, agility- balance- and explosive power tests

3.3.1. Informed consent form

Prior to the tests every participant needed to complete an informed consent form (Annexure A). The researcher explained the testing procedures to the subjects. The form included every participant's personal details as well as the telephone numbers of the team's coach, doctor and physiotherapist. The form also included the players' signatures confirming that they agree with the testing procedures. Only the players who completed the consent form were included in the study.

3.3.2. Injury Questionnaire

The participants completed an injury questionnaire (Annexure B) prior to the testing procedures. This form included current and previous injuries to any body part. Previous injuries were only mentioned if the player still struggled with this specific injury. The form consisted out of 11 columns: injured body part; date of injury; current / previous injury; side affected (left / right); mechanism of injury (e.g. collided with other player / tripped); doctor or physiotherapist's diagnosis; treatment (medical / physiotherapy); rehabilitation; number of days out of action; and the status of recovery (complete / incomplete). The player also had to mention if she is wearing any protective gear (braces) or strapping and for what purpose (preventative / protect current injury).

3.3.3. Injury report form

To monitor the injuries during the season the researcher held a free clinic session once a week on Mondays from the third week in March to the first week in August. The clinic was performed by a physiotherapist. The purposes of these clinics were to screen injured players; collect injury data; give advice regarding the management of the injury; and refer players for further treatment if necessary. The physiotherapist completed an injury report form (Annexure C) after each clinic. The form included the following information:

- Mechanism of injury;
- diagnosis of injury;
- severity of injury;
- type of injury;
- time off from training / playing games;
- recommended treatment;
- instruction to player, and;
- when to revisit.

The physiotherapist reported back to the coach involved, regarding the status of the player and the recommended management (further medical or physiotherapy attention; time off training and playing games) of the injury. At the end of the season the relevant data needed for the study was extracted from the forms and analysed.

3.3.4. Evaluation forms

The collected biomechanical data was documented on a coded biomechanical form (Annexure D) and the anthropometry results (Annexure E) plus the results of the motor variables (Annexure F) in table format.

1) The *biomechanical assessment form* evaluated:

- Postural symmetry;
- dynamic mobility (flexibility); and
- core stability

This assessment protocol evaluated the following five different body regions: lower limb-, pelvic girdle-, spinal regions; and neurodynamics (Hattingh, 2003).

2.) *Anthropometric data* included the following:

- Stature (height);
- body weight; and
- skinfold measurements

3.) *Physical/motor data* included the results of the following variables:

- Agility;
- balance; and
- explosive power

3.4. PROCEDURES AND METHODS OF DATA COLLECTION

The study commenced at the beginning of March and was completed at the end of August during 2007, therefore the study spread over a time period of five months. The tests were conducted by two physiotherapists and three biokineticists. During this time frame the tests were conducted twice: pre-season (March) and end-season (August). The first pre-season data collection began after the participants had completed a *current and previous injury questionnaire (*Annexure B). After the completion of this form the players were tested. These tests included a biomechanical analysis, anthropometric evaluation and motor ability (agility, balance and explosive power) assessment. The testing procedure was repeated end-season in August. The results of these tests were used to provide a profile for each player which highlighted the strengths and weaknesses and to identify possible factors that may contribute to potential injuries. The findings of the two testing procedure were also compared to determine whether variables changed through the season.

Data on injuries were collected from the players each week during the screening clinics (discussed under paragraph 3.3.1: *Injury report form).* A qualified physiotherapist (the researcher) documented the details of the injuries on the injury report form (Annexure C).

3.5. BATTERY OF TESTS

The tests and protocols which were used to determine the players' biomechanics, anthropometry and agility were chosen from the literature, thus these tests' validity had been proven in previous sports studies (Hattingh 2003). Balance and explosive power were tested electronically. For balance the computerised balance test (Techno-therapy, 1992) were used and for explosive power the tapeswitch sensory mat connected to a psion computer (Boscosystem ErgoJump www.boscosystem.com).

The literature does not include research studies which used these specific tests, possibly due to the lack of availability and financial costs involved in requiring the necessary equipment and programmes to perform these tests (balance and explosive power). These two tests are more accurate than manual tests, due to the fact that there is not room for personal subjectivity (Techno Therapy, 1992).

3.5.1. Biomechanical analysis

The first protocol can be classified under the biomechanical make-up of the netball players (Annexure D) (Watson, 2001). For this biomechanical data a recent approach which measures a combination of symmetry, dynamic mobility and local stability was used (Kapandji, 1970; Hoppenfield, 1976; McConnell, 1999; Hunt, 1990; Saudek, 1990; McPiol & Brocato, 1990; Arnheim & Prentice, 2000; Derman & Schwellnus, 2001; Hattingh, 2003). Measures were chosen from known clinical measures of posture and flexibility that could easily be used in a standard biomechanical and postural assessment. The biomechanical protocol evaluated different regions, namely lower limb-, pelvic girdle-, spinal region and neurodynamics.

Two physiotherapists performed the biomechanical analysis of each subject. The biomechanics was only analysed from L 2 down to the subject's toes. The position of the cranium (head), cervical and thoracic areas were included in the assessment of the coronal and sagital axis, due to the influence of these areas on the lumbar area (Kapandji, 1970; Hoppenfield, 1976; McConnell, 1999; Hunt, 1990; Saudek, 1990; McPiol & Brocato, 1990; Arnheim & Prentice, 2000; Derman & Schwellnus, 2001; Hattingh, 2003). No warm-up session is required for the biomechanical assessment procedure. For the test protocol subjects were dressed in shorts and gym tops. All tests were completed indoors. One examiner was used to perform the test procedure together with an assistant to record the data electronically. For consistency the same two qualified personnel performed these tests.

During the study, all tests were repeated on the left and right hand side of the subject's body. For clarity, tests will be described as if it were measured on the left-handed side of the subject's body.

(a) *Lower limb region (knee and ankle complex)*

- **Achilles tendon suppleness test (TA test)**

Equipment: One plinth.

Directions: The subject started in the supine position with both legs straight and the heels just over the edge of the plinth. From this position, the examiner took the posterior ankle with the left hand, while the right hand grabbed the ball of the foot and pushed the forefoot into dorsiflexion. Range of movement (ROM) was graded as 1) a range of 30° or more (ideal); 2) between 10° and 30° (non-ideal); and 3) less than 10° (highly unsatisfactory) (Kapandji, 1970; McPiol & Brocato, 1990).

- **Modified Thomas test**

Equipment: One plinth.

Directions: From the modified Thomas test, three lower limb flexibility aspects can be assessed (iliotibial band, quadriceps and iliopsoas). Thus, this test served as a functional combination test for all three components.

- For this test, the subject started at the end of the plinth; standing with the posterior aspect of her thighs firmly against the plinth.
- The subject then relaxed her left hip and knee towards her chest; and gripped her ankle at the anterior aspect with the fingers locking around the ankle.
- The subject then lay back in the supine position while keeping the left leg locked in the hand grip and extended her elbows. In this position, the right leg was relaxed and hung over the edge of the plinth. From this position the combined functional mobility of the lower limb (hanging limb) was assessed.

- *Iliotibial band mobility (ITB)*

The examiner clearly observes the anterior aspect of the ankle joint, then assesses the amount of deviation from the coronal mid-position (the amount of rotation or deviation of the sagital mid-position from the midline).

The measurements were classified as: 1) neutral or < 10 of deviation (ideal); 2) 10° - 30° of deviation (non-ideal); and 3) more than 30° (highly unsatisfactory) (Kapandji, 1970; Hunt, 1990; Saudek, 1990).

- *Quadriceps mobility*

The examiner clearly observes the midline of the knee joint on its lateral aspect. The examiner records the angle between the midline of the knee joint on its lateral aspect with the lower limb. Measurements were classified in three categories: 1) > 50° (ideal); 2) 30° - 50° (non-ideal); and 3) < 30° (highly unsatisfactory) (Kapandji, 1970; Hunt, 1990; Saudek, 1990).

- *Iliopsoas mobility*

For this test, the lateral midline of the hip was identified. The examiner assesses the angle between the lateral midline of the hip with the femoral shaft. This was classified as 1) > 30° (ideal); 2) 15° - 30° (non-ideal) and 3) < 15° (highly unsatisfactory) (Kapandji, 1970; Hunt, 1990; Saudek, 1990; Arnheim & Prentice, 2000).

- **Gluteus maximus mobility test (Short hip extensor mechanism mobility test)**

Equipment: Plinth.

Directions: The subject started supine on the plinth with her legs extended and the examiner positioned him at the side of the plinth, facing the subject's lower limbs. The examiner then flexed the subject's knee closest to him to 90°, and rested the lateral aspect of the ankle on the subject's opposite knee. The thigh closest to the examiner was then dropped into external rotation. From this position of 90° of knee flexion and external hip rotation, the knee was flexed cephalate by the examiner, while the examiner maintained the amount of external rotation of the hip up to maximum hip flexion (end ROM).

With the lower limb position maintained at full hip flexion, the ROM was assessed. Measurements were classified into 3 categories: 1) > 90° (ideal), 2) 60° - 90° (non-ideal) and 3) < 60° (highly unsatisfactory) (Kapandji, 1970; Hoppenfield, 1976).

- **Adductor mobility test**

Equipment: Plinth.

Direction: The subject was placed on the plinth, supine, with both her knees extended. The examiner stood facing the lower limbs of the subject. The subject's opposite leg was abducted and the heel hooked over the edge of the plinth. The observer then stabilised this limb and controlled its rotation. Thereafter, the limb closest to the examiner was abducted with hip rotation controlled in neutral. The examiner continued this movement until maximum range. The examiner then determined the angle between the umbilicus and the femoral shaft. Measurements were classified into three categories: 1) > 120° (ideal), 2) 100° - 120° (non-ideal); and 3) < 100° (highly unsatisfactory) (Kapandji, 1970; Hoppenfeld, 1976).

- **Internal rotation mobility test**

Equipment: Plinth.

Directions: The subject stood at the end of the plinth on her right leg, while the left was supported over the side of the plinth (knee crease at edge). The examiner clearly marked the apex of the patella on the flexed left knee. The examiner then positioned the subject supine on the plinth, with the subject's left knee and left hip flexed to 90°. A neutral thigh position (no rotation) represented the starting position (0). The left hand of the examiner was used to stabilise the inferior portion of the thigh, while the right held onto the ankle and internally rotated the hip joint to maximum. The amount of rotation from the identified area to the end of movement was assessed. Measurements were classified into three categories: 1) > 30° (ideal); 2) 15° - 30° (non-ideal); and 3) < 15° (highly unsatisfactory) (Kapandji, 1970; Hoppenfeld, 1976; Hattingh, 2003).

- **External rotation mobility test**

Equipment: Plinth.

Directions: The subject was positioned in the same position as for the *internal rotation mobility test.* Maximum ROM was achieved and measured for external rotation. Measurements were classified into three categories: 1) > 90° (ideal); 2) 60° - 90° (non-ideal); and 3) < 60° (highly unsatisfactory) (Kapandji, 1970; Hoppenfeld, 1976; Hattingh, 2003).

- **Quadriceps angle test (Q-angle test)**

Equipment: Plinth.

Directions: The subject was positioned supine on the plinth with both legs relaxed and extended. The examiner identified the tibial tuberosity and apex of the patella. The medial and lateral aspects of the patella base were also identified. The midpoint between these two landmarks was then measured and identified. Next, the anterior superior ileac spine was palpated and identified. An imaginary straight line was drawn from this high position through the superior patella mid-position, extending caudate. Following this, a second imaginary line was drawn from the tibial tuberosity through the apex of the patella, extending cephalate. The point at which these two points intersected indicated the Q-angle of the measured leg, this angle was assessed. Measurements were classified into two categories: 1) < 9° (ideal); and 2) 9° and more (non-ideal) (Kapandji, 1970; McConnell, 1986; Derman & Schwellnus, 2001).

- **Patella squint test**

Equipment: One plinth.

Directions: The subject was positioned relaxed, supine on the plinth with both legs extended. The examiner positioned him to the lateral side of the subject, at the level of the subject's left knee. The examiner began by identifying the apex of the patella. Afterwards he carefully identified the medial and lateral aspects of the patella base and identified the midpoint between these landmarks. An imaginary line was then drawn from this patella mid-position through the inferior pole of the patella.

The examiner now described the amount of patella squint (rotation) in comparison with the mid-limb sagital line as 1) < 10° (ideal); 2) = 10° (non-ideal) (McConnell, 1999).

- **Patella tilt test**

Equipment: One plinth.

Directions: The position of the subject and examiner was exactly as for the *patella squint test.*

Step one: The examiner used an imaginary coronal axis passing through the anterior surface base of the patella to note and document the amount of surface deviation from this line. If there was no deviation, the patella was categorised as 1) not tilted (ideal).

Step two: If deviation was visible, the examiner placed his thumbs on the lateral aspect of the patella and gently glided it medially (< 1cm). Only when the range was still limited, the patella was categorised as 2) tilted (non-ideal) (Wallace, Mangine & Malone, 1990; McConnell, 1999).

- **Vastus mediales obliquus – lateralis comparison test (VMO – L)**

Equipment: A plinth.

Directions: The subject was positioned supine on the bed, relaxed, with both knees extended. The examiner positioned himself at the lower limb level, facing the subject. The subject was instructed to contract the quadriceps isometrically and hold the contraction. The examiner compared the muscle bulk of vastus medialis to vastus lateralis. Observations were classified into two categories: 1) no apparent difference (ideal); and 2) apparent difference (non-ideal) (Wallace *et al.,* 1990; McConnell, 1999).

- **Longitudinal arch status test**

Equipment: None required.

Directions: The subject stood erect, relaxed, facing the examiner, with feet shoulder width apart. The participant's medial arch (plantar vault) was inspected by inserting the index finger between the plantar surface of the foot and the ground.

The foot arches were classified into three categories: 1) resisted movement (dropped arch/hypermobile); 2) easily inserted index finger (ideal); and 3) excessive play between plantar aspect and ground (high arch / hypomobile) (Hunt, 1990).

- **Forefoot positional test**

Equipment: None required.

Directions: The subject was positioned as for the *longitudinal arch status test.* The lateral aspect of the talus neck was identified. The examiner also identified the Z-axis. The examiner assessed the angle between the lateral aspect of the talus neck and the Z-axis. Measurements were classified into two categories: 1) 0 - 10° deviation from the Z-axis (ideal); 2) more than 10° deviation from the Z-axis (non-ideal) (Hunt, 1990; Derman & Schwellnus, 2001).

- **Rear foot positional test**

Equipment: A plinth and a bench.

Directions: The subject was positioned prone on a plinth with both her feet just over the edge of the plinth. The mid-point of insertion of the Achilles tendon (TA) into the calcaneus was identified. With the index finger and thumb of the left hand on either side of the calcaneus, the mid-position of the posterior calcaneus was also identified. An imaginary line bisecting the calcaneus was drawn by connecting these two identified landmarks. A third point was identified in the middle of the proximal calf muscle bulk. Finally, a fourth point was identified where the calf muscle bulk inserted into the TA. An imaginary line was drawn between these last two points which represented the pulling direction of the calf muscle complex.

Then, the subject was ordered to stand erect with her feet together on the bench, facing away from the examiner. The angle between the two imaginary lines was assessed. Measurements were classified into three categories: 1) > 9° (rear foot pronation); 2) 0° - 9° (ideal); and 3) < 0° (rear foot supination) (McPiol & Brocato, 1990).

- **Rear foot lying test**

Equipment: A plinth.

Directions: The subject was positioned as for the *rear foot standing test* protocol. The examiner positioned him at the end of the plinth and placed his right hand on either side of the subject's talus, approaching from the frontal aspect of the left foot.

With the thumb of the left hand placed on the plantar aspect of the fourth and fifth metatarsal heads, the examiner eased the foot into dorsiflexion, while controlling the neutrality of the talocrural joint system with the index finger and thumb of the right hand. The position was held in neutral (0) and the rear foot status was assessed. Measurements were classified the same as the *rear foot standing test* protocol (Kapandji, 1970; McPiol & Brocato, 1990).

- **Transverse arch area comparison test**

Equipment: A plinth.

Directions: The subject was in exactly the same position as for the *rear foot standing test* protocol. The examiner – seated at the end of the plinth – inspected the transverse arch area. The transverse arch areas were classified into two categories: 1) normal plantar aspect with a slight transverse arch (ideal); and 2) callus plantar aspect with a flat arch (non-ideal) (Kapandji, 1970; McPiol & Brocato, 1990).

- **Foot mobility test**

Equipment: A plinth.

Directions: The position of the subject and the examiner were the same as for the *transverse arch area comparison test.* The examiner first flexed and then extended the subject's medial aspect of the foot maximally. The amount of mobility was categorised into: 1) hypermobile status; 2) ideal status; 3) hypomobile status (Kapandji, 1970).

- **Toe positional test**

Equipment: None required.

Directions: The subject stood erect, facing the examiner, with her feet shoulder width apart.

The subject's toe position was evaluated and graded as 1) ideal position (no valgus; rotation or deviation); and 2) non-ideal (present valgus/rotation/deviation) (Hoppenfeld, 1976).

(b) Pelvic girdle region

- **Leg length discrepancy test**

Equipment: A plinth.

Directions: The subject was in the supine position on the plinth, with her heels just over the edge of the plinth. The examiner first ensured that the subject was positioned symmetrically. The examiner approached the subject from the end of the plinth and placed both his thumbs firmly against the inferior aspects of the medial malleoli. The subject's legs were kept straight, lifted up to 30°, elongated and then replaced in the original position. The differences in malleoli position were observed, recorded and categorised as 1) medial malleoli height left equals right (ideal); 2) > 0 cm, but = 1 cm discrepancy (slightly displaced) (non-ideal); and 3) > 1 cm discrepancy (highly unsatisfactory) (Hoppenfeld, 1976; Peers 1994; Rocabado, 2000).

- **Anterior superior ileac spine (ASIS) comparison**

Equipment: A plinth.

Directions: The examiner positioned the subject as for the *leg length discrepancy test*. The subject was requested to expose the anterior superior ileac spine. The examiner then carefully identified the inferior aspect of both the prominences. Next, the symmetrical position of the subject was ensured, after which the examiner placed his thumbs on the identified areas and recorded signs of asymmetry. The status was categorised as 1) symmetrical (ideal); or 2) asymmetrical (non-ideal) (Hoppenfeld, 1976; Peers, 1994; Rocabado, 2000).

- **Posterior superior ileac spine (PSIS) comparison test**

Equipment: A plinth.

Directions: The subject was placed on the plinth, in a four point kneeling position. The examiner then ordered her to sit back on her hells (with the gluteal area touching the heels) and while sustaining this position to flex forward until her head touched the plinth. The examiner carefully exposed, palpated, identified and marked the inferior edges of the two posterior superior ileac spines.

The examiner then placed his thumbs on the marked areas and assessed the symmetry. The status was classified as 1) symmetrical (ideal); and 2) asymmetrical (non-ideal) (Hoppenfeld, 1976; Porterfield & DeRosa, 1990; Peers, 1994; Rocabado, 2000).

- **Pelvic rami positional test**

Equipment: A plinth.

Directions: The subject was positioned supine with the superior pubic area just exposed. The examiner ensured her symmetrical positioning. The examiner placed his thumbs on the superior medial rami and assessed the area for asymmetry. The status was categorised as 1) symmetrical (ideal); and 2) asymmetrical (non-ideal) (Hoppenfeld, 1976; Peers, 1994; Rocabado, 2000).

- **Sacroiliac cleft test**

Equipment: A plinth.

Directions: The subject was positioned as for the *posterior superior ileac spine comparison test.* The sacroiliac joint (SIJ) area of the subject was carefully exposed. The examiner then placed his thumbs on the joint margin and assessed it for cleft asymmetry. The status was categorised as 1) symmetrical (ideal); and 2) asymmetrical (non-ideal) (Porterfield & DeRosa, 1990).

- **Bilateral pelvis positional test**

Equipment: A chair.

Directions: The subject stood erect and relaxed with both the ASIS and PSIS well exposed. The examiner sat on a chair, facing the subject's side.

Next, the inferior edge of the ASIS and then the PSIS were carefully palpated and identified. The examiner then assessed and recorded the difference in height between these two landmarks (lower ASIS and PSIS). Measurements were categorised as 1) = 2 but < 3 cm discrepancy (ideal); 3 - 5 cm discrepancy (non-ideal); and 3) > 5 cm discrepancy (highly unsatisfactory) (Kapandji, 1970).

(c) Spinal region

- **Thoraco-lumbar fascia**

Equipment: A plinth.
Directions: The subject was positioned on her side, lying with her head at the top edge of the plinth. Her top leg was bent to 90° at both her hip and knee. The subject was then aided first onto her bottom elbow (side-lying) and then onto her hand, which she placed at the top edge of the plinth. The examiner ensured the subject was positioned in a straight line before assessment. Measurements were categorised as 1) < 1 cm (ideal); 2) 1 - 3 cm (non-ideal); and 3) > 3 cm (highly unsatisfactory) (Kapandji, 1970).

- **Sacral rhythm test**

Equipment: A plinth.
Directions: The subject was positioned prone on the plinth with her head close to the top edge of the plinth. Her arms were positioned as for a push-up with the hands on the two top corners of the plinth. The examiner, positioned at the side of the plinth, placed both his thumbs on the L 5 transverse processes. The subject was then instructed to perform a push-up without lifting her hips, while the examiner assessed the symmetry of the extension movement in this region. This was categorised as 1) symmetrical movement (ideal); 2) asymmetrical movement (non-ideal) (Gould III, 1990).

- **Functional extension mobility test**

Equipment: A plinth.
Directions: The subject was positioned as for the *sacral rhythm test.* This time, the push-up was performed and the elbows locked in extension.

The examiner then assessed the distance between the ASIS and superior aspect of the plinth. Measurements were classified as 1) < 1 cm (ideal); 2) 1 - 3 cm (non-ideal); and 3) > 3 cm (highly unsatisfactory) (Gould III, 1990).

- **Functional flexion test**

Equipment: None.

Directions: The subject stood erect but relaxed with her feet at shoulder width. The subject flexed forward and attempted (with hands crossed) to touch the ground without bending at the knees. The subject was urged to flatten her palms on the floor if possible. Flexion was categorised as 1) palms placed on ground (ideal); 2) touched ground (non-ideal); and 3) unable (highly unsatisfactory) (Kapandji, 1970).

- **Rotational mobility test**

Equipment: A plinth.

Directions: The subject sat erect on the plinth, in a stable position, with her lower limbs over the edge of the plinth and arms crossed with hands on opposite shoulders. The examiner positioned himself behind the subject and then placed his hands on the subject's shoulders and rotated the trunk to the end of its range. The range in the transverse plane was noted, with the lateral axis (x-axis) representing 0°/180°. Range was categorised as 1) rotation of more than 90° (ideal); rotation of 70° - 90° (non-ideal); and 3) rotation less than 70° (highly unsatisfactory) (Kapandji, 1970).

- **Side flexion mobility test**

Equipment: A plinth.

Directions: The subject was positioned as for the *rotational mobility test.* For this test, her hands were placed on her shoulders and relaxed. From the rear, the examiner stabilised the pelvic girdle on the left while he laterally flexed the trunk to the right, up to the end of its range (no rotation was allowed). The range was categorised as 1) easy elbow contact with plinth without stretching sensation and resistance (ideal); 2) contact with stretching sensation and resistance (non-ideal); and 3) unable to touch surface (highly unsatisfactory) (Kapandji, 1970; Gould III, 1990).

- **Coronal axis**

Equipment: One high chair.

Directions: The subject stood erect and relaxed, feet at shoulder width, with the examiner seated on a high chair, on the lateral side of the subject, facing the subject. The examiner used an imaginary coronal axis passing through the midline of the subject, to evaluate the postural position. Spinal regions were categorised according to their position in relation to the coronal axis. These regions were the cranium (head), cervical, thoracic and lumbar regions. Regions were identified as 1) ideal (no deviation from the coronal axis); and 2) non-ideal (deviating from the coronal axis) (Kapandji, 1970).

- **Sagital axis**

Equipment: A high chair.

Directions: The subject was positioned as for the *coronal* evaluation, but the examiner was positioned posterior to the subject, on a high chair. For this test, the examiner used and imaginary sagital axis passing through the midline of the subject, to evaluate postural position. The following regions were evaluated according to their position in relation to the sagital axis: cranium (head), cervical, thoracic and lumbar. Regions were categorised as 1) ideal (no deviation from the sagital axis); and 2) non-ideal (deviating from axis) (Kapandji, 1970).

(d) Neurological assessment (neurodynamics)

- **Straight leg raise (SLR)**

Equipment: A plinth.

Directions: The examiner positioned the subject supine on the plinth, with trunk and hips in a neutral position. The examiner then placed his one hand under the Achilles tendon of the subject and the other above the knee. He then lifted the leg perpendicular to the plinth. The limb was lifted as a solid lever moving at a fixed point in the hip joint, while the hand above the knee prevented any knee flexion. The examiner took the limb up to a symptom response or the end of range and noted the end of range (as all tension testing). The examiner then assessed the ROM.

Range was categorised as 1) greater than 90° (ideal); 2) 70° - 90° (non-ideal); and 3) less than 70° (highly unsatisfactory) (Saunders, 1990).

- **L 3, 4 nerve suppleness test (Prone knee bend)**

Equipment: A plinth.

Directions: The subject was positioned prone on the plinth, facing the examiner. The subject's lower limb was passively flexed towards her gluteal area until a symptom response or the end of range was achieved. The range was noted. Subjects were then classified into three categories: 1) heel touching gluteus area with no tension (slight resistance from natural limiting factors is normal) (ideal); 2) heel touching gluteus area with strong resistance (non-ideal); and 3) heel not touching gluteus (highly unsatisfactory) (Gould III, 1990).

- **Slump test**

Equipment: A plinth.

Directions: The subject sat well back on the plinth (knee crease at edge) with her legs over the side of the plinth. The following procedure was followed:

1. The subject linked both her hands in a relaxed position behind her back
2. The subject was ordered to slump with her cervical spine in extension. The examiner now applied gentle overpressure to the thoracic and lumbar spine. This position was maintained.
3. The examiner then gave the order to flex the cervical spine and to place the chin to the chest, again with gentle overpressure by the examiner.
4. Now, with this position maintained, the subject was ordered to extend the knee, first the left and then the right. The examiner noted the angle and discomfort.
5. While holding the position in 4, dorsiflexion of the ankle and foot was carefully added. The range and discomfort were noted.
6. With the position in 5 held, the neck flexion was carefully released, and signs and symptoms were noted.
7. The same test was repeated on the other side.

8. Finally, both knees were extended with the subject in the slump position, while gentle overpressure was applied by the examiner. Again, discomfort and range were noted.

Subjects were classified as follows: 1) full range, with dorsiflexion, asymptomatic (ideal); 2) full range, with dorsiflexion and discomfort (non-ideal); and 3) limited range with tension (highly unsatisfactory) (Gould III, 1990; Brukner & Khan, 2001).

3.5.2. Anthropometry components

The anthropometric measurements were taken indoors at the NWU netball clubhouse. To calculate the anthropometric variables in this study, the internationally standardised measuring protocol prescribed by the International Body on Kinanthropometrics was used (Ross & Marfell-Jones, 1991). For these measurements six standardised variables were used: body fat percentage (Forsyth & Sinning, 1973), by using 6 skinfolds measurements (subscapular skinfold, abdominal skinfold, triceps skinfold, supraspinal skinfold, thigh skinfold, calf skinfold); stature (height) (Norton *et al.,* 1996), by using a measuring tape; and body weight (Norton *et al.,* 1996), by using an electronic scale. Apparent anthropometric definitions, variables and methods are discussed below.

3.5.2.1. Terminology

(a) Anatomical position

This position is were the participant is in the erect position, arms next to side, palms and feet facing forward (Norton *et al.*, 1996).

(b) The Frankfort plane

When body length is measured the head has to be held in the Frankfort plane. The head position is in the Frankfort plane when a horizontal line can be drawn from the orbital (inferior border of the eye socket) to the tragion (indentation above the tragus of the ear) (Norton *et al.*, 1996).

(c) Vertex

When the head is positioned in the Frankfort plane, the vertex is the highest position on the skull (Norton *et al.,* 1996).

(d) The acromial landmark

This landmark is the point on the most superior lateral border of the acromion when the subject is standing erect with the arms relaxed (Ross & Marfell-Jones, 1991).

(e) The radial landmark

This is the point at the proximal and lateral border of the head of the radius (Ross & Marfell-Jones, 1991).

(f) The subscapular landmark

This is the point directly below the inferior angle of the scapula (Ross & Marfell-Jones, 1991).

(g) The iliospinal landmark

This is a mark found on the lowest (most inferior) tip of the anterior superior iliac spine (Ross & Marfell-Jones, 1991).

(h) Xiphoidal / infrasternal landmark

This is a mark found on the bottom part of the sternum and is the inferior tip of the xiphion (Ross & Marfell-Jones, 1991).

(i) Ilio axilla line

This is an imaginary vertical line joining the observed mid-point of the armpit with the lateral superior edge of the ilium (Ross & Marfell-Jones, 1991).

3.5.2.2. Anthropometric variables, measuring methods and apparatus

The measuring protocols, as well as the measuring methods and apparatus used, are discussed next. The examiner that performed these measurements was right-handed. All measurements were taken on the right side of the participants.

(a) Body weight

Equipment: An electronic scale

Technique: The subjects were dressed in short tights and gym tops, and stood erect in the middle of the scale with their weight equally distributed on both feet. The subject had to stand with the head up, eyes facing forward and arms relaxed for measurement. Body mass was recorded to the nearest 0.01 kg (Norton *et al.,* 1996).

(b) Stature (body height)

Equipment: A measuring tape and pencil

Technique: With this measurement the maximum distance between the standing surface and the vertex of the skull was obtained (Norton *et al.,* 1996). The measurement was taken with the subject erect, barefoot with heels together, body weight equally distributed and arms relaxed. In this position, the heels, buttocks, upper trunk and back of skull had to touch the wall before measurement, while the head was held in the Frankfort plane. Firm contact was made between the wall and the vertex of the skull for measurement. The examiner made a pencil mark on the wall at the vertex landmark, thereafter the examiner measured the distance from the floor to the pencil mark with a measuring tape. The measurement was recorded to the nearest millimetre (0.01 cm).

(c) Skinfold measurements (Body fat percentage)

Equipment: Harpenden skinfold calliper with a constant pressure of 10 g/mm^2.

Technique: First, the correct anatomical landmarks were marked with a clear pencil mark that did not wipe off easily. The skinfold positions were then carefully located, using these anatomical landmarks.

Before measurement, a double layer of skin with its underlying adipose tissue was firmly gripped on the marked area, between the index finger and thumb. In order to ensure that there was a sufficiently large grasp of the skinfold, but that no underlying muscle tissue was grasped and measured, the skinfold was rolled slightly between the finger and thumb. Before pulling away the skinfold, the thumb and finger were positioned in line with the marked site, with the back of the hand facing the measurer. Then the fold was pulled away from the underlying musculature and the mouth of the skinfold calliper applied approximately 1 cm below the two fingers and 1 cm deep into the fold, with the calliper positioned at 90° to the surface of the skinfold. Now, the trigger was completely released, while a firm grip was maintained on the skinfold. Two to three seconds were allowed throughout the procedure to ensure full pressure measurement (Norton *et al.*, 1996).

The skinfold measurements were taken in a specific pre-planned rotational manner. To improve accuracy, two measurements of each skinfold were taken. If a discrepancy of more than 1 mm occurred between the two, a third measurement was obtained. When two measurements were taken, the mean value was used, and in instances where three measurements were needed, the median value was used. All measurements were rounded off to the nearest 0.1 mm (for the Harpenden calliper). The skinfold method of measuring fat percentage is considered by researchers to be an accurate, valid and reliable field method (± 3% error) (Heyward & Stolarczyk, 1996). The skinfolds measured were the following:

- *Triceps skinfold*

This fold is halfway between the acromion and radial landmarks on the posterior surface of the triceps. For measurement the subject had to relax the arm while keeping the shoulder joint slightly externally rotated and the elbow extended at the side of the body. This vertical skinfold was then taken parallel to the line of the upper arm, on the most posterior surface of the arm, over the triceps muscle when viewed from the side (Norton *et al.,* 1996).

- *Subscapular skinfold*

The thumb palpated the inferior angle of the scapula to determine the lowermost tip. This fold should be taken at a site 2 cm along a line running laterally and obliquely downward from the subscapular landmark at an angle (approximately 45° to the horizontal) as determined by the natural lines of the skin. The skinfold was raised at this marked site (Norton *et al.,* 1996).

- *Supraspinal skinfold*

A diagonal fold was taken in a downward and medial direction at an angle of 45° to the horizontal. The measurement was taken approximately 5-7 cm above the anterior superior ileac spine, depending on the size of the subject. The fold was raised at the point where a line from the iliospinal mark to the anterior axillary border intersected with a horizontal line from the superior border of the ilium at the level of the iliocristal (Norton *et al.*, 1996).

- *Abdominal skinfold*

This vertical fold was taken approximately 5 cm lateral to the midpoint of the umbilicus. This skinfold was measured on the right-hand side of the subject

- *Thigh skinfold*

This is a vertical fold taken on the anterior midline of the thigh, midway between the proximal border of the patella and the inguinal crease (hip) (Norton *et al.,* 1996).

- *Calf skinfold*

This is a vertical fold taken on the medial aspect of the calf at the point of largest circumference of the calf muscle. The subject was measured sitting with the knee at 90° and the foot supported on the floor, with the calf relaxed (Norton *et al.,* 1996).

3.5.3. Physical/motor components

For the physical/motor evaluation three tests were used. The three tests were: the Illinois *agility* run (Kirby, 1991), computerised *balance* test (Techno therapy, 1992), vertical jump for *explosive power*, measured by a tapeswitch sensory mat connected to a Psion organiser (Boscosystem ErgoJump www.boscosystem.com). The Illinois *agility* test (Kirby, 1991) was performed on the netball courts. In this scenario it is possible for strong winds to influence the test results. This can be seen as a possible limitation to this as well as other netball studies. The ideal situation would be to have a large enough indoors testing facility. For different reasons, such a facility was not available during this study. However, little to no perceptible wind was detected on the testing days. The *balance* and *explosive power* tests were performed indoors.

3.5.3.1. Illinois agility test

Equipment: Tape measure, 8 markers (cones), stop watch, whistle, an assistant
Directions: The length of the course is 10 metres and the width (distance between the start and finish points) is 5 metres. Four cones were used to mark the start, finish and the two turning points. Each cone in the centre was spaced 3.3 metres apart. The test was conducted as follows:

- The netball players lied face down on the floor at the starting point (point A)
- On the assistant's command (blow of the whistle) the players jumped to her feet and sprinted from point A and around marker B.

- She then continued to and turned left around marker C, then zigzagged through the three allocated markers (between C and D) and around marker D, hereafter she zigzagged back to C.
- She then sprinted around C and progressed at full speed to and around E, and then finally to F where she finished.

The assistant recorded the total time taken from the command to the athlete completing the course. The subjects were allowed two attempts, the median was used. Time was measured and rounded of to the nearest 0.01 second (Kirby, 1991; www.brianmac.demon.co.uk/illinois.htm).

3.5.3.2. Balance

Equipment: Balance board, connecting cable, base mat, computer
Directions: This computerised balance test is set to default after 30 seconds. The subject stood in an upright position with her eyes open. The participant stood with her feet in a comfortable position to maintain her balance on the board, she is not allowed to move her feet once the test has started. The balance score is recorded in percentage. The subjects were allowed two attempts, the median was used (Techno Therapy, 1992).

3.5.3.3. Explosive power

Equipment: A tapeswitch sensory mat, Psion organiser
Directions: The player will be asked to stand with feet hip width apart, arms at sides, on the tapeswitch sensory mat. The examiner will instruct the participant to jump vertically as high as possible. The Psion computer determines the elapsed time spent in the air and converts this to a height measurement in centimetres (Boscosystem ErgoJump www.boscosystem.com). The median of two attempts were used.

3.6. STATISTICAL ANALYSIS

A variety of statistical techniques was used to analyse the data. A purposive selection of non-equivalent experimental-control group design with multiple post-tests was used in this study.

The overall injury incidence was expressed as the number of injuries per 1000 player-hours of netball. For the calculation of playing hours as well as injury incidence this study took into account each player's exposure to risk (measured as combined duration of all games played or training sessions attended). The coaches noted the total duration time of each match and training session on this form, as well as the participation time of each player. These times were then used to calculate the exposure time, as well as injury prevalence (expressed as *injuries/1000 player-hours)* of each group of players. The overall injury incidence was determined by first adding each of the players' total number of match-play hours to his total number of training hours. This sum represented the total exposure times of all the players in the specific group. The incidence was now expressed as *numbers of injuries/player-hours of netball.* This was then converted to the amount of injuries per 1000 player hours of netball and expressed as *injuries/1000 player-hours.*

The National Athletic Injury Registration System (NAIRS) in the United States of America (USA) grades injuries according to the duration of the time that the athlete is unable to return to the specific sport: 1 to 7 days of incapacitation is graded as "minor", 8 to 21 days as "moderately serious", and over 21 days or permanent damage as "serious" (Van Mechelen *et al.*, 1992:85). Injuries which allowed a player to return to rugby practice within seven days of its occurrence are graded as transient (Lee *et al.,* 2001). Armsey and Hosey (2004) state that most definitions state that injuries are graded as significant if the athlete is incapacitated for 7 days or more. Duration of injury/time off was calculated as the difference between the date of injury and the date of return to play. Only minor-, moderately serious- and serious injuries were included in the statistical analysis.

3.6.1. Statistical methods of data processing

The Statistica (StatSoft, 2004) and the SAS-computer programme (SAS Institute Inc., 2005) of the North West University, Potchefstroom campus were used for statistical data analysis. Statistical software was used for all the data analysis. Data was processed by using the Statistica-7 for Windows program (StatSoft Inc., 2005). Descriptive statistics, repeated measures ANOVA, two-way frequency tables, and effect sizes (practical significance) were used (Ellis & Steyn, 2003).

First, descriptive statistics were done on the group of participants involved in the study. This was done for all the biomechanical, anthropometrical and physical/motor abilities (agility, balance and explosive power). Thereafter, injury incidence was analysed for practically significant differences between age groups (junior and senior), playing positions and A- or B-grade players. The injury records from the sports-medical clinics (distribution of severity of injury, type of injury, anatomical region affected, injured during match or training) were described with the help of frequency tables.

The practically significant relationship between pre- and post measurements were determined using effect sizes (Ellis & Steyn, 2003). Effect size is considered to provide an indication of the practical "meaningfulness" of differences. Effect sizes make the differences independent of units and sample size, and also relate it to the spread of the data (Ellis & Steyn, 2003). Effect size for injury incidence was calculated with the following formula: $d = \frac{|\bar{x}_1 - \bar{x}_2|}{s_{max}}$

where s_{max} = maximum of s_1 and s_2, the sample SDs (Ellis & Steyn, 2003). Cohen's guidelines are used for the interpretation of the effect sizes (Ellis & Steyn, 2003). The guidelines are the following:

(a) small effect: d = 0.2;

(b) medium effect: d = 0.5;

(c) large effect: d = 0.8

Data with $d \geq 0.8$ are considered practically significant, since such data are the result of a difference having a large effect (Ellis & Steyn, 2003). Repeated measures ANOVA was used to calculate how the different biomechanical; anthropometric; physical/motor variables of players changed over the two testing occasions (pre- and post-season testing). An analysis of the profiles of the different groups was used to examine the changes which occurred during the netball season. Differences between testing occasions and different groups (juniors and seniors; centre- and goal players; and A- and B-grade players) were again analysed for practical significance (effect size for difference between means). Because the biomechanical; anthropometric; and physical/motor data were dependant, standard deviations (SD's) were not used in the calculation of effect size. Instead of the standard deviation, the square root of the mean square error (*MSE*) of the repeated measures ANOVA was used as the denominator. The *MSE* is a measure of the variance of data, while $\sqrt{MSE}$ is a measure of the standard deviation in different measurements. Therefore the formula used for the effect sizes of the ANOVA was: $d = \frac{|\bar{x}_i - \bar{x}_j|}{\sqrt{MSE}}$ (Ellis & Steyn, 2003). Once again, $d \geq 0.8$ was considered as practically significant for all cases, since it is the result of a difference having a large effect (Ellis & Steyn, 2003).

CHAPTER 4

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CHAPTER 4

RESULTS AND DISCUSSION

4.1. INTRODUCTION

The primary aim of this study was to determine the physical profiles of club netball players from the North-West University aged between 18 and 23 years, with reference to the biomechanics, anthropometric measurements and physical/motor abilities (agility, balance and explosive power). The secondary aim was to identify biomechanical variables, anthropometrical components and physical/motor abilities (agility, balance and explosive power) that could contribute to musculoskeletal injuries of these netball players.

In this chapter the descriptive and inferential statistics (significance) for the total group as well as the descriptive and significant statistics for the different groups (juniors and seniors, centre and goal players; A- and B-grade players) participating in this study are presented and discussed. The descriptive- and significant statistics of the first- and second testing occasion will be discussed and thereafter the practical significant differences between the two testing occasions will be presented and discussed. Comparisons are made between the junior and senior players, the different player positions (centre or goal players) and different grades (A or B-grade players). The results will also be compared to existing literature. The comparison to the existing literature was extremely difficult: firstly, a lack of available studies conducted on netball players were identified; and secondly, the studies that were found in literature applied different tests and techniques, therefore implying incomparable results between existing studies and this particular study. Due to the lack of relevant existing literature, the researcher often refers to Brukner and Khan (2001), because during the literature review it was discovered that Brukner and Khan (2001) is one of the most informative and applicable references available.

4.2. DESCRIPTIVE STATISTICS AND DISCUSSION OF BIOMECHANICAL DATA OF THE TOTAL GROUP DURING TEST ONE

This study will only look at the total group's descriptive statistics. Table 4.1 presents the descriptive statistics of the biomechanical assessment of the total elite group of netball players during the first testing occasion. The data was collected under four main categories, namely lower limb, pelvic girdle, spinal region and neurodynamics. The grading method of the tests conducted in the four categories will be explained next. Grade 1 (ideal) and grade 2 (non-ideal) were applied in the following tests in the *lower limb region*: Q-angle test; patella squint, tilt and height tests; VMO-L-comparison test; forefoot positional test; the transverse arch area comparison; and the toe positional test. In the *pelvic girdle region*, the same grading method was applied by the ASIS, and PSIS comparison tests, the pelvic rami positional test, and the sacroiliac cleft test (grade 1 (ideal) and grade 2 (non-ideal). In the *spinal region* the sacral rhythm, head positional, cervical, thoracic, and lumbar tests used a similar grading system (1=ideal; 2=non-ideal).

In the following tests in the *lower limb region* the grading system differed from the previous tests, and the grades consisted of 1 (ideal), 2 (non-ideal) and 3 (highly unsatisfactory): the Achilles tendon suppleness test; ITB mobility test; quadriceps mobility test, iliopsoas mobility test; gluteus maximus mobility test; adductor mobility test; and the internal and external rotation mobility tests. The *pelvic girdle* and the *spinal region* used the same grading method (1=-ideal; 2-non=ideal; and 3=highly unsatisfactory) in the following tests: the leg length discrepancy test; bilateral pelvis positional tests; thoraco-lumbar fascia assessment; functional extension mobility test; functional flexion test; rotational mobility test; and the side flexion mobility test. The last category, namely, *neurodynamics*, applied the same grading protocol in the SLR and PKB tests.

The longitudinal arch status and foot mobility tests applied a differed grading system: 1 (hypermobile), 2 (ideal), 3 (hypomobile) and the rear foot standing and lying tests used 1 (pronation), 2 (ideal), 3 (supination). All these tests are in the section on lower limb biomechanics.

When analysing the first region of the biomechanical assessment, namely the *lower limb* region, it is apparent that among the netball players, two aspects of the modified Thomas test recorded high mean values, indicating that these areas are less mobile and dynamically loaded (Table 4.1). These two aspects are the ITB and the iliopsoas mobility tests. The ITB component presented with inadequate flexibility ($\bar{x}$ =1.6578) and was therefore identified as a biomechanical stressor. This tendency presented at 60% (57% non-ideal and 3% highly unsatisfactory) of the total group of netball players. The iliopsoas mobility test indicated a decreased flexibility ($\bar{x}$ =1.6578), meaning that 55% (45% non-ideal and 10% highly unsatisfactory) of the participants presented with this biomechanical deviation.

The literature explains the effects these biomechanical deviations (tight ITB and iliopsoas) could have on the performance and susceptibility to injuries of the athlete, including netball players, performance and susceptibility to injuries. Nicholas (1997) emphasises that adequate flexibility is an imperative factor in the performance of an athlete, due to the fact that flexible muscles move through a greater range of motion and therefore produces more power for extended periods of time, in other words, adequate flexibility means more strength and power to an athlete. Both Armstrong and McManus (1996) and Nicholas (1997) found that inadequate flexibility results in decreased performance, altered technique and uncoordinated movements and that it predisposes athletes to muscle strains and tears. Brukner and Khan (2001) agree that ITB tightness may be present in athletes who are diagnosed with overuse sport injuries such as patellar tendinitis, patellofemoral pain, stress fractures, periostitis and compartment syndrome. McConnell (2002) concludes that tight hip flexors, such as the iliopsoas muscle, are associated with anterior knee pain and chondromalacia. These injuries are often associated with netball players (Brukner & Khan, 2001).

The results of this particular study differed from the results of a study conducted by Venter *et al.* (2005). The players involved in this study presented with shortened lower back and hamstring muscles, whereas only 20.0% of the participants in this particular study were detected with inadequate hamstring length and 26% were detected with tight lower back muscles. Different tests were applied in these studies to examine the length of these muscles, Venter *et al.* (2005) used the sit-and-reach test while the current study applied the functional flexion test (lower back muscles) and the SLR test (flexibility testing component for the hamstring muscle); therefore the comparison of the results of these two studies are inadequate.

The following tests (lower limb region) scored high mean values: patella tilt test with $\bar{x}$ =1.6470; this abnormality was detected at 64% of the players. The patella height test presented with $\bar{x}$ =1.8823. This tendency was identified at 89% of the participants, meaning that 89% of the total group presented with asymmetrical patella height. The existing literature does not correlate with these findings: according to literature an excessive Q-angle (varus alignment) is usually detected at athletes, including netball players, with overuse injuries such as patellar tendinopathy, medial shin pain and patellofemoral syndrome (Hass *et al.,* 2005; Brukner & Khan, 2001). Only 12% of the participants of this particular study presented with non-ideal Q-angle values in the lower limb region (Table 4.1).

The rear foot positional standing and lying tests scored $\bar{x}$ =1.3030 and $\bar{x}$ =1.3636 respectively, therefore 74% of the participants presented with rear foot pronation in standing and 69% with rear foot pronation in lying (Table 4.1). A study conducted by Hopper and Elliot (1993) found that 42.1% of the netball players presented with rear foot varus with compensating subtalar pronation. In this study 25% of the 240 participants presented with overuse injuries, such as retropatellar pain (24%) and shin pain (38%), caused by abnormal biomechanics. According to Brukner and Khan (2001) pronation of a netball player's foot could contribute to overuse injuries such as patellar tendinopathy, medial shin pain and patellofemoral syndrome.

Excessive pronation may produce an unstable forefoot, therefore the netball player could also be susceptible to traumatic injuries such as ankle sprains (Donatelli, 1990). The transverse arch area comparison test (lower limb region) scored $\bar{x}$ =1.660, meaning that 94% of the total group presented with callus plantar aspects with a flat arch, known as pes planus (Table 4.1). Brukner and Khan (2001) confirm that pes planus is categorised as an intrinsic factor that could lead to overuse injuries in various sports, including netball. The last test performed in the lower limb region, namely the toe positional test, scored $\bar{x}$ =1.9393. This tendency was indicated at 94% of the netball players, therefore 94% of the participants presented with biomechanical abnormalities, such as valgus, rotation or deviation, of their toes (Table 4.1). Unfortunately, the researcher could not find any existing literature to explain this interesting phenomenon or to compare these findings.

The *pelvic girdle region* was the second biomechanical region to be evaluated. Five of the six tests in this region presented with high mean values, meaning that with most of these tests the participants presented with non-ideal values. The leg length discrepancy test ($\bar{x}$ =1.6666) indicated that 66% of the total group presented with a slight leg length discrepancy (Table 4.1). According to Bell-Jenje and Bourne (2003), leg length discrepancies are a subtle cause of overuse injuries, while Brukner and Khan (2001) classify leg length discrepancies as an intrinsic factor that could lead to overuse injuries. Brukner and Khan (2001) agree that leg length discrepancies may lead to overuse injuries in various sports. The ASIS ($\bar{x}$ =1.6363), PSIS-comparison tests ($\bar{x}$ =1.6363) and the pelvic rami positional test ($\bar{x}$ =1.6363) indicated that 63% of the participants presented with asymmetries in these (ASIS, PSIS and pelvic ramis) areas. According to Brukner and Khan (2001) these bony asymmetries could be the result of sports, such as cricket and tennis which consist of unilateral activities, thus leading to asymmetries in body development. As a result the athlete engages in poor mechanics of movement and therefore increases their risk to injuries. Brukner and Khan (2001) argue that asymmetries within the pelvis and the legs (leg length discrepancies) may be the cause of consistent knee injury patterns.

Netball players tend to use their dominant arm or leg more than their non-dominant side, especially with throwing and landing activities therefore this phenomenon (pelvic asymmetries) applies to netball players as well (Hopper *et al.*, 1999). The bilateral pelvis positional test ($\bar{x}$ = 1.9090) identified a non-ideal lumbar position among 91% of the players. This non-ideal position was defined as a hyperlordotic lumbar curve or an excessive anterior pelvic tilt (Table 4.1).

In the *spinal region* the assessment of the lumbar area from the coronal axis verified this non-ideal pelvic position (hyperlordotic lumbar curve). This test was the only test with a high mean value ($\bar{x}$ =1.9697). This test (assessment of the lumbar area) indicated that 91% of the total group presented with this biomechanical deviation (hyperlordosis) (Table 4.1). Excessive anterior pelvic tilt may lead to overuse injuries such as patellar tendinopathy, patellofemoral syndrome, fatpad impingement and hamstring strain in various sports, including netball (Brukner & Khan, 2001). According to Panjabi (1992) the difference in height between the lower ASIS and the PSIS is categorised as ideal when measured as $\geq$ 2; but if < 3 cm, this position is classified as an acceptable lumbar curve (Panjabi, 1992). For the fourth and last component, namely *neurodynamics*, most of the participants presented with ideal values.

Lastly, a summary will follow on the *biomechanical data* of the total group of netball players during the first testing occasion. Numerous biomechanical deviations were identified among the total group of netball players in the lower limb region. These biomechanical deviations consisted of ITB and iliopsoas tightness; tilted patella; asymmetrical patella height; rear foot pronation; callus plantar aspect with a flat arch; and finally, with valgus, rotation or deviation of their toes (Table 4.1). In the pelvic girdle region, biomechanical abnormalities such as excessive leg length discrepancies; asymmetries at the PSIS, ASIS, pelvic ramis as well as asymmetrical pelvic positions were recorded among numerous of the netball players. The assessment of the spinal region indicated that 91% of the total group of netball players presented with a hyperlordotic lumbar curve. With the other tests conducted in the spinal region and with neurodynamics, the majority of the participants tend to achieve ideal values (Table 4.1).

Table 4.1 Descriptive statistics of biomechanical data of the total elite group of netball players during test one (N=33-38)

TEST VARIABLES	Number	$\bar{x}$	Std.Dev.	Minimum	Maximum	Percentage of players		
BIOMECHANICS:								
LOWER LIMB REGION:						1	2	3
Achilles tendon suppleness test	38	1.26316	0.44626	1.00000	2.00000	72	28	0
Iliotibial band mobility test (ITB)	38	1.65789	0.53405	1.00000	3.00000	40	57	3
Quadriceps mobility	38	1.42105	0.50036	1.00000	2.00000	60	40	0
Iliopsoas mobility	38	1.65789	0.66886	1.00000	3.00000	45	45	10
Gluteus maximus mobility test	38	1.44737	0.55495	1.00000	3.00000	60	37	3
Adductor mobility test	38	1.07895	0.27328	1.00000	2.00000	93	7	0
Internal rotation mobility test	38	1.00000	0.00000	1.00000	1.00000	100	0	0
External rotation mobility test	38	1.44737	0.55495	1.00000	3.00000	60	38	2
Q-angle test	34	1.14706	0.35949	1.00000	2.00000	86	12	-
Patella squint test	34	1.17647	0.38695	1.00000	2.00000	83	17	-
Patella tilt test	34	1.64706	0.48507	1.00000	2.00000	36	64	-
Patella height test	34	1.88235	0.32703	1.00000	2.00000	11	89	-
VMO – L-comparison test	34	1.35294	0.48507	1.00000	2.00000	64	36	-
Longitudinal arch status test*	33	1.72727	0.45227	1.00000	2.00000	29	71	0
Forefoot positional test	33	1.21212	0.41515	1.00000	2.00000	77	23	-
Rear foot positional standing test*	33	1.30303	0.52944	1.00000	3.00000	74	23	3
Rear foot lying test*	33	1.36364	0.54876	1.00000	3.00000	69	29	2
Transverse arch area comparison test	33	1.60606	0.43592	1.00000	2.00000	6	94	-
Foot mobility test*	33	1.69697	0.63663	1.00000	3.00000	43	49	8
Toe positional test	33	1.93939	0.24231	1.00000	2.00000	6	94	-
PELVIC GIRDLE REGION:								
Leg length discrepancy test	33	1.66667	0.47871	1.00000	2.00000	34	66	0
ASIS comparison test	33	1.63636	0.48850	1.00000	2.00000	37	63	-
PSIS comparison test	33	1.63636	0.48850	1.00000	2.00000	37	63	-
Pelvic rami positional test	33	1.63636	0.48850	1.00000	2.00000	37	63	-
Sacroiliac cleft test	33	1.06061	0.24231	1.00000	2.00000	94	6	-
Bilateral pelvis positional test	33	1.90909	0.29194	1.00000	2.00000	9	91	0
SPINAL REGION:								
Thoraco-lumbar fascia	33	1.24242	0.43519	1.00000	2.00000	77	23	0
Sacral rhythm test	33	1.00000	0.00000	1.00000	1.00000	100	0	-
Functional extension mobility test	33	1.09091	0.29194	1.00000	2.00000	91	9	0
Functional flexion test	33	1.27273	0.45227	1.00000	2.00000	74	26	0
Rotational mobility test	33	1.06061	0.24231	1.00000	2.00000	94	6	0
Side flexion mobility test	33	1.09091	0.29194	1.00000	2.00000	91	9	0
Head positional	33	1.00000	0.00000	1.00000	1.00000	100	0	-
Cervical	33	1.00000	0.00000	1.00000	1.00000	100	0	-
Thoracic	33	1.15152	0.36411	1.00000	2.00000	86	14	-
Lumbar	33	1.96970	0.29464	1.00000	2.00000	9	91	-
NEURODYNAMICS								
Straight leg raise (SLR)	33	1.18182	0.39167	1.00000	2.00000	80	20	0
Prone knee bend test (PKB)	33	1.27273	0.51676	1.00000	3.00000	77	20	3

4.3. DESCRIPTIVE STATISTICS AND DISCUSSION OF ANTHROPOMETRY AND PHYSICAL/MOTOR DATA OF THE TOTAL GROUP DURING TEST ONE

The *anthropometry* status of the group in total presented that the mean value for body mass index (weight/height^2) is 22.19 (Table 4.2). According to De Ridder (2004) the acceptable body mass index (BMI) for female athletes of 18 years and older, is between 18.5 and 24.9; therefore the mean value for the total group is in the ideal category. The mean values for the weight and height of the group in total is 67.57kg and 1.74m irrespectively. The netball players participating in the study conducted by Venter *et al.* (2005) presented with an average weight of 66.8kg and an average height of 1.7m, whereas the Australian counterparts, on the other hand, scored mean values of 68.5kg (weight) and 1.8m (height). Therefore the netball players of the North-West University (NWU) Netball Club are 0.77kg heavier and 4.70mm taller than the Boland netball players, and 0.92kg lighter and 1cm shorter than the state-level Australian netball players. De Ridder (2004) points out that BMI is an inaccurate method to determine body composition and obesity, due to the fact that it does not distinguish between body and fat mass, therefore one must combine BMI with fat percentage to determine an athlete's anthropometry status (Table 4.2).

The mean value for fat percentage for the group in total is 26.26%, indicating that the group falls in the above average category (25 - 31%) (De Ridder, 2004). The ideal for a female athlete of 18 years and older is between 22% and 24% (De Ridder, 2004). The study conducted by Venter *et al.* (2005) concluded that the Boland netball players, aged between 18 and 24 years, presented with an average fat percentage of 25%; therefore 1.26% less that the NWU Club netball players. Unfortunately, this study by Venter *et al.* (2005) applied a different formula for determining the fat percentage, which makes it difficult to compare results. The in-depth analysis of the skinfold measurements is beyond the scope of this study, but considering these measurements it seems that the participants in this particular study carried their most subcutaneous fat in the tricep, abdominal and thigh areas (Table 4.2).

In conclusion, the average BMI for the total group fell in the ideal category, while the average fat percentage of the total group was considered above average, meaning that the NWU Club netball players presented with above average subcutaneous fat especially in the tricep, abdominal and thigh areas.

The statistics for *physical/motor abilities* reported a mean value for agility of 19.45sec (Table 4.2). According to the normative data, for female athletes, for the Illinois Agility Run Test, the mean value fell in the average category (18.0 - 21.7sec), whereas one would expect the NWU Club netball players to perform above average (17.0 - 17.9sec), due to their status as elite netball players (www.brianmac.demon.uk/illinois.htm). The netball players scored a mean value of 69.80% with the balance test, but this percentage is unacceptable for elite netball players. According to the norm for elite athletes, including netball players, 75% and above is considered acceptable (Techno therapy, 1992). The last motor ability test, namely explosive leg power, presented a mean value of 33.02. A score above 30 is considered acceptable for elite athletes; thus the NWU Club netball players presented with an acceptable score with the explosive power test (Boscosystem ErgoJump www.boscosystem.com) (Table 4.2). The NWU Club netball players performed relatively acceptable regarding the agility and explosive power tests, but underperformed with the balancing test, according to the norm set for elite netball players.

To conclude the *anthropometry* and *physical/motor abilities* of the total group of netball players a summary will follow: the average BMI of the group fell in the ideal category with an above average fat percentage, meaning that the group presented with above average subcutaneous fat especially in the tricep, abdominal and thigh areas. According to the norms set for elite netball players, the averages for agility and explosive power were considered acceptable but the group underperformed with the balancing test.

Table 4.2 Descriptive statistics of anthropometry and physical/motor data of the total group of netball players during test one (N=38-40)

TEST VARIABLES	Number	$\bar{x}$	Std dev	Minimum	Maximum
ANTHROPOMETRY:					
Weight (kg)	40	67.57500	10.58758	48.00000	90.00000
Height (m)	40	1.74475	0.08221	1.56000	1.89000
Body mass index (BMI)	40	22.19000	2.55993	17.20000	26.10000
Fat percentage (%)	40	26.26675	2.82086	20.69000	30.41000
SKINFOLDS:					
Tricep	40	16.77000	4.44085	9.00000	25.200002
Subscapular	40	11.65250	3.21040	7.50000	21.50000
Supraspinal	40	13.81250	4.22333	5.00000	26.50000
Abdominal	40	20.28500	4.35022	7.00000	26.90000
Thigh	40	22.54000	4.14542	11.80000	35.00000
Calf	40	16.57000	4.66774	6.00000	26.80000
PHYSICAL/MOTOR ABILITIES:					
Agility (sec)	40	19.45750	0.76019	18.10000	21.40000
Balance (%)	38	69.80789	10.27246	47.80000	91.90000
Explosive power	40	33.02500	5.19609	19.00000	43.00000

4.4. INTERGROUP COMPARISONS OF BIOMECHANICS, ANTHROPOMETRY AND PHYSICAL/MOTOR ABILITIES DURING TEST ONE

4.4.1. Descriptive statistics and significant differences for junior and senior players during test one

The netball players were categorised in junior and senior players according to their age. The junior group consisted of players 19 years and younger (≤19 years), while players 20 years and older (≥20 years) were considered as senior players. From the total group of 40 players, 27 players were categorised as juniors and 13 as senior players.

Table 4.3 reports the results of the *biomechanics* of the junior players compared to the senior players. The data was collected for four main categories, namely lower limb, pelvic girdle, spinal region and neurodynamics. The biomechanical grading method used with the juniors and seniors was based on the same protocol applied for the total group of netball players (Section 4.2).

Firstly, the results of the tests performed in the *lower limb region* of the junior and the senior players will be compared. The junior players tend to score ideal values for thirteen of the twenty tests; thus fewer biomechanical deviations have been detected among the junior players than the senior players. A significant difference ($p \leq 0.05$) between the junior and senior players was detected with the toe positional test ($p=0.0400$). Secondly, the *pelvic girdle region* was analysed. The junior players performed better with five of the six tests in this region, meaning that the junior players have less biomechanical abnormalities in the pelvic girdle region than the senior players. Thirdly, the *spinal region* was assessed, where the juniors and the seniors tend to score ideal values in five of the ten tests; in other words, biomechanical abnormalities were detected in five of the ten tests at both groups. *Neurodynamics* was the last component which was evaluated. The junior players performed better than the seniors in both tests (SLR and PKB) in this category, which means that fewer biomechanical deviations were detected at the junior players than at the senior players. No significant differences ($p \leq 0.5$; $d \geq 0.8$) were detected between the two groups (juniors and seniors) with any tests conducted in the pelvic girdle, spinal regions or with neurodynamics.

Table 4.4 summarises the anthropometry and physical/motor data of the junior and senior players. Comparing the *anthropometry* of the junior and the senior players, the junior players presented with an average BMI of 22.27 and the senior players with an average BMI of 22.02; thus both groups scored values in the ideal category of 22 - 24 (De Ridder, 2004). The ideal fat percentage according to De Ridder (2004) for female athletes older than 18 years is between 22% and 24%. Both groups presented with fat percentages higher than the ideal value, but the juniors ($\bar{x}$ =25.97%) presented with an average fat percentage closer to the ideal than the seniors ($\bar{x}$ =26.87%). No practically significant differences ($p \leq 0.05$; $d \geq 0.08$) were detected with the comparison of anthropometrical status of the junior to the senior players.

When comparing the *physical/motor abilities* of the junior to the senior players, the juniors performed better than the seniors in two of the three motor ability tests.

With the agility test, the junior players reached an average of 19.36 sec, with the seniors presenting with an average of 19.64 sec, meaning that the juniors completed the agility run test in a better time than the senior players; however, the difference is not significant. Averages of 19.4 sec and 19.6 sec fell in the average category (www.Brian-mac.demon.uk/illinois.htm). With the balance test the juniors presented with a non-significant higher average value ($\bar{x}$ =69.99) than the seniors ($\bar{x}$ =69.40), meaning that the juniors have better balancing abilities than the seniors. These values are less than the acceptable value of 75% (Techno therapy, 1992) for elite netball players; thus both the junior and senior players underperformed. The senior players ($\bar{x}$ =34.46) performed better than the junior players ($\bar{x}$ =32.33) with the explosive power test. A score above 30 is considered as acceptable for elite netball players; therefore the scores of both groups (juniors and seniors) are considered acceptable (Boscosystem ErgoJump www. Bosco-system.com). With the physical/motor tests no significant differences ($p \leq 0.05$; $d \geq 0.8$) presented between the junior and senior groups.

To summarise; in the lower limb-, pelvic girdle region and with neurodynamics the juniors performed better than the seniors, which mean that fewer *biomechanical* deviations were detected at the junior players than at the senior players. A significant difference was identified with the toe positional test (lower limb region). No significant differences were detected between the two groups (juniors and seniors) with any tests conducted in the pelvic girdle, spinal region or with neurodynamics. The *anthropometrical assessment* recorded that the juniors performed better than the seniors in two (agility and balance) of the three *physical/motor tests*. The average agility scores for both groups fell in the average category, while the average value for the ability to balance was unacceptable. The seniors presented with a better average score for explosive power than the juniors, and the averages of both groups were considered as acceptable according to the norm set for elite netball players. However, the physical/motor differences between the junior and senior players were not significant.

Table 4.3 Descriptive statistics and significant differences of biomechanical data for junior (N=27) and senior players (N=13) during test one

TEST VARIABLES	X̄ Juniors	X̄ Seniors	Std.Dev. Juniors	Std.Dev. Seniors	p	Effect size (d)
BIOMECHANICS:						
LOWER LIMB REGION:						
Achilles tendon suppleness test	1.26923	1.25000	0.45234	0.45227	0.90371	0.04251
Iliotibial band mobility test (ITB)	1.61538	1.75000	0.49614	0.62158	0.47768	0.21656
Quadriceps mobility	1.34615	1.58333	0.48516	0.51493	0.17778	0.46060
Iliopsoas mobility	1.61538	1.75000	0.63730	0.75378	0.57126	0.17858
Gluteus maximus mobility test	1.46154	1.41667	0.50839	0.66856	0.82039	0.06711
Adductor mobility test	1.07692	1.08333	0.27175	0.28868	0.94750	0.02220
Internal rotation mobility test	1.00000	1.00000	0.00000	0.00000	-	0.00000
External rotation mobility test	1.42308	1.50000	0.50383	0.67420	0.69691	0.11409
Q-angle test	1.13043	1.18182	0.34435	0.40452	0.70290	0.12702
Patella squint test	1.17391	1.18182	0.38755	0.40452	0.95657	0.01954
Patella tilt test	1.60870	1.72727	0.49901	0.46710	0.51326	0.23762
Patella height test	1.86957	1.90909	0.34435	0.30151	0.74715	0.11478
VMO – L-comparison test	1.30435	1.45455	0.47047	0.52223	0.40664	0.28760
Longitudinal arch status test*	1.77273	1.63636	0.42893	0.50452	0.42290	0.27028
Forefoot positional test	1.13636	1.36364	0.35125	0.50452	0.14066	0.45046
Rear foot positional standing test*	1.27273	1.36364	0.45584	0.67420	0.64927	0.13480
Rear foot lying test*	1.31818	1.45455	0.47673	0.68755	0.50966	0.19833
Transverse arch area comparison test	2.90909	2.00000	2.94245	0.44721	0.31985	0.30895
Foot mobility test*	1.68182	1.72727	0.56790	0.78625	0.85022	0.05781
Toe positional test	2.00000	1.81818	0.00000	0.40452	0.04006*	0.44946
PELVIC GIRDLE REGION:						
Leg length discrepancy test	1.59091	1.81818	0.50324	0.40452	0.20338	0.45162
ASIS comparison test	1.54545	1.81818	0.50965	0.40452	0.13268	0.53513
PSIS comparison test	1.54545	1.81818	0.50965	0.40452	0.13268	0.53513
Pelvic rami positional test	1.54545	1.81818	0.50965	0.40452	0.13268	0.53513
Sacroiliac cleft test	1.04545	1.09091	0.21320	0.30151	0.61919	0.15075
Bilateral pelvis positional test	1.95455	1.81818	0.21320	0.40452	0.21096	0.33710
SPINAL REGION:						
Thoraco-lumbar fascia	1.22727	1.27273	0.42893	0.46710	0.78229	0.09731
Sacral rhythm test	1.00000	1.00000	0.00000	0.00000	-	0.00000
Functional extension mobility test	1.04545	1.18182	0.21320	0.40452	0.21096	0.33710
Functional flexion test	1.22727	1.36364	0.42893	0.50452	0.42290	0.27028
Rotational mobility test	1.04545	1.09091	0.21320	0.30151	0.61919	0.15075
Side flexion mobility test	1.09091	1.09091	0.29424	0.30151	-	0.00000
Head positional	1.00000	1.00000	0.00000	0.00000	-	0.00000
Cervical	1.00000	1.00000	0.00000	0.00000	-	0.00000
Thoracic	1.18182	1.09091	0.39477	0.30151	0.50764	0.23028
Lumbar	2.00000	1.90909	0.00000	0.53936	0.42772	0.16855
NEURODYNAMICS						
Straight leg raise (SLR)	1.18182	1.18182	0.39477	0.40452	-	0.00000
Prone knee bend test (PKB)	1.22727	1.36364	0.42893	0.67420	0.48361	0.20226

Table 4.4 Descriptive statistics and significance of anthropometry and physical/ motor data for junior (N=27) and senior players (N=13) during test one

TEST VARIABLES	$\bar{X}$ Juniors	$\bar{X}$ Seniors	Std.Dev. Juniors	Std.Dev. Seniors	p	Effect size (d)
ANTHROPOMETRY:						
Weight (kg)	67.25926	68.23077	9.78457	12.49769	0.78971	0.07773
Height (m)	1.74037	1.75385	0.07470	0.09870	0.63345	0.13652
Body mass index	22.27037	22.02308	2.64471	2.46953	0.77889	0.09350
Fat percentage (%)	25.97519	26.87231	2.92343	2.59910	0.35280	0.30687
SKINFOLDS:						
Tricep	16.90370	16.49231	4.68241	4.05780	0.78774	0.08786
Subscapular	11.82963	11.28462	3.66174	2.05623	0.62134	0.14884
Supraspinal	13.41852	14.63077	4.36666	3.94723	0.40219	0.27761
Abdominal	20.32593	20.20000	3.93257	5.29009	0.93298	0.02380
Thigh	21.83704	24.00000	3.65568	4.84493	0.12362	0.44643
Calf	16.25556	17.22308	5.13572	3.60258	0.54612	0.18839
PHYSICAL/MOTOR ABILITIES:						
Agility (sec)	19.36667	19.64615	0.50763	1.12370	0.28181	0.24872
Balance (%)	69.99615	69.40000	10.36411	10.51441	0.87057	0.05669
Explosive power	32.33333	34.46154	5.29150	4.87537	0.22965	0.40219

$d = \frac{|\bar{x}_1 - \bar{x}_2|}{s_{max}}$ = effect size for difference between means; a measurement of practical significance

$p \leq 0.05$

$d \geq 0.2$ (small effect)

$d \geq 0.5$ (medium effect)

$d \geq 0.8$ (large effect)

$\bar{X}$ = average value

* = Large significant difference between groups

4.4.2. Descriptive statistics and significant differences between centre and goal players during test one

The participants were categorised as centre or goal players. The following positions are considered as centre players: centre (C); wing defence (WD); and wing attack (WA), while positions such as, goalkeeper (GK), goal defender (GD) and goal attack (GA) are considered as goal players. These categories were defined according to the unique work profile and somatotype of the different playing positions.

In netball the centre players' (C, WD and WA) work profile consists more of running, jumping and changing direction than that of the goal players (G, GA, GK and GD); therefore the centre players would tend to have a mesomorphic physique while the goal players and defenders would be divided into the ectomorphic category (Jordaan, 2001). From the total group of 40 netball players, 20 participants were classified as centre players and 20 as goal players.

Table 4.5 represents the data of the *biomechanical* assessments of the centre players compared to the goal players. The data was collected under four main categories, namely lower limb, pelvic girdle, spinal region and neurodynamics. The grading method of the tests conducted in the four categories followed the same protocol as the biomechanical assessment of the total group (Section 4.2). The *lower limb* was the first region to be analysed, and twenty tests were performed in this area. The goal players tend to score ideal values with more of these tests than the centre players, meaning that fewer biomechanical deviations were detected in goal players than in the centre players. The goal players scored better values than the centre players in 14 of the 20 tests. With the longitudinal arch status test a practical significant difference ($p \leq 0.05$; $d \geq 0.8$) was identified ($p=0.0073$; $d=0.7931$); most of the centre players ($\bar{x}=1.52$) presented with a more ideal longitudinal arch while a dropped longitudinal arch was detected in most of the goal players ($\bar{x}=1.93$). In the lower limb region the only practically significant biomechanical difference between the centre and goal players was detected with this test (longitudinal arch status test). No relevant literature could be found to explain this interesting phenomenon (dropped longitudinal arch). A possible reason for this biomechanical deviation (dropped longitudinal arch) could be the result of repetitive strenuous activities such as jumping and landing combined with weak intrinsic foot muscles to absorb the shock when landing.

The second region to be looked at was the *pelvic girdle region*, where the goal players performed better than the centre players. The goal players tended to score ideal values in five of the six tests conducted in this region (pelvic girdle), meaning that less biomechanical stressors have been identified for the goal players than for the centre players. For the third area, namely the *spinal region*, it was found that the centre players performed better than the goal players in seven of the ten tests. In other words, in the spinal region less biomechanical abnormalities were detected in the centre players than the goal players. Tests for the last component, namely *neurodynamics*, showed that the centre players performed better in the first test (SLR) in this area and the goal players performed better in the second and last test (PKB). No significant biomechanical differences were detected in the pelvic girdle region or the spinal region, or for neurodynamics.

Table 4.6 summarises the *anthropometrical status* and the results of the *physical/motor tests* of the centre and goal players. The centre players and goal players presented with an average BMI (weight/height^2) value of 22.96 and 22.42 respectively, indicating that both groups fell within the ideal category of 18.5 - 24.9 (De Ridder, 2004). The centre players presented with a mean weight of 62.85 kg, compared to the goal players, with a mean weight of 72.3000 kg. A mean value of 1.69 m was recorded for height for the centre players, compared to the mean height of 1.79 m for the goal players. Practical significant differences ($p \leq 0.05$; $d \geq 0.8$) were detected for both these variables (weight $p=0.0034$, $d=0.9048$ and height $p=0.00004$, $d=1.4536$) of the centre players, compared to the goal players. These findings are similar to those made by Jordaan (2001), who classifies centre players in the mesomorphic and goal players in the ectomorphic category, which indicates that a mesomorphic stature is usually shorter in height than their ectomorphic counterparts.

An interpretation of the fat percentages of both groups showed that the centre players ($\bar{x}$ =25.66%) have a better fat percentage than the goal players ($\bar{x}$ =26.87%), but according to the norm (22 - 24%) both groups fell in the above average category (De Ridder, 2004). No significant differences were detected with regard to the fat percentages of the two groups (centre and goal players) (Table 4.6).

Next, the results of the *physical/motor abilities* of the centre players to the goal players were compared (Table 4.6). In all three tests the centre players performed better than the goal players. With the agility run test, the centre players scored an average time of 19.07 sec compared to the goal players with an average time of 19.84 sec, meaning that the centre players outperformed the goal players. This finding correlates with that of Jordaan (2001), who concluded that the centre players are expected to be more agile than the goal players due to the fact that they have to perform more running and direction-changing activities, according to their work profile, than the goal players (Jordaan, 2001). An average of 19.1 sec and 19.8 sec respectively places both groups in the average category (www.brianmac.demon.uk/illinois.htm). A practically significant difference ($p \leq 0.05$; $d \geq 0.8$) was detected for the agility run test ($p=0.00078$; $d=1.0604$).

On the balance test the centre players scored an average of 72.35%, while the goal players scored an average of 66.98%, meaning that the centre players have better balancing abilities than the goal players. However, both groups underperformed according to the norm (75%) set for elite netball players (Techno Therapy, 1992). The results of the explosive power test indicated that the centre as well as the goal players had acceptable (≥ 30) explosive power abilities (Boscosystem ErgoJump www.boscos-ystem.com). The centre players scored an average of 33.25, which is better than the average for the goal players (32.80).

Below, a conclusion will be formulated regarding the biomechanical, anthropometrical and physical/motor data of the centre and goal players. The *biomechanical data* will be summarised first.

In the lower limb- and pelvic girdle regions the goal players presented with fewer biomechanical deviations than the centre players, while less biomechanical stressors were identified among the centre players in the spinal region. With neurodynamics the two groups scored similar results. The *anthropometric* assessment indicated that the centre players presented with a lower BMI than the goal players and that both groups fell in the ideal category. The centre players presented with a better fat percentage average than the goal players; however, according to the norm both groups fell in the above average category. The *physical/motor* tests revealed that for all three tests (agility, balance and explosive power) the centre players performed better than the goal players. With the agility and explosive power tests both groups performed acceptably, but they underperformed in the balance test.

Table 4.5 Descriptive statistics and significant differences between biomechanical data for centre players (N=20) and goal players (N=20) during test one

TEST VARIABLES	$\bar{X}$ Centre players	$\bar{X}$ Goal players	Std.Dev. Centre Players	Std.Dev. Goal Players	p	Effect size (d)
BIOMECHANICS:						
LOWER LIMB REGION:						
Achilles tendon suppleness test	1.21053	1.31579	0.418854	0.47757	0.47476	0.22041
Iliotibial band mobility test (ITB)	1.68421	1.63158	0.582393	0.49559	0.76590	0.09037
Quadriceps mobility	1.36842	1.47368	0.495595	0.51299	0.52412	0.20519
Iliopsoas mobility	1.73684	1.57895	0.805682	0.50726	0.47441	0.19597
Gluteus maximus mobility test	1.47368	1.42105	0.611775	0.50726	0.77448	0.08603
Adductor mobility test	1.10526	1.05263	0.315302	0.22942	0.55997	0.16692
Internal rotation mobility test	1.00000	1.00000	0.000000	0.00000	1.00000	0.00000
External rotation mobility test	1.47368	1.42105	0.611775	0.50726	0.77448	0.08603
Q-angle test	1.11111	1.18750	0.323381	0.40311	0.54449	0.18949
Patella squint test	1.16667	1.18750	0.383482	0.40311	0.87829	0.05168
Patella tilt test	1.66667	1.62500	0.485071	0.50000	0.80693	0.08333
Patella height test	1.94444	1.81250	0.235702	0.40311	0.24621	0.32731
VMO – L-comparison test	1.38889	1.31250	0.501631	0.47871	0.65376	0.15228
Longitudinal arch status test*	1.52941	1.93750	0.514496	0.25000	0.00736*	0.79318*
Forefoot positional test*	1.23529	1.18750	0.437237	0.40311	0.74671	0.10930
Rear foot positional standing test	1.29412	1.31250	0.469668	0.60208	0.92246	0.03053
Rear foot lying test*	1.35294	1.37500	0.492592	0.61914	0.91027	0.03562
Transverse arch area comparison test	2.00000	3.25000	0.000000	3.43511	0.14325	0.36388
Foot mobility test*	1.64706	1.75000	0.492592	0.77460	0.64982	0.13289
Toe positional test	2.00000	1.87500	0.000000	0.34157	0.14106	0.36596
PELVIC GIRDLE REGION:						
Leg length discrepancy test	1.70588	1.62500	0.469668	0.50000	0.63516	0.16176
ASIS comparison test	1.64706	1.62500	0.492592	0.50000	0.89926	0.04411
PSIS comparison test	1.64706	1.62500	0.492592	0.50000	0.89926	0.04411
Pelvic rami positional test	1.64706	1.62500	0.492592	0.50000	0.89926	0.04411
Sacroiliac cleft test	1.05882	1.06250	0.242536	0.25000	0.96607	0.01470
Bilateral pelvis positional test	1.94118	1.87500	0.242536	0.34157	0.52378	0.19374
SPINAL REGION:						
Thoraco-lumbar fascia	1.23529	1.25000	0.437237	0.44721	0.92453	0.03288
Sacral rhythm test	1.00000	1.00000	0.000000	0.00000	1.00000	0.00000
Functional extension mobility test	1.00000	1.18750	0.000000	0.40311	0.06413	0.46513
Functional flexion test	1.17647	1.37500	0.392953	0.50000	0.21269	0.39705
Rotational mobility test	1.00000	1.12500	0.000000	0.34157	0.14106	0.36596
Side flexion mobility test	1.05882	1.12500	0.242536	0.34157	0.52378	0.19374
Head positional	1.00000	1.00000	0.000000	0.00000	1.00000	0.00000
Cervical	1.00000	1.00000	0.000000	0.00000	1.00000	0.00000
Thoracic	1.23529	1.06250	0.437237	0.25000	0.17694	0.39519
Lumbar	2.05882	1.87500	0.242536	0.34157	0.08303	0.53818
NEURODYNAMICS						
Straight leg raise (SLR)	1.11765	1.25000	0.332106	0.44721	0.33993	0.29595
Prone knee bend test (PKB)	1.35294	1.18750	0.606339	0.40311	0.36630	0.27285

Table 4.6 Descriptive statistics and significance of anthropometry and physical/motor data for centre players (N=20) and goal players (N=20) during test one

TEST VARIABLES	$\bar{X}$ Centre players	$\bar{X}$ Goal players	Std.Dev. Centre Players	Std.Dev. Goal players	p	Effect size (d)
ANTHROPOMETRY:						
Weight (kg)	62.85000	72.30000	8.604008	10.44333	0.00341*	0.90488*
Height (m)	1.69600	1.79350	0.067074	0.06612	0.00004*	1.45361*
Body mass index (BMI)	21.96000	22.42000	2.494288	2.66806	0.57657	0.17241
Fat percentage (%)	25.66100	26.87250	2.684676	2.89022	0.17765	0.41917
SKINFOLDS:						
Tricep	15.96000	17.58000	4.409129	4.43379	0.25383	0.36537
Subscapular	12.20000	11.10500	3.207229	3.19975	0.28654	0.34141
Supraspinal	12.59500	15.03000	3.705398	4.44535	0.06755	0.54776
Abdominal	19.33000	21.24000	4.960910	3.50915	0.16794	0.38501
Thigh	21.13000	23.95000	3.057364	4.66267	0.02950*	0.60480
Calf	16.21500	16.92500	4.548022	4.87571	0.63664	0.14562
PHYSICAL/MOTOR ABILITIES:						
Agility (sec)	19.07500	19.84000	0.598133	0.72140	0.00078*	1.06043*
Balance (%)	72.35000	66.98333	9.073530	11.02741	0.10874	0.48666
Explosive power	33.25000	32.80000	5.260328	5.25758	0.78817	0.08554

$d = \frac{|\bar{x}_1 - \bar{x}_2|}{s_{max}}$ = effect size for difference between means; a measurement of practical significance

$p \leq 0.05$

$d \geq 0.2$ (small effect)

$d \geq 0.5$ (medium effect)

$d \geq 0.8$ (large effect)

$\bar{X}$ = average value

* = Large significant differences between groups

4.4.3. Descriptive statistics and significant differences between A- and B-grade players during test one

Players were classified as either A- or B-grade players according to the team for which the players were selected. Players of the first team of the North-West University Netball Club and the u/19A team were considered as the A-grade players while the second, third, fourth and u/19B teams were classified as B-grade players. Sixteen players were categorised as A-grade and 24 players as B-grade. Table 4.7 summarises the test results of the A-grade players, compared to the B-grade players.

In Table 4.7 the *biomechanical data* of the two groups (A- and B-grade players) will be presented. The data was collected for four main categories, namely lower limb, pelvic girdle, spinal region and neurodynamics. The grading method of the tests conducted in the four categories was the same as during the biomechanical assessment of the total group (Section 4.2).

In the *lower limb region*, the B-grade players scored values closer to the ideal in 11 of the 20 tests, compared to the A-grade players, who scored results closer to the ideal in 9 of the 20 tests. This means that fewer biomechanical abnormalities were identified in the B-grade players than in the A-grade players. The results of the *pelvic girdle region* reported that biomechanical stressors were indicated in three of the six tests performed in this area by both the A- and B-grade players, meaning that biomechanical deviations were identified in both group in three tests respectively. In the *spinal region* the A- and B-grade players were identified with the same amount of biomechanical abnormalities in three of the ten tests conducted in this area. In four of the ten tests the B-grade players performed better than the A-grade players, meaning that they presented with fewer biomechanical stressors than the A-grade players. No significant differences ($p \leq 0.05$; $d \geq 0.08$) were detected between the two groups (A- and B-grade players) in the lower limb, pelvic girdle, and spinal regions. The results for the *neurodynamics* showed that for the one test (SLR), the B-grade performed better, meaning that they exhibited fewer biomechanical deviations than the A-grade players, while the A-grade players performed better in the second test (PKB). No significant biomechanical differences ($p \leq 0.05$; $d \geq 0.8$) were detected for neurodynamics between the A- and B-grade players (Table 4.7).

Secondly, the *anthropometrical status* of the two groups (A- and B-grade players) was studied (Table 4.8). Both groups presented with ideal BMI values (18.5 - 24.4), with the A-grade players scoring an average of 22.61 and the B-grade group an average of 21.90 (De Ridder, 2004). Both groups fell in the above average classification (24 - 31%) (De Ridder, 2004).

The A-grade players presented with an average fat percentage of 26.23% and the B-grade players with an average of 26.29%, meaning that the B-grade players have more subcutaneous fat than the A-grade players. No significant anthropometrical differences ($p \leq 0.05$; $d \geq 0.8$) were detected between the A- and B-grade players (Table 4.8).

The results of the *physical/motor tests* were studied next (Table 4.8). The A-grade players performed better in all three motor tests. The first test in which the A-grade players performed better was the agility run test, where the A-grade group scored an average of 19.29 sec compared to the B-grade group's average of 19.56 sec; therefore the A-grade completed the test in a better time than the B-grade players. Both groups (A- and B-grade) fell in the average category (18.0 - 21.7sec) (www.brianmac.demon.uk/ illinois.htm). With the balance test the A-grade ($\bar{x}$ =85.25%) group outperformed the B-grade players ($\bar{x}$ =78.66%) and according to the norm (≥75%) set for elite netball players, both groups performed acceptable. A practical significant difference ($p \leq 0.05$; $d \geq 0.08$) was noted between the two groups (A- and B-grade players) for the balance test ($p=0.0477$; $d=2.9805$). The third test is the explosive power test, where the A-grade players presented with a better average ($\bar{x}$ =35.93) than the B-grade players ($\bar{x}$ =31.08). The acceptable score for elite netball players is ≥30; therefore both groups' performance was considered acceptable (Boscosystem ErgoJump www.boscosystem.com). Significant differences ($p \leq 0.05$; $d \geq 0.8$) were detected with this particular test (explosive power test) ($p=0.0025$; $d=1.0190$), where the A-grade outperformed the B-grade players (Table 4.8).

Below, a summary is presented of the biomechanical, anthropometrical and physical/motor data of the A- and B-grade players. The *biomechanical data* will be summarised first. The B-grade players presented with better biomechanics in the lower limb and spinal regions. For the tests conducted in the pelvic girdle region and for neurodynamics, the A- and B-grade players presented with similar results. For the *anthropometric assessment*, the B-grade players scored a lower BMI than the A-grade players, and both groups (A- and B-grade players) presented with ideal averages.

The fat percentages indicated that the A-grade players have a lower fat percentage than the B-grade players, but that both groups fell in the above average category. The *physical/motor tests* revealed that the A-grade players performed better than the B-grade players with the agility run-, balance- and the explosive power test. The averages of the A- and B-grade players were considered acceptable for all three physical/motor tests (agility-, balance- and explosive power).

Table 4.7 Descriptive statistics and significance of biomechanical data for A- (N=16) and B-grade players (N=24) during test one

TEST VARIABLES	$\bar{X}$ A-grade players	$\bar{X}$ B-grade players	Std.Dev. A-grade players	Std.Dev. B-grade players	p	Effect size (d)
BIOMECHANICS:						
LOWER LIMB REGION:						
Achilles tendon suppleness test	1.26667	1.26087	0.45774	0.44898	0.96941	0.01266
Iliotibial band mobility test (ITB)	1.60000	1.69565	0.50709	0.55880	0.59632	0.17117
Quadriceps mobility	1.53333	1.34783	0.51640	0.48698	0.26971	0.35923
Iliopsoas mobility	1.80000	1.56522	0.67612	0.66237	0.29646	0.34724
Gluteus maximus mobility test	1.33333	1.52174	0.48795	0.59311	0.31284	0.31765
Adductor mobility test	1.06667	1.08696	0.25820	0.28810	0.82648	0.07042
Internal rotation mobility test	1.00000	1.00000	0.00000	0.00000	1.00000	0.00000
External rotation mobility test	1.40000	1.47826	0.50709	0.59311	0.67686	0.13195
Q-angle test	1.28571	1.05000	0.46881	0.22361	0.05861	0.50279
Patella squint test	1.28571	1.10000	0.46881	0.30779	0.17202	0.39614
Patella tilt test	1.78571	1.55000	0.42582	0.51042	0.16656	0.46180
Patella height test	1.85714	1.90000	0.36314	0.30779	0.71299	0.11801
VMO – L-comparison test	1.14286	1.50000	0.36314	0.51299	0.03234*	0.69619
Longitudinal arch status test*	1.78571	1.68421	0.42582	0.47757	0.53255	0.21254
Forefoot positional test	1.28571	1.15789	0.46881	0.37463	0.39054	0.27264
Rear foot positional standing test*	1.28571	1.31579	0.61125	0.47757	0.87485	0.04920
Rear foot lying test*	1.35714	1.36842	0.63332	0.49559	0.95456	0.01780
Transverse arch area comparison test	2.71429	2.52632	2.70124	2.29416	0.83056	0.06958
Foot mobility test*	1.71429	1.68421	0.72627	0.58239	0.89580	0.04141
Toe positional test	1.92857	1.94737	0.26726	0.22942	0.82967	0.07033
PELVIC GIRDLE REGION:						
Leg length discrepancy test	1.64286	1.68421	0.49725	0.47757	0.81066	0.08316
ASIS comparison test	1.64286	1.63158	0.49725	0.49559	0.94897	0.02268
PSIS comparison test	1.64286	1.63158	0.49725	0.49559	0.94897	0.02268
Pelvic rami positional test	1.64286	1.63158	0.49725	0.49559	0.94897	0.02268
Sacroiliac cleft test	1.00000	1.10526	0.00000	0.31530	0.22286	0.33384
Bilateral pelvis positional test	1.78571	2.00000	0.42582	0.00000	0.03490*	0.50323
SPINAL REGION:						
Thoraco-lumbar fascia	1.21429	1.26316	0.42582	0.45241	0.75539	0.10802
Sacral rhythm test	1.00000	1.00000	0.00000	0.00000	1.00000	0.00000
Functional extension mobility test	1.14286	1.05263	0.36314	0.22942	0.38872	0.24846
Functional flexion test	1.28571	1.26316	0.46881	0.45241	0.89002	0.04811
Rotational mobility test	1.14286	1.00000	0.36314	0.00000	0.09453	0.39339
Side flexion mobility test	1.07143	1.10526	0.26726	0.31530	0.74780	0.10730
Head positional	1.00000	1.00000	0.00000	0.00000	1.00000	0.00000
Cervical	1.00000	1.00000	0.00000	0.00000	1.00000	0.00000
Thoracic	1.14286	1.15789	0.36314	0.37463	0.90884	0.04013
Lumbar	2.00000	1.94737	0.39223	0.22942	0.63135	0.13418
NEURODYNAMICS						
Straight leg raise (SLR)	1.28571	1.10526	0.46881	0.31530	0.19541	0.38491
Prone knee bend test (PKB)	1.21429	1.31579	0.42582	0.58239	0.58519	0.17428

Table 4.8 Descriptive statistics and significance of anthropometry and physical/motor data for A- (N=16) and B-grade players (N=24) during test one

TEST VARIABLES	$\bar{X}$ A-grade players	$\bar{X}$ B-grade players	Std.Dev. A-grade players	Std.Dev. B-grade players	p	Effect size (d)
ANTHROPOMETRY:						
Weight (kg)	70.81250	65.41667	10.45128	10.32901	0.11545	0.51628
Height (m)	1.76688	1.73000	0.09075	0.07431	0.16753	0.40631
BMI	22.61875	21.90417	2.26752	2.74693	0.39407	0.26013
Fat percentage (%)	26.23125	26.29042	2.49696	3.07004	0.94918	0.01927
SKINFOLDS:						
Tricep	15.70625	17.47917	3.46477	4.92941	0.22050	0.35966
Subscapular	11.31250	11.87917	3.04124	3.36310	0.59103	0.16849
Supraspinal	14.96250	13.04583	4.72834	3.75904	0.16244	0.40535
Abdominal	20.53125	20.12083	3.35176	4.96912	0.77425	0.08259
Thigh	23.06250	22.19167	5.50550	3.00910	0.52216	0.15817
Calf	15.29375	17.42083	4.17747	4.86567	0.16067	0.43716
PHYSICAL/MOTOR ABILITIES:						
Agility (sec)	19.29375	19.56667	0.61043	0.84012	0.27149	0.32485
Balance (%)	85.25583	78.66251	2.21210	2.03331	0.04774*	2.98056*
Explosive power	35.93750	31.08333	4.50879	4.76323	0.00259*	1.01909*

$d = \frac{|\bar{x}_1 - \bar{x}_2|}{s_{max}}$ = effect size for difference between means; a measurement of practical significance

$p \leq 0.05$ — $d \geq 0.2$ (small effect)

$d \geq 0.5$ (medium effect) — $d \geq 0.8$ (large effect)

$\bar{X}$ = average value — * = Large significant difference between groups

4.5. SUMMARY OF THE RESULTS OF TESTING OCCASION ONE

To conclude, a summary will follow of the data collected during the first testing occasion:

The data of the *group in total* will be summarised first:

1. *Biomechanics, anthropometry and physical/motor abilities of the total group:*

- The *biomechanical data* revealed that numerous biomechanical deviations existed among the netball players in the lower limb region.

These biomechanical deviations consisted of ITB and iliopsoas tightness; tilted patella; asymmetrical patella height; rear foot pronation; callus plantar aspect with a flat arch; and valgus, rotation or deviation of their toes (Table 4.1). In the pelvic girdle region, biomechanical abnormalities such as excessive leg length discrepancies; asymmetries at the PSIS, ASIS, pelvic ramis as well as asymmetrical pelvic positions were recorded among numerous netball players. The assessment of the spinal region indicated that most of the netball players presented with a hyperlordotic lumbar curve. With the other tests conducted in the spinal region and with neurodynamics, the majority of the participants tended to achieve ideal values (Table 4.1).

- The *anthropometrical status* of the total group will follow next (Table 4.2). The average BMI for the total group fell in the ideal category, while the average fat percentage of the total group was considered above average, and the netball players presented with above average subcutaneous fat especially in the tricep, abdominal and thigh areas.

- The *physical/motor data* was then concluded. The NWU Club netball players performed relatively acceptable regarding the agility and explosive power tests, but underperformed in the balancing test, in terms of the norm set for elite netball players.

Secondly, the data of the *juniors and seniors* was studied:

2. *Biomechanics, anthropometry and physical/motor abilities of the juniors and seniors:*

- With the *biomechanical assessment* the juniors presented with less biomechanical abnormalities than the seniors. One significant difference was observed in the lower limb region, namely the toe positional test (Table 4.3).

- The *anthropometrical assessment* revealed that the BMI results of both groups (juniors and seniors) fell in the ideal category. The juniors as well as the seniors presented with above average values for fat percentage (Table 4.4). No signify-cant differences were identified for the anthropometry.

- The *physical/motor data* showed that the juniors performed better than the seniors in two (agility and balance) of the three motor tests. The average agility scores for both groups fell in the average category, while the average value for the ability to balance was unacceptable. The seniors presented with a better average score for explosive power than the juniors. The averages of both groups were considered acceptable according to the norm set for elite netball players. No significant differences occurred regarding the physical/motor tests (Table 4.4).

Thirdly, a summary is presented of the biomechanical, anthropometrical and physical/motor data of the *centre and goal players*:

3. *Biomechanics, anthropometry and physical/motor abilities of the centre- and goal players:*

- The *biomechanical data* will be summarised first. In the lower limb and pelvic girdle regions the goal players presented with fewer biomechanical deviations than the centre players, while less biomechanical stressors were identified among the centre players in the spinal region. One significant difference was identified in the lower limb region (longitudinal arch status test). With neurodynamics the two groups achieved similar results (Table 4.5).

- The *anthropometry assessment* indicated that the centre players presented with a lower BMI than the goal players and that both groups fell in the ideal category. The goal players weighed significantly more and were significantly taller than the centre players.

The centre players presented with a better fat percentage average than the goal players, but according to the norm both groups fell in the above average category. A significant difference was identified with the thigh skinfold measurement (Table 4.6).

- The *physical/motor tests* revealed that with all three tests (agility, balance and explosive power) the centre players performed better than the goal players. In the agility and explosive power tests both groups performed acceptable but they underperformed in the balance test. A significant difference occurred with the agility run test (Table 4.6).

Finally, a summary is given of the biomechanical, anthropometrical and physical/motor data of the *A- and B-grade players*:

4. Biomechanics, anthropometry and physical/motor abilities of the A- and B-grade players:

- The *biomechanical data* will be summarised first (Table 4.7). The B-grade players presented with better biomechanics in the lower limb and spinal regions. One significant difference occurred in the lower limb region (VMO-L comparison test). With the tests conducted in the pelvic girdle region and with neurodynamics the A- and B-grade players presented with similar results. One significant difference was identified with the bilateral pelvis positional test in the pelvic girdle test.

- With the *anthropometric assessment* the B-grade players scored a lower BMI than the A-grade players and both groups presented with ideal averages. The fat percentages indicated that the A-grade players had a lower fat percentage than the B-grade players, but both groups fell in the above average category. No significant differences were observed with regard to the anthropometry assessments (Table 4.8).

- The *physical/motor tests* revealed that the A-grade players performed better than the B-grade players in all three motor tests (agility-, balance and the explosive power test). The averages of the A- and B-grade players were considered acceptable with all three tests. Significant differences occurred in terms of the balance and explosive power tests (Table 4.8).

4.6. DESCRIPTIVE STATISTICS AND DISCUSSION OF BIOMECHANICAL DATA OF THE TOTAL GROUP DURING TEST TWO

The second testing procedure was performed at the end of the netball season during August. The testing modalities which were applied were the same as during the first testing occasion in March 2007; therefore the tests consisted of a biomechanical analysis, an anthropometry assessment and motor tests (agility run test, balancing test and explosive power test). The same protocols for the different tests under similar circumstances were applied during the second than the first testing occasion.

Due to personal reasons and numerous serious injuries sustained during the season, not all netball players could attend the second testing occasion. The injured players were expected to participate in the tests which did not cause any pain or discomfort during the testing procedure; therefore most of the injured players completed the biomechanical analysis and anthropometry assessments, but not the physical/motor tests. From the forty players that took part in the first testing occasion, only twenty-five could participate in the second testing occasion. The effect of this decreased number of participants during the second tests was taken into consideration. Only the data of the twenty-five players who participated in the pre- (first tests) and end-season (second tests) testing procedures were compared. The data of the biomechanics of the total group will follow.

This study only presents the total group's descriptive statistics. Table 4.9 presents the descriptive statistics of the *biomechanical assessment* of the total group of netball players during the second testing occasion. The data was collected in four main categories, namely lower limb, pelvic girdle, spinal region and neurodynamics.

The same grading system as for the first biomechanical tests was used for the second tests. The data of the *lower limb region* is discussed first (Table 4.9). In nine of the twenty tests conducted in this region (lower limb), the majority of the netball players (>50%) tended towards non-ideal values. According to the test results, inadequate mobility (biomechanical deviation) was detected at the ITB ($\bar{x}$ = 1.84); quadriceps ($\bar{x}$ = 1.68) and the iliopsoas ($\bar{x}$ = 1.76). The tendency of the inadequate mobility at the ITB; quadriceps and the iliopsoas presented at 84%; 68% and 60% of the total group of netball players respectively. Many authors comment on the effects of tight structures on the performance and probability for injuries among athletes, including netball players. Nicholas (1997) emphasises that adequate flexibility is an imperative factor in the performance of an athlete, due to the fact that flexible muscles move through a greater range of motion and therefore produces more power for extended periods of time; in other words, adequate flexibility means more strength and power for an athlete. Both Armstrong and McManus (1996) and Nicholas (1997) indicate that inadequate flexibility results in decreased performance, altered technique and uncoordinated movements and that it predisposes athletes to muscle strains and tears. Brukner and Khan (2001) agree that ITB tightness may be present in athletes who are diagnosed with overuse sport injuries such as patellar tendinitis, patellofemoral pain, stress fractures, periostitis and compartment syndrome. McConnell (2002) argues that tight hip flexors, such as the iliopsoas muscle, are associated with anterior knee pain and chondromalacia. These injuries are often associated with netball players (Brukner & Khan, 2001).

The results of this particular study differ from the results of a study conducted by Venter *et al.* (2005), in that the netball players participating in the study conducted by Venter *et al.* (2005) presented with shortened lower back and hamstring muscles, whereas only 20% of the participants in this particular study presented with inadequate hamstring length, and 26% with tight lower back muscles. Different tests were applied in these studies to examine the length of these muscles: Venter *et al.* (2005) used the sit-and-reach, test while the current study applied the functional flexion test (lower back muscles) and the SLR test (flexibility testing component for the hamstring muscle). Therefore no comparison is possible of the results of these two studies.

Non-ideal values were detected with the patella tilt test, where 56% ($\bar{x}$ =1.56) of the total group of netball players presented with this biomechanical deviation (tilted patella) (Table 9). Asymmetrical patella height was identified at 76% ($\bar{x}$ =1.76) of the participants. The existing literature does not support these findings: according to literature an excessive Q-angle (varus alignment) is usually detected in athletes, including netball payers, with overuse injuries such as patellar tendinopathy, medial shin pain and patellofemoral syndrome (Hass *et al.,* 2005; Brukner & Khan, 2001). Only 12% of the participants of this particular study presented with non-ideal Q-angle values of their knees.

The rear foot positional standing ($\bar{x}$ =1.24) and rear foot lying ($\bar{x}$ =1.28) tests indicated that 80% and 76% of the total group, irrespectively, presented with rear foot pronation, which is a biomechanical stressor (Table 4.9). Hopper and Elliot (1993) found that 42.1% of the netball players presented with rear foot varus with compensating subtalar pronation. In the study by Hopper and Elliot (1993), 25% of the 240 participants presented with overuse injuries, such as retropatellar pain (24%) and shin pain (38%), caused by abnormal biomechanics. According to Brukner and Khan (2001), pronation of a netball player's foot could contribute to overuse injuries such as patellar tendinopathy, medial shin pain and patellofemoral syndrome. Excessive pronation may produce an unstable forefoot; therefore the netball player could also be susceptible to traumatic injuries such as ankle sprains (Donatelli, 1990).

With the transverse arch area comparison test, 84% ($\bar{x}$ =1.92) of the participants presented with a flat transverse arch and a callus plantar aspect, known as pes planus (Table 4.9). Brukner and Khan (2001) confirm that pes planus is categorised as an intrinsic factor that could lead to overuse injuries in various sports, including netball. The toe positional test indicated that 92% of the total group presented with biomechanical abnormalities, such as valgus, rotation or deviation of their toes (Table 4.9). Unfortunately, the researcher could not find any existing literature to explain this phenomenon or with which to compare these findings.

A possible explanation could be weak intrinsic foot muscles combined with strenuous activities such as jumping and landing, cause these biomechanical deviations (valgus, rotation or deviation of their toes).

The *pelvic region* is discussed in the following sections. In five of the six tests performed in this region (pelvic girdle) the majority of the participants (>50%) presented with non-ideal values. These five tests as well as their findings are discussed below. In the leg length discrepancy, ASIS comparison, PSIS comparison, and the pelvic rami positional tests, 84% ($\bar{x}$ =1.84) of the participants presented with biomechanical abnormalities, namely asymmetries in the pelvic area. According to Bell-Jenje and Bourne (2003), leg length discrepancies are a subtle cause of overuse injuries, and Brukner and Khan (2001) classify leg length discrepancies as an intrinsic factor that could lead to overuse injuries. Brukner and Khan (2001) also confirm that bony asymmetries could be the result of sports such as cricket and tennis, which involves unilateral activities; thus leading to asymmetries in body development. As a result the athlete engages in poor mechanics of movement and therefore increases their risk to injuries. Brukner and Khan (2001) state that asymmetries with in the pelvis and the legs (leg length discrepancies) may be the cause of consistent knee injury patterns. Netball players tend to use their dominant arm or leg more than their non-dominant side, especially in throwing and landing activities; therefore this phenomenon (pelvic asymmetries) applies to netball players as well (Hopper *et al.*, 1999). The bilateral pelvis positional test in this study indicated that 88% ($\bar{x}$ =1.88) of the participants presented with a non-ideal pelvic position, known as lumbar hyperlordosis.

In the *spinal region*, the lumbar area assessment identified a hyperlordotic curve at 96% ($\bar{x}$ =1.96) of the netball players. Excessive anterior pelvic tilt may lead to overuse injuries such as patellar tendinopathy, patellofemoral syndrome, fatpad impingement and hamstring strain in various sports including netball (Brukner & Khan, 2001). According to Panjabi (1992), the difference in height between the lower ASIS and the PSIS is categorised as ideal when measured as ≥ 2 but if <3 cm, this position is classified as an acceptable lumbar curve (Panjabi, 1992).

Results for the fourth and last component of the biomechanical assessment, namely *neurodynamics*, showed that 80% ($\bar{x}$ =1.80) of the participants presented with non-ideal values in the SLR test, meaning that the majority of the total group's neural mobility was inadequate.

In summary; the majority of the total group of netball players revealed the following *biomechanical deviations* in the lower limb region among the netball players (Table 4.9). These deviations included ITB, quadriceps, and iliopsoas tightness; tilted patella with asymmetrical patella height; rear foot pronation with callus plantar aspect; and valgus, rotation or deviation of their toes. In the pelvic girdle region, biomechanical stressors such as excessive leg length discrepancies; asymmetries at the PSIS, ASIS, pelvic ramis as well as non-ideal pelvic positions (lumbar hyperlordosis) were identified in the majority of the total group of netball players. In the last two categories, namely spinal region and neurodynamics, the total group of netball players presented with a hyperlordotic lumbar curve and inadequate neural mobility.

Table 4.9 Descriptive statistics of biomechanical data of the total elite group (N=25) of netball players during test two

TEST VARIABLES	Number	$\bar{X}$	Std.Dev.	Minimum	Maximum	Percentage of players (%)		
BIOMECHANICS:								
LOWER LIMB REGION:						1	2	3
Achilles tendon suppleness test	25	1.12	0.33166	1	2	88	12	0
Iliotibial band mobility test (ITB)	25	1.84	0.37417	1	2	16	84	0
Quadriceps mobility	25	1.68	0.47610	1	2	32	68	0
Iliopsoas mobility	25	1.76	0.59722	1	3	32	60	8
Gluteus maximus mobility test	25	1.44	0.50662	1	2	56	44	0
Adductor mobility test	25	1.04	0.20000	1	2	96	4	0
Internal rotation mobility test	25	1.00	0.00000	1	1	100	0	0
External rotation mobility test	25	1.28	0.54160	1	3	76	20	4
Q-angle test	25	1.12	0.33166	1	2	88	12	-
Patella squint test	25	1.12	0.33166	1	2	88	12	-
Patella tilt test	25	1.56	0.50662	1	2	44	56	-
Patella height test	25	1.76	0.43589	1	2	24	76	-
VMO – L-comparison test	25	1.20	0.40825	1	2	80	20	-
Longitudinal arch status test*	25	1.64	0.48990	1	2	36	64	0
Forefoot positional test	25	1.16	0.37417	1	2	84	16	-
Rear foot positional standing test*	25	1.24	0.52281	1	3	80	16	4
Rear foot lying test*	25	1.28	0.54160	1	3	76	20	4
Transverse arch area comparison test	25	1.92	0.40000	1	2	16	84	-
Foot mobility test*	25	1.76	0.66332	1	3	36	52	12
Toe positional test	25	1.92	0.27689	1	2	8	92	-
PELVIC GIRDLE REGION:								
Leg length discrepancy test	25	1.84	0.37417	1	2	16	84	0
ASIS comparison test	25	1.84	0.37417	1	2	16	84	-
PSIS comparison test	25	1.84	0.37417	1	2	16	84	-
Pelvic rami positional test	25	1.84	0.37417	1	2	16	84	-
Sacroiliac cleft test	25	1.04	0.20000	1	2	96	4	-
Bilateral pelvis positional test	25	1.88	0.33166	1	2	12	88	0
SPINAL REGION:								
Thoraco-lumbar fascia	25	1.20	0.40825	1	2	80	20	0
Sacral rhythm test	25	1.04	0.20000	1	2	96	4	-
Functional extension mobility test	25	1.24	0.43589	1	2	76	24	0
Functional flexion test	25	1.44	0.50662	1	2	56	44	0
Rotational mobility test	25	1.12	0.33166	1	2	88	12	0
Side flexion mobility test	25	1.00	0.00000	1	1	100	0	0
Head positional	25	1.00	0.00000	1	1	100	0	-
Cervical	25	1.00	0.00000	1	1	100	0	-
Thoracic	25	1.20	0.40825	1	2	80	20	-
Lumbar	25	1.96	0.20000	1	2	4	96	-
NEURODYNAMICS:								
Straight leg raise (SLR)	25	1.80	0.40825	1	2	20	80	0
Prone knee bend test (PKB)	25	1.24	0.43589	1	2	76	24	0

4.7. DESCRIPTIVE STATISTICS AND DISCUSSION OF ANTHROPOMETRY AND PHYSICAL/MOTOR DATA OF THE TOTAL GROUP DURING TEST TWO

The *anthropometry* of the group in total will be presented in Table 4.10. The anthropometry status of the group in total presented that the mean value for body mass index (height/weight^2) was 23.07. According to De Ridder (2004), the acceptable body mass index (BMI) for female athletes of 18 years and older, is between 18.5 and 24.9; therefore the mean value for the total group is in the ideal category. The mean value for the weight and height of the group in total is 70.72 kg and 1.74 m respectively. The netball players participating in the study conducted by Venter *et al.* (2005) presented with a mean value of 66.8 kg (weight) and with the same mean value for height ($\bar{x}$ =1.74), whereas the Australian counterparts, on the other hand, scored mean values of 68.5 kg (weight) and 1.80 m (height). Therefore the netball players of the NWU Club are 3.92 kg heavier but the same height as the Boland netball players, and 2.22 kg heavier and 6 cm shorter than the state-level Australian netball players. De Ridder (2004) points out that BMI is an inaccurate method to determine body composition and obesity, due to the fact that it does not distinguish between body mass and fat mass; therefore one must combine BMI with fat percentage to determine an athlete's anthropometry status (Table 4.10).

The mean value for fat percentage for the group in total is 27.55, indicating that the group fell in the above average category (25% - 31%) (De Ridder, 2004) (Table 4.10). The ideal for a female athlete of 18 years and older is between 22% and 24% (De Ridder, 2004). The study conducted by Venter *et al.* (2005) concluded that the Boland netball players aged between 18 and 24 years presented with an average fat percentage of 25%; therefore 2.55% less than the NWU Club netball players. Unfortunately, this study by Venter *et al.* (2005) applied a different formula to determine the fat percentage, which makes it difficult to compare the results. The in-depth analysis of the skinfold measurements is beyond the scope of this study, but considering these measurements it seems that the participants carry their most subcutaneous fat in the tricep, abdominal and thigh areas (Table 4.10).

The data on *physical/motor abilities* reported a mean value for agility of 18.94 sec. According to the normative data for female athletes for the Illinois agility run test the mean value fell in the average category (18.0 sec - 21.7 sec), whereas one would expect the NWU Club netball players to perform above average (17.0 sec - 17.9 sec), in accordance with their status as elite netball players (www.brianmac.demon. uk/illinois.htm). The netball players scored a mean value of 81.13% with the balance test, which is considered acceptable for elite netball players (Techno Therapy, 1992). The last motor ability, namely explosive leg power, obtained a mean value of 28.60. A score above 30 is considered acceptable for elite athletes; thus the NWU Club netball players underperformed with the explosive power test (Boscosystem ErgoJump www.boscosystem.com).

A summary will follow to conclude the *anthropometry* and *physical/motor abilities* of the total group of netball players: the average BMI for the total group fell in the ideal category, while the average fat percentage of the total group was considered above average. This meant that the NWU Club netball players presented with above average subcutaneous fat, especially in the tricep, abdominal and thigh areas. In terms of the physical/motor abilities the club netball players performed relatively acceptable in the agility- and balancing tests, but underperformed in the explosive power test according to the norm set for elite netball players.

Table 4.10 Descriptive statistics of anthropometry (N=25) and physical/motor data (N=21-23) of the total group of netball players during test two

TEST VARIABLES	Number	$\bar{x}$	Std dev	Minimum	Maximum
ANTHROPOMETRY:					
Weight (kg)	25	70.72	11.91	50.0	98.0
Height (m)	25	1.74	0.08	1.57	1.88
Body mass index	25	23.07	2.50	18.40	27.70
Fat percentage (%)	25	27.55	3.28	21.59	34.96
SKINFOLDS:					
Tricep	25	17.01	3.64	10.30	23.30
Subscapular	25	12.95	3.45	7.00	20.30
Supraspinal	25	14.86	4.60	7.80	24.80
Abdominal	25	20.85	4.41	11.30	25.50
Thigh	25	29.01	7.08	16.00	45.30
Calf	25	15.71	3.74	10.30	24.50
MOTOR ABILITIES:					
Agility (sec)	21	18.94	0.83	17.20	20.80
Balance (%)	23	81.13	9.21	58.00	91.60
Explosive power	23	28.60	3.91	21.00	36.00

$\bar{x}$ = average value

4.8. INTERGROUP COMPARISONS OF BIOMECHANICS, ANTHROPOMETRY AND PHYSICAL/MOTOR ABILITIES DURING TEST TWO

4.8.1. Descriptive statistics and significant differences for junior and senior players during test two

The data presented in the following section is the test results of the junior and senior netball players. The classification of junior and senior players was made in a similar manner than for the first testing occasion. Participants 19 years of age and younger (≤19 years) were categorised as junior players while the senior players consisted of participants 20 years and older (≥20 years).

From the total group of 25 netball players who participated in the second testing occasion, 15 players were classified as juniors and 10 players as seniors. First, the results of the *biomechanical assessments* of the two groups (seniors and juniors) will be compared (Table 4.11). The assessment was sectioned in regions, namely lower limb, pelvic girdle and spinal region and neurodynamics. The same biomechanical grading system was used throughout the study (the system is explained in section 4.2). In the *lower limb region* the juniors presented with fewer biomechanical deviations than the senior players. The juniors tended towards ideal values in 14 of the 20 tests performed in this region (lower limb), and the seniors in 4 of the 20 tests. In 2 tests the juniors and seniors scored the same averages. This meant that participants from the junior group presented with less biomechanical stressors in this region (lower limb) than the senior players. Numerous significant differences between the junior and senior players were detected in terms of the tests conducted in the lower limb region. In all tests which indicated significant differences, the juniors performed better than the seniors. Practical significant differences ($p \leq 0.05$; $d \geq 0.8$) were indicated for the Achilles tendon suppleness test ($p=0.0221$; $d=3.1784$); the ITB mobility test ($d=2.0392$); the quadriceps mobility test ($d=1.0590$); the gluteus maximus mobility test ($p=0.0330$; $d=2.9371$); the adductor mobility test ($d=2.1375$); VMO-L-comparison test ($p=0.0427$); and the forefoot positional test ($p=0.0059$).

The *pelvic girdle region* is analysed below (Table 4.11). In four of the six tests conducted in this region the juniors tended more towards ideal values than the seniors. This data indicate that more biomechanical stressors were identified in the pelvic girdle region among the seniors than the juniors. Practically significant differences ($d \geq 0.8$) were detected with the leg length discrepancy test; ASIS and PSIS comparison tests; and the pelvic rami positional test ($d=2.5584$). The biomechanical assessment of the *spinal region* indicated that the juniors tended towards ideal values in more tests than the seniors. In 4 of the 10 tests conducted in this area (spinal region) the juniors performed better; in 3 tests the seniors performed better; and in 3 tests the juniors and seniors scored the same averages.

Evidently, the juniors performed better than the seniors in 4 tests, meaning that fewer biomechanical deviations in this region were identified among the juniors than the seniors (Table 4.11). In three of the ten tests performed in the spinal region, practically significant differences ($p \leq 0.05$; $d \geq 0.8$) were detected. In two (thoracic, d=1.0562; and lumbar area evaluations, d=1.1078) of these tests which found practical significant differences, the juniors tended more towards ideal values than the seniors and in the thoraco-lumbar fascia test (d=1.4064) the seniors tend more to ideal. In the evaluation of *neurodynamics* the juniors performed better than the seniors in the first test (SLR test), and the seniors in the second and last test (PKB test) of this category. Practical significant differences ($d \geq 0.8$) were detected by both tests (SLR test, d=0.9961; PKB test, d=1.6129) conducted in the neurodynamics category (Table 4.11).

Table 4.12 presents the results of the *anthropometry* during test two for the juniors and seniors. The BMI (weight/height^2) results of both groups (juniors and seniors) indicate that both groups fell in the ideal category (18.5-24.9) (De Ridder, 2004). The juniors presented with an average BMI of 23.05 and the seniors with an average of 23.03. No significant differences were detected with regard to the BMI results. However, a practical significant difference was detected between the two groups with regard to weight (d=1.1684), with the juniors being the heavier group. On average, the seniors ($\bar{x}$ =70.23 kg) weighed less than the juniors ($\bar{x}$ =71.13 kg). In terms of fat percentages the juniors and seniors fell in the above average category (25% - 31%) (De Ridder, 2004). According to De Ridder (2004) the ideal category is between 22% - 24%, and the juniors presented with an average fat percentage of 28.20% and the seniors with 26.79%. Therefore, the seniors presented with a lower and better average (fat percentage) than the juniors. A practically significant difference ($d \geq 0.8$) was identified between the results of the fat percentages (d=2.1023), with the seniors presenting with a better fat percentage than the juniors. Evidently, the most subcutaneous fat among the netball players is located in the tricep, abdominal and thigh areas. Practical significant differences ($d \geq 0.8$) between the juniors and seniors were detected with the abdominal (d=0.8388), thigh (d=1.9060) and calf (d=1.4915) skinfold measurements; the seniors presented with lower and better values for all six skinfold measurements than the juniors (Table 4.12).

The results of the *physical/motor ability* tests are presented in Table 4.12. With the first motor ability, namely agility, the senior players ($\bar{x}$ =18.92 sec) completed the test in a quicker time than the junior players ($\bar{x}$ =19.00 sec). Both groups were placed in the average category (18.0 sec - 21.7 sec). Above average was defined as a time less than 18 sec (www.brianmac.demon.uk/illinois.htm). The test to determine the participants' balance concluded that the senior players ($\bar{x}$ =83.89%) have better balancing abilities than the junior players ($\bar{x}$ =80.52%). According to the norm set for elite netball players, both groups fell in the acceptable category (≥75%) (Techno Therapy, 1992). The last motor ability to be tested was explosive power. According to the standards (≥30) set for elite netball players, both groups (juniors and seniors) underperformed (Boscosystem ErgoJump www.boscosystem.com). The seniors ($\bar{x}$ =29.15), however, presented with a better score than the juniors ($\bar{x}$ =28.40). The only practical significant difference for junior and senior players (d≥0.8) in terms of motor abilities was detected with the balancing test (d=1.3889), where the seniors presented with better balancing abilities than the juniors.

Below is a summary of the differences between the junior and senior players, according to their biomechanics, anthropometry and physical/motor abilities (agility, balance and explosive power). Firstly, the *biomechanical analysis* showed that in the first three categories (lower limb, pelvic girdle and spinal regions) the juniors performed better than the seniors. Fourteen practically significant differences were identified in these three categories (lower limb, pelvic girdle and spinal regions). With neurodynamics, the two groups presented with similar results. Practically significant differences were found between the results for both tests performed in the neurodynamics category. Second, the *anthropometry* evaluation indicated that both groups (juniors and seniors) fell in the ideal category regarding their BMI results. A practically significant difference occurred with the weight comparison between the junior and senior players. The seniors presented with a better fat percentage than the juniors, but both groups were categorised in the above average category. A practically significant difference was found for the fat percentages.

The interpretation of the six skinfold measurements identified that the juniors presented with more subcutaneous fat than the seniors. For four of the six skinfold measurements, practically significant differences were identified. Thirdly, the *physical/motor abilities* indicated that the senior players have better agility, balancing and explosive power abilities than the junior players. A significant difference presented with the balance test.

Table 4.11 Descriptive statistics and significant differences of biomechanical data for junior (N=15) and senior players (N=10) during test two, corrected for test one measurements with ANCOVA

TEST VARIABLES	$\bar{X}$ Juniors	$\bar{X}$ Seniors	Std.Dev. Juniors	Std.Dev. Seniors	p	Effect size (d)
BIOMECHANICS:						
LOWER LIMB REGION:						
Achilles tendon suppleness test	1.00033	1.33299	0.08391	0.10466	0.02217*	3.17848*
Iliotibial band mobility test (ITB)	1.73327	1.98100	0.09776	0.12148	0.13077	2.03920*
Quadriceps mobility	1.68580	1.84593	0.12333	0.15120	0.43808	1.05901*
Iliopsoas mobility	1.69404	1.83770	0.16331	0.20228	0.59216	0.71020
Gluteus maximus mobility test	1.27372	1.67865	0.11056	0.13786	0.03302*	2.93710*
Adductor mobility test	0.99458	1.11653	0.04575	0.05705	0.11116	2.13757*
Internal rotation mobility test	1.00000	1.00000	0.00000	0.00000	-	0.00000
External rotation mobility test	1.28151	1.33753	0.12978	0.16186	0.78993	0.34606
Q-angle test	1.15277	1.15277	0.00000	0.00000	-	0.00000
Patella squint test	1.06667	1.20000	0.25819	0.42163	0.33531	0.31622
Patella tilt test	1.46667	1.70000	0.51639	0.48304	0.26810	0.45184
Patella height test	1.66666	1.90000	0.48795	0.31622	0.19583	0.47820
VMO – L-comparison test	1.06666	1.40000	0.25819	0.51639	0.04276*	0.64551
Longitudinal arch status test*	1.66666	1.60000	0.48795	0.51639	0.74657	0.12908
Forefoot positional test	1.00000	1.40000	0.00000	0.51639	0.00591*	0.77460
Rear foot positional standing test*	1.13333	1.40000	0.35186	0.69920	0.21857	0.38139
Rear foot lying test*	1.13333	1.50000	0.35186	0.70710	0.09789	0.51855
Transverse arch area comparison test	1.86667	2.00000	0.35186	0.47140	0.42587	0.28283
Foot mobility test*	1.73333	1.80000	0.59361	0.78881	0.81145	0.08451
Toe positional test	2.00000	1.80000	0.00000	0.42163	0.07610	0.47434
PELVIC GIRDLE REGION:						
Leg length discrepancy test	1.75000	1.91666	0.05670	0.06514	0.07394	2.558400*
ASIS comparison test	1.75000	1.91666	0.05670	0.06514	0.07394	2.558400*
PSIS comparison test	1.75000	1.91666	0.05670	0.06514	0.07394	2.558400*
Pelvic rami positional test	1.75000	1.91666	0.05670	0.06514	0.07394	2.558400*
Sacroiliac cleft test	1.00000	1.10000	0.00000	0.31622	0.22810	0.31623
Bilateral pelvis positional test	1.93333	1.80000	0.25819	0.42163	0.33531	0.31622
SPINAL REGION:						
Thoraco-lumbar fascia	1.28513	1.187092	0.06040	0.06970	0.30287	1.40642*
Sacral rhythm test	1.00000	1.10000	0.00000	0.31622	0.22810	0.31623
Functional extension mobility test	1.23049	1.24172	0.13079	0.15059	0.95612	0.07461
Functional flexion test	1.45954	1.40157	0.14235	0.16387	0.79457	0.35375
Rotational mobility test	1.16453	1.11324	0.10792	0.12460	0.75943	0.41155
Side flexion mobility test	1.00000	1.00000	0.00000	0.00000	-	0.00000
Head positional	1.00000	1.00000	0.00000	0.00000	-	0.00000
Cervical	1.00000	1.00000	0.00000	0.00000	-	0.00000
Thoracic	1.12500	1.23611	0.09239	0.10519	0.45837	1.05628*
Lumbar	1.91666	2.00000	0.06514	0.07522	0.41332	1.10781*
NEURODYNAMICS						
Straight leg raise test (SLR)	1.75010	1.88878	0.12058	0.13922	0.46131	0.99614*

TEST VARIABLES	$\bar{X}$ Juniors	$\bar{X}$ Seniors	Std.Dev. Juniors	Std.Dev. Seniors	p	Effect size (d)
BIOMECHANICS:						
NEURODYNAMICS						
Prone knee bend test (PKB)	1.32684	1.11759	0.11235	0.12972	0.23860	1.61297*

Table 4.12 Descriptive statistics and significant differences of anthropometry and physical/motor data for junior (N=15) and senior players (N=10) during test two, corrected for test one measurements with ANCOVA

TEST VARIABLES	$\bar{X}$ Juniors	$\bar{X}$ Seniors	Std.Dev. Juniors	Std.Dev. Seniors	p	Effect size (d)
ANTHROPOMETRY:						
Weight (kg)	71.13255	70.23412	0.62785	0.76892	0.37531	1.16842*
Height (m)	1.74037	1.75385	0.07470	0.09870	0.63345	0.13652
Body mass index	23.05667	23.03000	0.31136	0.38120	0.95732	0.06996
Fat percentage (%)	28.20479	26.79554	0.54882	0.67031	0.12033	2.10236*
SKINFOLDS:						
Tricep	17.14209	16.63125	0.85312	1.04017	0.71074	0.49111
Subscapular	13.09791	12.68209	0.80751	0.98846	0.74797	0.42067
Supraspinal	16.12923	13.46077	0.82351	1.00057	0.05564*	2.66693*
Abdominal	21.25447	20.19220	1.03439	1.26634	0.52304	0.83885*
Thigh	30.64897	27.19436	1.49147	1.81242	0.16259	1.90606*
Calf	16.16667	14.93667	0.67373	0.82464	0.26114	1.49155*
PHYSICAL/MOTOR ABILITIES:						
Agility (sec)	19.00488	18.92493	0.12183	0.15483	0.69143	0.51635
Balance (%)	80.52416	83.89892	2.02198	2.42974	0.29926	1.38893*
Explosive power	28.40375	29.15181	0.88405	1.09859	0.60446	0.68807

$d = \frac{|\bar{x}_1 - \bar{x}_2|}{s_{max}}$ = effect size for difference between means; a measurement of practical significance

p≤0.05 d≥0.2 (small effect)

d≥0.5 (medium effect) d≥0.8 (large effect)

$\bar{X}$ = average value * = Large significant differences between groups

4.8.2. Descriptive statistics and significant differences between centre and goal players during test two

The categorisation of centre and goal players was based on the same principle as during the first testing occasion. The following positions are considered as centre players: centre (C); wing defence (WD); and wing attack (WA), while positions such as goalkeeper (GK), goal defender (GD) and goal attack (GA) are considered as goal players.

These categories were defined according to the unique work profile and somatotype of the different playing positions. In netball, the work profile of the centre players (C, WD and WA) involves more running, jumping and changing direction than that of the goal players (G, GA, GK and GD); therefore the centre players would tend to have a mesomorphic physique, while the goal players and defenders would fall in the ectomorphic category (Jordaan, 2001). From the total group of 25 netball players who participated in the second testing occasion, 13 participants were classified as centre players and 12 as goal players.

Table 4.13 represents the data of the *biomechanical* assessments of the centre players compared to the goal players. The assessment was sectioned in regions, namely lower limb, pelvic girdle, spinal region and neurodynamics. The same biomechanical grading system was used throughout the study (the system is explained in section 4.2). Twenty tests were conducted in the *lower limb region* (first region). The centre players tended more towards ideal values in 7 of these 20 tests, and the goal players in 11 of the tests. In 2 tests both groups presented with the same average values (Table 4.13). This means that in the lower limb region the goal players presented with fewer biomechanical deviations than the centre players. In the quadriceps mobility- (d=1.4760) and the adductor mobility tests (d=1.0887) the goal players scored better averages than the centre players, and practically significant differences (d≥0.8) were identified with both tests. The third test which indicated a practically significant difference (d≥0.8) was the external rotation mobility test (d=0.9242). With this test (external rotation mobility test) the centre players ($\bar{x}$ =1.23) tended more towards ideal values than the goal players ($\bar{x}$ =1.23) (Table 4.13).

In the second region, namely the *pelvic girdle region*, the goal players presented with better scores than the centre players, which meant that in this region fewer biomechanical deviations existed among the goal players than the centre players (Table 4.13). Six tests were conducted in the pelvic girdle region and with all six tests the goal players tended more towards ideal values than the centre players.

Practical significant differences ($d \geq 0.8$) were detected at four tests in the pelvic girdle region (d=1.1746), namely the leg length discrepancy test; the ASIS and PSIS comparison tests; and the pelvic rami positional test.

In the sections below, the results of the 10 tests for the *spinal region* are presented. The goal players tended more towards ideal values in 5 of the 10 tests, and the centre players in 1 test. For four tests, both groups (centre and goal players) scored the same values. Therefore, in the spinal region the goal players presented with less biomechanical abnormalities than the centre players. In the thoraco-lumbar fascia assessment (d=1.4459); functional extension mobility (d=1.5261) and rotation mobility (d=2.4031) tests; and lumbar (d=1.5301) assessment, practically significant differences ($p \leq 0.05$; $d \geq 0.8$) were detected between the two groups (centre and goal players). In the thoraco-lumbar assessment the centre players performed better but in the other four tests where significant differences were detected, the goal players outperformed the centre players. In the last category, namely *neurodynamics*, the centre players tended more towards ideal values than the goal players for both tests conducted in this category (Table 4.13). The SLR test indicated a practically significant difference ($d \geq 0.8$) among the two groups (centre and goal players), with the centre players presenting with fewer deviations (d=1.3536).

Table 4.14 records the *anthropometrical status* and the *physical/motor abilities* of the centre and goal players. When analysing the BMI (weight/height^2) of the two groups (centre and goal players), it is clear that both groups was categorised as ideal (18.5 - 24.9) (De Ridder, 2004). The centre players ($\bar{x}$ =22.63) presented with a practically significant better average than the goal players ($\bar{x}$ =23.4148) (d=2.2728). The centre players (70.31 kg) weighed on average less than the goal players (70.51 kg), while the goal players ($\bar{x}$ =1.79 m) were taller than the centre players ($\bar{x}$ =1.69 m). These findings correlate with the findings made by Jordaan (2001), where centre players are classified in the mesomorphic and goal players in the ectomorphic category, indicating that a mesomorphic stature is usually shorter in height than the ectomorphic counterpart.

A practical significant difference ($p \leq 0.05$; $d \geq 0.8$) was found between the height of the centre and goal players ($p=0.00004$; $d=1.4536$).

The average fat percentages of the two groups placed both groups in the above average category (25% - 31%) (De Ridder, 2004). The ideal fat percentage for female athletes (18 - 24 years) is considered between 22% and 24% (De Ridder, 2004). The centre players presented with a practically significant ($p=0.0168$; $d=3.7520$) better average ($\bar{x}$ =26.37%) than the goal players ($\bar{x}$ =28.58%). With all six skinfolds measurements, the centre players presented with better results than the goal players (Table 4.14). Practical significant differences ($p \leq 0.05$; $d \geq 0.08$) were detected for all six skinfold measurements, namely tricep ($d=2.8919$); subscapular ($p=0.0409$, $d=3.0148$); supraspinal ($d=2.2798$); abdominal ($p=0.0149$; $d=3.7068$); thigh ($d=2.5803$); and calf ($p=0.0193$, $d=3.5912$). According to the skinfold measurements, both groups (centre and goal players) presented with the most subcutaneous fat in the tricep, abdominal and thigh areas (Table 4.14).

The results of the *physical/motor ability* tests are presented in Table 4.14. The results of the motor tests indicated that the centre players performed better than the goal players in all three tests (agility, balance and explosive power). The centre players completed the agility run test in 18.86 sec, compared to the goal players' time of 18.99 sec; therefore the centre players completed the test practically significant ($d=0.8554$) quicker than the goal players. Both groups (centre and goal players) fell in the average category (18.0 sec - 21.7 sec), whereas above average is considered to be between 17.0 sec and 17.9 sec (www.brianmac.demon.uk/illinois.htm). The data of the balance test is analysed next. The centre players presented with an average of 83.78% while the goal players scored an average of 79.95%. The scores of both groups (centre and goal players) were considered acceptable (≥75%) (Techno Therapy, 1992). With this test (balance test) a practically significant difference ($d \geq 0.8$) was found between the centre and goal players ($d=1.6740$). The last motor test, namely the explosive power test, indicated that the centre players presented with a better average score ($\bar{x}$ =30.18) than the goal players ($\bar{x}$ =27.18).

A score of 30 is defined as acceptable for elite netball players between the ages of 18 and 24 years, which means that the average score ($\bar{x}$ =30.18) of the centre players was acceptable and that the goal players ($\bar{x}$ =27.18) underperformed (Boscosystem ErgoJump www.boscosystem.com). Significant differences ($p \leq 0.05$; $d \geq 0.8$) were detected with the explosive power test (p=0.0224; d=3.4400), when the results of the centre and goal players are compared.

Below follows a summary of the differences between the centre and goal players according to their biomechanics, anthropometry and motor abilities (agility, balance and explosive power). The *biomechanical evaluation* found that in the lower limb, pelvic girdle and spinal regions, the goal players performed better, but in the neurodynamics category the centre players presented with better averages. In three tests in the lower limb region practically significant differences were identified, while three occurred in the pelvic girdle region; five significant differences were noted in the spinal region and one in the neurodynamics category. The assessment of the *anthropometry* indicated that the averages of both groups obtained with the BMI fell in the ideal category for female netball players between the ages of 18 to 24 yrs. However, the fat percentages of both groups (centre and goal players) were classified as above average. The centre players presented with a better fat percentage than the goal players. Practical significant differences were identified with the height, BMI and fat percentage averages. The six skinfold measurements indicated that the goal players have more subcutaneous fat than the centre players. Practically significant differences were identified with all six skinfold measurements. The centre players scored better averages in all three *physical/motor tests* (agility, balance and explosive power) than the goal players. Practically significant differences were found in all three motor tests.

Table 4.13 Descriptive statistics and significant differences between biomechanical data for centre players (N=12) and goal players (N=13) during test two, corrected for test one measurements with ANCOVA

TEST VARIABLES	$\bar{X}$ Centre players	$\bar{X}$ Goal players	Std.Dev. Centre Players	Std.Dev. Goal Players	p	Effect size (d)
BIOMECHANICS:						
LOWER LIMB REGION:						
Achilles tendon suppleness test	1.09912	1.15844	0.11026	0.10578	0.70812	0.53798
Iliotibial band mobility test (ITB)	1.80174	1.84977	0.11592	0.11102	0.76880	0.41429
Quadriceps mobility	1.83941	1.64543	0.13142	0.12587	0.30136	1.47608*
Iliopsoas mobility	1.78169	1.70315	0.18284	0.17517	0.76130	0.42950
Gluteus maximus mobility test	1.42767	1.44353	0.14043	0.13449	0.93601	0.11291
Adductor mobility test	1.07512	1.01578	0.05450	0.05221	0.44333	1.08877*
Internal rotation mobility test	1.00000	1.00000	0.00000	0.00000	-	0.00000
External rotation mobility test	1.23576	1.37029	0.14556	0.13941	0.51355	0.92422*
Q-angle test	1.14545	1.14545	0.00000	0.00000	-	0.00000
Patella squint test	1.08333	1.15384	0.28867	0.37553	0.60598	0.18776
Patella tilt test	1.50000	1.61538	0.52223	0.50637	0.58039	0.22093
Patella height test	1.83333	1.69230	0.38924	0.48038	0.43066	0.29358
VMO – L-comparison test	1.25000	1.15384	0.45226	0.37553	0.56744	0.21262
Longitudinal arch status test*	1.58333	1.69230	0.51492	0.48038	0.58931	0.21162
Forefoot positional test	1.16666	1.15384	0.38924	0.37553	0.93393	0.03293
Rear foot positional standing test*	1.25000	1.23076	0.45226	0.59914	0.92909	0.03211
Rear foot lying test*	1.25000	1.30769	0.45226	0.63042	0.79651	0.09151
Transverse arch area comparison test	2.00000	1.84615	0.00000	0.55470	0.34745	0.27735
Foot mobility test*	1.75000	1.76923	0.45226	0.83205	0.94408	0.02311
Toe positional test	2.0000	1.84615	0.00000	0.37553	0.16995	0.40968
PELVIC GIRDLE REGION:						
Leg length discrepancy test	1.84755	1.77062	0.06245	0.06548	0.40728	1.17464*
ASIS comparison test	1.84755	1.77062	0.06245	0.06548	0.40728	1.17464*
PSIS comparison test	1.84755	1.77062	0.06245	0.06548	0.40728	1.17464*
Pelvic rami positional test	1.84755	1.77062	0.06245	0.06548	0.40728	1.17464*
Sacroiliac cleft test	1.08333	1.00000	0.28867	0.00000	0.30791	0.28866
Bilateral pelvis positional test	1.91666	1.84615	0.28867	0.37553	0.60598	0.11635
SPINAL REGION:						
Thoraco-lumbar fascia	1.19313	1.28868	0.06300	0.06607	0.30930	1.44591*
Sacral rhythm test	1.08333	1.00000	0.28867	0.00000	0.30791	0.28866
Functional extension mobility test	1.34220	1.12142	0.13860	0.14466	0.30749	1.52611*
Functional flexion test	1.43181	1.43181	0.15199	0.15895	1.00000	0.00000
Rotational mobility test	1.27272	1.00000	0.10852	0.11348	0.10908	2.40319*
Side flexion mobility test	1.00000	1.00000	0.00000	0.00000	-	0.00000
Head positional	1.00000	1.00000	0.00000	0.00000	-	0.00000
Cervical	1.00000	1.00000	0.00000	0.00000	-	0.00000
Thoracic	1.31013	1.05350	0.08406	0.08806	0.05183*	2.91434*
Lumbar	2.00527	1.89472	0.06904	0.07224	0.29461	1.53019*

TEST VARIABLES	$\bar{X}$ Centre players	$\bar{X}$ Goal players	Std.Dev. Centre Players	Std.Dev. Goal Players	p	Effect size (d)
BIOMECHANICS:						
NEURODYNAMICS						
Straight Leg Raise (SLR)	1.72489	1.90244	0.12526	0.13132	0.34298	1.35366*
Prone knee bend test (PKB)	1.20927	1.27253	0.12225	0.12816	0.72640	0.49357

Table 4.14 Descriptive statistics and significance of anthropometry and physical/motor data for centre players (N=12) and goal players (N=13) during test two, corrected for test one measurements with ANCOVA

TEST VARIABLES	$\bar{X}$ Centre players	$\bar{X}$ Goal players	Std.Dev. Centre Players	Std.Dev. Goal players	p	Effect size (d)
ANTHROPOMETRY:						
Weight (kg)	70.31696	70.51637	0.83494	0.81109	0.88082	0.23883
Height (m)	1.69600	1.79350	0.06707	0.06612	0.00004*	1.45361*
Body mass index	22.63767	23.41489	0.34195	0.32951	0.12849	2.27288*
Fat percentage (%)	26.37400	28.58632	0.58962	0.56853	0.01680*	3.75206*
SKINFOLDS:						
Tricep	15.61709	18.25855	0.91337	0.88098	0.05955	2.89199*
Subscapular	11.67380	14.14992	0.82106	0.78894	0.04095*	3.01485*
Supraspinal	13.69884	15.86847	0.95165	0.91634	0.12411	2.27984*
Abdominal	18.85884	22.67129	1.02848	0.98911	0.01497*	3.70687*
Thigh	26.68157	31.05112	1.69341	1.63458	0.09281	2.58031*
Calf	14.38138	16.89298	0.69937	0.67331	0.01936*	3.59121*
MOTOR ABILITIES:						
Agility (sec)	18.86214	18.99149	0.15119	0.14542	0.57784	0.85549*
Balance (%)	83.78111	79.95525	2.28523	2.28523	0.26941	1.67407*
Explosive power	30.18745	27.18377	0.87315	0.83627	0.02243*	3.44003*

$d = \frac{|\bar{x}_1 - \bar{x}_2|}{s_{max}}$ = effect size for difference between means; a measurement of practical significance

$p \leq 0.05$

$d \geq 0.2$ (small effect)

$d \geq 0.5$ (medium effect)

$d \geq 0.8$ (large effect)

$\bar{X}$ = average value

* = Large significant differences between groups

4.8.3. Descriptive statistics and significant differences between A- and B-grade players during test two

In the final instance, the participants were divided into A- and B-grade players. This classification was based on the same principle upon which the first tests were based, namely the team for which the players were selected. The first team of the North-West University Netball Club and the u/19A team were considered as the A-grade players while the second, third, fourth and u/19B teams were classified as B-grade players. Twelve players were categorised as A-grade and thirteen players as B-grade.

Table 4.15 and Table 4.16 present the tests results of the A-grade players, compared to the B-grade players. The *biomechanical results* are discussed first (Table 4.15). The assessment was sectioned in regions, namely lower limb, pelvic girdle, spinal region and neurodynamics. The same biomechanical grading system was used throughout the study (the system is explained in section 4.2). In the *lower limb region* the B-grade players performed better than the A-grade players. From the 20 tests conducted in this region (lower limb region) the B-grade players tended more towards ideal values with 11 and the A-grade players tended more towards the ideal in 7 of the 20 tests. Both groups scored the same values with two tests. This meant that in the lower limb region the B-grade players presented with fewer biomechanical stressors than the A-grade players (Table 4.15). Practically significant differences ($d \geq 0.8$) were identified with the Achilles tendon suppleness test ($d=0.9829$); the adductor mobility test ($d=1.0813$); and the external rotation mobility tests ($d=0.8666$). In the Achilles tendon suppleness test the B-grade players performed better, but with the other two tests (adductor and external rotation mobility tests) the A-grade players tended more towards ideal values than the B-grade players.

In the *pelvic girdle region* the A-grade players performed better than the B-grade players in all six tests performed in this region. These results indicate that in the pelvic girdle region fewer biomechanical deviations were detected among the A-grade players than the B-grade players.

Practical significant differences ($d \geq 0.8$) of the same value ($d=2.7109$) were found for the first four tests (leg length discrepancy-; ASIS and PSIS comparison tests; and the pelvic rami positional test) conducted in the pelvic girdle region. The results of the tests performed in the *spinal region* reported less biomechanical stressors among the B-grade players than among the A-grade players (Table 4.15). The B-grade players tended more towards the ideal in 6 of the 10 tests performed in this region (spinal region), while the A-grade players tended more towards the ideal in 1 of the tests. In 3 of the tests the two groups (A- and B-grade players) scored the same averages. Practically significant differences ($p \leq 0.05$; $d \geq 0.8$) were detected for the thoraco-lumbar fascia assessment ($d=0.9909$); functional extension mobility test ($d=2.1771$); functional flexion test ($p=0.0124$; $d=3.8559$); rotational mobility test ($d=1.0209$); and the assessment of the lumbar area ($d=1.4142$): in all these tests the B-grade players presented with fewer biomechanical deviations than the A-grade players.

In the last category, namely *neurodynamics,* the B-grade players performed better than the A-grade players in both tests (SLR and PKB) in this category. In other words, the B-grade players presented with fewer biomechanical deviations in this category (neurodynamics) than the A-grade players. With the SLR test, a practical significant difference ($d \geq 0.8$) between the results of the A- and B-grade players was detected ($d=1.6344$).

The *anthropometry* results are interpreted next, as summarised in Table 4.16. The results of the BMI (weight/height^2) tests indicate that the A- ($\bar{x}=23.34$) and B-grade players ($\bar{x}=22.88$) fell in the ideal category (18.5 - 24.9) (De Ridder, 2004). A practically significant difference ($d \geq 0.8$) was detected for the BMI ($d= 1.2863$) results, with the B-grade players presenting a better BMI than the A-grade players. The A-grade players ($\bar{x}=71.13$ kg; $\bar{x}=1.76$m) weighed insignificantly more and were taller than the B-grade players ($\bar{x}=70.71$kg; $\bar{x}=1.73$m).

With regard to the fat percentages, the B-grade players ($\bar{x}$ =27.10%) presented with better results than the A-grade players ($\bar{x}$ =28.08%), but according to De Ridder (2004) both groups fell in the above average category (25% - 31%). A practically significant difference (d≥0.8) was detected with the fat percentage comparison between the two groups (A- and B-grade players) (d=1.5470). The B-grade players presented with better results than the A-grade players for the 6 skinfold measurements. According to these measurements (skinfold measurements), both groups (A- and B-grade players) presented with the most subcutaneous fat in the tricep, abdominal and thigh areas. Practical significant differences (p≤0.05; d≥0.8) between the A- and B-grade players were detected with the subscapular (d=1.5514); supraspinal (d=1.5141); abdominal (p= 0.0126; d=3.8363); and calf (d=0.8516) skinfold measurements.

Table 4.16 also presents the results of the *physical/motor abilities* of the A- and B-grade players. With the agility test the A-grade players scored an average of 18.75sec, compared with the average value of the B-grade players of 19.05sec. According to the norm set for elite netball players between the ages of 18 and 24 years, both groups fell in the average category (18.0 sec - 21.7 sec), whereas above average is considered between 17.0 sec and 17.9 sec (www.brianmac.demon.uk/ illinois.htm). The balance test revealed that the A-grade players ($\bar{x}_2$=85.25%) have better balancing abilities than the B-grade players ($\bar{x}_2$= 78.66%). The explosive power test indicated an average of 30.47 for the A-grade players and an average of 27.34 for the B-grade players. According to the norm (≥30), the average scored by the A-grade players ($\bar{x}_2$ = 30.47) is considered acceptable, while the B-grade players ($\bar{x}_2$= 27.34) underperformed (Boscosystem ErgoJump www.boscosystem.com). The A-grade players performed practically significant better than the B-grade players in all three motor tests, namely agility- (d=2.1864), balance- (p=0.0477; d=2.9805) and explosive power (p=0.0367; d=3.1696) tests (Table 4.16). Evidently, the A-grade players performed better than the B-grade players during the physical/motor tests. One would expect the A-grade players to perform better than the B-grade players because they were selected for the first grade teams based on their physical abilities being superior to the abilities of the B-grade players.

In conclusion, the comparison between the physical profile (biomechanics, anthropometry and motor abilities) of the A-grade players and that of the B-grade players reveals that the B-grade players performed better than the A-grade players in three of the four categories of the *biomechanical analysis* (lower limb region, spinal region and neurodynamics) during the second testing occasion. Practically significant differences were identified with three tests in the lower limb region; four in the pelvic girdle region; five in the spinal region and one in the neurodynamics category. The A-grade players presented with better averages than the B-grade players in the pelvic girdle region. The *anthropometry assessment* indicated that both groups (A- and B-grade players) fell in the ideal category regarding their BMI averages and in the above average category in terms of fat percentages. The B-grade players presented with a lower and better fat percentage than the A-grade players. Practically significant differences were found with regard to BMI and fat percentage. The B-grade players presented with less subcutaneous fat than the A-grade players according to the six skinfold measurements. Practically significant differences were identified for four of the six skinfold measurements. The A-grade players performed better than the B-grade players in all three *physical/motor tests* (agility, balance and explosive power). Practically significant differences were identified by the agility and explosive power tests.

Table 4.15 Descriptive statistics and significance of biomechanical data for A- (N=12) and B-grade players (N=13) during test two, corrected for test one measurements with ANCOVA

TEST VARIABLES	$\bar{x}$ A-grade players	$\bar{x}$ B-grade players	Std.Dev. A-grade players	Std.Dev. B-grade players	p	Effect size (d)
BIOMECHANICS:						
LOWER LIMB REGION:						
Achilles tendon suppleness test	1.18520	1.07994	0.10708	0.10254	0.48666	0.98296*
Iliotibial band mobility test (ITB)	1.82155	1.82995	0.11572	0.11080	0.95869	0.07261
Quadriceps mobility	1.79017	1.69467	0.13512	0.12950	0.61948	0.70678
Iliopsoas mobility	1.78169	1.70315	0.18284	0.17517	0.76130	0.42906
Gluteus maximus mobility test	1.44730	1.41633	0.14425	0.13848	0.88198	0.21471
Adductor mobility test	1.01225	1.07107	0.05439	0.05209	0.44538	1.08132*
Internal rotation mobility test	1.00000	1.00000	0.00000	0.00000	-	0.00000
External rotation mobility test	1.23806	1.36511	0.14659	0.14025	0.54166	0.86664*
Q-angle test	1.13636	1.13636	0.00000	0.00000	-	0.00000
Patella squint test	1.25000	1.00000	0.45226	0.00000	0.05783	0.55277
Patella tilt test	1.75000	1.38461	0.45226	0.50637	0.07051	0.72158
Patella height test	1.83333	1.69230	0.38924	0.48038	0.43066	0.29358
VMO – L-comparison test	1.16666	1.23076	0.38924	0.43852	0.70362	0.14617
Longitudinal arch status test*	1.66666	1.61538	0.49236	0.50637	0.79996	0.10115
Forefoot positional test	1.25000	1.07692	0.45226	0.27735	0.25635	0.38270
Rear foot positional standing test*	1.16666	1.30769	0.57735	0.48038	0.51206	0.24427
Rear foot lying test*	1.25000	1.30769	0.62158	0.48038	0.79651	0.09281
Transverse arch area comparison test	2.00000	1.84615	0.42640	0.37553	0.34745	0.36081
Foot mobility test*	1.75000	1.76923	0.75377	0.59914	0.94408	0.02551
Toe positional test	1.91666	1.92307	0.28867	0.27735	0.95533	0.02220
PELVIC GIRDLE REGION:						
Leg length discrepancy test	1.73374	1.90261	0.05935	0.06229	0.07187	2.71092*
ASIS comparison test	1.73374	1.90261	0.05953	0.06229	0.07187	2.71092*
PSIS comparison test	1.73374	1.90261	0.05953	0.06229	0.07187	2.71092*
Pelvic rami positional test	1.73374	1.90261	0.05953	0.06229	0.07187	2.71092*
Sacroiliac cleft test	1.0000	1.07692	0.00000	0.27735	0.34745	0.27733
Bilateral pelvis positional test	1.75000	2.0000	0.45226	0.00000	0.05783	0.55277
SPINAL REGION:						
Thoraco-lumbar fascia	1.27027	1.202703	0.06492	0.06819	0.48855	0.99082*
Sacral rhythm test	1.08333	1.00000	0.28867	0.00000	0.30791	0.28866
Functional extension mobility test	1.37697	1.08665	0.12710	0.13326	0.13356	2.17716*
Functional flexion test	1.66818	1.16818	0.12368	0.12966	0.01242*	3.85597*
Rotational mobility test	1.20202	1.07979	0.11441	0.11971	0.48064	1.02096*
Side flexion mobility test	1.00000	1.00000	0.00000	0.00000	-	0.00000
Head positional	1.00000	1.00000	0.00000	0.00000	-	0.00000
Cervical	1.00000	1.00000	0.00000	0.00000	-	0.00000
Thoracic	1.18810	1.19371	0.09242	0.09693	0.96700	0.05795
Lumbar	2.00000	1.90000	0.06742	0.07071	0.31961	1.41420*

TEST VARIABLES	$\bar{X}$ A-grade players	$\bar{X}$ B-grade players	Std.Dev. A-grade players	Std.Dev. B-grade players	p	Effect size (d)
BIOMECHANICS:						
NEURODYNAMICS:						
Straight Leg Raise (SLR)	1.91031	1.69877	0.12342	0.12942	0.25311	1.63440*
Prone knee bend test (PKB)	1.25559	1.21713	0.12213	0.12807	0.83070	0.30030

Table 4.16 Descriptive statistics and significance of anthropometry and physical/motor data for A- (N=12) and B-grade players (N=13) during test two, corrected for test one measurements with ANCOVA

TEST VARIABLES	$\bar{X}$ A-grade players	$\bar{X}$ B-grade players	Std.Dev. A-grade players	Std.Dev. B-grade players	p	Effect size (d)
ANTHROPOMETRY:						
Weight (kg)	71.13451	70.71165	0.74986	0.72336	0.70262	0.56391
Height (m)	1.76688	1.73000	0.09075	0.07431	0.16753	0.40631
Body mass index	23.34903	22.88559	0.36027	0.34757	0.38770	1.28636*
Fat percentage (%)	28.08107	27.10463	0.63116	0.60678	0.28038	1.54703*
SKINFOLDS:						
Tricep	17.35097	16.68685	0.94012	0.90337	0.61621	0.70641
Subscapular	13.66835	12.30408	0.87932	0.84486	0.27553	1.55149*
Supraspinal	15.65853	14.19018	0.96975	0.93297	0.29486	1.51414*
Abdominal	22.92305	18.98016	1.02776	0.98891	0.01265*	3.83636*
Thigh	29.28028	28.81523	1.71285	1.64650	0.84757	0.27150
Calf	16.04654	15.39128	0.76937	0.73932	0.54632	0.85167*
MOTOR ABILITIES:						
Agility (sec)	18.75348	19.05485	0.13783	0.11982	0.12074	2.18645*
Balance (%)	85.25583	78.66251	2.21210	2.03331	0.04774*	2.98056*
Explosive power	30.47036	27.34502	0.98602	0.87846	0.03676*	3.16962*

$d = \frac{|\bar{x}_1 - \bar{x}_2|}{s_{max}}$ = effect size for difference between means; a measurement of practical significance

$p \leq 0.05$

$d \geq 0.2$ (small effect)

$d \geq 0.5$ (medium effect)

$d \geq 0.8$ (large effect)

$\bar{X}$ = average value

* = Large significant differences between groups

4.9. SUMMARY OF THE RESULTS OF TESTING OCCASION TWO

The section will be concluded by a summary of all the data collected during the second testing occasion.

Firstly, the data of the *group in total* will be summarised:

1. *Biomechanics, anthropometry and physical/motor abilities of the total group:*

- The *biomechanical data* revealed the following biomechanical deviations in the lower limb region among the netball players (Table 4.9). These deviations included ITB, quadriceps, and iliopsoas tightness; tilted patella with asymmetrical patella height; rear foot pronation with callus plantar aspect; and valgus, rotation or deviation of their toes. In the pelvic girdle region, biomechanical stressors such as excessive leg length discrepancies; asymmetries at the PSIS, ASIS, pelvic ramis as well as non-ideal pelvic positions (lumbar hyperlordosis) were identified in the majority of the total group of netball players. In the last two categories, namely spinal region and neurodynamics, the total group of netball players presented with a hyperlordotic lumbar curve and inadequate neural mobility.

- The *anthropometry* of the total group of NWU Club netball players are discussed below (Table 4.10). The average BMI for the total group fell in the ideal category, while the average fat percentage of the total group is considered above average. This meant that the NWU Club netball players presented with above average subcutaneous fat especially in the tricep, abdominal and thigh areas.

- In terms of the *physical/motor tests*, the club netball players performed relatively acceptable in the agility and balancing tests, but underperformed in the explosive power test, according to the norm set for elite netball players (Table 4.10).

Secondly, the differences between the *junior and senior players* according to their biomechanics, anthropometry and physical/motor abilities (agility, balance and explosive power) are summarised:

2. *Biomechanics, anthropometry and physical/motor of the juniors and seniors:*

- The *biomechanical analysis* showed that in the first three categories (lower limb, pelvic girdle and spinal regions), the juniors performed better than the seniors. Fourteen practically significant differences were identified in these three categories (lower limb, pelvic girdle and spinal regions). For neurodynamics, the two groups presented with similar results. Both tests performed in the neurodynamics category found practically significant differences (Table 4.11).

- The *anthropometry* evaluation indicated that both groups (juniors and seniors) fell in the ideal category regarding their BMI results (Table 4.12). A practically significant difference occurred with the weight comparison between the junior and senior players. The seniors presented with a better fat percentage than the juniors, but both groups were categorised in the above average category. A practically significant difference occurred with the fat percentages. The interpretation of the six skinfold measurements indicated that the juniors presented with more subcutaneous fat than the seniors. With four of the six skinfold measurements, practically significant differences were identified.

- The *motor abilities* indicated that the senior players have better agility, balancing and explosive power abilities than the junior players. A significant difference was found with regard to the balance test (Table 4.12).

Thirdly, the data obtained from the *centre and goal players* is summarised:

3. *Biomechanics, anthropometry and physical/motor abilities of the centre and goal players:*

- The *biomechanical evaluation* showed that in the lower limb, pelvic girdle and spinal regions the goal players performed better, but in the neurodynamics category the centre players presented with better averages. For three tests in the lower limb region, practically significant differences were identified, while three occurred in the pelvic girdle region; five significant differences were observed in the spinal region and one in the neurodynamics category (Table 4.13).

- The assessment of the *anthropometry* indicated that the averages of both groups obtained with the BMI fell in the ideal category for female netball players between the ages of 18 and 24. However, the fat percentages of both groups (centre and goal players) were classified as above average. The centre players presented with a better fat percentage than the goal players. Significant differences were identified with the height, BMI and the fat percentage averages. The six skinfold measurements indicated that the goal players have more subcutaneous fat than the centre players. Practically significant differences were identified for all six skinfold measurements (Table 4.14).

- The centre players scored better averages for all three *physical/motor tests* (agility, balance and explosive power) than the goal players. Practically significant differences were found with all three motor tests (Table 4.14).

Finally, a summary will follow of the comparisons of the physical profiles (biomechanics, anthropometry and physical/motor abilities) of the *A-grade players* with the *B-grade players*:

4. *Biomechanics, anthropometry and physical/motor abilities of the A- and B-grade players:*

- Evidently, the B-grade players performed better than the A-grade players in three of the four categories of the *biomechanical analysis* (lower limb region, spinal region and neurodynamics) (Table 4.15). Practically significant differences were identified for three tests in the lower limb region; four in the pelvic girdle region; five in the spinal region and one in the neurodynamics category. The A-grade players presented with better averages than the B-grade players in the pelvic girdle region.

- The *anthropometry assessment* indicated that both groups (A- and B-grade players) fell in the ideal category regarding their BMI averages. According to the fat percentages the A- and B-grade players fell in the above average category. The B-grade players presented with a lower and better fat percentage than the A-grade players. The BMI and fat percentage presented with practically significant differences. The B-grade players presented with less subcutaneous fat than the A-grade players, according to the six skinfold measurements. Practically significant differences were identified by four of the six skinfold measurements (Table 4.16).

- The A-grade players performed better than the B-grade players in all three of the *physical/motor tests* (agility, balance and explosive power) (Table 4.16). Practically significant differences were identified for the agility and explosive power tests.

4.10. DESCRIPTIVE STATISTICS AND SIGNIFICANT DIFFERENCES FOR THE TOTAL GROUP OF NETBALL PLAYERS BETWEEN TESTING OCCASION ONE AND TWO

Table 4.17 presents the comparison of the biomechanical results of the pre- (test one) and post-season testing occasion (test two) for the total group of elite NWU netball players. The reason for the comparison is to determine whether biomechanical changes occurred during the netball season. In the *lower limb region* only two practical significant differences ($p \leq 0.05$; $d \geq 0.8$) were identified. The first one was with the quadriceps mobility test ($p=0.0159$), which indicated that the flexibility of the quadriceps for the total group decreased significantly during the season, but there is only a medium effect size ($d=0.6004$). The second practical significant difference ($p \leq 0.05$; $d \geq 0.8$) occurred with the external rotation mobility test ($p=0.0304$), which identified that the external rotation mobility improved during the course of the netball season, but the difference was small compared to the d-value of 0.4423.

In the *pelvic girdle region* high practically significant differences ($p \leq 0.05$; $d \geq 0.8$) were found in the ASIS comparison, PSIS comparison, and the pelvic rami positional tests. All three tests rendered the same value ($d=1.1091$), which means that the asymmetries at the ASIS, PSIS and the pelvic ramis increased during the season. These pelvic asymmetries place more strain on the pelvic girdle of the players. No significant differences were identified in the *spinal region.* In the neurodynamics category, the SLR test found significant differences ($p=0.0002$; $d=1.3093$), which means that the *neurodynamics* of the players deteriorated during the season. In conclusion, only five significant biomechanical differences among the total group occurred during the season. The reason for this could be the fact that every netball player has a unique mechanical make-up due to structural characteristics, and in the absence of a specific conditioning programme the player's biomechanics will not alter during a season (Brukner & Khan, 2001). No other literature offered an explanation for these few biomechanical changes during the season.

The practical significant differences which did occur were with regard to the quadriceps mobility; external mobility; ASIS comparison; PSIS comparison; and the pelvic rami positional tests.

The *anthropometry* results are summarised in Table 4.18. Significant differences occurred with regard to the weight, BMI, fat percentage, and subscapular, thigh and calf skinfold measurements. The weight of the total group (p=0.00003) as well as the BMI (p=0.0058) and fat percentage (p=0.0399) increased significantly, although practical significant differences only indicated small effects (d≥0.2). Their subcutaneous fat increased practically significant especially in the subscapular (p=0.0435), thigh (p=0.00001; d=1.0644) and calf (p=0.0201) areas. Literature do not explain the increases in weight, BMI, fat percentage and skinfold measurements, but possible reasons for these increases could be, firstly, that the conditioning programme did not include adequate exercise routines during the season to increase their muscle mass and reduce their fat percentages, and secondly, that the second tests occurred three weeks into the players' off-season, meaning that for three weeks prior to the tests they did not train. Thus, significant increases occurred with regard to the weight, BMI, fat percentage, and the subscapular, thigh and calf skinfold measurements among the total group of netball players. No explanations for these increases could be found in literature. This occurrence could be an indication that the training program during the season did not include adequate exercises to improve muscle tissue and decrease body fat.

The data of the *physical/motor abilities* for the total group is discussed below (Table 4.18). Significant differences (p≤0.05; d≥0.8) were identified with all three motor tests (agility, balance and explosive power). The agility (p=0.00002) and the balancing abilities (p=0.000005; d=1.0936) of the total group improved significantly. However, a significant decrease in performance was identified with the explosive power test (p=0.000003, d=1.0693).

According to literature, the physical/motor abilities (agility, balance and explosive power) of a netball player could be enhanced during the netball season with the correct exercises (Baltaci & Kohl, 2003; Verhagen *et al.,* 2004; Clark & Burden, 2005; Swanik & Swanik, 1999; Moss, 2002). However, literature did not explain the decrease in performance with explosive power. One possible reason for the decrease in explosive power could be that the conditioning programme did not include adequate plyometric exercises to improve the netball players' explosive power.

Below is a summary of the practical significant differences of the total group during testing occasion one and two will follow. Two practical significant differences occurred between the two *biomechanical assessments* of the lower limb; first with the quadriceps mobility test and second with the external rotation mobility test. The pelvic girdle region indicated significant differences with the ASIS comparison, PSIS comparison, and the pelvic rami positional tests. Evidently, the asymmetries at the ASIS, PSIS and the pelvic ramis increased during the season. No practical significant differences were identified in the spinal region. In the neurodynamics category practical significant differences were identified with the SLR test, indicating that the neurodynamics of the players deteriorated during the season. Secondly, a summary of the *anthropometry* results between the pre- and post-season is presented. Practical significant differences occurred with regard to the weight, BMI, fat percentage, and the subscapular, thigh and calf skinfold measurements. Thirdly, the data of the *physical/motor ability* tests for the total group is discussed. Practical significant differences ($p \leq 0.05$; $d \geq 0.8$) were identified with all three physical/motor tests (agility, balance and explosive power). The agility and balance of the total group improved significantly. However, a practically significant decrease in performance was measured with the explosive power test.

Table 4.17 Changes in biomechanical data from test one to test two for the total group for significant differences in performance (N=25)

TEST VARIABLES	$\overline{x}_1$	$\overline{x}_2$	$\overline{x}_2 - \overline{x}_1$	Sd	p	D
BIOMECHANICS:						
LOWER LIMV REGION:						
Achilles tendon suppleness test	1.2173	1.1304	-0.0869	-0.1689	0.4264	0.2061
Iliotibial band mobility test (ITB)	1.6251	1.8260	0.1739	0.3018	0.1618	0.3036
Quadriceps mobility	1.4347	1.7391	0.3043	0.5446	0.0159*	0.6004
Iliopsoas mobility	1.7826	1.7391	-0.0434	-0.0566	0.7883	0.0590
Gluteus maximus mobility test	1.4782	1.4347	-0.0434	-0.0773	0.7143	0.0733
Adductor mobility test	1.1304	1.0434	-0.0869	-0.3018	0.1618	0.2525
Internal rotation mobility test	1.0000	1.0000	0.0000	0.0000	-	0.0000
External rotation mobility test	1.5652	1.3043	-0.2608	-0.4823	0.0304*	0.4423
Q-angle test	1.1428	1.1428	0.0000	0.0000	-	0.0000
Patella squint test	1.1428	1.1428	0.0000	0.0000	-	0.0000
Patella tilt test	1.6666	1.6666	0.0000	0.0000	-	0.0000
Patella height test	1.9047	1.9047	0.0000	0.0000	-	0.0000
VMO – L comparison test	1.2380	1.2380	0.0000	0.0000	-	0.0000
Longitudinal arch status test	1.7619	1.7619	0.0000	0.0000	-	0.0000
Fore foot positional test	1.1904	1.1904	0.0000	0.0000	-	0.0000
Rear foot positional standing test	1.2857	1.2857	0.0000	0.0000	-	0.0000
Rear foot lying test	1.3333	1.3333	0.0000	0.0000	-	0.0000
Transverse arch area comparison test	2.0000	2.0000	0.0000	0.0000	-	0.0000
Foot mobility test	1.8095	1.8095	0.0000	0.0000	-	0.0000
Toe positional test	1.9047	1.9047	0.0000	0.0000	-	0.0000
PELVIC GIRDLE REGION:						
Leg length discrepancy test	1.7619	1.8095	0.0476	0.2182	0.3292	0.1091
ASIS comparison test	1.7619	1.8095	0.0476	0.2182	0.3292	1.1091*
PSIS comparison test	1.7619	1.8095	0.0476	0.2182	0.3292	1.1091*
Pelvic rami positional test	1.7619	1.8095	0.0476	0.2182	0.3292	1.1091*
Sacroiliac cleft test	1.0476	1.0476	0.0000	0.0000	-	0.0000
Bilateral pelvis positional test	1.8571	1.8571	0.0000	0.0000	-	0.0000
SPINAL REGION:						
Thoraco-lumbar fascia	1.2857	1.2380	-0.0476	-0.2182	0.3292	0.1028
Sacral rhythm test	1.0000	1.0000	0.0000	0.0000	-	0.0000
Functional extension mobility test	1.4285	1.2380	0.0952	0.1524	0.4929	0.2656
Functional flexion test	1.3333	1.4285	0.0952	0.1767	0.4275	0.1971
Rotational mobility test	1.4285	1.1428	0.0476	0.0956	0.6657	0.1583
Side flexion mobility test	1.0476	1.0000	-0.0476	-0.2182	0.3292	0.2182
Head positional	1.0000	1.0000	0.0000	0.0000	-	0.0000
Cervical	1.0000	1.0000	0.0000	0.0000	-	0.0000
Thoracic	1.1904	1.1904	0.0000	0.0000	-	0.0000
Lumbar	2.0000	1.9523	-0.0476	-0.1239	0.5763	0.1505
NEURODYNAMICS						
Straight leg raise (SLR)	1.2380	1.8095	0.5714	0.9561	0.0002*	1.3093*
Prone knee bend test (PKB)	1.2380	1.2380	0.0000	0.0000	-	0.0000

$d = \frac{|\overline{x}_1 - \overline{x}_2|}{s_{max}}$ = effect size for difference between means; a measurement of practical significance

$p \leq 0.05$

$d \geq 0.2$ (small effect)

$d \geq 0.5$ (medium effect)

$d \geq 0.8$ (large effect)

$\overline{x}_1$ = mean value (test 1)

* = Large significant *intra-group* difference between testing episodes

$\overline{x}_2$ = mean value (test 2)

Table 4.18 Changes in anthropometry and physical/motor data from test one to test two for the total group for significant differences in performance (N=25)

TEST VARIABLES	$\bar{x}_1$	$\bar{x}_2$	$\bar{x}_2 - \bar{x}_1$	Sd	p	D
ANTHROPOMETRY:						
Weight (kg)	68.2000	70.7200	2.5200	1.0209	0.00003*	0.2293
Height (m)	1.7460	1.7456	-0.0004	-0.0331	0.8697	0.0045
Body mass index (BMI)	22.3720	23.0720	0.7000	0.6052	0.0058*	0.3033
Fat percentage (%)	26.6172	27.5568	0.9396	0.4345	0.0399*	0.4372
SKINFOLDS:						
Tricep	16.9760	17.0120	0.0360	0.0102	0.9594	0.0104
Subscapular	11.6240	12.9560	1.3320	0.4261	0.0435*	0.5093
Supraspinal	14.1160	14.8640	0.7480	0.2303	0.2608	0.2191
Abdominal	20.8120	20.8560	0.0440	0.0110	0.9563	0.0143
Thigh	22.9920	29.0120	6.0200	1.0644	0.00001*	1.0644*
Calf	17.0240	15.7160	-1.3080	-0.4977	0.0201*	0.3973
PHYSICAL/MOTOR ABILITIES:						
Agility (sec)	19.4428	18.9476	-0.4952	-1.1890	0.00002*	0.7181
Balance (%)	69.3136	81.8681	12.5545	1.3027	0.000005*	1.0936*
Explosive power	33.7391	28.6087	-5.1304	-1.2851	0.000003*	1.0693*

$d = \frac{|\bar{x}_1 - \bar{x}_2|}{s_{max}}$ = effect size for difference between means; a measurement of practical significance

p≤0.05

d≥0.2 (small effect)

d≥0.5 (medium effect)

d≥0.8 (large effect)

$\bar{x}_1$ = mean value (test 1)

$\bar{x}_2$ = mean value (test 2)

* = Large significant *intra-group* difference between testing episodes

4.11. DESCRIPTIVE STATISTICS AND SIGNIFICANT DIFFERENCES FOR THE JUNIORS AND SENIORS BETWEEN TESTING OCCASION ONE AND TWO

Table 4.19 presents the biomechanical data of the junior players during testing occasion one and two. When analysing the *biomechanical data*, the only significant difference ($p \leq 0.05$; $d \geq 0.8$) between the results of test one and the results of test two for the junior players occurred with the SLR ($p=0.0261$) test. With the SLR test, the average tends more towards non-ideal (non-ideal=2) during the second testing procedure, meaning that the neural mobility of the junior players decreased during the season. Among the senior players, the SLR test ($p=0.0039$; $d=1.3334$) was the only test which indicated a significant difference ($p \leq 0.05$; $d \geq 0.8$). The average for the second test tend more towards non-ideal (non-ideal=2) than the pre-season test results. No reasons for the decrease in neural mobility could be found in literature. A possible reason could be that the conditioning programme during the season lacked exercises to improve and maintain neural mobility such as neural mobilizing exercises.

Table 4.20 presents the *anthropometrical changes* that occurred during the netball season among the junior and senior players. Practical significant increases ($p \leq 0.05$; $d \geq 0.8$) were identified among the juniors in terms of weight ($p=0.0012$; $d=1.0431$); fat percentages ($p=0.0128$); and with the supraspinal ($p=0.0126$) and thigh ($p=0.0006$; $d=1.1400$) skinfold measurements. Among the senior players, practical significant increases ($p \leq 0.05$; $d \geq 0.8$) were detected with regard to weight ($p=0.0115$; $d=1.0000$); BMI ($p=0.0135$; $d=0.9684$); and thigh ($p=0.0067$; $d=1.1076$) and calf skinfold measurements ($p=0.0200$; $d=0.8920$). Literature did not explain the increases anthropometrical data for the juniors and seniors, but possible reasons for these increases could be, firstly, that the conditioning programme did not include adequate exercise routines during the season to increase their muscle mass and reduce their fat percentages, and secondly, that the second tests occurred three weeks into the players' off-season, meaning that for three weeks prior to the tests they did not train.

The data for the *physical/motor tests* is summarised in Table 4.20. Significant differences ($p \leq 0.05$; $d \geq 0.8$) were detected between the first and the second test results for the juniors in all three motor tests (agility, balance and explosive power). The juniors' agility ($p=0.0063$; $d=0.9156$) and ability to balance ($p=0.0011$; $d=1.1826$) improved practically significant, while their explosive power decreased significantly ($p=0.0008$; $d=1.1542$). The seniors presented with similar results: practical significant differences ($p \leq 0.05$; $d \geq 0.8$) were identified for all three motor tests (agility, balance and explosive power). With the agility run test ($p=0.0002$; $d=2.5992$) and the balance test ($p=0.0027$; $d=1.4286$), the seniors improved significantly, but their explosive power ability ($p=0.0022$; $d=1.4802$) decreased significantly. According to literature the physical/motor abilities (agility, balance and explosive power) of a netball player could be enhanced with the correct exercises during the netball season (Baltaci & Kohl, 2003; Verhagen *et al.*, 2004; Clark & Burden, 2005; Swanik & Swanik, 1999; Moss, 2002). However, literature did not explain the decrease in performance with regard to explosive power; a possible reason could be that the conditioning programme did not include adequate plyometric exercises to improve the netball players' explosive power during the season.

To summarise the changes in results between testing occasion one and two for the juniors and seniors; in terms of pre- and post-season *biomechanical data*, the only significant differences among juniors occurred with the quadriceps mobility and the SLR tests. Among the senior players, the SLR test identified a significant reduction in neural mobility. In terms of the *anthropometrical changes* that occurred during the netball season among the juniors; significant increases were identified in terms of weight, fat percentages, and the supraspinal and thigh skinfold measurements. The senior players also presented with significant increases with regard to their weight, BMI, and their thigh skinfold measurements but a significant decrease occurred with the calf skinfold measurement. In terms of the *physical/motor data*, the juniors' as well as the seniors' agility and balancing abilities improved significantly, while their explosive power worsened significantly. Evidently with most of these significant differences (biomechanics, anthropometry and physical/motor abilities) the same tendencies occurred at both groups (juniors and seniors).

Table 4.19 Changes in biomechanical data from test one to test two between the junior (N=15) and senior players (N=10) for significant differences in performance

BIOMECHANICS:	**JUNIOR PLAYERS**				**SENIOR PLAYERS**			
LOWER LIMB REGION:	$\bar{x}_2 - \bar{x}_1$	**Sd**	**p**	**d**	$\bar{x}_2 - \bar{x}_1$	**Sd**	**p**	**D**
Achilles tendon suppleness test	-0.2140	0.4258	0.0823	0.5025	0.1111	0.6009	0.5943	0.1848
Iliotibial band mobility test (ITB)	0.1429	0.5345	0.3356	0.2673	0.2222	0.6667	0.3466	0.3332
Quadriceps mobility	0.3571	0.6333	0.0548*	0.5638	0.2222	0.4410	0.1690	0.5038
Iliopsoas mobility	0.0000	0.8771	-	0.0000	-0.1110	0.6009	0.5943	0.1847
Gluteus maximus mobility test	-0.2140	-0.2140	0.0823	0.5025	0.2222	0.6667	0.3466	0.3332
Adductor mobility test	-0.1430	-0.1430	0.1648	0.3938	0.0000	0.0000	-	0.0000
Internal rotation mobility test	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
External rotation mobility test	-0.2860	-0.2860	-	0.6100	-0.2220	0.6667	0.3466	0.3329
Q-angle test	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
Patella squint test	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
Patella tilt test	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
Patella height test	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
VMO – L comparison test	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
Longitudinal arch status test	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
Fore foot positional test	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
Rear foot positional standing test	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
Rear foot lying test	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
Transverse arch area comparison test	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
Foot mobility test	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
Toe positional test	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
PELVIC GIRDLE REGION:								
Leg length discrepancy test	0.0000	0.0000	-	0.0000	0.1111	0.3333	0.3466	0.3333
ASIS comparison test	0.0000	0.0000	-	0.0000	0.1111	0.3333	0.3466	0.3333
PSIS comparison test	0.0000	0.0000	-	0.0000	0.1111	0.3333	0.3466	0.3333
Pelvic rami positional test	0.0000	0.0000	-	0.0000	0.1111	0.3333	0.3466	0.3333
Sacroiliac cleft test	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
Bilateral pelvis positional test	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
SPINAL REGION:								
Thoraco-lumbar fascia	0.0000	0.0000	-	0.0000	-0.1110	0.3333	0.3466	0.3330
Sacral rhythm test	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
Functional extension mobility test	0.1667	0.5774	0.3388	0.2887	0.0000	0.7071	-	0.0000
Functional flexion test	0.1667	0.5774	0.3388	0.2887	0.0000	0.5000	-	0.0000
Rotational mobility test	0.0833	0.5149	0.5863	0.1617	0.0000	0.5000	-	0.0000
Side flexion mobility test	-0.0830	0.2887	0.3388	0.2875	0.0000	0.0000	-	0.0000
Head positional	0.0000	0.0000	-	0	0.0000	0.0000	-	0.0000
Cervical	0.0000	0.0000	-	0	0.0000	0.0000	-	0.0000
Thoracic	-0.0830	0.2887	0.3388	0.2875	0.1111	0.3333	0.3466	0.3333
Lumbar	-0.0830	0.2887	0.3388	0.2875	0.0000	0.5000	-	0.0000
NEURODYNAMICS								
Straight leg raise (SLR)	0.5000	0.6742	0.0261*	0.7416	0.6667	0.5000	0.0039*	1.3334*
Prone knee bend test (PKB)	0.0833	0.2887	0.3388	0.2885	-0.1110	0.6009	0.5943	0.1847

$d = \frac{|\bar{x}_1 - \bar{x}_2|}{s_{max}}$ = effect size for difference between means; a measurement of practical significance

$p \leq 0.05$

$d \geq 0.2$ (small effect)

$d \geq 0.5$ (medium effect)

$d \geq 0.8$ (large effect)

$\bar{x}_1$ = mean value (test 1)

* = Large significant *intra-group* difference between testing episodes

$\bar{x}_2$ = mean value (test 2)

Table 4.20 Changes in anthropometrical- and physical/motor data from test one to test two between the junior (N=15) and senior players (N=10) for significant differences in performance

	JUNIOR PLAYERS				SENIOR PLAYERS			
ANTHROPOMETRY:	$\bar{x}_2 - \bar{x}_1$	**Sd**	**p**	**d**	$\bar{x}_2 - \bar{x}_1$	**Sd**	**P**	**d**
Weight (kg)	2.8660	2.7482	0.0012*	1.0431*	2.0000	2.0000	0.0115*	1.0000*
Height (m)	0.0007	0.0139	0.8550	0.0503	-0.0020	0.0092	0.5086	0.2173
Body mass index (BMI)	0.7067	1.4023	0.0713	0.5039	0.6900	0.7125	0.0135*	0.9684*
Fat percentage (%)	1.4440	1.9619	0.0128*	0.7360	0.1830	2.3282	0.8093	0.0786
SKINFOLDS:								
Tricep	-0.027	3.5754	0.9774	0.0075	0.1300	3.5796	0.9111	0.0363
Subscapular	1.4467	2.7767	0.0632	0.5210	1.1600	3.7432	0.3527	0.3098
Supraspinal	1.7667	2.3927	0.0126*	0.7383	-0.7800	3.8603	0.5388	0.2020
Abdominal	0.4200	3.8430	0.6785	0.1092	-0.5200	4.3204	0.7123	0.1203
Thigh	7.3533	6.4500	0.0006*	1.1400*	4.0200	3.6294	0.0067*	1.1076*
Calf	-0.8530	2.8438	0.2646	0.2999	-1.990	2.2308	0.0200*	0.8920*
PHYSICAL/MOTOR ABILITIES:								
Agility (sec)	-0.779	0.5122	0.0063*	0.9156*	-0.537	0.2066	0.0002*	2.5992*
Balance (%)	11.392	9.6323	0.0011*	1.1826*	14.2330	9.9623	0.0027*	1.4286*
Explosive power	-5.071	4.3934	0.0008*	1.1542*	-5.2222	3.5277	0.0022*	1.4802*

$d = \frac{|\bar{x}_1 - \bar{x}_2|}{s_{max}}$ = effect size for difference between means; a measurement of practical significance

$p \leq 0.05$

$d \geq 0.2$ (small effect)

$d \geq 0.5$ (medium effect)

$d \geq 0.8$ (large effect)

$\bar{x}_1$ = mean value (test 1)

* = Large significant *intra-group* difference between testing episodes

$\bar{x}_2$ = mean value (test 2)

4.12. DESCRIPTIVE STATISTICS AND SIGNIFICANT DIFFERENCES FOR THE CENTRE- AND GOAL PLAYERS BETWEEN TESTING OCCASION ONE AND TWO

The pre- and post season test results of the centre and goal players are summarised in Table 4.21. The data of the centre players is summarised first. The *biomechanical analysis* presented practical significant differences ($p \leq 0.05$; $d \geq 0.8$) with regard to the quadriceps mobility-, external rotation mobility-, functional extension mobility- and the SLR tests. The quadriceps mobility test ($p=0.0162$; $d=0.8703$), (*lower limb region*) indicated that the flexibility of the quadriceps decreased during the netball season. Similar findings were made with the functional extension mobility test ($p=0.0379$) conducted in the *spinal region*, and the SLR test ($p=0.0251$) performed under *neurodynamics*. This meant that these biomechanical aspects (functional extension mobility and neural mobility) deteriorated during the season. However, the external rotation mobility ($p=0.0379$) (lower limb region) improved throughout the course of the netball season. No practical significant differences were identified in the pelvic girdle region, indicative of no significant differences occurring in this region during the season. In the *lower limb region* the centre players scored similar values for 14 of the 20 tests, meaning that numerous biomechanical aspects of the centre players did not change during the season.

In terms of *biomechanical data* of the goal players, 15 of the 20 tests conducted in the *lower limb region* indicated that no biomechanical changes occurred among the goal players during the season. In the *pelvic girdle region* no changes occurred for all six tests performed in this region; therefore the biomechanics of the goal players did not change during the season. In the *spinal region* 6 of the 10 tests conducted in this region indicated no changes. The SLR test ($p=0.0051$; $d=1.1618$) performed in the *neurodynamics* category presented practical significant differences ($p \leq 0.05$; $d \geq 0.8$) between the test results of the first test compared to the results of the second test of the goal players. This means that during the season the neurodynamics of the goal players deteriorated.

These biomechanical findings could not be explained by literature, but Brukner and Khan (2001) offered a possible reason: the biomechanics of a player will not alter during a season, given the unique mechanical make-up of every netball player due to structural characteristics, and in the absence of a specific conditioning programme (Brukner & Khan, 2001).

Table 4.22 presents the *anthropometrical* changes of the centre and goal players which occurred during the season. The anthropometrical data of the centre players is discussed below. Practical significant differences ($p \leq 0.05$; $d \geq 0.8$) occurred with regard to the weight ($p=0.0087$; $d=0.9198$), thigh ($p=0.0180$; $d=0.8020$) and calf ($p=0.0149$; $d=0.8318$) skinfold measurements. However, the calf skinfold measurement decreased, meaning that the subcutaneous fat of the centre players decreased in the calf area. In terms of the anthropometrical data of the goal players, practical significant differences ($p \leq 0.05$; $d \geq 0.8$) were identified with regard to the weight, BMI, fat percentage and the subscapular, supraspinal, abdominal, and thigh skinfold measurements. The weight ($p=0.0018$; $d=1.1078$), BMI ($p=0.0005$; $d=1.3251$) and fat percentage ($p=0.0001$; $d=1.6796$) of the goal players increased significantly. The subcutaneous fat of the goal players increased significantly during the season at the subscapular ($p=0.0066$; $d=0.9097$), supraspinal ($p=0.0073$; $d=0.8935$), abdominal ($p=0.0503$), and thigh ($p=0.0004$; $d=1.3448$) areas. The literature do not explain these increases in anthropometry, but possible reasons could be, firstly, that the conditioning programme did not include adequate exercise routines during the season to increase their muscle mass and reduce their fat percentages, and secondly, that the second tests occurred three weeks into the players' off-season, meaning that for three weeks prior to the tests they did not train.

The results of the *physical/motor abilities* of the centre and goal players are discussed below (see Table 4.22). Among the centre players the results improved for the agility run and the balance test, while the explosive power test showed a decrease in performance.

The agility (p=0.0069; d=1.1019) and balance (p=0.0036; d=1.1383) of the centre players improved significantly, while a decrease in performance was identified with the explosive power test (p=0.0001; d=2.2234). The goal players presented with similar results than the centre players. The goal players showed a practical significant improvement in agility (p=0.0013; d=1.3357), while a significant enhancement of their balancing abilities (p=0.0008; d=1.4311) was identified. However, the explosive power abilities of the goal players deteriorated significantly (p=0.0014; d=1.2209) during the season. According to literature the physical/motor abilities (agility, balance and explosive power) of a netball player could be enhanced with the correct exercises during the netball season (Baltaci & Kohl, 2003; Verhagen *et al.,* 2004; Clark & Burden, 2005; Swanik & Swanik, 1999; Moss, 2002). However, literature did not explain the decrease in performance with regard to explosive power; a possible reason could be that the conditioning programme did not include adequate plyometric exercises to improve the netball players' explosive power during the season.

To conclude this section a summary will follow of the significant differences among the centre and goal players during the course of the netball season between the two testing occasions. For the *biomechanical analysis*, significant differences were found among the centre players in terms of the quadriceps mobility, external rotation mobility; functional extension mobility and the SLR test. The majority of the tests conducted in the lower limb region indicated that no biomechanical changes occurred among the goal players during the season. In the pelvic girdle region no changes occurred, meaning that the biomechanics of the goal players in the pelvic girdle region did not change during the season. Most tests conducted in the spinal region, among the goal players, indicated that no changes occurred during the season. The SLR test performed in the neurodynamics category, presented significant differences. The *anthropometrical* data of the centre players showed that their weight, as well their thigh and calf skinfold measurements varied significantly. The average weight and thigh skinfold measurement of the centre players increased, while the calf skinfold measurement decreased significantly.

Among the goal players, significant differences were identified in terms of the weight, BMI, fat percentage and with the subscapular, supraspinal, abdominal, and thigh skinfold measurements. All these parameters (weight, BMI, fat percentage, subscapular, supraspinal, abdominal, and thigh skinfold measurements) increased significantly during the season. The *physical/motor abilities* results of the of the centre and goal players improved significantly for the agility run and the balance tests, while the explosive power test showed a decrease in performance. Similar tendencies were identified among both groups (centre- and goal players) in terms of biomechanics, anthropometry and physical/motor abilities.

Table 4.21 Changes in biomechanical data from test one to test two between the centre (N=12) and goal players (N=13) for significant differences in performance

BIOMECHANICS:	CENTRE PLAYERS				GOAL PLAYERS			
LOWER LIMB REGION:	$\bar{x}_2 - \bar{x}_1$	Sd	p	d	$\bar{x}_2 - \bar{x}_1$	Sd	p	D
Achilles tendon suppleness test	0.0000	0.4472	-	0.0000	-0.1670	0.5774	0.3388	0.2892
Iliotibial band mobility test (ITB)	0.0909	0.5394	0.5884	0.1685	0.2500	0.6216	0.1911	0.4021
Quadriceps mobility	0.4545	0.5222	0.0162*	0.8703*	0.1667	0.5774	0.3388	0.2887
Iliopsoas mobility	-0.0910	1.0445	0.7787	0.0871	0.0000	0.4264	-	0.0000
Gluteus maximus mobility test	-0.0910	0.5394	0.5884	0.1687	0.0000	0.6030	-	0.0000
Adductor mobility test	-0.0910	0.3015	0.3409	0.3018	-0.0830	0.2887	0.3388	0.2875
Internal rotation mobility test	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
External rotation mobility test	-0.3640	0.5045	0.0379*	0.7215	-0.1670	0.5774	0.3388	0.2892
Q-angle test	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
Patella squint test	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
Patella tilt test	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
Patella height test	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
VMO – L comparison test	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
Longitudinal arch status test	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
Fore foot positional test	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
Rear foot positional standing test	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
Rear foot lying test	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
Transverse arch area comparison test	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
Foot mobility test	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
Toe positional test	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
PELVIC GIRDLE REGION:								
Leg length discrepancy test	0.0909	0.3015	0.3409	0.3014	0.0000	0.0000	-	0.0000
ASIS comparison test	0.0909	0.3015	0.3409	0.3014	0.0000	0.0000	-	0.0000
PSIS comparison test	0.0909	0.3015	0.3409	0.3041	0.0000	0.0000	-	0.0000
Pelvic rami positional test	0.0909	0.3015	0.3409	0.3041	0.0000	0.0000	-	0.0000
Sacroiliac cleft test	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
Bilateral pelvis positional test	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
SPINAL REGION:								
Thoraco-lumbar fascia	-0.0910	0.3015	0.3409	0.3018	0.0000	0.0000	-	0.0000
Sacral rhythm test	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
Functional extension mobility test	0.3636	0.5045	0.0379*	0.7207	-0.2000	0.6325	0.3434	0.3162
Functional flexion test	0.1818	0.6030	0.3409	0.3014	0.0000	0.4714	-	0.0000
Rotational mobility test	0.2727	0.4671	0.0816	0.5838	-0.2000	0.4216	0.1679	0.4743
Side flexion mobility test	0.0000	0.0000	-	0.0000	-0.1000	0.3162	0.3434	0.3162
Head positional	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
Cervical	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
Thoracic	0.0909	0.3015	0.3409	0.3014	-0.1000	0.3162	0.3434	0.3162
Lumbar	-0.091	0.3015	0.3409	0.3018	0.0000	0.4714	-	0.0000
NEURODYNAMICS								
Straight leg raise (SLR)	0.5455	0.6876	0.0251*	0.7933	0.6000	0.5164	0.0051*	1.1618*
Prone knee bend test (PKB)	0.0000	0.4472	1.0000	0.0000	0.0000	0.4714	-	0.0000

$d = \frac{|\bar{x}_1 - \bar{x}_2|}{s_{max}}$ = effect size for difference between means; a measurement of practical significance

$p \leq 0.05$

$d \geq 0.2$ (small effect)

$d \geq 0.5$ (medium effect)

$d \geq 0.8$ (large effect)

$\bar{x}_1$ = mean value (test 1)

* = Large significant *intra-group* difference between testing episodes

$\bar{x}_2$ = mean value (test 2)

Table 4.22 Changes in anthropometrical- and physical/motor data from test one to test two between the centre (N=12) and goal players (N=13) for significant differences in performance

	CENTRE PLAYERS				GOAL PLAYERS			
ANTHROPOMETRY:	$\bar{x}_2 - \bar{x}_1$	**Sd**	**p**	**d**	$\bar{x}_2 - \bar{x}_1$	**Sd**	**p**	**D**
Weight (kg)	2.0000	2.1742	0.0087*	0.9198*	3.0000	2.7080	0.0018*	1.1078*
Height (m)	0.0017	0.0134	0.6742	0.1268	-0.0020	0.0109	0.4608	0.1834
Body mass index (BMI)	0.3833	1.4478	0.3787	0.2647	0.9923	0.7488	0.0005*	1.3251*
Fat percentage (%)	-0.1640	2.4824	0.8230	0.0660	1.9585	1.1660	0.0001*	1.6796*
SKINFOLDS:								
Tricep	-0.4170	4.6456	0.7618	0.0897	0.4538	2.0879	0.4484	0.2173
Subscapular	-0.0170	2.9584	0.9848	0.0057	2.5769	2.8326	0.0066*	0.9097*
Supraspinal	-0.2170	4.1709	0.8605	0.0520	1.6385	1.8337	0.0073*	0.8935*
Abdominal	-1.6330	4.5884	0.2432	0.3559	1.5923	2.6386	0.0503*	0.6034
Thigh	4.3333	5.4029	0.0180*	0.8020*	7.5769	5.6340	0.0004*	1.3448*
Calf	-2.3080	2.7747	0.0149*	0.8318*	-0.3850	2.1980	0.5399	0.1751
MOTOR ABILITIES:								
Agility (sec)	-0.5600	0.5082	0.0069*	1.1019*	-0.4360	0.3264	0.0013*	1.3357*
Balance (%)	11.7000	10.2780	0.0036*	1.1383*	13.4090	9.3691	0.0008*	1.4311*
Explosive power	-3.9090	1.7581	0.0001*	2.2234*	-6.2500	5.119	0.0014*	1.2209*

$d = \frac{|\bar{x}_1 - \bar{x}_2|}{s_{max}}$ = effect size for difference between means; a measurement of practical significance

$p \leq 0.05$

$d \geq 0.2$ (small effect)

$d \geq 0.5$ (medium effect)

$d \geq 0.8$ (large effect)

$\bar{x}_1$ = mean value (test 1)

* = Large significant *intra-group* difference between testing episodes

$\bar{x}_2$ = mean value (test 2)

4.13. DESCRIPTIVE STATISTICS AND SIGNIFICANT DIFFERENCES FOR THE A- AND B-GRADE PLAYERS BETWEEN TESTING OCCASION ONE AND TWO

Table 4.23 summarises the *biomechanical* results of the A- and B-grade players. The biomechanics of the A-grade players will be discussed first, 14 of the 20 tests conducted in the *lower limb region*, revealed that no biomechanical changes ($\bar{x}_2 - \bar{x}_1 = 0$) occurred during the netball season. All six tests performed in the *pelvic girdle region* indicated that no biomechanical changes occurred during the season among the A-grade players. Seven of the ten tests conducted in the *spinal region* showed that no biomechanical changes occurred during the season.

The only test in the spinal region which indicated a practical significant difference ($p \leq 0.05$) was the functional flexion test ($p=0.0379$). This test (functional flexion test) identified a deterioration of functional flexion among the A-grade players. The *neurodynamics* category revealed a significant difference ($p \leq 0.05$; $d \geq 0.8$) with regard to the SLR test ($p=0.0107$), which indicated that the neural mobility of the A-grade players worsened during the season. No explanations could be found in literature for these biomechanical changes. The deteriorations in biomechanics (functional flexion and SLR) could be the result of inadequate exercises such as stretches and neural mobilizing exercises during the season.

No significant differences ($p \leq 0.05$; $d \geq 0.8$) were identified in the *lower limb-, pelvic girdle-* and *spinal regions*. The only significant difference ($p \leq 0.05$; $d \geq 0.8$) occurred in the *neurodynamics* category with the SLR test ($p=0.0107$; $d=0.9439$). This test (SLR test) indicated that the neural mobility of the B-grade players deteriorated during the season. Significant differences were found for the A-grade players with the functional flexion (*spinal region*) and the SLR tests (*neurodynamics*), while the only significant difference was identified with the SLR test among the B-grade players. No significant differences were identified for the *lower limb-* and *pelvic girdle regions*. Literature did not explain these biomechanical changes during the season among the A- and B-grade players.

The *anthropometry* of the A- and B-grade players is recorded in Table 4.24. Practical significant differences ($p \leq 0.05$; $d \geq 0.8$) occurred in the weight ($p=0.0007$; $d=1.3540$), BMI ($p=0.0017$; $d=1.1914$), fat percentage ($p=0.0122$; $d=0.8638$), as well as with the subscapular ($p=0.0313$) and thigh ($p=0.0003$; $d=1.4726$) skinfold measurements of the A-grade players. The weight, BMI and fat percentage of the A-grade players increased practically significant, while the subcutaneous fat of the A-grade players increased in the subscapular and thigh areas. Practical significant differences ($p \leq 0.05$; $d \geq 0.8$) occurred in the weight ($p=0.0166$) and the thigh skinfold measurement ($p=0.0100$; $d=0.8465$) of the B-grade players.

The B-grade players' weight and skinfold measurement of the thigh increased significantly, meaning that their subcutaneous fat increased significantly in the thigh area. The literature do not explain these increases in anthropometry, but possible reasons could be, firstly, that the conditioning programme did not include adequate exercise routines during the season to increase their muscle mass and reduce their fat percentages, and secondly, that the second tests occurred three weeks into the players' off-season, meaning that for three weeks prior to the tests they did not train.

The *physical/motor abilities* of the A- and B-grade players are presented in Table 4.24. Practical significant differences ($p \leq 0.05$; $d \geq 0.8$) were identified for all three motor abilities (agility, balance and explosive power) among both groups (A- and B-grade players). Practical significant increases occurred in the agility ($p=0.0004$; $d=1.9669$) and the balancing ($p=0.0001$; $d=2.7263$) tests of the A-grade players, while the explosive power test revealed a decrease in performance ($p=0.0004$; $d=1.7206$). The results of the B-grade players presented similar data, meaning that the agility ($p=0.0140$; $d=0.8427$) and the balance ($p=0.0143$; $d=0.8389$) of the B-grade players improved significantly, with a decrease in explosive power ($p=0.0019$; $d=1.0941$). The literature explains that with the correct exercises during the netball season the physical/motor abilities such as agility and balance could be enhanced (Baltaci & Kohl, 2003; Verhagen *et al.,* 2004; Clark & Burden, 2005; Swanik & Swanik, 1999; Moss, 2002). However, literature did not explain the decrease in performance with regard to explosive power; a possible reason could be that the conditioning programme did not include adequate plyometric exercises to improve the netball players' explosive power during the season.

Finally, a summary will follow of the significant differences between the pre- and post-season tests of the A- and B-grade players. With most of the tests conducted in the lower limb and spinal regions, no *biomechanical* changes were identified for the A-grade players. The only test in the spinal region which indicated a significant difference was the functional flexion test, which identified a reduction in the functional flexion of the A-grade players during the season.

The neurodynamics category revealed a significant difference with regard to the SLR test, which indicated that the neural mobility of the A-grade players worsened during the season. All the tests performed in the pelvic girdle region indicated that no biomechanical changes occurred during the season among the A-grade players. No significant differences were identified in the lower limb, pelvic girdle and spinal regions for the B-grade players. The only practical significant difference occurred in the neurodynamics category with the SLR test, which revealed that the neural mobility of the B-grade players worsened during the season. In terms of *anthropometry*, there were practical significant increases in the weight, BMI, fat percentage, and the subscapular and thigh skinfold measurements for the A-grade players. The B-grade players' weight and thigh skinfold measurement increased practically significant as well.

With *physical/motor abilities*; practically significant increases were identified for all three motor tests (agility, balance and explosive power) among both groups (A- and B-grade players), while both groups presented with a decrease in performance with the explosive power test. Evidently, both groups (A- and B-grade players) presented with the same changes regarding their physical profile (biomechanics, anthropometry and physical/motor abilities) during the season.

Table 4.23 Changes in biomechanical data from test one to test two between the A- (N=12) and B-grade players (N=13) for significant differences in performance

BIOMECHANICS:	A-GRADE PLAYERS				B-GRADE PLAYERS			
LOWER LIMB REGION:		Sd	p	d		Sd	p	d
Achilles tendon suppleness test	0.0000	0.4472	-	0.0000	-0.1670	0.5774	0.3388	0.2892
Iliotibial band mobility test (ITB)	0.1818	0.4045	0.1669	0.4494	0.1667	0.7177	0.4382	0.2322
Quadriceps mobility	0.2727	0.4671	0.0816	0.5838	0.3333	0.6513	0.1039	0.5117
Iliopsoas mobility	-0.0910	0.9439	0.7560	0.0964	0.0000	0.6030	-	0.0000
Gluteus maximus mobility test	0.0909	0.5394	0.5884	0.1685	-0.1670	0.5774	0.3388	0.2892
Adductor mobility test	-0.0910	0.3015	0.3409	0.3018	-0.0830	0.2887	0.3388	0.2875
Internal rotation mobility test	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
External rotation mobility test	-0.2730	0.6467	0.1921	0.4221	-0.2500	0.4523	0.0819	0.5527
Q-angle test	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
Patella squint test	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
Patella tilt test	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
Patella height test	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
VMO – L comparison test	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
Longitudinal arch status test	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
Fore foot positional test	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
Rear foot positional standing test	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
Rear foot lying test	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
Transverse arch area comparison test	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
Foot mobility test	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
Toe positional test	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
PELVIC GIRDLE REGION:								
Leg length discrepancy test	0.0000	0.0000	-	0.0000	0.1000	0.1000	0.3434	0.3162
ASIS comparison test	0.0000	0.0000	-	0.0000	0.1000	0.1000	0.3434	0.3162
PSIS comparison test	0.0000	0.0000	-	0.0000	0.1000	0.1000	0.3434	0.3162
Pelvic rami positional test	0.0000	0.0000	-	0.0000	0.1000	0.1000	0.3434	0.3162
Sacroiliac cleft test	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
Bilateral pelvis positional test	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
SPINAL REGION:								
Thoraco-lumbar fascia	0.0000	0.0000	-	0.0000	-0.1000	-0.1000	0.3434	0.3162
Sacral rhythm test	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
Functional extension mobility test	0.1818	0.7508	0.4405	0.2421	0.0000	0.0000	-	0.0000
Functional flexion test	0.3636	0.5045	0.0379*	0.7207	-0.2000	-0.2000	0.1679	0.4743
Rotational mobility test	0.0000	0.6325	-	0.0000	0.1000	0.1000	0.3434	0.3162
Side flexion mobility test	-0.0910	0.3015	0.3409	0.3018	0.0000	0.0000	-	0.0000
Head positional	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
Cervical	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
Thoracic	0.0000	0.0000	-	0.0000	0.0000	0.0000	-	0.0000
Lumbar	0.0000	0.4472	-	0.0000	-0.1000	-0.1000	0.3434	0.3162
NEURODYNAMICS								
Straight leg raise (SLR)	0.6364	0.6742	0.0107*	0.9439*	0.5000	0.5000	0.0150*	0.9487*
Prone knee bend test (PKB)	0.0000	0.6325	-	0.0000	0.0000	0.0000	-	0.0000

$d = \frac{|\bar{x}_1 - \bar{x}_2|}{s_{max}}$ = effect size for difference between means; a measurement of practical significance

$p \leq 0.05$

$d \geq 0.2$ (small effect)

$d \geq 0.5$ (medium effect)

$d \geq 0.8$ (large effect)

$\bar{x}_1$ = mean value (test 1)

$\bar{x}_2$ = mean value (test 2)

* = Large significant *intra-group* difference between testing episodes

Table 4.24 Change in anthropometrical- and physical/motor data from test one to test two between the A- (N=12) and B-grade players (N=13) for significant differences in performance

	A-GRADE PLAYERS				B-GRADE PLAYERS			
ANTHROPOMETRY:		**Sd**	**p**	**d**		**Sd**	**p**	**D**
Weight (kg)	3.0000	2.2156	0.0007*	1.3540*	2.0769	2.6914	0.0166*	0.7716
Height (m)	0.0033	0.0115	0.3388	0.2869	-0.0040	0.0119	0.2676	0.3361
Body mass index (BMI)	0.8583	0.7204	0.0017*	1.1914*	0.5538	1.4666	0.1984	0.3776
Fat percentage (%)	1.4933	1.7286	0.0122*	0.8638*	0.4285	2.4541	0.5408	0.1746
SKINFOLDS:								
Tricep	0.5167	3.4356	0.6127	0.1503	-0.4080	3..6431	0.6937	0.1119
Subscapular	2.0000	2.8078	0.0313*	0.7123	0.7154	3.3852	0.4608	0.2113
Supraspinal	1.4250	3.5178	0.1881	0.4050	0.1231	2.9789	0.8841	0.0413
Abdominal	1.6917	3.9942	0.1703	0.4235	-1.4770	3.4390	0.1475	0.4294
Thigh	6.2167	4.2213	0.0003*	1.4726*	5.8385	6.8966	0.0100*	0.8465*
Calf	-0.9170	1.8110	0.1073	0.5063	-1.6690	3.2423	0.0881	0.5147
MOTOR ABILITIES:								
Agility (sec)	-0.6670	0.3391	0.0004*	1.9669*	-0.3670	0.4355	0.0140*	0.8427*
Balance (%)	18.2400	6.6902	0.0001*	2.7263*	7.8167	9.3168	0.0143*	0.8389*
Explosive power	-5.0000	2.9059	0.0004*	1.7206*	-5.2310	4.7811	0.0019*	1.0941*

$d = \frac{|\bar{x}_1 - \bar{x}_2|}{s_{max}}$ = effect size for difference between means; a measurement of practical significance

$p \leq 0.05$

$d \geq 0.2$ (small effect)

$d \geq 0.5$ (medium effect)

$d \geq 0.8$ (large effect)

$\bar{x}_1$ = mean value (test 1)

* = Large practically significant *intra-group* difference between testing episodes

$\bar{x}_2$ = mean value (test 2)

4.14. SUMMARY OF THE DIFFERENCES BETWEEN TESTING OCCASION ONE AND TWO

1. Biomechanics, anthropometry and physical/motor abilities of the total group:

- The *biomechanical analysis* presented two significant differences in the lower limb, namely the quadriceps mobility test, which indicated that the flexibility of the quadriceps for the total group decreased during the season, and the external rotation mobility test which identified that the external rotation mobility improved during the course of the netball season. The pelvic girdle region indicated significant differences with the ASIS comparison, PSIS comparison, and the pelvic rami positional tests. The asymmetries at the ASIS, PSIS and the pelvic ramis increased during the season.

No significant differences were identified in the spinal region. In the neurodynamics category, significant differences were identified with the SLR test, showing that the neurodynamics of the players deteriorated during the season.

- A summary of the *anthropometry results* between the pre and post season tests would follow. Significant differences occurred in the weight, BMI, fat percentage, and the subscapular, thigh and calf skinfold measurements.

- The data of the *physical/motor ability* tests for the total group would be discussed next. Significant differences ($p \leq 0.05$; $d \geq 0.8$) were identified for all three motor tests (agility, balance and explosive power). The agility and balance of the total group improved significantly. However, a practically significant decrease in performance was occurred with the explosive power test.

2. *Biomechanical data, anthropometry and physical/motor abilities of the juniors and seniors:*

- To conclude the significant *biomechanical* differences between the pre and post season data for the juniors and seniors, a summary will follow. Among the juniors, the only significant differences occurred with regard to the quadriceps mobility and the SLR tests. According to the quadriceps mobility test, the flexibility of the quadriceps worsened during the course of the netball season, while the SLR test indicated that the neural mobility of the junior players deteriorated during the season. Among the senior players, the SLR test identified a significant reduction in neural mobility.

- Significant *anthropometrical changes* were identified in terms of weight; fat percentages; and with the supraspinal and thigh skinfold measurements among the juniors. The senior players presented with significant differences with their weight; BMI; and with their thigh and calf skinfold measurements.

- The juniors' as well as the seniors' physical/motor abilities (agility and balancing abilities) improved significantly, while their explosive power worsened significantly.

3. *Biomechanics, anthropometry and physical/motor abilities of the centre and goal players:*

- The *biomechanical analysis* presented significant differences with the quadriceps mobility, external rotation mobility; functional extension mobility and the SLR test. In three of the four tests (quadriceps mobility-; functional extension mobility and the SLR test), the findings worsened during the season. However, the external rotation mobility (lower limb region) improved throughout the course of the netball season. Next, the biomechanical data of the goal players would be concluded. The majority of the tests conducted in the lower limb region indicated that no biomechanical changes occurred among the goal players during the season. In the pelvic girdle region no changes occurred, meaning that the biomechanics of the goal players in the pelvic girdle region did not change during the season. Most tests conducted in the spinal region indicated that no changes occurred during the season. The SLR test performed in the neurodynamics category presented significant differences. The neurodynamics of the goal players deteriorated during the season.

- A summary of the *anthropometrical changes* of the centre and goal players which occurred during the season will follow. The anthropometrical features of the centre players (their weight, as well their thigh and calf skinfold measurements) varied significantly. The average weight and thigh skinfold measurement of the centre players increased, while the calf skinfold measurement decreased significantly. Among the goal players, significant differences were identified for the weight, BMI, fat percentage and the subscapular, supraspinal, abdominal, and thigh skinfold measurements.

All these parameters (weight, BMI, fat percentage, subscapular, supraspinal, abdominal, and thigh skinfold measurements) increased significantly during the season. The results of the motor abilities of the centre and goal players would be discussed next.

- Among the centre and goal players, the results for *physical/motor abilities* improved significantly for the agility run and the balance tests, while the explosive power test showed a decrease in performance.

4. *Biomechanics, anthropometry and physical/motor abilities of the A- and B-grade players:*

- The *biomechanics* of the A-grade players would be discussed first. With most of the tests conducted in the lower limb and spinal regions, no biomechanical changes were identified regarding the biomechanics of the A-grade players. The only test in the spinal region which indicated a significant difference was the functional flexion test, which identified a reduction in the functional flexion of the A-grade players during the season. The neurodynamics category revealed a significant difference for the SLR test, which indicated that the neural mobility of the A-grade players worsened during the season. All the tests performed in the pelvic girdle region indicated that no biomechanical changes occurred during the season among the A-grade players. A summary of the results of the B-grade players would follow. No significant differences were identified in the lower limb, pelvic girdle and spinal regions of the B-grade players. The only significant difference occurred in the neurodynamics category with the SLR test, which revealed that the neural mobility of the B-grade players worsened during the season.

- The *anthropometry* of the A- and B-grade players will be summarised next. The data of the A-grade players would be discussed first. Significant increases occurred with the weight; BMI; fat percentage; as well as with the subscapular and thigh skinfold measurements of the A-grade players in terms of anthropometry. The B-grade players' weight and thigh skinfold measurement increased significantly.

- Significant increases were identified for all three *physical/motor tests* (agility, balance and explosive power) among both groups (A- and B-grade players), while the players of both groups presented with a decrease in performance with the explosive power test.

4.15. INCIDENCE OF INJURY

The secondary aim of this study was to identify the shortcomings of the physical profiles (biomechanical variables, anthropometrical components and motor abilities) of the netball players that could contribute to musculoskeletal injuries. The physical profiles have been discussed in the previous sections while this section on injury incidence will study the occurrence of injuries, the mostly affected body parts and the mechanisms of injuries. Furthermore, this section will discuss the descriptive statistics and the significant differences of the injury rates / 1000 player-hours of netball for the total group, the juniors and seniors; centre and goal players; as well as for the A- and B-grade players. These statistics would be followed by literature that correlates or differs from these data.

The injuries sustained by the netball players during the season were monitored by means of an injury assessment clinic once a week. The physiotherapist who conducted the clinics recorded the mechanism of injury; diagnosis of injury; severity of injury; type of injury; time off from training/playing games; recommended treatment; instruction to player; and when to revisit.

The severity of an injury was classified according to the duration of the time that the netball player was unable to return to the specific sport: 1 to 7 days of incapacitation was graded as "minor" (Grade I), 8 to 21 days as "moderately serious" (Grade II), and over 21 days or permanent damage as "serious" (Grade III) (Van Mechelen *et al.*, 1992:85). Duration of injury/time off was calculated as the difference between the date of injury and the date of return to play.

Table 4.25 reflects the mean injury rates per 1000 player-hours for the total group of netball players as well as for the different groups (juniors and seniors; centre and goal players; A- and B-grade players). Injuries were recorded per 1000 player-hours of netball. Player hours included training as well as game time. The first and second team of the North-West University (NWU) Netball Club completed 175 player-hours during the netball season, while the third, fourth, u/19 A and u/19 B teams participated in 114 player-hours. The data for the total group of netball players would be interpreted first. The injury incidence for the group in total was 7.63 injuries/1000 player-hours, which is higher than previous studies performed on netball players. Hopper *et al.* (1999) did a study on the effects of taping and bracing at the ankle joint of netball players. In that study, an injury incidence of 3.3 injuries/1000 player-hours was reported. A survey conducted in Western Australia on netball injuries and conditions related to these injuries, presented an injury incidence of 5.2 injuries/1000 player-hours (Hopper, 1986). A study performed by Hopper (1986) presented an injury incidence of 5.4 injuries/1000 player-hours.

Evidently, the injury incidence of the North-West Club netball players was higher than the injury incidences reported with previous studies performed on netball players. The reasons for this high injury incidence could be the numerous biomechanical deviations that were identified among the NWU Club netball players who participated in this study.

These biomechanical deviations included: ITB-, quadriceps- and iliopsoas tightness; tilted patella; asymmetrical patella height; rear foot pronation; callus plantar aspect with a flat arch; and with valgus, rotation or deviation of their toes; excessive leg length discrepancies; asymmetries at the PSIS, ASIS, pelvic ramis as well as asymmetrical pelvic positions; hyperlordotic lumbar curve; and finally inadequate neural mobility (Table 4.1, p 102). According to the literature these biomechanical deviations could alter a netball player's technique and overstrain the joint structures, in other words demoting the netball player's physical performance and increasing their susceptibility to injuries; therefore biomechanical abnormalities could contribute to traumatic as well as overuse injuries (Arnheim & Prentice, 2000; Brukner & Khan, 2001; Bell-Jenje & Bourne, 2003; Kendall *et al.,* 1993; Fuller & Drawer, 2004; Rossouw & Rossouw, 2003). According to existing literature poor anthropometry and physical/motor abilities could also contribute to injuries (traumatic and overuse injuries) (Whiting & Zernicke, 1998; Jones & Knapik, 1999; Murphy *et al.,* 2003; Trojian & Mckeag, 2006; Moss 2002; Swanik & Swanik, 1999). The total group did present with unacceptable anthropometry during both testing occasions; an above average fat percentage was determined which could have made the netball players more prone to injuries.

During the first tests the group performed acceptable regarding agility and explosive power but underperformed with the balance test according to the norm set for elite netball players. With the second tests the group recorded acceptable agility and balancing averages but unacceptable explosive power abilities, and therefore these unacceptable physical/motor abilities (balance and explosive power) could have lead to the occurrences of the injuries.

The following statistics would be discussed under three sections, namely the severity of the injury (grade of injury); the body part mostly affected; and the mechanism of injury.

Of the 46 injuries that occurred during the season, 34.78% were classified as Grade I (minor) injuries, while 56.52% were categorised as Grade II (moderately serious) and 8.69% as Grade III (serious) injuries (Van Mechelen *et al.*, 1992:85), thus, the majority of the injuries were classified as moderately serious, meaning that these injured players were unable to return to netball (training and games) for 8-21 days (Table 4.26).

The body parts mostly affected by injuries were the ankle joint (39.13%), followed by the knee joint (28.26%) and thirdly the cervical region (8.69%) (Table 4.26). Similar findings were made in literature. According to literature, the joints mostly affected by traumatic injuries in netball are the ankle and knee joint. In a study conducted by Hopper (1986), the incidence of injury revealed that 58.2% of injuries occurred at the ankle; 15.2% at the knee; 13.3% at the hand and 13.3% at other parts of the body. A study conducted by Steele (1990) on lower limb and back injury patterns of elite netball players reported 30.2% ankle injuries, followed by 15.9% shin/calf injuries. These findings were similar to the results of a one day veterans' netball tournament, where 29.6% of players presented with ankle injuries and 13.6% complained of leg/calf problems (Steele, 1990). According to Hopper and Jones (1983) the ankle, knee and hand are the most common sites to be injured. Many studies conclude that statistically the ankle and knee joints are the most susceptible to injury.

The most common mechanism of injury was incorrect landing technique (52.17%) (Table 4.26). A fall incident was reported as the mechanism of injury with 4.34% of the injuries. The existing literature correlated with these data. Incorrect landing (73.8%), a slip or a fall (74.2%) was the main causes of injuries with a study conducted by Hopper (1986). A similar incidence of perceived reason for injury was recorded for contact with another player (29%), and incorrect landing (29%) followed by a slip, trip or sudden stop (21%) (Hopper *et al.,* 1995). With some of the injuries (34.78%), the players could not report a specific traumatic incident that caused the injury, meaning that the origin of these injuries could be due to overuse. The existing literature correlates with these data. Overuse injuries are defined as injuries to a body part of an athlete or individual where no trauma was involved (Brukner & Khan, 2001).

Incorrect biomechanics is considered as a potential cause of overuse injuries (Arnheim & Prentice, 2000; Brukner & Khan, 2001; Bell-Jenje & Bourne, 2003; Kendall *et al.,* 1993; Fuller & Drawer, 2004; Arnheim & Prentice, 2000; Rossouw & Rossouw, 2003; Hopper & Elliot, 1993).

Hopper and Elliot (1993) did a study on the relations between lower limb and back injuries with perceived landing patterns and podiatric variables for injured and uninjured elite netball players. More than 25% of the 240 participants in that study had overuse type injuries. These injuries involved retropatellar pain (24%) and shin pain (38%) (Hopper & Elliot, 1993). Ninety two percent of the 228 participants were given a podiatric assessment. The study found that 22.5% of the players were cleared as "normal" and an astonishing 42.1% of the players presented with rear foot varus with compensating subtalar pronation. Excessive pronation may produce an unstable forefoot; therefore the netball player could be susceptible to an ankle sprain (Donatelli, 1990). Interestingly, during this study the pre-season testing procedure identified that 74% and 69% of the participants presented with rear foot pronation with the rear foot standing and lying tests respectively. With the post-seasonal tests, of this study, this tendency (rear foot pronation) occurred in 80% and 76% of the participants with the same tests (rear foot standing and lying tests).

In other words, a large number of the netball players presented with rear foot pronation, which is considered a biomechanical deviation. Rear foot pronation could contribute to the occurrence of overuse injuries such as sesamoiditis; plantar fasciitis; Achilles tendinopathy; Peroneal tendinopathy; medial shin pain; patellar tendinopathy; patellofemoral syndrome; metatarsal stress fracture; navicular stress fracture. This biomechanical stressor (rear foot pronation) could have been the cause of a number of the overuse injuries which occurred during the season among the netball players participating in this study. These overuse injuries included injuries such as, patellofemoral syndrome; medial shin pain; groin and popliteus strains; lumbar facet joint impactions; and navicular ligament strain.

The data of the different groups (juniors and seniors; centre and goal players; A- and B-grade players) would be interpreted next. According to the statistics no significant differences ($p \leq 0.05$; $d \geq 0.8$) occurred among any of the three groups' injury rates (juniors and seniors; centre and goal players; A- and B-grade players). The junior players sustained less injuries/1000 players-hours (6.97) than the senior players (9.02). The only study which elaborated on the effect of age on injury incidence was the study conducted by Hass *et al.* (2005). That study found that post-pubescent female netball players (18-25 years) were more prone to injuries, especially lower-limb injuries, than pre-pubescent female netball players (8-11 years). A study conducted by Hopper (1986) found that most of the injured players (113) involved players between the ages 16 and 22 years, while 45 of the injured players were between 12 and 15 years. All the netball players (juniors and seniors) participating in this study fell in the post-pubescent category (18 - 25 years); therefore the results could not be compared to the data of the study performed by Hass *et al.* (2005) and Hopper (1986).

Unfortunately, no other literature could be found during the literature review to explain why the senior players sustained more injuries than the junior players. Possible reasons are the age difference; according to Hopper (1986) the seniors are more mature and therefore more determined and focused on winning, which could lead to greater risks during play.

Furthermore, the seniors presented with more biomechanical deviations than the juniors, which could make them more susceptible to traumatic and overuse injuries (Arnheim & Prentice, 2000; Brukner & Khan, 2001; Bell-Jenje & Bourne, 2003; Kendall *et al.,* 1993; Fuller & Drawer, 2004; Rossouw & Rossouw, 2003), and lastly, during the first testing occasion the seniors presented with worse anthropometry, agility and balance than the juniors, which could have contributed to injuries (traumatic and overuse) (Whiting & Zernicke, 1998; Jones & Knapik, 1999; Murphy *et al.,* 2003; Trojian & Mckeag, 2006; Moss 2002; Swanik & Swanik, 1999).

The centre players (8.51 injuries/1000 players-hours) presented with more injuries than the goal players (6.76 injuries/1000 player-hours). This tendency could be due to the differences in work profiles between the centre and the goal players. The centre players' work profile involves more strenuous activities, such as running, jumping and changing direction, than that of the goal players, which could expose them more to injury than the goal players (Jordaan, 2001). No other literature could be found to elaborate on this tendency in netball. A possible reason why the centre players had more injuries than the goal players is the presence of more biomechanical deviations among the centre than the goal players, which could lead to traumatic and overuse injuries (Arnheim & Prentice, 2000; Brukner & Khan, 2001; Bell-Jenje & Bourne, 2003; Kendall *et al.,* 1993; Fuller & Drawer, 2004; Rossouw & Rossouw, 2003).

The A-grade players sustained more injuries (9.16 injuries/1000 players-hours) than the B-grade players (6.62). A study performed by Hopper (1986) correlated with these findings. This study revealed that 35.3% of the injuries occurred in the highest grade (A-grade), players while only 3.5% occurred in the lowest grade (G grade) players. Thus, a higher injury rate was reported among the more skilled players (A-grade players), because these players are more determined and focused on winning, and therefore take greater risks during play, which makes them more vulnerable to injury (Hopper, 1986). This study by Hopper (1986) was the only study that could be found that gave possible reasons why the A-grade players presented with a higher injury rate than the B-grade players. According to the biomechanical analysis performed during this study, the A-grade players presented with more biomechanical deviations than the B-grade players, meaning that the A-grade players could have been more prone to injuries than the B-grade players during the season. Numerous other studies also found that biomechanical deviations could lead to injuries (Arnheim & Prentice, 2000; Brukner & Khan, 2001; Bell-Jenje & Bourne, 2003; Kendall *et al.,* 1993; Fuller & Drawer, 2004; Rossouw & Rossouw, 2003).

Table 4.25 Descriptive statistics and significant differences between injury rates among juniors and seniors; centre and goal players; A- and B-grade players

$\bar{X}$ **Juniors**	$\bar{X}$ **Seniors**	**Std.Dev. Juniors**	**Std.Dev. Seniors**	**p**	**Effect size (d)**
6.97259	9.02307	7.99876	8.86823	0.46787	0.23
$\bar{X}$ **Centre players**	$\bar{X}$ **Goal players**	**Std.Dev. Centre players**	**Std.Dev. Goal players**	**p**	**Effect size (d)**
8.51600	6.76200	8.92020	7.61416	0.50764	0.20
$\bar{X}$ **A-grade players**	$\bar{X}$ **B-grade players**	**Std.Dev. A-grade players**	**Std.Dev. B-grade players**	**p**	**Effect size (d)**
9.16625	6.62083	7.57091	9.17822	0.34472	0.28

Table 4.26 Descriptive statistics of injury epidemiology among the total group of netball players

Injury Incidence	**%**
1. Severity of injury:	
Grade I	34.78
Grade II	56.52
Grade III	8.69
2. Body part:	
Ankle	39.13
Knee	28.26
Cervical	8.69
3. Mechanism of injury:	
Incorrect landing	52.17
No incident	34.78
Fall incident	4.34

To conclude the section of injury incidence a summary will follow: the NWU club netball players presented with a higher injury incidence than previous studies done on netball injuries. A relation could exist between the high injury incidence and the numerous biomechanical deviations, poor anthropometry and inadequate motor abilities (average agility and balance and unacceptable explosive power) which were detected at these netball players. Most of the injuries which were recorded among the netball players classified as moderately serious injuries, while the body part mostly affected was the ankle joint and incorrect landing technique as the most common mechanism of injury.

The literature correlate with these findings of mostly affected body part and mechanism of injury. The injury incidences of the different groups reported that the seniors sustained more injuries than the juniors, this higher incidence do correlate with the status of the seniors' biomechanical-, anthropometrical-, and motor ability profiles, which were more unacceptable than the juniors' profile (during test one). The centre players presented with more injuries than the goal players, which could be, firstly, due to the more strenuous work profile of the centre players and secondly, due to the more biomechanical abnormalities identified among the centre- than the goal players. When studying the injury incidence of the A- and B-grade players it is evident that the A-grade players had more injuries during the season. The literature do correlate with these findings and confirm that A-grade players take more risks during the game which make them more susceptible to injury. Another possible reason could be due to the fact that more biomechanical stressors were identified among the A- than the B-grade players during the biomechanical analysis.

CHAPTER 5

SUMMARIES, CONCLUSIONS AND RECOMMENDATIONS

5.1. INTRODUCTION

5.2. SUMMARY OF LITERATURE REVIEW

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CHAPTER 5

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1. INTRODUCTION

The primary aim of this study was to determine the physical profiles of club netball players from the North-West University (NWU), aged between 18 and 23 years, with reference to their biomechanics, anthropometry and physical/motor abilities (agility, balance and explosive power). The secondary aim was to identify a relation between these netball players' physical profiles (biomechanics, anthropometry and physical/motor abilities) and the musculoskeletal injuries occurring during the netball season. A summary of the literature review and the results of the study as well as conclusions drawn from the empirical study and recommendations are presented in this chapter.

5.2. SUMMARY OF LITERATURE REVIEW

The relevant literature was discussed in detail in Chapter 2 (p 14) of this study, and the following is a summary of the most applicable and important information regarding this particular study. Existing literature found that a netball player's biomechanics, anthropometry and physical/motor abilities play a key role in the player's performance during a netball game (Venter *et al.,* 2005), and these aspects were therefore included in this study. Furthermore, as very few studies have been conducted on netball players, this research study aimed to make a contribution to the netball community by providing a detailed overview of a netball player's physical profile and by identifying the possible relation between a player's physical shortcomings and her susceptibility to injuries. This data could be used to prescribe an adequate conditioning programme to enhance the netball player's physical profile.

In the available literature, a variety of definitions are used for *biomechanics*, *anthropometry*, *physical/motor abilities* (*agility*, *balance* and *explosive power*), and *injuries*. Yet, regardless of the numerous definitions, existing literature agrees on the key role which components such as biomechanics, anthropometry and motor abilities play in the performance and injury incidence of athletes, including netball players (Brukner & Khan, 2001). Unacceptable biomechanics and anthropometry, as well as a lack of physical/motor abilities could contribute significantly to the incidence of traumatic and overuse injuries among netball players.

The definitions and value of biomechanics were discussed in depth in Chapter 2 of this study (Section 2.2, p 14). The definition of biomechanics formulated by Neely (1998) was adopted for this study: it describes ideal biomechanics as near symmetry, good dynamic mobility and core stability of the human body. When deviations occur in any of these components (near symmetry, good dynamic mobility and core stability), a netball player's performance could be altered and this could result in traumatic and overuse injuries (Hopper & Elliot, 1993; Brukner & Khan, 2001). These biomechanical abnormalities should preferably be detected before the start of the netball season and the necessary exercises should be prescribed accordingly (Koester & Amunson, 2003; Gabbet, 2004; Armsey & Hosey, 2004). Fortunately, these individualistic rehabilitation programmes are very effective and can improve these biomechanical deviations to a great extent (Erasmus, 2006; Elphinston & Hardman, 2006).

The second parameter to be discussed was anthropometry (see Section 2.3, p 50). The definition of anthropometry offered by Ross *et al.* (1987) was used in this study. Anthropometry is defined as the study of a human's size, physique, proportion, composition, puberty, and motor function to comprehend the growth, training, performance, and nutrition of humans, which has direct effects on medicine, education and the authorities. These studies must, however, be performed with respect to the individual's rights and in service to humanity.

An athlete's anthropometry could influence his/her choice of a specific sport, as well as the position the athlete would play in that sport (De Ridder, 2002). Jordaan (2001) concluded that in netball, centre players, such as the centre, wing attack and wing defence, would tend to have a mesomorphic physique while goal shooters and defenders would have an ectomorphic physique. Anthropometry has a direct effect on the probability of injuries, the athlete's performance and the athlete's biomechanics (body posture and flexibility) and physical/motor abilities (Whiting & Zernicke, 1998; Jones & Knapik, 1999; Arnheim & Prentice, 2000).

Agility was the first motor ability to be discussed in this study (Section 2.4, p 54). Various authors describe this ability as an essential parameter required for playing netball (Bloomfield *et al.,* 1994; Ellis & Smith, 2000; Venter *et al.,* 2005). The definition by Van Gent (2003) was adopted here: agility is the ability to make sudden, effective changes in direction without losing much speed. As the outcome of a netball game is determined by the players' ability to rapidly change body direction and position in the horizontal plane after reaching a high speed, this ability (agility) is essential during a netball game (Ellis & Smith, 2000; Venter *et al.,* 2005). There are numerous exercises to improve a netball player's agility, with excellent results.

Another essential parameter required to play netball is the ability to balance (Section 2.5, p 57). Many authors emphasise the important role of balance in the game of netball, especially when the player is standing on one leg during throwing and receiving actions (Jordaan, 2001; Venter *et al.,* 2005). For the purpose of this study, balance is defined as the ability to maintain a position, to voluntarily move and to react to a perturbation (Blackburn & Voight, 2001). Literature indicates a significant correlation between inadequate balance and the occurrence of lower limb injuries in various sports, especially netball (Baltaci & Kohl, 2003; Murphy *et al.,* 2003; Stasinopoulos, 2004; Verhagen *et al.,* 2004). Fortunately, programmes to improve netball players' ability to balance can be applied with very good results (Stasinopoulos, 2004).

Explosive power was the final motor ability to be discussed in this study (Section 2.6, p 62). Explosive power is essential in sports associated with jumping activities, such as netball (Swanik & Swanik, 1999; Venter *et al.,* 2005). Power is an important aspect of explosive power. Power is the rate of doing work and has a time component; therefore an athlete must have the ability to generate power by producing a stretch-shortening cycle in which the muscle is eccentrically stretched and slowly loaded. This pretensioning phase is followed by a rapid concentric contraction to develop a large amount of momentum and force (Voight & Tippett, 1999; Brukner & Khan, 2001). The inclusion of plyometric exercises to improve a netball player's explosive power is essential to increase performance and also to rehabilitate a player after an injury (Swanik & Swanik, 1999; Moss 2002).

Netball is considered a very demanding game and therefore is associated with numerous traumatic and overuse injuries. A study conducted by Eggar (1990) reported that netball has a higher injury rate than football, hockey, cricket and basketball in Australia. A traumatic sports injury is defined as the occurrence of a soft tissue and/or a bone lesion after a specific physical incident, while an overuse injury is describe as an injury to a body part of an athlete or individual where no trauma was involved (Brukner & Khan, 2001). According to literature, injuries (traumatic and overuse injuries) could be associated with incorrect biomechanics, unacceptable anthropometry and poor motor abilities (agility, balance and explosive power) (Arnheim & Prentice, 2000; Brukner & Khan, 2001; Bell-Jenje & Bourne, 2003; Kendall *et al.,* 1993; Fuller & Drawer, 2004; Rossouw & Rossouw, 2003; Whiting & Zernicke, 1998; Jones & Knapik, 1999; Murphy *et al.,* 2003; Trojian & Mckeag, 2006; Moss 2002; Swanik & Swanik, 1999).

Literature suggests that the amount of injuries occurring during a netball season should be expressed as the number of injuries per exposure time, therefore the number of injuries per 1000 hours of participation (game and training time) (Van Mechelen *et al.,* 1992).

A study performed on netball players by Ekstrand and Tropp (1990) reported an injury incidence of 3.3 injuries per 1000 player-hours of participation, which is higher than that reported for soccer (1.7-2.0 injuries per 1000 hours) (Ekstrand & Tropp, 1990), volleyball (2.6 injuries per 1000 hours) (Bahr *et al.*, 1994) and rugby union (2.34/1000 player hours) (Roux *et al.*, 1987), but lower than that of basketball (5.5 injuries per 1000 hours) (Leanderson & Wredmark, 1995). A survey conducted in Western Australia on netball injuries and conditions related to these injuries, reported a total of 158 injuries in a population of 3108 participants; therefore 5.2% of the total population sustained an injury (Hopper, 1986). Hopper *et al.* (1995) completed a descriptive epidemiology of netball injuries during competitive tournaments in Western Australia. The study was conducted over a five year period (1985-1989), during which 608 players of the 11228 participants presented with an injury, bringing the overall incidence rate of injury to 5.4%. In conclusion, netball is considered a safe sport, but despite the low injury rates, studies reported that netball still has a higher injury rate than Australian football, basketball, hockey, cricket, soccer and volleyball in Australia. For that reason it is essential to incorporate preventative measures in each player's conditioning programme.

Many authors involved in the sports community stress the importance of a pre-season "screening" occasion during which the shortcoming of the netball player's physique (biomechanics, anthropometry and physical/motor abilities) could be identified and then addressed with the correct conditioning programme (Junge *et al.*, 2004; Gabbet, 2004; Armsey & Hosey, 2004; Schwellnus & Derman, 2001). Evidently, these conditioning programmes positively influence a netball player's performance and reduce the player's susceptibility to injuries (traumatic and overuse injuries) (Junge *et al.*, 2004; Gabbet, 2004; Armsey & Hosey, 2004; Schwellnus & Derman, 2001).

Evidently, existing literature emphasises the significant roles which biomechanics, anthropometry and physical/motor abilities (agility, balance and explosive power) could play in a netball player's performance and their susceptibility to injuries; therefore the aims of this study were to determine the physical profiles of club netball players from the North-West University (NWU) aged between 18 and 23 years, with reference to the

biomechanics, anthropometric measurements and motor abilities (agility, balance and explosive power) and to identify possible aspects of these profiles which could contribute to musculoskeletal injuries of netball players.

5.3. SUMMARY OF THE RESULTS OF THE STUDY

5.3.1. The results of testing occasion one

- **Biomechanics**

During the first testing occasion, physical profiles of the *total group* were compiled. The group was also divided into three groups: juniors and seniors, centre and goal players, and A- and B-grade players. The profiles of these groups were compared with each other (juniors with seniors, centre with goal players, and A- with B-grade players). The data of the group in total is described below.

The biomechanical data revealed that numerous biomechanical deviations existed among the netball players in the lower limb region. These biomechanical deviations consisted of ITB and iliopsoas tightness; tilted patella; asymmetrical patella height; rear foot pronation; callus plantar aspect with a flat arch; and lastly, with valgus, rotation or deviation of their toes (Table 4.1, p 107). In the pelvic girdle region biomechanical abnormalities such as excessive leg length discrepancies; asymmetries at the PSIS, ASIS, pelvic ramis as well as asymmetrical pelvic positions, were recorded among numerous of the netball players. The assessment of the spinal region indicated that most of the netball players presented with a hyperlordotic lumbar curve. With the other tests conducted in the spinal region and with neurodynamics, the majority of the participants tended to achieve ideal values (Table 4.1, p 107).

Secondly, the data of the *juniors and seniors* was analysed. The juniors presented with better biomechanical profiles than the seniors.

One practical significant difference presented in the lower limb region for the toe positional test (Table 4.3, 113), where the seniors presented with a better average than the juniors.

Thirdly, the biomechanical data of the *centre and goal players* was studied. In the lower limb and pelvic girdle regions, the goal players tended to score ideal values in more of the tests conducted in these two regions than the centre players, while the centre players performed better in the pelvic girdle region. One practically significant difference was identified in the lower limb region (longitudinal arch status test), where the goal players tended more towards ideal values than the centre players. For neurodynamics, the two groups scored similar results (Table 4.5, 119).

Lastly, the biomechanical data of the *A- and B-grade players* was compared. The biomechanical data was summarised in Table 4.7 (p 124). The B-grade players presented with better biomechanics in the lower limb- and spinal regions. One practically significant difference occurred in the lower limb region (VMO-L comparison test), where the A-grade players presented with a better average than the B-grade players. One practically significant difference was identified in the pelvic girdle region, with the bilateral pelvis positional test, where the A-grade players tended more towards ideal values than the B-grade players.

These biomechanical deviations which were identified among the netball players (total group, juniors and seniors, centre and goal players, A- and B-grade players) correlate with studies conducted on sport injuries, including netball injuries (Arnheim *et al.*, 2000; Brukner & Khan, 2001; Bell-Jenje & Bourne, 2003; Kendall *et al.*, 1993; Fuller & Drawer, 2004; Rossouw & Rossouw, 2003).

These biomechanical deviations could be ascribed to a lack of conditioning exercises to improve the netball players' joint symmetry, flexibility, and core stability, in other words their biomechanics, prior and during the season.

- **Anthropometry**

The anthropometrical status of the *total group* was described in Table 4.2 (p 110). The average BMI for the total group fell in the ideal category (22-24), while the average fat percentage of the total group was considered above average (25-31%). The netball players presented with above-average subcutaneous fat, especially in the tricep, abdominal and thigh areas. A study conducted by Venter *et al.* (2005) reported similar anthropometry results, but used different formulas to determine the fat percentages, which influenced the comparability of the studies. The average fat percentage above the norm, for the total group, could be the result of inadequate exercises to decrease fat mass and improve lean muscle tissue.

In terms of BMI and fat percentages the *juniors and seniors* (Table 4.4, p 114), *centre and goal players* (Table 4.6, p 120), *A- and B-grade players* (Table 4.8, 125) presented with similar anthropometrical results than the total group, in other words, with ideal BMI averages and above average fat percentages. The juniors, centre players and A-grade players presented with better fat percentages than their counterparts. No practical significant differences were identified with the juniors and seniors and with the A- and B-grade players. Three practical significant differences were presented with the weight, height and thigh skinfold measurement of the centre and goal players. The goal players weighed significantly more, were taller than the centre players and presented with significantly more subcutaneous fat in the thigh area.

- **Physical/motor abilities**

Next, the physical/motor data was discussed (Table 4.2, 110). The *total group* of NWU Netball Club players performed relatively acceptably regarding the agility (18.0 – 21.7sec) and explosive power tests (30), but underperformed in the balancing test, according to the norm (75%) set for elite netball players. Venter *et al.* (2005) performed a similar study but applied different physical/motor testing protocols, which made it difficult to compare the test results.

No other studies similar to the current study were identified during the literature review. The unacceptable average for balance could be the result of inadequate balance training.

When studying the results of the different groups, two of the three groups (juniors and seniors; centre and goal players) revealed similar results compared to the total group of netball players with the physical/motor tests; meaning that these two groups performed acceptable regarding the agility and explosive power tests but underperformed with the balance test. The *juniors* performed better than the *seniors* in two (agility and balance) of the three physical/motor tests. No practically significant differences were identified with the juniors and seniors (Table 4.4, p 114). Hopper (1986) concludes that senior players tend to take their sport more serious and are more skilled than the juniors, and therefore usually outperforms the junior players; but the results of this study differ with Hopper (1986) because the juniors outperformed the seniors with the agility and balance tests. No other studies were found to collaborate on the physical/motor abilities of junior and senior netball players. In all three physical/motor tests (agility, balance and explosive power) the *centre players* performed better than the *goal players*. A practically significant difference occurred in the agility run test (Table 4.6, p 120). No other studies which compared centre to goal players could be found, therefore this study is considered the first to investigate the differences between centre and goal players.

The *A-grade players* performed better than the *B-grade players* with regard to all three physical/motor tests (agility run, balance and explosive power test). The averages of the A- and B-grade players were considered acceptable for all three tests.
Practical significant differences occurred with the balance and explosive power tests (Table 4.8, p 125). One would expect the A-grade players to perform better than the B-grade players due to the higher grading of the A-grade players' physical and motor abilities than the B-grade players. No studies on A- and B-grade netball players could be found, and this research is therefore considered the first study which analyses and compares the physical profiles of A- and B-grade netball players.

5.3.2. The results of testing occasion two

- **Biomechanics**

The biomechanical analysis during the second testing occasion of the *total group* reported similar results than the first testing occasion. The biomechanical data revealed that numerous biomechanical deviations existed among the netball players in the lower limb region (Table 4.9, p 134). These deviations included ITB, quadriceps, and iliopsoas tightness; tilted patella with asymmetrical patella height; and rear foot pronation with callus plantar aspect and valgus, rotation or deviation of their toes. In the pelvic girdle region biomechanical stressors such as excessive leg length discrepancies; asymmetries at the PSIS, ASIS, pelvic ramis as well as non-ideal pelvic positions (lumbar hyperlordosis) were identified among the majority of the total group of netball players. For the last two categories, namely spinal region and neurodynamics, it was found that the total group of netball players presented with a hyperlordotic lumbar curve and inadequate neural mobility. These biomechanical deviations which were identified among the netball players correlate with studies conducted on sport injuries, including netball injuries (Arnheim & Prentice, 2000; Brukner & Khan, 2001; Bell-Jenje & Bourne, 2003; Kendall *et al.*, 1993; Fuller & Drawer, 2004; Rossouw & Rossouw, 2003). These biomechanical deviations could be the result of inadequate conditioning exercise programmes to improve the netball players' biomechanics (joint symmetry, flexibility and core stability) before and during the season.

Secondly, the differences between the *junior and senior players* according to their biomechanics were considered. The biomechanical analysis found that in the first three categories (lower limb, pelvic girdle and spinal regions) the juniors performed better than the seniors (Table 4.11, p 142). Fourteen practically significant differences were identified in these three categories (lower limb, pelvic girdle and spinal regions). With both tests performed in the neurodynamics category practically significant differences were found: for the SLR test the juniors presented with a better average and for the PKB test the seniors tended more towards ideal values.

No similar studies were found and therefore this particular study is considered the first to study and compare the physical profiles of junior and senior netball players.

Thirdly, the data obtained from the *centre and goal players* was presented. The data include both groups' (centre and goal players) biomechanical profiles. The biomechanical evaluation found that in the lower limb, pelvic girdle and spinal regions the goal players performed better, but with the neurodynamics category the centre players presented with better averages (Table 4.13, p 148). In three tests in the lower limb region practically significant differences were identified, while three were found in the pelvic girdle region; five significant differences presented in the spinal region and one in the neurodynamics category.

Lastly, the biomechanical profiles of the *A-grade players* and *the B-grade players* were compared. Evidently, the B-grade players performed better than the A-grade players in three of the four categories of the biomechanical analysis (lower limb region, spinal region and neurodynamics). Practically significant differences were identified for three tests in the lower limb region; four in the pelvic girdle region; five in the spinal region and one in the neurodynamics category. The A-grade players presented with better averages than the B-grade players in the pelvic girdle region. No similar studies were found in literature, and therefore this particular study is considered the first to study and compare the biomechanical profiles of A- and B-grade netball players (Table 4.15, p 154).

- **Anthropometry**

The anthropometry of the *total group* of NWU Netball Club players during the second testing occasion was recorded in Table 4.10 (p 137). The average BMI for the total group fell in the ideal category (22-24), while the average fat percentage of the total group was considered above average (25-31%). This meant that the NWU Netball Club players presented with above average subcutaneous fat, especially in the tricep, abdominal and thigh areas.

A study conducted by Venter *et al.* (2005) reported similar anthropometry results, but used different formulas to determine the fat percentages and therefore the studies cannot be compared. The above-average fat percentage, for the total group, could be the result of inadequate exercises to decrease fat mass and improve lean muscle tissue.

The anthropometry evaluations of the juniors and seniors, centre and goal players and A- and B-grade players revealed similar results than the total group of players; meaning that these groups presented with ideal BMI averages and with above-average fat percentages. The *seniors* presented with better anthropometrical status than the *juniors*. The juniors and seniors presented with practically significant differences with the average weight, fat percentage and four skinfold measurements (Table 4.12, p 143). Literature did not reveal similar studies and therefore this particular study is considered the first to study and compare the anthropometry of junior and senior netball players.

The *centre players* presented with better anthropometry than the *goal players* (Table 4.14, p 149). Practical significant differences were identified for the height, BMI, fat percentage averages and for all six skinfold measurements. No other studies which compared the physical profiles of centre and goal players existed and therefore this study is considered the first to investigate the differences between the profiles of these players. The centre players have a more strenuous work profile than the goal players, which could explain why the centre players presented with better anthropometry than the gaol players (Jordaan, 2001).

The data revealed that the *B-grade players* presented with better anthropometry than the *A-grade players*. Practically significant differences were found with regard to the BMI, fat percentage and with four skinfold measurements. This study is considered the first research attempt to investigate and compare the anthropometry of A- and B-grade players (Table 4.16, p 155).

- **Physical/motor abilities**

In the physical/motor tests the performance of the *total group* of netball players was relatively acceptable with regard to the agility (18 – 21.7sec) and balancing tests (75%), but they underperformed with regard to the explosive power test according to the norm (30) set for elite netball players. Venter *et al.* (2005) conducted a similar study, but applied different physical/motor testing protocols; therefore the results could not be compared with the results of this study. No other studies similar to the current study were identified during the literature review. The unacceptable average for explosive power could be ascribed to inadequate plyometric training to improve the netball players' explosive power during the season (Table 4.10, p 137).

The findings of this study revealed that the juniors, seniors, centre and goal players as well as the A- and B-grade players presented with similar physical/motor averages than the total group of players; except with the explosive power test where the centre and A-grade players did exceed the norm and therefore performed acceptably. In other words, all three groups scored acceptable averages with regard to the agility and balance tests but underperformed with regard to the explosive power test. The *senior players* had better agility, balancing and explosive power abilities than the *junior players* (Table 4.12, p 143). A significant difference presented with regard to the balance test. No similar studies were found in literature and therefore this particular study is considered the first to study and compare the physical profiles of junior and senior netball players. Hopper (1986) explains that senior players tend to take their sport more serious and are more skilled than the juniors, which may explain why the seniors outperformed the juniors.

The *centre players* scored better averages for all three physical/motor tests (agility, balance and explosive power) than the *goal players*. Practically significant differences were found for all three physical/motor tests (Table 4.14, p 149). The centre players have a more strenuous work profile, involving more running, jumping and changing direction, than the goal players, which could explain why the centre players presented with better physical/motor abilities than the goal players (Jordaan, 2001).

During the literature review no other studies which compared the physical profiles of centre and goal players could be found and therefore this study is considered the first to investigate the differences between the profiles of these players (centre and goal players).

The *A-grade players* performed better than the *B-grade players* in all three the physical/motor tests (agility, balance and explosive power). Practically significant differences were identified for the agility and explosive power tests (Table 4.16, p 155). During the literature review no other studies which compared the physical/motor abilities of A- and B-grade players could be found and therefore this study is considered the first to investigate the differences between the profiles of these players. The A-grade players are expected to be more skilled due to their status as elite players and therefore are expected to have better physical/motor abilities than B-grade players.

5.3.3. A comparison of the results of testing occasion one and two

- **Biomechanics**

Firstly, the practically significant differences between the data of the *total group* for testing occasion one and testing occasion two were presented (Table 4.17, p 163). With regard to the biomechanics of the total group, in the lower limb region only two significant differences were identified, namely the quadriceps mobility test, which indicated that the flexibility of the quadriceps for the total group decreased during the season and the external rotation mobility test, which identified that the external rotation mobility improved during the course of the netball season.

In the pelvic girdle region, practically significant differences were found with the ASIS comparison, PSIS comparison, and the pelvic ramis positional tests. Evidently, the asymmetries at the ASIS, PSIS and the pelvic ramis increased during the season. No practically significant differences were identified in the spinal region. In the neurodynamics category significant differences were identified with the SLR test, showing that the neurodynamics of the players deteriorated during the season.

Thus, the overall biomechanics of the total group deteriorated during the course of the netball season.

The practically significant differences between the pre- and post season data for the *juniors and seniors* with regard to their biomechanical data were presented in Table 4.19 (p 167). Among the juniors, practically significant differences occurred with regard to the quadriceps mobility and the SLR tests. According to the quadriceps mobility test the flexibility of the quadriceps worsened during the course of the netball season, while the SLR test indicated that the neural mobility of the junior players deteriorated during the season. Among the senior players the SLR test identified a practically significant reduction in neural mobility. These biomechanical findings of the juniors and seniors correlate with the results of the total group of netball players. No existing studies compared the physical profiles of junior and senior players.

Thirdly, the practically significant differences among the *centre and goal players* during the course of the netball season with regard to biomechanics were considered. These findings correlate with the results of the total group. No other studies investigated the physical profiles of centre and goal players and therefore this study is considered the first attempt to shed light on the physical profiles of centre and goal players. The biomechanical data of the centre players was analysed first. The biomechanical analysis presented practical significant differences with the quadriceps mobility, external rotation mobility; functional extension mobility and the SLR test (Table 4.21, p 173). For three of the four tests (quadriceps mobility, functional extension mobility and the SLR test) the results decreased during the season. However, the external rotation mobility (lower limb region) improved throughout the course of the netball season.

The biomechanical data of the goal players was set out in Table 4.21 (p 173). In the lower limb region the majority of the tests indicated that no biomechanical changes occurred among the goal players during the season. In the pelvic girdle region no changes occurred, meaning that the biomechanics of the goal players in the pelvic girdle region did not change during the season.

Most tests conducted in the spinal region indicated that no changes occurred during the season. The SLR test performed in the neurodynamics category found practically significant differences. Evidently, the neurodynamics of the goal players deteriorated during the season.

Lastly, the significant differences between the pre- and post season tests of the *A- and B-grade players* were considered. These differences are similar to the test results of the total group of netball players. The biomechanics of the A-grade players were described in Table 4.23 (p 178). For most of the tests conducted in the lower limb and spinal regions, no biomechanical changes were identified. The only test in the spinal region which found a practically significant difference was the functional flexion test, which identified a reduction in the functional flexion of the A-grade players during the season. The neurodynamics category revealed a significant difference with regard to the SLR test, which indicated that the neural mobility of the A-grade players decreased during the season. All the tests performed in the pelvic girdle region indicated that no biomechanical changes occurred during the season among the A-grade players. The results of the B-grade players showed that no practically significant differences were identified in the lower limb, pelvic girdle and spinal regions. The only significant difference was found in the neurodynamics category, with the SLR test, which revealed that the neural mobility of the B-grade players decreased during the season (Table 4.23, p 178).

Literature did not explain the increases in biomechanical deviations among the total group and the different groups (juniors and seniors, centre and goal players, A- and B-grade players) during the season, but this phenomenon could be ascribed to a lack of conditioning exercises during the season to improve and maintain the players' joint symmetry, flexibility and core stability – in other words, their biomechanics.

- **Anthropometry**

The anthropometry results of the *total group* between the pre- and post-season tests (test one and test two) were compared (Table 4.18, p 164). Practically significant differences occurred with regard to the weight, BMI, fat percentage and subscapular, thigh and calf skinfold measurements. Table 4.20 (p 168) presents the anthropometrical changes among the *juniors and seniors* that occurred during the netball season. Practically significant differences were identified in terms of weight; fat percentages; and the supraspinal and thigh skinfold measurements among the juniors. The senior players presented with practically significant differences with regard to their weight, BMI, and thigh and calf skinfold measurements.

A summary of the anthropometrical changes of the *centre and goal players* which occurred during the season was presented in Table 4.22 (p 174). Their anthropometrical data (weight, thigh and calf skinfold measurements) varied significantly. The average weight and thigh skinfold measurement of the centre players increased, while the calf skinfold measurement decreased significantly. Among the goal players, significant differences were identified with the weight, BMI, fat percentage and with the subscapular, supraspinal, abdominal, and thigh skinfold measurements. The anthropometry of the *A- and B-grade players* was set out in Table 4.24 (p 179). The data of the A- and B-grade players correlate with the results of the total group. Practically significant increases occurred with regard to the weight, BMI, fat percentage and the subscapular and thigh skinfold measurements. The weight and thigh skinfold measurement of the B-grade players increased significantly.

The anthropometry of the total group and the various groups (juniors and seniors, centre and goal players, A- and B-grade players) became more unacceptable during the season, and although existing literature did not offer explanations for these occurrences, it could be the result of inadequate exercise regimes to increase the netball players' muscle tissue and decrease their body fat during the season.

- **Physical/motor abilities**

Thirdly, the results of the physical/motor ability tests for the *total group* were presented (Table 4.18, p 164). Practically significant differences were identified in terms of all three physical motor tests (agility, balance and explosive power). The agility and balance of the total group improved significantly. However, a practically significant decrease in performance occurred with the explosive power test. The physical/motor data for the *juniors and seniors* (Table 4.20, p 168), *centre and goal players* (Table 4.22, p 174), as well as the *A- and B-grade players* (Table 4.24, p 179) was analysed and presented similar results than the total group, in other words, practical significant improvements in agility and balance were identified with practical significant decreases in their explosive power abilities.

According to literature, the physical/motor abilities could improve during the season by means of adequate exercise regimes; therefore it is concluded that the existing programme included effective exercises to improve the agility and balance of the total group and the different groups (juniors and seniors, centre and goal players, A- and B-grade players) but not to maintain and enhance their explosive power abilities.

5.3.4. A summary of the results of the injury incidences

The overall injury incidence (7.63 injuries/1000 player-hours) of the total group of netball players in this study was higher than the injury incidences of existing studies on netball (Ekstrand & Tropp, 1990).

The reasons for this high injury incidence could be the numerous biomechanical deviations, unacceptable anthropometry and poor physical/motor abilities that were identified among the NWU Netball Club players who participated in this study.

When the injury incidences of the three groups (juniors and seniors; centre and goal players; A- and B-grade players) were compared, it was evident that the seniors, centre players and A-grade players had more injuries/1000 player-hours (injury incidence) than their counterparts. The groups (seniors: 9.02; centre players: 8.51; and A-grade players: 9.16) with higher injury incidences presented with more biomechanical deviations than the groups with less injuries/1000 player-hours (juniors: 6.97; goal players: 6.76; and B-grade players: 6.62). This phenomenon correlates with existing literature (Table 4.25, p 190).

5.4. CONCLUSIONS OF THE STUDY

Aim 1: To determine the physical profiles of club netball players from the North-West University (NWU) aged between 18 and 23 years, with reference to the biomechanics, anthropometric measurements and motor abilities (balance, agility and explosive power).

A physical profile of every NWU Netball Club player (aged between 18 and 23 years) was documented. The parameters, namely biomechanics, anthropometry and physical/motor abilities were included in the physical profiles because numerous studies on netball stress the effects of these parameters on the performance of a netball player and the effect it could have on a player's probability for injuries.

The test results of the second testing occasion were in many instances similar to the data obtained during the first testing occasion, except with regard to the balance and explosive power test results. The physical profile (biomechanics, anthropometry and physical/motor abilities) of the total group of netball players correlates with the profiles of the juniors and seniors; centre and goal players; and the A- and B-grade players. Therefore the physical profile of the total group is presented. The physical profiles of the NWU Netball Club players between the ages of 18 and 23 years are as follows:

- *Biomechanics of the total group (juniors and seniors; centre and goal players; A- and B-grade players):*

The physical profiles compiled during the first testing occasion identified biomechanical deviations for the lower limb region, such as ITB and iliopsoas tightness, tilted patella with asymmetrical patella height, rear foot pronation, callus plantar aspect with a flat arch, and with valgus, rotation or deviation of their toes (Table 4.1); the pelvic girdle region presented with excessive leg length discrepancies, asymmetries at the PSIS, ASIS, pelvic ramis as well as asymmetrical pelvic position; the assessment of the spinal region indicated that most of the netball players presented with a hyperlordotic lumbar curve. In the other tests conducted in the spinal region and with neurodynamics, the majority of the participants tended to achieve ideal values. The results of the second biomechanical analysis added tight quadriceps and neural immobility, meaning that the biomechanical deviations increased during the season (Table 4.9, p 129).

The test results of testing occasion one and two for the total group are summarised in Table 4.1 (p 102) and Table 4.9 (p 129). As mentioned above, similar biomechanical deviations were identified among the juniors and seniors, centre and goal players as well as among the A- and B-grade players. These biomechanical deviations which were identified among the netball players correlate with studies conducted on sport injuries, including netball injuries (Arnheim & Prentice, 2000; Brukner & Khan, 2001; Bell-Jenje & Bourne, 2003; Kendall *et al.*, 1993; Fuller & Drawer, 2004; Rossouw & Rossouw, 2003). Venter *et al.* (2005) determined the physical profiles of provincial netball players but did not include a biomechanical assessment. No similar studies were found and thus this study is considered as the first research attempt to compile the biomechanical profiles of club netball players.

These biomechanical deviations could be ascribed to a lack of conditioning exercises to improve and maintain the netball players' joint symmetry, flexibility, and core stability, in other words biomechanics, prior and during the season.

- *Anthropometry of the total group; juniors and seniors; centre and goal players; A- and B-grade players:*

The anthropometry status of the group in total presented an ideal BMI during test one and two, with above-average fat percentages. The anthropometry for the different groups (juniors and seniors; centre and goal players; and A- and B-grade players) fell in the same categories as for the total group; in other words the BMI was considered ideal and their fat percentages above average and therefore unacceptable (Table 4.2, p 105; Table 4.10, p 132). Venter *et al.* (2005) applied a different formula for determining the fat percentages, which makes it difficult to compare results. No other studies conducted on the anthropometry of netball players could be found during the literature review.

- *Physical/motor abilities of the total group; juniors and seniors; centre and goal players; A- and B-grade players:*

The statistics for physical/motor abilities reported an average value for agility with the first and second testing occasion. The netball players scored an unacceptable mean value for the balance test during the first testing occasion but presented with an acceptable average in the second batch of tests. The final motor ability test, namely explosive leg power, yielded an acceptable average during the first testing occasion (Table 4.2, p 105), but the second testing occasion reported a decrease in performance, resulting in an unacceptable average for explosive power (Table 4.10, p 132). The different groups (juniors and seniors; centre and goal players; and A- and B-grade players) presented with similar occurrences as the total group of netball players for the first and second physical/motor tests, and therefore the results will not be repeated.

The increases in physical/motor abilities (agility and balance) during the season correlate with literature, which found that physical/motor abilities could improve during a season with the correct exercise regimes, although no reasons are offered for the decrease in explosive power. The decrease in performance could imply that the training programme did not include adequate plyometric exercises to maintain and enhance the players' explosive power. Venter *et al.* (2005) compiled physical profiles of provincial netball players but applied different testing protocols for agility, balance and explosive power, which complicates the comparison of test results with this study.

In conclusion; the physical profiles of club netball players from the NWU (aged between 18 and 23 years) with reference to their biomechanics, anthropometric measurements and physical/motor abilities (agility, balance and explosive power) were documented and therefore the primary aim of this study was met.

Aim 2: To identify biomechanical variables, anthropometrical components and physical/motor abilities (agility, balance and explosive power) that could contribute to musculoskeletal injuries of netball players between the ages of 18 and 23 years at the Netball Club of the NWU.

The parameters, namely biomechanics, anthropometry and physical/motor abilities, were assessed and documented by means of two testing occasions during which the physical profiles of the NWU Netball Club players were determined (aim 1). The netball injuries among the players were monitored throughout the season by means of a weekly "screening" clinic every Monday. The injury incidence for the total group of netball players revealed a higher prevalence than previous studies on netball players.

The reasons for this higher injury incidence could be the numerous biomechanical deviations which were identified among the netball players (see aim 1).

No similar studies were found and thus this study is considered as the first research attempt to compile the biomechanical profiles of club netball players and relate their physical shortcomings to the netball injuries which occurred during the season.

Other reasons for the high injury rate for the total group could be the results of poor anthropometry and relatively average physical/motor abilities, which presented during the assessments. The average BMI of the group was considered ideal, with an unacceptable above-average fat percentage (Table 4.2; Table 4.10). For the physical/motor tests during testing occasion one, the total group presented with average agility and explosive power abilities but with poor balance. During the second testing occasion, the averages for agility and balance were considered acceptable, but the explosive power abilities were below average (Table 4.2; Table 4.10). These inadequate physical/motor abilities could have contributed to the netball players' injuries. Literature emphasises that alterations of or shortcomings with regard to any of these parameters (biomechanics, anthropometry and physical/motor abilities) could make the netball player more susceptible to traumatic and overuse injuries.

The comparison of the injury incidences of the different groups (juniors and seniors; centre and goal players; and A- and B-grade players) indicated that the groups (seniors, centre players and A-grade players) which presented with more biomechanical stressors, also presented with more injuries during the season (higher injury incidences) than their counterparts (juniors, goal players and B-grade players) which performed better with the biomechanical assessments. In many instances, the anthropometry and physical/motor abilities did not correlate with the higher injury incidences of the seniors, centre players and A-grade players; hence, these three groups presented with higher injury incidences than their counterparts (juniors, goal players and B-grade players) but performed better with regard to the anthropometry assessments and the physical/motor tests.

Therefore, the conclusion could be made that netball players with more biomechanical deviations sustain more injuries.

This finding correlates with findings in the existing literature. Therefore to conclude; the shortcomings in the netball players' physical profiles (biomechanical, anthropometry and physical/motor abilities) which could have contributed to the occurrences of musculoskeletal injuries were identified and therefore the secondary aim of this study was reached.

5.5. RECOMMENDATIONS

Prior to and during the netball season, coaches should facilitate "screening" occasions during which the physical profile of every netball player is determined. This should involve a biomechanical analysis, anthropometrical assessment and physical/motor tests (agility, balance and explosive power). The multidisciplinary team must apply testing protocols to address their needs and therefore they could apply the same tests performed in this study or those in other applicable studies (Venter *et al.,* 2005; Elphinston & Hardman, 2006; Young *et al.*, 2002). These "screening" occasions must include parameters which are essential for a netball player to perform her best during a game and to decrease her probability for injuries. The results of these "screening" occasions could be compared to the data of this study to determine whether the results correlate or differ with the findings of this study.

Every netball player must receive an individualistic conditioning programme which addresses the shortcomings identified during the "screening" procedures. The players ought to start following this programme 6 weeks prior to the start of the season to ensure improvements of their shortcomings at the start of the netball season. Exercise Pro (2004) compiled a collection of extensive rehabilitation exercises which could be applied in the conditioning programme to address the identified shortcomings.

5.5.1. Shortcomings of this study

- Post-season testing of many players did not realise, due to unforeseen circumstances.

This negatively affected the data of the second testing occasion. The participation of an identical group in testing occasions one and two could have presented more reliable results. More attention should be paid to communication between researchers, individual coaches and players regarding the test dates and player commitment.

5.5.2. Recommendations for further research

Research should be undertaken to:

1) Conduct a study which incorporates a conditioning programme which addresses a netball player's biomechanical, anthropometry and physical/motor abilities (agility, balance and explosive power), and to determine the effects of the programme on the netball player's physical profile and deficiencies, over a period of six weeks.

2) Create a cost-effective and more extensive (more tests) "screening" protocol for the multidisciplinary team (coach, physiotherapist and biokineticist) to be performed pre- and post-season, to identify shortcomings among the netball players. The more tests included in the testing occasions, the more accurate the physical profiles will be; therefore a biomechanical assessment, anthropmetry analysis and physical/motor tests to determine the netball player's agility, balance, explosive power, strength, speed and endurance, must be included.

This study succeeded in determining the physical profiles of North-West University Netball Club players aged between 18 and 23 years, with reference to their biomechanics, anthropometric measurements and physical/motor abilities (balance, agility and explosive power). This study also found a correlation between the players' physical profiles (biomechanics, anthropometry and physical/motor abilities) and their musculoskeletal injuries which occurred during the season.

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ANNEXURE A

INFORMED CONSENT FORM

DEEL 1: Algemene Projekinligting

Die onderstaande gedeelte verskaf aan u as deelnemer aan die projek meer inligting, sodat u 'n ingeligte besluit kan maak oor u vrywillige deelname, al dan nie.

1. **Titel van die Projek:**

   Biomechanical, anthropometrical and physical profile of the North West University club netball players and the relationship to musculoskeletal injuries

2. **Instelling / Skool / Vakgroep / Instituut:**

NWU Netbal Klub

3. **Name & kontakbesonderhede van projekleiers:**

	Kontakpersoon	**Geneesheer**	**Projekleier**	**Toesighouer**
Titel, naam & van	MA Ferreira	Geen	Prof M Spamer	Dr JHB Hattingh
Vollename		Geen	Manie	Johannes Hendrikus Bernhard
Funksie in Projek	Navorser	Geen	Projekleier	Toesighouer
Kwalifikasies		Geen	Prof in opvoedkunde	Ph.D. Fisioterapie
Profess. Registr.		Geen	Tik hier	HPCSA PT 342232
Telefoon (tuis)	Geen	Geen		
Telefoon (werk)	018 297 7657	Geen	018 299 1760	018 297 7657
Selfoon	083 655 5846	Geen		
Noodnommer	083 655 5846	Geen		
Posadres	Bus 19 630 Potchefstroom 2520			

4. **U is genader om as deel te neem aan hierdie projek en mag nou die volgende vrae hê:**

   a. Wat is die gestelde vereistes waaraan persone moet voldoen om aan die projek te mag deelneem? Waarom en hoe is ek gekies?

   U moet 'n speller wees van die NWU netbal klub

   b. Wat is die doel met hierdie projek?

   To determine the physical profiles of club netball players aged between 18 – 23 years from the North-West University, with reference to the biomechanics, anthropometric measurements and motor abilities (balance, agility and explosive power).

To identify biomechanical variables, anthropometrical components and motor abilities (agility, balance and explosive power) that could contribute to musculoskeletal injuries of netball players between the ages of 18 – 23 years at the Netball Club of the North-West University.

c. Wat sal van my as deelnemer verwag word? Aan watter intervensies / prosedures sal ek moet deelneem? Wat presies sal dit alles behels?:

Moet aan die toetse (biomeganika; antropometrie; ratsheid; balans; plofkrag) deel neem, 7 of 10 Mrt 2007 en 25 Aug 2007 asook om die klinieke by te woon elke Maandag 17:30 indien u presenter met 'n besering.

d. Wat is die potensiële ongerief en/of potensiële gevare en/of potensiële permanente nagevolge (hoe gering ook al) wat deelname aan hierdie projek inhou?

Slegs 'n moontlike val of gly insident tydens die uitvoering van die balans-, ratsheid- of plofkrag toetse.

e. Watter voorsorgmaatreëls is getref om my as deelnemer te beskerm?

Deelnemers word versoek om gepaste skoene, om moontlike gly insidente te voorkom, aan te trek tydens toets prosedures en die fasiliteite waar die toetse uitgevoer word is veilig en geskik (geen gate of ongelyke oppervlaktes). Die deelnemer sal versoek word om voor motoriese toetse voldoende op te warm.

f. Hoe lank word voorsien dat ek by die projek betrokke sal wees (bv. aantal en duur van besoeke)?

Besoek	Datum	Tyd In	Tyd Uit	Duur
1	07/03/07 OF 10/03/07	08 – 13:00	1 h later	1 h
2	25/08/07	08 – 16:00	1 h later	1 h

Totale Duur Betrokke: 2 ure

g. Watter direkte voordele kan ek uit die projek verwag? Watter vergoeding (monetêr of dienste) kan ek vir my deelname verwag?

Na verloop van die studie ontvang u die toets resultate asook 'n af-seisoen rehabilitasie program wat u biomeganiese tekortkominge aanspreek.

h. Watter potensiële algemene voordele is daar vir die breër gemeenskap wat uit die projek mag voortspruit?

Die tekortkominge van die spelers word ge-identifiseer, dus in die af seisoen kan spelers/afrigters op hierdie areas konsentreer en sodoende die moontlikheid van beserings verminder asook prestasie bevorder.

i. Hoe sal die bevindings van die projek (algemene resultate, asook individueel oor myself) beskikbaar gestel word of aan my oorgedra word?

'n Verslag sal aan u oorgehandig word

j. Watter maatreëls is getref om my gegewens vertroulik te hanteer en te bewaar?

Slegs persone wat deel is van die navorsings groep het toegang tot die data

k. Watter beperkings is daar om die vertroulikheid van data te verseker?

Geen

l. Indien van toepassing, wat is die beleid vir die hantering van resultate van genetiese toetse en familiële genetiese inligting om die vertroulikheid daarvan te verseker?

NVT

m. Indien van toepassing, waar geneesmiddels getoets word en as dit dan effektief sal blyk te wees, sal dit dan na die projek steeds aan my beskikbaar gestel word, of sal ek self daarvoor moet betaal?

NVT

n. Indien van toepassing, hoe gaan biologiese monsters wat nie dadelik gebruik gaan word nie vernietig, gestoor of later gebruik word?

NVT

o. Hoe sal ek en ander deelnemers of die gemeenskap deel in enige toekomstige kommersiële gebruik van die data se winste?

Die bestaande oefen program kan aangepas word nav die tekortkominge wat tydens die studie ge-identifiseer is, sodoende kan die moontlikhede vir besering verminder word en prestasie bevorder word.

p. Indien daar enige nadelinge effekte van die projek op my is, tot watter mate is gratis behandeling beskikbaar en is daar voldoende fondse om die behandeling te finansier? Indien daar enige besering, mediese ongeskiktheid of dood volg uit deelname aan die projek, tot watter mate sal die ek, my afhanklikes en/of naasbestaandes vergoed word?

Geen nadelige effekte

As projekleier bevestig ek aan deelnemers dat die bogenoemde inligting volledig en korrek is.

2	0	0	7	-	0	7	-	0	5
c	c	y	y		m	m		d	D

Handtekening van Projekleier **Datum**

Onderteken te Potchefstroom

Plek van Ondertekening

DEEL 2: Algemene Beginsels

Aan die ondertekenaar van die toestemming vervat in Deel 3 van hierdie dokument:

U word uitgenooi om deel te neem aan die navorsingsprojek soos beskryf in Deel 1 van hierdie ingeligte toestemmingsvorm. Dit is belangrik dat u ook die volgende algemene beginsels, wat op alle deelnemers aan ons navorsingsprojekte van toepassing is, sal lees en verstaan:

1. Deelname aan die projek is heeltemal vrywillig en geen druk, hoe subtiel ook al, mag op u geplaas word om deel te neem nie.
2. Dit is moontlik dat u persoonlik nie enige voordeel uit u deelname aan die projek sal trek nie, alhoewel die kennis wat deur middel van die projek opgedoen mag word vir ander persone of gemeenskappe tot voordeel mag strek.
3. Dit staan u vry om uself te enige tyd, sonder opgawe van redes, aan die projek te onttrek en u sal op geen wyse daardeur benadeel word nie. U mag ook versoek dat u data nie verder in die projek gebruik mag word nie. U word egter vriendelik versoek om nie sonder deeglike besinning aan die projek te onttrek nie, aangesien dit o.a. die statistiese betroubaarheid van die projek nadelig mag beïnvloed.
4. Deur toe te stem tot deelname aan die projek, gee u ook toestemming dat die data wat gegenereer sal word deur die navorsers vir wetenskaplike doeleindes na goeddunke gebruik kan word, met die voorbehoud dat dit vertroulik sal wees en dat u naam nie sonder u toestemming met enige van die data verbind sal word nie.
5. U sal op versoek toegang tot u eie data kan verkry, tensy die Etiekkomitee tydelike nie-bekendmaking goedgekeur het (in laasgenoemde geval sal die redes in Deel 1 aan u verduidelik wees).
6. 'n Samevatting van die aard van die projek, die potensiële risiko's, faktore wat moontlik ongerief of ongemak vir u kan veroorsaak, die voordele wat verwag kan word en die bekende en/of waarskynlike permanente nagevolge wat u deelname aan die projek op u as deelnemer mag hê, word in Deel 1 hiervan vir u uiteengesit.
7. U word aangemoedig om op enige stadium enige vrae wat u in verband met die projek en die prosedures in verband daarmee mag hê aan die projekleier of medewerkers te stel, wat u navrae graag sal beantwoord. Hulle sal ook die projek volledig met u bespreek.
8. Indien u minderjarig is, is die skriftelike toestemming van u ouer of wettige voog nodig alvorens u aan hierdie projek mag deelneem asook u (skriftelik indien moontlik) vrywillige instemming om deel te neem – geen dwang mag op u geplaas word nie.
9. Die projekdoelwitte kom altyd sekondêr tot u welstand en daar sal altyd in u beste belang bo dié van die projek opgetree word.
10. Geen projek mag aanvang neem alvorens dit deur die etiekkomitee goedgekeur is nie. Die projekleier moet verder enige nadelige effekte wat tydens die uitvoering van die projek ervaar word volledig en onverwyld aan die voorsitter van die Etiekkomitee rapporteer. Indien daar enige onvoorsiene ernstige nadelige effekte tydens die

    projek waargeneem word, mag dit nodig wees dat die projek onmiddellik getermineer word.

DEEL 3: Toestemming

Titel van die Projek:

Biomechanical, anthropometrical and physical profile of the North West University club netball players and the relationship to musculoskeletal injuries

Ek, die ondergetekende

Vollename & Van

het die voorafgaande gegewens in verband met die projek, soos bespreek in ***Deel 1*** en ***Deel 2*** van hierdie ingeligte toestemmingsvorm, gelees en ook die mondelinge weergawe daarvan aangehoor en ek verklaar dat ek dit verstaan. Ek het ook elke bladsy van ***Deel 1*** en ***Deel 2*** geparafeer. Ek was die geleentheid gegun om tersaaklike aspekte van die projek met die projekleier te bespreek en ek verklaar hiermee dat ek vrywillig aan die projek deelneem.

2	0	0		-			-		
c	c	y	Y		m	m		d	d

Handtekening van Deelnemer **Datum**

Onderteken te

Plek van Ondertekening

GETUIES

2	0	0		-			-		
c	c	y	y		m	m		d	d

Handtekening van Getuie 1 **Datum**

Onderteken te

Plek van Ondertekening

2	0	0		-			-		
c	c	y	y		m	m		d	d

Handtekening van Getuie 2 **Datum**

Onderteken te

Plek van Ondertekening

Wettige Ouer / Voog

Vir alle navorsing en intervensies op deelnemers onder die ouderdom van 21 jaar is die skriftelike gevolmagtigde toestemming van die ouer of wettige voog nodig.

Hiermee gee ek

Vollename & Van *(ouer of wettige voog)* **Verwantskap** *(ouer of wettige voog)*

van die deelnemer hierbo genoem gevolmagtigde toestemming dat hy/sy aan hierdie projek mag deelneem en ek vrywaar hiermee die Universiteit asook enige werknemer of student van die Universiteit, van enige aanspreeklikheid van enige nadelige effek wat in die loop van die projek mag ontstaan, tensy sodanige besering, skade of dood veroorsaak is deur die nalatigheid van die Universiteit, sy personeel en/of sy studente. Ek verklaar verder dat ek die voorafgaande gegewens in verband met die projek, soos bespreek in ***Deel 1*** en ***Deel 2*** van hierdie ingeligte toestemmingsvorm, gelees en ook die mondelinge weergawe daarvan aangehoor en ek verklaar dat ek dit verstaan. Ek het ook elke bladsy van ***Deel 1*** en ***Deel 2*** geparafeer. Ek was die geleentheid gegun om tersaaklike aspekte van die projek met die projekleier te bespreek.

2	0	0		-			-		
c	c	y	y		m	m		d	d

Handtekening van Wetlike Ouer/Voog **Datum**

Onderteken te

Plek van Ondertekening

Hiermee gee ek

	Vollename & Van *(minderjaringe deelnemer)*	**Verwantskap** *(deelnemer)*

minderjarige kind van bogenoemde ouer/voog my vrywillige instemming om deel te neem aan die projek en verklaar ek dat ek verstaan wat die deelname behels.

2	0	0		-			-		
c	c	y	y		m	m		d	d

Handtekening van Minderjarige Deelnemer **Datum**

Onderteken te

Plek van Ondertekening

ANNEXURE B

INJURY QUESTIONNAIRE

1. Injuries:

Body part	Date	Current	Previous	L /R	Mechanism of injury	Diagnosis (dr/physio)	Treatment	Rehab	Amount of resting days	Recovery
Toes										
Ankle										
Calve										
Shins										
Knee										
Thigh										
Hamstring										
Groin										
Hip										
Buttock										
Lower back										
Upper back										
Neck										
Shoulder										
Elbow										
Wrist										
Hand										
Fingers										

2. Do you wear any protective braces or taping? Why (prevention / extra stability after partial recovered injury)?

ANNEXURE C

INJURY REPORT FORM

Name & Surname:

- Mechanism of injury:

- Diagnosis of injury:

- Severity of injury:
- Type of injury:
- Time off from training / playing games:
- Recommended treatment:

- Instruction to player:

ANNEXURE D: BIOMECHANICAL ASSESSMENT FORM

DATE		GROUP	

PERSONAL INFORMATION:				
NAME		AGE	WEIGHT	LENGTH
SPORT		TEAM LEVEL		

DOMINANT HAND	LEFT / RIGHT	DOMINANT FOOT	LEFT / RIGHT
POSITION			

MEDICAL HISTORY	
PRESENT	PAST

BIOMECHANICS

LOWER LIMB

AREA	**GRADE**				**GRADE DETAIL**
	L	**R**			
TA			*1*:30° + / *2*:20° - 30° / *3*:20°		
ITB			*1*:12H00/*2*:11H55 or 12H05/ *3*:11H50 or 12H10		
QUAD			*1*:50° + / *2*:30° - 50° / *3*:30° -		
ILLIOPSOAS			*1*:30° + / *2*:15° - 30° / *3*:15° -		

ADDUCTOR		*1*:120°+/*2*:100°-120°/*3*:100°-	
HIP INTERN ROT		*1*:30° + / *2*:15° - 30° / *3*:15° -	
HIP EXT ROT		*1*:90° + / *2*:60° - 90° / *3*:60° -	
KNEE Q-ANGLE		*1*:9° - / *2*:9° +	
KNEE SQUINT		*1*:9° - / *2*:9° +	
KNEE TILT		*1*:0° - / *2*:0° +	
KNEE HEIGHT		*1*:Normal / *2*:Anomalies	
VMO		*1*:Normal / *2*:Anomalies	
Detail Anomalies:			

ANNEXURE D
(continue)

AREA	GRADE		GRADE DETAIL
	L	R	
FOOT LONGITUDINAL			*1*:Flat / *2*:Normal / *3*:High
FORE FOOT			*1*:Normal / *2*:Anomalies
Detail Anomalies:			
REAR FOOT STANDING			*1*:0°-9° / *2*:0°- / *3*:9°+
REAR FOOT LYING			*1*:0°-9° / *2*:0°- / *3*:9°+
ASIS			*1*:L=R / *2*:Discrepancy
PSIS			*1*:L=R / *2*:Discrepancy
RAMI			*1*:L=R / *2*:Discrepancy
CLEFT			*1*:L=R / *2*:Discrepancy
PELVIS BILATERAL POSITION			*1*:2-3cm / *2*:3-5cm / *3*:5cm+
SPINAL			
THORACO LUMBAR FASCIA			*1*:2cm / *2*:4cm / *3*:4cm+
SACRUM RHYTHM			*1*:L=R / *2*:Aberrant
EXTENSION			*1*:Easy ROM / *2*:Limited ROM / *3*:Hyper
FLEXION			*1*:Easy ROM / *2*:Limited ROM / *3*:Hyper
ROTATION			*1*:Easy ROM / *2*:Limited ROM / *3*:Hyper
SIDE FLEXION			*1*:Easy ROM / *2*:Limited ROM / *3*:Hyper
CORONAL MID			
HEAD POSITION			*1*:Normal / *2*:Anomalies
CERVICAL			*1*:Normal / *2*:Anomalies
THORASIC			*1*:Normal / *2*:Anomalies
LUMBAR			*1*:Normal / *2*:Anomalies
Detail Anomalies:			

ANNEXURE D
(continue)

AREA	GRADE		GRADE DETAIL
	L	R	
SAGITAL MID			
HEAD POSITION			*1*:Normal / *2*:Anomalies
CERVICAL			*1*:Normal / *2*:Anomalies
THORASIC			*1*:Normal / *2*:Anomalies
LUMBAR			*1*:Normal / *2*:Anomalies
Detail Anomalies:			
NEUROLOGICAL			
STRAIGHT LEG RAISE			*1*:90° / *2*:70°+ / *3*:70°-
UPPER LIMB TENSION TEST			*1*:180°-0° No tension / *2*:180°-0° With tension / *3*:180°-0°+
L4			*1*:Full ROM No tension/*2*:Full ROM With tension/*3*:No touching
SLUMP			
COMMENTS			

ANNEXURE E

ANTHROPOMETRY ASSESSMENT FORM

Nr	Name & Surname	TRICEP			SUBSCAPULAR			SUPRASPINAL		
		1	2	3	1	2	3	1	2	3
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										

Nr	Name & Surname	ABDOMINAL			THIGH			CALF		
		1	2	3	1	2	3	1	2	3
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										

Nr	Name & Surname	WEIGHT	LENGTH
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

ANNEXURE F
PHYSICAL/MOTOR ABILITIES

1. AGILITY:

Nr	Name & Surname	Attempt 1	Attempt 2	Average
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

2. BALANCE:

Nr	Name & Surname	Attempt 1	Attempt 2	Average
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

3. EXPLOSIVE POWER:

Nr	Name & Surname	Attempt 1	Attempt 2	Average
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				