An Investigation into Reference Values for Ankle Muscle Strength Using the Cybex Norm Isokinetic Dynamometer

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My ankle story
Dedicated to Rhian, Lydia and Alice
With Love

Abstract

Introduction and purpose

The importance of measuring ankle muscle strength (AMS) has been demonstrated in a variety of research, clinical and sporting areas. Isokinetic dynamometry is a common method of AMS measurement and it has been demonstrated that the Cybex Norm isokinetic dynamometer is a reliable and valid measure of AMS. Reference values are commonly used to contextualise the understanding of measured values, however no AMS reference values using the Cybex Norm exist.

Design / methodology

A systematic review identified sixty papers which used the Cybex Norm to measure AMS. From those papers eight common methodological variables were identified and a protocol was produced based on these. It was demonstrated that the protocol was reliable and was subsequently used to test 100 participants.

Results

A stepwise linear regression analysis based on height, body mass, age, gender and shoe size was performed to produce a predictive model for each of the eight measures of AMS. The reference models were validated by accurately predicting AMS in a validation group. Furthermore, a t-test showed there was no statistical difference between the predicted and actual measures of AMS.

The validated equations were then used to predict AMS in elite football players. The results indicated that concentric and eccentric eversion AMS was higher than the predicted normal range in the footballers. All other measures were within the predicted range.

Applications / limitations

The limitations of the predicted values are in the absolute accuracy. Whilst the predictive equations have been validated for small groups, it is not possible to predict an individual's normal range. Further research into variables that predict AMS would enable a more accurate set of equations to be produced.

The eight reference value equations described could be used in a range of sporting and clinical settings. For example in examining relationships between AMS and both falling episodes and functional movement in the elderly as well as general ankle stability. A reference range could be used as an indicator of the effectiveness of intervention strategies and the effectiveness of rehabilitation. Where reduced strength is due to disease rather than injury an AMS reference range could inform on the progress of disease.

The research presented here has demonstrated the importance of eight different variables in terms of isokinetic testing of the ankle. It was concluded that all eight of these variables should be addressed when measuring isokinetic ankle strength and, furthermore, should be taken into consideration when comparing results.

Originality / value

This thesis has produced eight novel validated reference equations which can predict normal average AMS in groups of individuals using the Cybex Norm isokinetic dynamometer. These equations could aid the understanding of disease progression, injury, rehabilitation and athletic performance.

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Glossary of Abbreviations.

1RM – 1 rep max

AMS – ankle muscle strength

ANOVA – analysis of variance

CAI – chronic ankle instability

CI – confidence interval

con - concentric

DF – dorsiflexion

ecc - eccentric

EMG - electromyography

eve - eversion

FAI – functional ankle instability

ICC – intraclass correlation coefficient

inv - inversion

Nm – Newton meters

PF – plantar flexion

ROM – range of movement

RSD –residual standard deviation

SD – standard deviation

SE – standard error

SEM – standard error of measurement

VIF – Variance inflation factor

Glossary of Terms

Concentric and eccentric strength

Muscles can contract both concentrically and eccentrically. During a concentric contraction the muscle generates force as its length shortens. These movements are mainly propulsive for example the gastrocnemius and soleus muscles contract concentrically to generate a plantar flexion movement which pushes the body forward during the gait cycle. During an eccentric contraction the muscle generates force but the length of the muscle increases. This movement type has a breaking function for example the gastrocnemius and soleus muscles contract eccentrically when landing from a jump, slowing the body down and absorbing the impact.

Plantar flexion

Plantar flexion (PF) is brought about by contraction of the gastrocnemius and soleus muscles and to a lesser extent peroneus brevis and peroneus longus to produce downward movement of the forefoot centered around the talocrural joint.

Dorsiflexion

Dorsiflexion (DF) is produced by contraction of muscles whose tendons run into the foot anterior to the ankle joint. These include tibialis anterior as the prime mover as well as extensor digitorum longus and extensor hallucis longus. This is the antagonistic movement to PF around the talocrural joint.

Inversion

Inversion (inv) movement rotates the foot medially about the subtalar joint. This is brought about by contraction of the tibialis posterior and tibialis anterior

Eversion

Eversion (eve) movement rotates the foot laterally about the subtalar joint and is the antagonistic movement to inv. This movement is brought about by contraction of peroneus longus and peroneus brevis.

Within all four of these movements the muscles can act concentrically or eccentrically

Isokinetic test

A muscle contraction where the resistance is altered to produce a fixed speed throughout the range of movement (ROM)

Isometric test

A test in which the muscle / tendon complex length neither increases nor decreases.

Isotonic test

A test in which the external load is constant throughout the range of motion.

For further information on these terms refer to Tortora and Derrickson (2008).

Chapter 1

Introduction and research aims

1. Introduction

1.1 Reference Values

A frame of reference is necessary in order to fully understand the implications of a measurement. A common method of achieving this frame of reference is the use of reference values, also referred to as normal or normative values. These values represent the expected score or measurement for a given set of circumstances. A common example is dietary reference values that allow the comparison of actual calorie and nutrient intake to recommended values (Aranceta & Pérez-Rodrigo, 2012). In terms of ankle muscle strength (AMS), a reference value would indicate how much torque should be produced at the ankle in a given movement for a given population (Harbo, Brincks, & Andersen, 2011). Indeed, Kaminski and Hartsell (2002) observed with reference to AMS:

> "*A normative strength database is needed, consisting of values that will allow the clinician and researcher to make comparisons among studies and to develop rehabilitation goals and objectives*."
> (Kaminski & Hartsell, 2002) p403

If reference data sets are available then it is possible to quantify individual scores relative to their peers, from which deviations below 'normal' can be identified and response to interventions monitored.

1.2 The Importance of ankle muscle strength reference values

This thesis is specifically concerned with reference values for AMS. AMS is defined here as the torque production capability of the muscles that act across the ankle. There are a number of muscles which contribute to AMS and they can be grouped into physiological movements namely, plantar flexion (PF), dorsiflexion (DF), inversion (inv) and eversion (eve) strength (see Glossary of Terms (p.14) for definitions). The importance of measuring AMS has been demonstrated in a variety of research, clinical and sporting areas. These include investigating relationships between AMS and increased risk of falling (Rubenstein & Josephson, 2006) and mobility in terms of a sit to walk movement in the elderly (Dehail et al., 2007) and general ankle stability (Fox, Docherty, Schrader, & Applegate, 2008). Measurement of AMS has been suggested as a predictor of injury in athletic populations (Tsiokanos, Jamurtas, Kellis, & Kellis, 2002; Witchalls, Blanch, Waddington, & Adams, 2011) as well as an indicator of the effectiveness of intervention strategies (Li, Xu, & Hong, 2009) and the effectiveness of rehabilitation (Sekir, Yildiz, Hazneci, Ors, & Aydin, 2007). Where reduced strength is due to disease rather than injury measurement of AMS can indicate the progress of certain diseases (Schiottz-Christensen et al., 2001). The literature suggests that AMS plays a role in predicting and assessing severity of injury and disease as well as assessing the efficacy of rehabilitation and intervention measures. In order to quantify the severity of an injury or the effect of disease AMS reference values would be of benefit as they would demonstrate the difference between healthy and affected ankles. These reference values would also enable the determination of an appropriate rehabilitation strategy and possible prediction of future injury.

1.3 Measuring Ankle Strength

AMS can be measured using a number of different types of equipment isometrically, isotonically and isokinetically, concentrically and eccentrically (see Glossary of Terms (p.14) for definitions). Measurement of strength for each of these movement modes requires a different type of test. For example Andrews et al (1996) produced reference values for isometric strength in multiple muscle groups including ankle DF using a hand held dynamometer. Although this system has been shown to have good test-retest reliability (C. Y. Wang, Olson, & Protas, 2002) and good inter-rater reliability (Bohannon & Andrews, 1987) isometric muscle contractions are not representative of functional movement at the ankle. During an isometric contraction the muscle neither lengthens nor shortens. As the muscle produces torque in a fixed position any results are angle specific so the full ROM of the ankle is not easily tested. An isotonic contraction is a better representation of functional movement as, during an isotonic contraction, the joint moves full the full ROM with fixed resistance. A common isotonic test is the one rep max (1RM). However, a review by Kaminski and Hartsell (2002) concluded that 1RM data for AMS are scarce due to the small muscle groups involved and lack of available equipment for this type of measurement. The gold standard for testing muscle strength is considered to be isokinetic dynamometry and this is the preferred option of most clinical studies (Martin et al., 2006). A review by Caruso, Brown, and Tufano (2012) indicated that the reliability of isokinetic dynamometry as a whole was acceptable or better. The isokinetic contraction provides maximal torque data throughout the ROM as the resistance varies to match the torque produced. It has been demonstrated that the Cybex Norm isokinetic dynamometer is a reliable piece of equipment with which to measure strength at the ankle and so is suitable for use in determining AMS reference values.

The Cybex Norm can also be used to indicate strength impairment due to injury and, with subsequent testing, efficacy of a treatment programme and rate of recovery. Equally, the Cybex Norm can assess the extent of disease and be used to monitor the effect of an intervention.

1.4 Research Aims

A review of the literature suggested that reference values for the eight measures of AMS using the Cybex Norm Isokinetic Dynamometer do not exist. As such, one of the objectives of this thesis was to undertake a systematic review to identify all of the papers that have used the Cybex Norm to measure AMS. The systematic review found no papers which set out to produce reference values for AMS, furthermore, due to variations in the protocols used, reference values could not be produced by meta-analysis. In the absence of reference values the main body of this thesis is concerned with the production and testing of reference values for AMS. Specifically the following research aims were explored and empirically tested:

a. As there are a number of variables which need to be defined when measuring AMS, once the systematic review was complete, the first aim of this thesis was to develop a protocol for measuring AMS with each variable justified (Chapter 4). This included determining the effect of altering the angle at which the knee is fixed on AMS (Chapter 6).

b. As this protocol was to be used to take measurements of AMS from which reference values would be generated, the second objective was to ensure the protocol and the Cybex Norm were robust using a test re-test experimental design. (Chapter 7).

c. Using the justified and reliable protocol, the main aim of this thesis was to determine reference ranges for AMS collecting data and using a linear regression analysis to produce reference range equations (Chapter 8).

d. Previous research has indicated that there is variation in strength with variation in different anthropometric measurements, for example height, weight, age and gender. In the production of reference values knowledge of the factors which affect AMS are crucial. Thus, the data collected was also used to explore a fourth aim, the effect of variations in anthropometric measurements on AMS (Chapter 8).

e. Validated reference equations for AMS could have a range of clinical, rehabilitation and sporting applications. The fifth aim of this thesis was to demonstrate an application of the validated reference equations. (Chapter 9).

Before undertaking the experimentation which would address the aims of the thesis, it is first necessary to understand the rationale behind the need for AMS reference values. The following chapter addresses the literature relevant to this.

Chapter 2

Literature review

2. Literature Review

In order to fully understand the need for reference values for AMS, this chapter explores the usefulness of reference values alongside the importance of ankle muscle strength and the robustness of AMS testing using the Cybex Norm isokinetic dynamometer.

2.1 Reference Values

A review of the literature by Danneskiold-Samsøe et al (2009) noted a lack of reference values for strength. They subsequently tested muscle strength in 121 women and fifty-three men of mixed age to produce reference values for the wrist, elbow, shoulder, trunk, hip, knee and ankle using a Lido Active isokinetic dynamometer. These reference values have subsequently been used as a benchmark in several studies, thus demonstrating the importance of reference values. Eitzen et al. (2010) used the reference values produced by Danneskiold-Samsøe et al (2009) whilst demonstrating the efficacy of a five week post-surgery exercise programme on knee strength. They argued that the patients in their study had regained adequate muscle strength as their post-exercise programme torque measurements were similar to the reference values supplied by Danneskiold-Samsøe et al. (2009).

Harbo et al. (2011) stated that an evaluation of all major muscle groups both isometrically and isokinetically had not been performed before in the same population. They tested eighty-five females and ninety-three males between 15 years and 83 years old. They produced reference values for the hip, knee, ankle, shoulder, elbow and wrist using the Biodex System 3 PRO isokinetic dynamometer. Severinsen, Jakobsen, Overgaard, and Andersen (2011) then used knee strength reference values published by Harbo et al. (2011) to interpret severity of muscle impairment in chronic hemiparetic stroke patients. The reference values enabled the researchers to quantify the level of impairment, thus allowing for assessment of potential for resistance training in the rehabilitation programme. The same reference values have also been used in the assessment of taping to treat musculoskeletal injuries (Fratocchi et al., 2012) and to compare the joint torque in patients with a reverse shoulder prosthesis (Alta, Veeger, Janssen, & Willems, 2012).

2.2 Using AMS to predict injury

2.2.1 Predicting injury in older populations

Research suggests that falls in the elderly have multifactorial predisposing causes, one of which is AMS. This was demonstrated by Wolfson et al (1995) who compared concentric PF and DF between a group of seventeen older 'fallers' (nursing home residents, average age 84.6 years, who had two episodes of unexplained falls in the prior year) and an age and gender matched control group with no history of falls, also nursing home residents. They found reduced PF and DF strength in the fallers compared to the control. From this they concluded that strength is a major factor in balance, gait and the occurrence of falls. A systematic review by Moreland et al (2004) produced thirty studies from two databases that examined muscle weakness as a risk factor for falls in older adults. They concluded that lower extremity muscle strength including ankle DF should be assessed in elderly populations at risk of falls. This conclusion was supported by Rubenstein and Josephson (2006) who presented a review of evidence of falls and their prevention in elderly populations. They found that from sixteen studies examining multiple risk factors, lower extremity weakness was the most significant risk factor. Pijnappels, van der Burg, Reeves, and van Dieën (2008) also supported this conclusion, demonstrating a correlation between isometric ankle PF strength and fallers in an elderly population. Furthermore, Cattagni et al. (2014) concluded from testing 90 individuals aged from 18 to 90 years that measuring ankle torque could be used in clinical practice to identify potential fallers.

Elderly people who fall are associated with a high cost both in monetary terms and in quality of life. In the UK three million people aged over 65 years of age fall every year costing the NHS £2.3billion. The most common injury suffered when falling is a fractured hip. Half of the people with this injury never regain their former level of function and 20% will die within three months (AgeUK, 2011). The research described here suggests AMS strength is a significant risk factor for falls in older populations. While there are other fall risk factors, the evidence presented here suggests treating AMS deficits could help retain quality of life and save money. An appropriate reference value for AMS could inform as to who is at risk and where interventions should be targeted.

2.2.2 Predicting injury in younger populations

A key concept in predicting ankle injury is determining the physiological abnormalities that predispose an individual to an injury and then differentiating these abnormalities from those that are caused by the actual injury. If muscle weakness, for example, is the cause of ankle injury then reference values indicating what normal muscle strength should be could be used to predict and prevent injury. Research has indicated that previous injury is a significant predictor of future injury although the reasons for this are not clear (Brinkman & Evans, 2011). It has been postulated that subsequent injury is a result of physiological weakness caused by the initial injury (Kaminski & Hartsell, 2002). In terms of AMS several studies have set out to determine if diminished peak torque can predict injury. If this was the case improving strength could prevent injury in healthy individuals or prevent re-injury in those with existing conditions. A number of literature reviews examining the relationship between ankle strength and injury within the literature have, however, produced apparently contradictory results.

An example of this apparent contradiction was demonstrated in a literature review by Beynnon, Murphy, and Alosa (2002). They investigated predictive factors for lateral ankle sprains and concluded that the literature was divided as to whether muscle strength was a predictive factor. This was, however, based on only two papers, both of which they published. The first paper by Baumhauer, Alosa, Renström, Trevino, and Beynnon (1995) examined twenty-one college athletes before and after one athletic season to determine potential risk factors for ankle ligament injuries. They found that higher PF torque as well as higher inv/eve ratios and lower DF/PF strength ratios may predispose an individual to injury. It may not be that the high PF torque is directly related to injury susceptibility, rather that higher PF torque is related to higher sports participation rates, which then increase the likelihood of injury. The second paper by Beynnon, Renström, Alosa, Baumhauer, and Vacek (2001) investigated the predictive value of ankle strength in ankle ligament injuries in college athletes again, but using a larger cohort of 118 students. They found no correlation between any of the eight measures of AMS or AMS strength ratios and ankle injury. However, from the credible sample size of 118, the injury rate remained low. Thirteen women and seven men were injured which limits the statistical power of the findings. They attributed the difference in findings to different methods of statistical analysis used in each study. The effect of using different statistical analysis methods will be examined in Chapter 4. Thus, these papers suggest a lack of clarity regarding the effect of AMS in predicting injury.

A review by de Noronha, Refshauge, Herbert, and Kilbreath (2006) searched four databases for papers which measured intrinsic predictors of injury and then monitored injury occurrence. Their search revealed twenty-one studies which met their search criteria. They concluded that none of these studies provided evidence that voluntary ankle strength was predictive of future injury. It is of interest to note that this review considered the previously mentioned paper by Baumhauer et al. (1995) as well as two papers by (Willems et al., 2005a; Willems et al., 2005b) all of which demonstrated a relationship between AMS and future ankle injury. However, these findings were discounted by de Noronha et al. (2006) as the papers did not provide data on predictive accuracy.

A systematic review with meta-analysis by Witchalls et al. (2011) searched five relevant databases for papers which examined pre-existing deficits in ankle structure and function related to future ankle injury in previously healthy ankles. The meta-analysis combined the results of the five papers that examined AMS. The results indicated that reduced eccentric eve strength was associated with increased risk of ankle injury. Based on the combined data from the papers by Willems et al (Willems et al., 2005a; Willems et al., 2005b) Witchalls et al (2011) also concluded increased PF strength was associated with future ankle injury in agreement with Baumhauer et al. (1995). It is interesting to note that these papers were included in the review by Witchalls et al. (2011) whereas they were not in the review by Noronha et al (2006). This inclusion would account for the differences in conclusions between the two reviews. Furthermore, neither of the papers by Willems et al (Willems et al., 2005a; Willems et al., 2005b) individually found concentric PF strength to be predictive of future injury. It was only when the data was combined in the meta-analysis that the relationship was revealed. Although the type of ankle injury being investigated was different, an experiment by Mahieu, Witvrouw, Stevens, Van Tiggelen, and Roget (2006) also indicated a relationship between PF and ankle injury. They concluded from examining sixty-nine army recruits that reduced PF strength was a significant predictor of Achilles overuse injury. This further supports the need for reference values for AMS as this conclusion suggests they could be used to predict and prevent Achilles overuse injuries.

Both studies by Willems et al (Willems et al., 2005a; Willems et al., 2005b) found increased concentric DF strength to predict future injury. These results did not influence the conclusions of the review as the significance of the ankle strength was only apparent after a regression analysis. There was no significant difference between injured and uninjured ankles in the populations tested. The review by Witchalls et al. (2011) also indicated that the large effect size of the eve/inv ratio, whilst not significant (P = 0.052) is worthy of future study.

The apparent disagreement between these studies indicates that any investigation into the relationship between ankle strength and injury should use all the data available as well as appropriate statistical analysis techniques. Causes of ankle injury are likely to be multi-factorial and from the evidence presented here it is clear that further research is needed in assessing the influence of AMS. The availability of reference values for AMS would enable future researchers to identify groups with low ankle strength and compare injury rates to a group with high ankle strength.

2.2.3 AMS and Functional movement

Papers by Reeves et al. (Reeves, Spanjaard, Mohagheghi, Baltzopoulos, & Maganaris, 2008, 2009) examined the role of AMS in stair ascent and decent in older and younger populations. Their aim was to establish the strength needed to ascend and descend stairs relative to the muscle's maximum capability. When examining stair descent Reeves et al (2008) found that an elderly population used the same percentage of their maximum capacity of ankle extension (PF) as a younger population. However, because the maximum capacity of the muscles in the older population was significantly less than that of the younger population the absolute power produced was less. Increasing the torque production at the ankle to the same of that in the younger population would mean exerting over 90% of the maximum force, which would make stair decent exhausting and unsafe. From this research they concluded that the ankle was essential in stair descent and ankle strength should be the major focus of exercise based interventions to improve stair descent safety. Reeves et al (2009) examined stair ascent in the same population and found that older population used 93% of their maximal PF capacity to perform the task. Because this figure is so high Reeves et al (2009) concluded that PF strength at the ankle is the most critical factor in terms of ability to climb stairs unaided. Based on the measurements they had taken they suggested a torque threshold value of 1.5 Nm kg^{-1} below which individuals would experience difficulties in climbing stairs unaided. This is, however, based on the data from seventeen participants in the study which limits extrapolation of the data to the wider population. A larger number of participants would need to be studied to give this figure greater external validity.

2.2.4 AMS Interventions

If measures of AMS are able to predict injury as described above then it is possible to target those populations with interventions to strengthen ankles and possibly reduce the occurrence of injuries. A number of interventions have been examined which aim to prevent injury in populations that are deemed at risk of ankle injury. Xu et al (2006) examined an older population for differences in muscle strength and endurance between long term Tai Chi practitioners, joggers and a sedentary control group. They found that PF and DF AMS was higher in the Tai Chi and jogging groups compared to the control group. The conclusion from this was that Tai Chi and jogging were both useful in preserving muscle strength in an older population. If reference values were available then it would be possible to comment as to whether these interventions preserve 'normal' muscle strength. If this is the case reference values would also be able to identify 'at risk' individuals to be able to recommend these interventions. Li et al (2009) measured ankle strength pre and post a 16 week Tai Chi course. Their results showed a significant increase in ankle strength in the Tai Chi intervention group as well as the control group who were asked to continue with their normal exercise. They concluded that a longer exercise programme may be needed in order to elicit improvements. The availability of reference values would indicate if the initial AMS was greater or less than 'normal'. The initial strength of the participants could influence the magnitude of strength gains of a training programme. This could account for the lack of improvement in the Tai Chi group compared to the control group.

2.2.5 Determining the effects of ankle injury on AMS

The previous section described research investigating the predictive value of AMS and injury. Across the globe ankle instability is a major issue. In the UK ankle sprains account for 1-1.5 million visits to accident and emergency departments every year (NHS, 2012) and in the US 25,000 people sprain their ankle every day (Hannafin, Kitaoka, & Panagis, 2009). A number of papers have sought to determine the effect of ankle injury on AMS. A systematic review by Loudon et al., (2008) concluded that treatment which included muscle strengthening exercise reduced the reoccurrence of 'giving-way' episodes (defined as an uncontrolled ankle joint inversion episode by Delahunt et al. (2010)) in patients with functional ankle instability. Ankle injuries are also common in sport. Ankle injuries in sport are costly both in terms of lost revenue to players through time off and in terms of training missed. Research by Woods et al (2003) found that 2033 matches were missed in the English FA over two seasons because of ankle injuries. A systematic review on epidemiological studies on sports injuries by Fong et al. (2007) found that the ankle was the most commonly injured body site in twenty-four sports including basketball, cricket, gymnastics, netball, football and ultra-marathon running. In this review ankle sprain was the most common ankle injury in thirty-three out of forty-three of these sports. Equally, Hootman et al. (2007), found ankle injuries, specifically ankle ligament sprains, to be the most common injury from 182,000 injuries in fifteen sports examined over a 16 year time period and 49.3% of ankle injuries in the US between 2002 and 2006 occurred during athletic activity (Brian, Brett, Shaunette, Michael, & Philip, 2010).The annual cost to the Dutch nation through sport related ankle injuries is £157 million (Hupperets et al., 2010). The prevalence and cost of ankle related injuries detailed here highlights the importance of research in this area. The following sections will discuss implications of strength associated with the different physiological movements.

2.2.5.1 Inversion and eversion strength

Sekir et al. (2007) presented eleven papers that concerned inv and eve AMS in populations with ankle injuries. Details of these papers are listed in Appendix 1. Although this is not the totality of research in this area these papers demonstrate the varied results produced when examining the relationship between AMS and functional ankle instability (FAI). For example, six of the eleven papers found no significant difference in eve AMS between injured and non-injured ankles. However, five of these six papers compared unilateral injuries to the contralateral ankle (Bernier, Perrin, & Rijke, 1997; Heitman, KovaleskiI, & Gurchiek, 1997; Lentell et al., 1995; Lentell, Katxman, & Walters, 1990; Munn, Beard, Refshauge, & Lee, 2003). Several papers have concluded that there is no difference between dominant and non-dominant inv and eve peak torque (Ersoz, Simsir Atalay, Kumbara, & Akyuz, 2009; Konradsen, Olesen, & Hansen, 1998; Leslie, Zachazewski, & Browne, 1990). Hence, it could be argued that in cases of unilateral ankle injury both ankles are predisposed to injury due to muscle weakness. This argument is consistent with the results of Hiller et al (2008) who examined eighteen different measures as potential predictors of subsequent ankle injury in 115 dancers. They found that a history of previous ankle sprain was associated with increased risk of future sprains in the contralateral ankle. Weakness in both ankles would explain the apparently contradictory results from Hartsell and Spaulding (1999), Willems et al (2002) and Yildiz et al (2003) also cited by Sekir et al (2007). These papers compared individuals with injured ankles to a healthy control group and found a significant difference in AMS between groups. As the healthy control groups had no history of ankle injury they were less likely to be predisposed to injury. Thus, if eve AMS is a predisposing factor, the control group were likely to have stronger muscles.

Of note, data produced by Kaminski et al. (1999) contradicts the above research theory. They compared concentric and eccentric eve AMS between a group with FAI and a healthy control group and found no difference in any AMS measures. These results should, however, be taken with caution. One reason they suggested for the lack of difference was a number of their participants were intercollegiate athletes who, despite injury, continued to play their respective sports. The inclusion criteria for the experiment included experiencing one significant lateral ankle sprain in the last year and one subsequent episode of 'giving way'. The average time between the last giving-way episode and testing was 6 weeks. This may allow the subject time to recover their strength if they were still playing sport, particularly as the injuries were not debilitating as they were able to continue with their sport whilst injured.

This argument appears to be consistent for measurements of eve AMS, however, this is not the case for inv AMS. Two papers cited by Sekir et al. (2007) namely Ryan (1994) and Wilkerson et al. (1997) found a significant difference in concentric invertor strength between the injured ankle and uninjured contralateral ankle. Hartsell and Spaulding (1999), was another of the papers presented by Sekir et al. (2007). They tested concentric inv, however, they compared injured individuals to a healthy control group. They found the injured group significantly weaker compared to the control group. Conversely Bernier et al. (1997) compared eccentric inv and eve both with the contralateral ankle and a healthy control group. They found no significant difference in inv AMS between injured and contralateral ankles or between the injured and control groups. Interestingly they did find a significant difference between dominant and non-dominant ankles in the uninjured group but not in the injured group with the non-dominant ankle producing greater torque. If the injured ankles were the non-dominant ones and ankle strength were reduced then it follows that there would be no difference between injured and uninjured ankles if the non-dominant inv AMS was the greater from the start.

The results of the papers described by Sekir et al. (2007) highlight the complex nature of the muscle actions acting across the ankle. Studies have examined individuals with ankle injuries and monitored for subsequent injuries, however, this does not address the question of reduced functionality being a consequence of or the reason for the initial ankle injury (Gross 1987). It may be that certain muscle weakness, for example in concentric inv, predispose an individual to injury hence the results shown by Ryan (1994) and Wilkerson et al. (1997). Equally research suggests that other muscle actions are weakened because of injury as concluded from the results of Willems et al. (2002) and Y. Yildiz et al. (2003).

This inconsistency within the conclusions of the papers would be resolved if results could be compared to reference values. By comparing the results to reference values it could be ascertained if unilaterally injured individuals have weaker muscles bilaterally. The effect of ankle injury on AMS could also be determined with comparison to a reference value. Unfortunately reference values are not available for inv and eve AMS. Furthermore, analysis of the papers described by Sekir (2007) indicate that the protocol used to measure AMS varied from paper to paper. Variations in the protocol used to generate AMS will alter the outcome measure irrespective of strength (this will be discussed in detail in Chapter 3). Variability in the protocols suggests results may not be comparable which is consistent with the contradictory results. Hence, it is also argued that standardisation of testing is needed to allow comparison of results to reference values.

2.2.5.2 Plantar flexion and dorsiflexion strength

Delahunt's (2010) definition of giving way suggests instability injuries are a result of going over in a lateral movement. As the inv and eve muscle groups control this action it is these that ankle stability research has focussed on. There are, however, a number of papers that have examined PF and DF strength in terms of stability at the ankle. In a case – control study Fox et al (2008) demonstrated reduced eccentric PF strength in twenty individuals with a history of FAI compared to a healthy control group. They argued that this could be due to damage of the muscle as a result of the initial injury or reduced post injury motor unit excitability. However, they did not find any difference between the injured and uninjured side of the FAI group. This suggests that both ankles were weaker to start with and as such susceptible to injury compared with the healthy controls. Furthermore these results also suggest that the ankle injury did not cause a drop in muscle strength. Use of reference values would have been beneficial to clarify the results, particularly in determining if the healthy ankles were inherently weaker in the affected individuals.

As discussed previously there are several muscles involved in PF and DF as well as inv and eve. For example tibialis anterior is involved with DF as well as inv, the peroneals are involved with eve as well as PF. Because of this dual role there is likely to be some correlation between strength of the PF and DF and lateral ankle stability. However, because the roles of the inv and eve muscles in PF and DF are minor then it is likely that any significant correlation, for example between peroneals and stability, could be masked by the strength of the gastrocnemius or soleus.

2.2.6 Evaluation the effects of disease on AMS

There are a number of diseases that affect the ability of the muscles which act across the ankle to produce functional movement. Durmus et al. (2010) demonstrated reduced PF and DF strength in twenty-four patients diagnosed with Parkinson's disease. They observed that muscle weakness was related to the clinical severity of the disease as assessed using the Unified Parkinson's Disease Rating Scale. Furthermore, fall risk, as determined by self-reported number of fall events in the last 6 months, was also found to be related to muscle weakness. These relationships were determined using a mean average of hip, knee and ankle muscle strength; however, they also demonstrated that both ankle PF and DF concentric strength was significantly reduced in Parkinson's patients. No comment was made as to whether the individual hip, knee and ankle measurements were individually related to fall risk or clinical severity. However, these results suggest that reference values could be used to determine the extent of the disease.

The use of muscle strength to assess the extent of disease activity was demonstrated by Schiottz-Christensen et al. (2001) in patients with Rheumatoid arthritis. They studied thirty-six females diagnosed with classic rheumatoid arthritis over a 1 year period and isokinetic muscle strength was measured five times during this period. From the results they concluded that isokinetic muscle strength was a valid measure of disease activity and could be used to describe the degree of disability in patients. While this research examined muscle strength at the knee, Valderrabano et al. (2006) also found a decrease in strength associated with disease when they examined PF and DF strength in fifteen osteoarthritis patients. If reference values for healthy individuals or individuals diagnosed with mild to severe forms of a disease were available then it would be possible to assess the clinical severity of the disease with a single test.

Charcot-marie-tooth disease (CMT) is a neuropathic disorder which produces atrophy and weakness in distal muscles, particularly the muscles involved in DF (Burns, Ryan, & Ouvrier, 2009). In a case study by Burns, Raymond, and Ouvrier (2009) it was demonstrated that ankle strength training in a 15 year old girl significantly improved PF and DF muscle strength which resulted in improved walking ability in terms of cadence, step length, step time and speed. Again, reference values would enable clinicians to plot the course of the disease in patients with CMT and monitor improvements due to AMS training interventions.

Similar arguments for the benefits of reference values can be put forward in other areas. For example Ng, Lo, and Cheing (2014) used the Cybex Norm to measure AMS in eighty-five older adults with type 2 diabetes. They were investigating the factors affecting mobility as measured by a timed up and go test. They found that concentric PF and DF AMS correlated significantly with the time it took to stand up, walk 6m and sit back down again. The availability of reference values would allow a minimum level of AMS for mobility to be known, thus allowing clinicians to know if mobility could be improved by increasing AMS.

Johansen et al. (2003) demonstrated a drop in DF strength in thirty-six patients undergoing haemodialysis compared to healthy controls; P.-Y. Lin, Yang, Cheng, and Wang (2006) investigated the relationship between isometric PF and DF strength and gait velocity in sixty-eight stroke patients. They found that reduced gait velocity in stroke patients was due to a drop in DF strength; Engsberg, Ross, and Collins (2006) determined that increasing PF and DF strength in children with Cerebral Palsy improved function, gait speed and quality of life as determined by the PedsLQ questionnaire. In all of these medical conditions the availability of reference values would aid clinicians in either determining the severity of disease or setting rehabilitation targets. Section 1.2.1.1 discussed the role of AMS in prediction of falling episodes. From the arguments outlined above it may also be possible to use AMS reference values to assess the risk of falling in arthritis patients, diabetic patients, haemodialysis patients, stroke patients and patients with any disease that affects AMS and so initiate preventative treatment.

In addition to the above there are instances in the published literature where the availability of reference values would add clarity to the results. For example Gigante et al (2008) used isokinetic testing for the measurement of Achilles strength (determined by PF AMS) post Achilles rupture repair. They compared three approaches to the management of an Achilles rupture: conservative treatment where a cast is worn to immobilise the joint in maximal PF, open surgical repair and percutaneous surgical repair. Testing the strength of the Achilles post repair was an appropriate outcome measure as it is the strength of a tendon that is crucial to normal operation. They concluded that percutaneous repair produced the best results but did not state whether PF AMS in any of the experimental conditions had returned to 'normal'. The availability of a reference value for PF strength would have enabled the researchers to assess how effective each method was in terms of returning the Achilles to 'normal' function as measured by AMS PF magnitude. Urguden et al (2010) used Cybex Norm to measure concentric inv and eve as an indicator of ankle sprain rehabilitation. AMS was tested before and 1.5 months after the rehabilitation period. There was a significant increase in strength after the training period in both the injured and uninjured ankles indicating that the rehabilitation increased strength. However, there was no significant difference in strength between the injured and uninjured ankles either before or after the rehabilitation. It was, therefore not possible to ascertain if both ankles were weak to start with and it was chance that only one was injured. In both of these studies if relevant AMS reference values were available it would be possible to determine if there was muscle insufficiency in both ankles prior to the rehabilitation period as well as whether the ankle was fully rehabilitated by the end of the study.

2.2.7 Prediction of performance in athletic populations

The previous sections have discussed AMS reference values in terms of predicting injury, assessing the effectiveness of rehabilitation and the severity of disease. It is also possible that measurement of AMS may be useful in the prediction of performance. For example Nesser et al (1996) examined the relationship between lower limb strength and sprint speed using a regression analysis. They identified concentric DF and 10m sprint time as predictors of 40m sprint performance. In a computer simulated model Cheng (2008) stated that the ankle as well as the knee were the most important joints in generating jump height.

Koutsioras et al. (2009) demonstrated a correlation between concentric PF strength and long jump performance but only in a combined group of males and females. When the genders were separated there was no such correlation. From this it could be concluded that the correlation between strength and jump performance was not causative but was due to males being stronger and able to jump further than females.

The evidence presented here suggests there is some relationship between AMS and performance in sport. The availability of reference values would allow researchers to identify relationships between AMS and performance as well as providing targets for individuals for performance optimisation. Screening for potential athletic capability may also be possible. Schemes such as 'Sporting Giants', 'Power2Podium' and 'Fighting Chance' have been used to screen athletes for beneficial physiological characteristics. Based on the results of the screening athletes have been directed towards sports to which they are physiologically suited (Sport, 2012). If there is a relationship between AMS and athletic performance, using AMS reference values to help determine the athletic potential of individuals would be of benefit to the screening process.

2.3 Isokinetic Dynamometry

Measurement of isokinetic movement has been available since the late 1950s with the first speed controlled device, the Cybex 1, introduced by Perrine in 1967. Since then there have been many adaptations and modifications designed to improve the accuracy and reliability of the equipment. Major recent advances have been the introduction of brush motors and improved force transducers which increase the accuracy of the readings and improved algorithms within the software which reduce noise and artefact. Torque measurement has increased in sophistication from model to model and the Cybex Norm with Humac 2009 software can be considered the industry standard (Whimpenny, 2011). Humac bought the system in 2003 and rebranded it the Humac Norm. Although other isokinetic dynamometers are available such as the Biodex System 4, the KinCom, Con-Trex or the Lido active, the Humac (Cybex) Norm was ranked highest for measuring and improving performance in an independent poll of 30,000 isokinetic equipment users (Whimpenny, 2011). For this reason it is the dynamometer that will be used in this research. There are many papers which have demonstrated the reliability, reproducibility and validity of isokinetic testing using the

Cybex Norm as well as other isokinetic dynamometers. It is these papers that will be discussed in this section.

2.3.1 Inter model reproducibility

Dynamometers generate torque readings by measuring application of torque around a central point. The distance from the central point to the point where force is applied will affect the torque produced. The further from the centre the force is applied, the greater the torque produced. Thus, any variation in the adapter that attaches the limb to the equipment will affect the torque produced. This would account for the results in an experiment by English et al. (2011) who compared AMS measurements between the Cybex Norm and MARES (muscle atrophy and research exercise system). They found that both systems provided reliable results, however, the MARES produced consistently higher values and as such had poor agreement with the Cybex Norm. Bardis et al (2004) demonstrated the Com-Trex MJ and Cybex Norm dynamometers produced consistently different results when testing knee extension and flexion at 60°/s and 180°/s in thirty-five males. Conversely Cotte and Ferret (2003) found a significant difference between the Com-Trex MJ and Cybex Norm dynamometers when testing knee flexors at 180°/s but no difference when testing extensors at the same speed. They also found no difference between machines when testing knee extensors and flexors at 60°/s. The reasons for the differences in results between these two papers are not clear as both papers tested at the same speed and used similar protocols. One reason may be, although the distance between the centre of the axis of motion and the application of force was standardised in both papers, each paper standardised the positioning in a different way. For instance Cotte and Ferret (2003) positioned the tibial pad 0.3m from the centre of the axis of movement of the knee. This does not take the limb length of the participants into account, whereas Bardis et al. (2004) positioned the tibial pad one finger width above the lateral malleolus. It is possible that the variations in limb length skewed the data which may account for the differences in conclusions. The arguments presented here suggest that, providing the same protocol is used and particular attention is paid to the setup of the equipment and the positioning of the participant, the reference ranges produced by one machine would be relevant to users of other isokinetic dynamometers.

2.3.2 Intra model reproducibility

The popularity of the Cybex Norm described by Whimpenny (2011) means reference values generated using this equipment would be valuable in a range of areas. The Cybex Norm produces repeatable peak torque results when used to measure muscle torque across many joints in the body. For example Impellizzeri, Bizzini, Rampinini, Cereda, and Maffiuletti (2008) performed a test-retest reliability study on eighteen physically active healthy subjects. They found the Cybex Norm to be reliable when testing concentric and eccentric knee flexion and extension. Other papers have found the Cybex Norm to be reliable when measuring peak torque around various joints. These include knee extension and flexion in cancer patients (Wilcock et al., 2008), trunk extension and flexion (Karatas, Gögüs, & Meray, 2002), eccentric hip adductor (but not concentric and eccentric hip flexors, suggested as the result of the unfamiliar movement needed to produce torque) (Emery, Maitland, & Meeuwisse, 1999). In terms of AMS, Sekir et al. (2008) found concentric and eccentric inv and eve peak torque to be a reliable measurement on the Cybex Norm when testing at 120°/s. Laughlin et al (2009) used the Cybex Norm to assess test-retest reliability of isokinetic knee, ankle and trunk extension and flexion concentrically and eccentrically. They found all of the measures to be highly reliable apart from concentric ankle DF. They explained this result as a consequence of lack of variability in DF strength between subjects as opposed to a limitation of the dynamometer. van Cingel et al., (2009) also demonstrated test-retest reliability of inv and eve peak torque using the Humac Norm isokinetic dynamometer. A review of the literature indicated that not all eight measures of AMS have been tested for reliability using the Cybex Norm. A test-retest experiment described in Chapter 4 demonstrates the reliability of this piece of equipment in concentric and eccentric PF, DF inv and eve.

2.4 Conclusion

The review of the literature presented here indicates that AMS is indeed and important measure in terms of research, clinical and sporting applications and reference values would be useful in each of these fields. It can also be concluded that isokinetic dynamometry and specifically the Cybex norm isokinetic dynamometer is an appropriate reliable and popular measurement tool.

Chapter 3

A study on the need for AMS reference values

3. A study on the need for reference values for AMS

The previous chapter concluded there is a need for information on reference values for AMS due to their relevance to ankle injury and rehabilitation. It was further concluded that the Cybex Norm is a popular and reliable piece of equipment with which to test ankle strength. These conclusions give a clear rationale for further investigation of AMS reference values produced using the Cybex Norm Isokinetic Dynamometer. This chapter will identify studies within the literature that have used the Cybex Norm to measure ankle strength. These studies will then be analysed to determine the current understanding of reference values for AMS. A summary of the process and findings of this research has been published in Fish, Milligan, and Killey (2014).

3.1 Literature Search

3.1.1 Rationale for the search

As stated in section 2.1 several studies have produced AMS reference values. At the time of embarking on this doctoral study Danneskiold-Samsøe et al. (2009) had suggested that reference values had not previously been published and produced reference values for the wrist, elbow, shoulder, trunk, hip, knee and ankle using the Lido Active isokinetic dynamometer. Harbo et al. (2011) stated that an evaluation of all major muscle groups both isometrically and isokinetically had not been performed before in the same population and went on to produce reference values for the hip, knee, ankle, shoulder, elbow and wrist using the Biodex System 3 PRO isokinetic dynamometer. However, as previously discussed, differences in measurements between dynamometers means any reference values produced are specific to that machine. Therefore, reference values relevant to the appropriate dynamometer should be used when making comparisons.

The previous chapter indicated that a number of studies have used the Cybex Norm to measure AMS. However, a brief review of the literature revealed no reference values for AMS have been produced using the Cybex Norm. Thus, an in-depth narrative review was necessary to determine this was true across all of the literature.

3.1.2 Search methodology

This chapter describes a narrative review based on the principles of a systematic review which was performed to identify those studies which have measured AMS in terms of peak torque using the Cybex Norm. Traditional reviews of academic literature aim to give an overview of certain aspects of research. The systematic review is increasingly replacing traditional reviews as a way of summarising research evidence (Hemingway & Brereton, 2009). This type of review systematically identifies previous work using defined criteria. A systematic review incorporates a protocol that justifies the search process and analysis. This transparency allows the reader to assess whether all of the relevant literature has been covered and identify any potential bias in the analysis process. It attempts to apply the same level of rigour to reviewing research evidence as was used conducting the studies (Hemingway & Brereton, 2009). In this thesis a narrative review was performed using the principles of a systematic review. The difference between a systematic review and the narrative review performed here is the number of researchers undertaking the review. A systematic review will typically employ multiple researchers to assess whether potential papers meet the inclusion criteria for the search. The nature of a PhD means that only one researcher undertakes the literature review. However, because the remaining principles of a systematic review were followed, the review process was rigorous and the data gathered was a true reflection of the level of research into AMS using the Cybex Norm.

Green et al. (2011) suggested that for a systematic review to be considered robust and to be able to draw meaningful conclusions from the data gathered, it must itself satisfy a number of criteria including:

- *1. A clearly stated set of objectives with pre-defined eligibility criteria for studies;*
- *2. An explicit, reproducible methodology;*
- *3. A systematic search that attempts to identify all studies that would meet the eligibility criteria;*

(Green et al., 2011) p.6

Each of these criteria represents a separate step in the review process and is concerned with the thoroughness of the search. These principles will be followed here.

3.1.3 Objectives of the search and eligibility criteria

The objective of the narrative review was to identify those studies which have measured AMS in terms of peak torque (PT) using the Cybex Norm. Paper inclusion criteria consisted of a defined dynamometer (Cybex Norm) for the assessment of strength using concentric or eccentric active isokinetic PF, DF, inv or eve. For a paper to be considered it must have present data from healthy adults as part or all of the population tested. The search was not restricted to one experimental type, as the outcome measures listed above could come from multiple experimental designs.

3.1.4 An explicit, reproducible method for a systematic search

The academic literature databases searched were chosen based on their coverage of relevant topic areas. This process was described by Fish et al. (2014):

> In order to access the maximum number of papers six electronic databases were searched and three academic search engines used. Four of these six databases could be searched through the National Library for Health website (NICE, 2011), thus allowing the automatic elimination of duplicate results from these databases. These were MEDLINE, EMBASE (Excerpta Medical Database), CINAHL (Cumulative Index of National Allied Health Literature) and AMED (Allied and Complimentary Medicine). The span of the search was January 1995 (when the Cybex Norm Isokinetic Dynamometer was first introduced) to August 2015. The remaining two of the six databases, namely Science Direct (ScienceDirect, 2011) and Pubmed (PubMed, 2011) were searched outside of the National Library for Health website. Three academic search engines were also used; Summon (Summon, 2011), a search engine used in some higher education institutions which provides access to scholarly material; The Web of Science (WebofScience, 2011) and Google Scholar (Google, 2005). Manual removal of duplicate papers was necessary from these five resources.

The search terms determine the number of journal papers found. If a general term is used for example ‘ankle’ then a large number of papers will be returned. As Fish et al. (2014) explain:

> To identify studies likely to meet the eligibility criteria the terms ‘Cybex’, ‘norm’, ‘isokinetic’ and ‘ankle’ were used to search the databases and in the search engines.

There are a number of different isokinetic dynamometers such as Kin-Com, Biodex and Lido so the term 'Cybex' was used to limit the search to the relevant machine. There is a large amount of physiological testing equipment under the Cybex brand and a number of older versions of the isokinetic dynamometer (CSMi, 2005c). To isolate the specific piece of equipment the term 'norm' was also used. The National Library for Health website (NICE, 2011) and Google Scholar allows quotation marks to enable searching for exact phrases. "Cybex Norm" was used to determine only papers which contain this phrase.

The Boolean phrase AND (which ensures only papers containing all of the search terms are returned) was used to include the search terms 'ankle' and 'isokinetic' to discount unrelated research concerning the shoulder, elbow, wrist, hip and knee as well as isometric and isotonic tests. The search terms '"Cybex Norm" AND ankle AND isokinetic' would ensure only papers in the database that contained all of these terms would be returned. One of the potential failings of a traditional review is the absence of a search protocol. If the review is not explicit regarding the selection and assessment of the papers included it is not possible for the reader to assess if selection, publication or the reviewers' personal bias has influenced the review process (Hemingway & Brereton, 2009).

3.1.5 Systematic search results

The objective of this narrative review was to identify those studies which have measured AMS using the Cybex Norm. The six databases were searched using the search term '"Cybex norm" AND isokinetic AND ankle', the same search terms were entered into the three academic search engines. The results of the searches are shown in Table 3-1.

Table 3-1

Search engine and database search results for journal papers using the search term '"Cybex norm" AND isokinetic AND ankle'

Database or search engine used	Number of papers found
Medline, EMBASE, CINAHL, AMED	14
Pubmed	14
Science Direct	79
Summon	147
Web of Science	5
Google Scholar	678

3.1.6 Application of eligibility criteria

Table 3-1 indicates that the search of the literature found 937 papers. The titles and abstracts of all the papers, and where necessary the full paper, were examined to ascertain whether they met the eligibility criteria described in the previous section. The Science Direct results are discussed here to illustrate this process as they were typical of the results across the databases. Of the seventy-nine results from Science Direct only seven were accepted. Forty-eight did not test the ankle, one did not measure PF or DF strength, nine did not contain data from healthy participants, one was a review paper, one did not use the Cybex Norm, three did not measure strength, five were did not measure isokinetic strength, and five were not journal papers and had no relevance to this search. Although only one reason for rejecting each of the papers is listed here many of the papers were discounted as they failed to meet multiple eligibility criteria. An overview of the application of the eligibility criteria is shown in Figure 3-1.

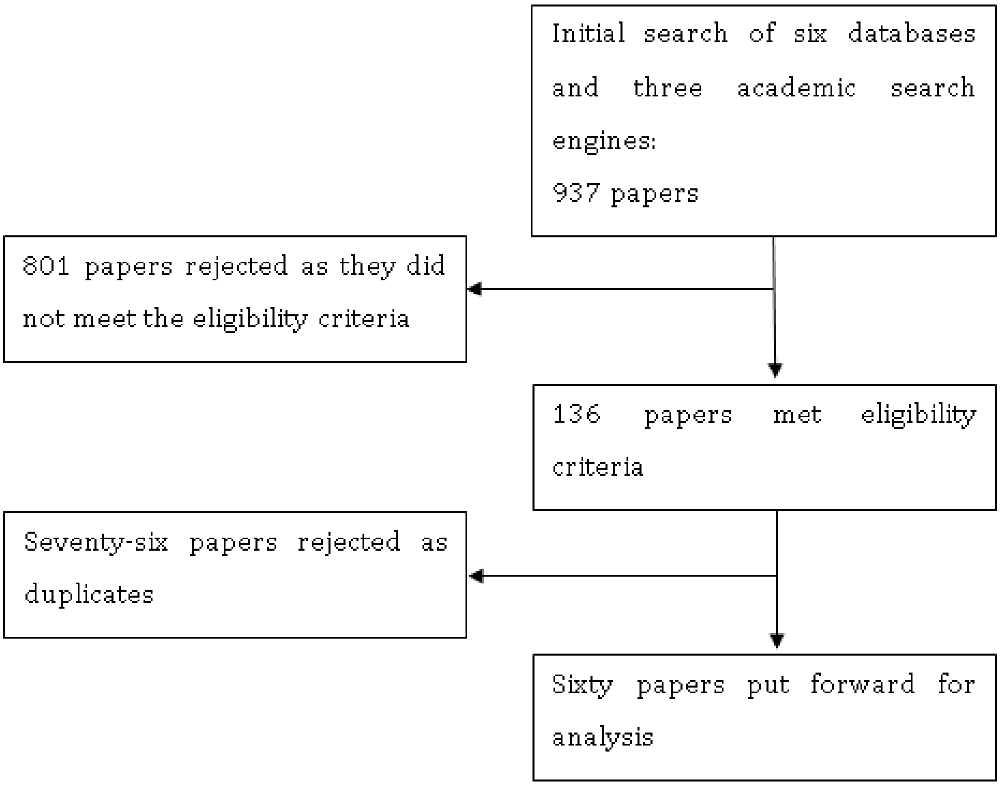


Figure 3-1 A flow chart showing the number of papers at each stage of the search process based on Fish et al. (2014).

Application of the eligibility criteria resulted in 801 papers being rejected. Of the remaining 136 papers seventy-six were duplicates leaving sixty papers which have used the Cybex Norm to measure AMS.

3.2 Meta-analysis of control populations

A meta-analysis is the synthesis of results from two or more separate studies. This is often used to produce a synthesis of the findings in the studies identified in a systematic or narrative review. In this way the statistical power of the data increases and patterns can be identified which may not be evident when analysing smaller populations (Deeks, Higgins, & Altman, 2011). Of the sixty papers which have used the Cybex Norm to measure AMS there was no single paper which set out to produce reference values, however, many of the papers measuring AMS in specific populations have compared their findings to a control group. The control group provides reference values for that specific population so a meta-analysis combining the results of several control groups could produce reference values for a wider population. However, before this was done it was necessary to determine the homogeneity of the data, i.e. to ensure the populations used to collect the data from are comparable.

Appendix 2 shows each of the sixty papers in terms of the experimental and control populations. It has been demonstrated that changes in population demographics such as gender and age can affect the amount of torque produced (Danneskiold-Samsøe et al., 2009). The graph in Figure 3-2 shows the breakdown of populations described in Appendix 2 in terms of age and gender. For reference values to have sufficient external validity a large amount of data should be considered. Significant numbers of a single gender were only tested in the under 18 years, 18 – 29 years and 50-59 years, 60 – 69 years and 70-79 years age ranges. As such reference values could potentially be produced by combining the data for these studies.

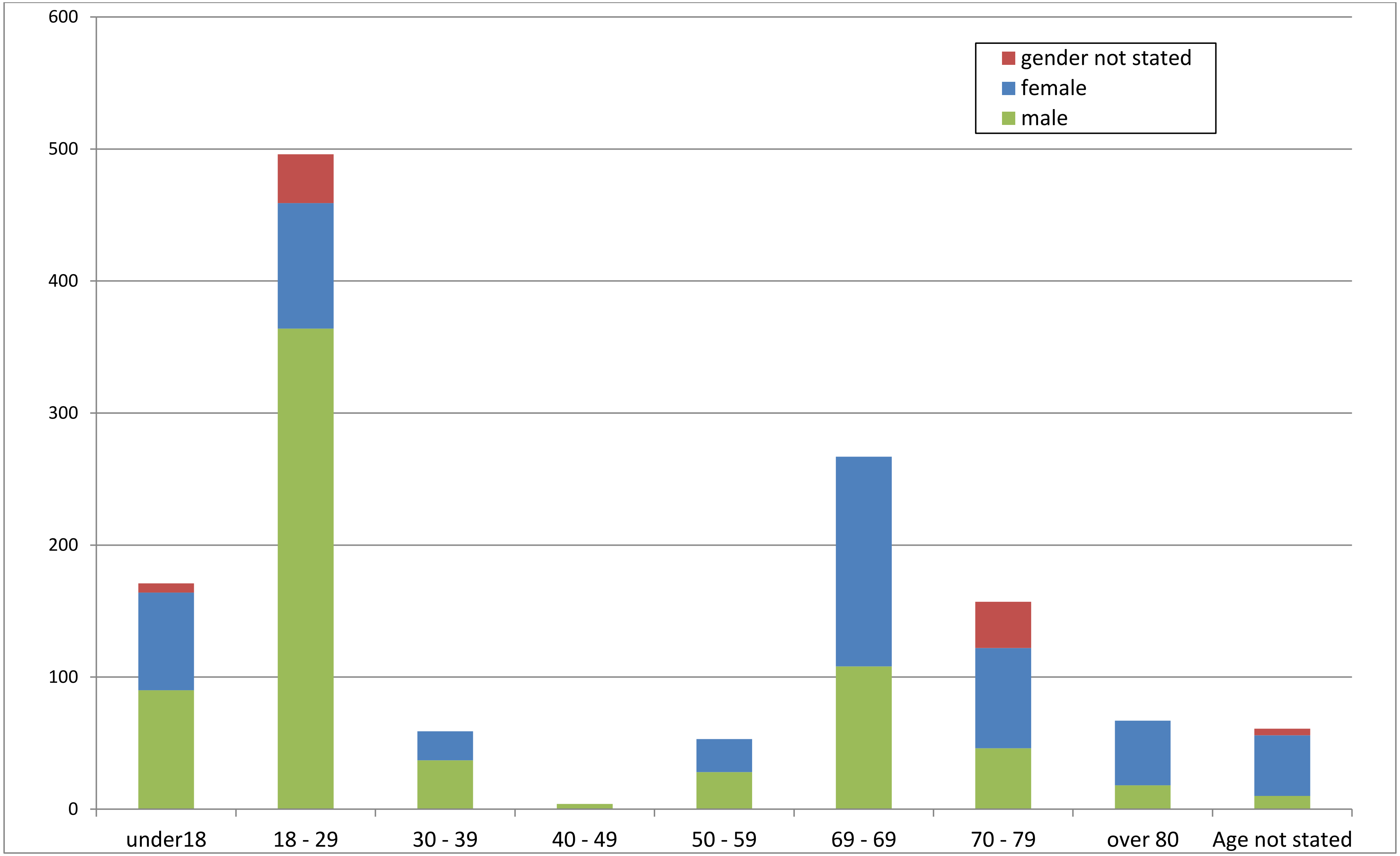


Figure 3-2 A graph showing the numbers of males and females tested in each of the age groups.

Keating and Matyas (1996) investigated measurement of extremity muscles across 200 papers and concluded that both the subject and test design had a large influence on the outcome measures. As such each of the papers which used the Cybex Norm to measure AMS were studied and the test design examined in detail. Each paper discussed its own methodological variables. When comparing these variables between papers it became apparent that there were eight common methodological variables. These were: position of the body, degree of knee flexion, warm up procedure, contraction type and speed, the number of sets and repetitions used, foot dominance, feedback and encouragement and the experimental population. Appendix 3 describes the sixty research papers which used the Cybex Norm to measure AMS in terms of these key variables. The influence of these variables on AMS peak torque production will be discussed in the following chapter with a view to producing a reliable protocol with which to produce reference values.

Chapter 4

Analysis of the methods used to measure AMS using the Cybex Norm isokinetic dynamometer

4. Analysis of the methods used to measure AMS using the Cybex Norm isokinetic dynamometer

The previous chapter described a systematic review of the literature that identified a limited number of studies that used the Cybex Norm isokinetic dynamometer to measure AMS. The search revealed zero studies that produced AMS reference values. Furthermore a meta-analysis found that it is not possible to produce AMS reference values from these papers due to the variations in population and experimental protocols used. Hence, the key variables that affect the measurement of AMS derived from these papers will be presented and discussed in detail. The conclusions drawn from this discussion will be used as justification for the recommended data collection method described in Chapter 4. This chapter will also discuss the statistical methods used in the literature to produce reference values from a given set of data and discuss the effects these methods have on the resulting values.

4.1 Discussion of the key variables

Analysis of the papers identified in the previous chapter revealed eight key variables which, if altered, may affect the AMS outcome measures. These eight key variables are: body position, degree of knee flexion, warm up procedure, contraction type and speed, the number of sets and repetitions, foot dominance, feedback and encouragement, and the population tested. These variables will be discussed in detail here.

4.1.1 Body position

The table in Appendix 3 indicates that out of the forty papers which measured PF and / or DF eleven tested the participant in a prone position, twenty-two in a supine position and seven did not state the position or indicated that a 'standard positioning' was used. Seymour and Bacharach (1990) found that when using a Cybex II+ to measure ankle PF there was a significantly lower peak torque produced in a prone position compared to a supine position at 0°/s (50.22ft lbs compared to 31.00ft lbs $P < 0.05$) and at 30°/s (55.22ft lbs compared to 39.00ft lbs $P < 0.05$). As they used the Cybex II+ and not the Cybex Norm isokinetic dynamometer it is difficult to draw an exact comparison. However, due to the lack of empirical evidence using the Cybex Norm as described in the previous chapter, it is necessary to infer the effect of an alteration in body position from a closely related protocol. Thus, it can be concluded that a meta-analysis combining data from different papers and any reference values produced should consider the position of the participant on the Cybex Norm.

Inv and eve strength were measured in a supine position in all of the studies identified in Chapter 2. The relative position of the dynamometer and the chair make it impossible to perform this test in a prone position. The prone position is possible when testing PF or DF; however, due to the ergonomics of the Cybex Norm when the participant is in the prone position, it is necessary for the leg to be straight and so the knee is at 0°. In the supine position the knee can be flexed which is beneficial for the accuracy of AMS data collection. This will be discussed in the next section. As this thesis is concerned with PF, DF, inv and eve is it recommended that a supine position is used for all tests as this would allow the knee to be flexed, reduce the test time and standardise the visual field for each participant.

4.1.2 The degree of knee flexion

Research has indicated that altering the degree of knee flexion will alter the amount of AMS peak torque produced. The degree to which AMS peak torque is altered depends upon the aspect of AMS being measured and the angle at which the knee is flexed (Lentell, 1988; Wakahara, Kanehisa, Kawakami, & Fukunaga, 2009). Twenty-four of the papers, described in Appendix 3, that measured PF and DF placed the leg in a straight position described variously as 0°, 180° or 'straight leg'. This included the papers that measured peak torque in a prone position which necessitates full extension of the knee. The gastrocnemius is a two-joint muscle acting over the knee and the ankle joint. Extending the knee stretches the muscles involved in PF and reduces ROM as the DF displacement angle is reduced (Souza, Fonseca, Gonçalves, Ocarino, & Mancini, 2009). This limit of movement of agonist by the antagonist as it stretches over a joint is termed 'passive insufficiency' (Lehmkuhl & Smith, 1983p.133). PF peak torque occurs at near full DF (Billot, Simoneau, Ballay, Van Hoecke, & Martin, 2011) so the passive insufficiency caused by fully extending the knee may limit development of peak torque during a concentric contraction. However, during an eccentric contraction, the increased tension in the PF muscles as a result of extending the knee produces higher peak torque compared to a flexed knee as demonstrated by Wakahara et al. (2009). When measuring Achilles tendon force (calculated as PF peak torque divided by the moment arm of the tendon) with the knee in full extension (0°) compared to the knee flexed at 90° they found that the tendon force (and so PF torque) increased from 2.7kN (±0.7 SD) to 3.7kN (±0.8 SD); ($P < 0.05$) indicating the knee in full extension produced more eccentric torque. To avoid the problems of passive insufficiency the leg could be flexed. Twelve of the papers identified in Chapter 2, which tested PF or DF, did so with the knee fixed in a flexed position. Stabilising the knee in a flexed position when testing PF and DF would allow the full ROM but could also allow recruitment of the quadriceps and so give an artificially high peak torque reading. Another factor which must be acknowledged is the possible effect of active insufficiency. Active insufficiency occurs when the muscle fibres are too short to produce a noteworthy contractile force per the sliding filament theory, an example of this would be the gastrocnemius when the knee is fully flexed. As previously discussed, the gastrocnemius acts across both the knee and ankle joints, when the knee is fully flexed the gastrocnemius is shortened and so has a reduced ability to produce power irrespective of the angle of the ankle. (Herzog, 2000). Kennedy and Cresswell (2001) argue that this is due to an increase in the motor unit activation threshold in the shortened muscle fascicles. As this will affect the amount of PF torque an individual can produce, the occurrence of active insufficiency is a further argument for stating the angle at which the knee is fixed. Fifteen of the papers identified in Chapter 2 did not state the angle at which the knee was fixed suggesting either a lack of robustness in the research or that the authors of these papers did not think that knee angle was a relevant factor.

In terms of inv and eve, due to the design of the Cybex Norm it is not possible to use the Cybex Norm chair to measure inv and eve AMS with the knee in full extension. Because of this, with the exception of van Cingel et al. (2009), all of the papers that have tested inv and eve peak torque using the Cybex Norm have done so with the knee flexed between 80° and 110°. Instead, van Cingel et al. (2009) tested ankle inv and eve using the Cybex Norm with the knee fixed at 10°. In order to achieve this a bench was used instead of the Cybex chair to raise the participants to a sufficient height allowing the testing. Based on the findings of Lentell (1988), van Cingel et al. (2009) stated 10° of flexion was the most appropriate angle as it minimised use of the hamstrings and also minimised tibial rotation in inv and eve. Lentell (1988) demonstrated a significant ($P < 0.05$) increase in inv and eve peak torque when the ankle of the knee was changed from 10° flexion to 70° flexion when testing on the Cybex II. (Actual data was not given on this paper, however, it was stated that when changing between 70° and 10° knee flexion there was a 25% and 29% drop in inv peak torque when testing at 30°/s and 120°/s respectively. There was also a 24% and 37% drop in eve peak torque when testing at 30°/s and 120°/s respectively). When testing inv and eve it is possible that flexing the knee could allow the recruitment of other muscle groups, for example the hamstrings, which would lead to an over estimation of muscle strength. Indeed, they had recorded an increase in the electromyography (EMG) activity of the hamstrings and concluded that it was the activity of the hamstrings that lead to the increase in torque production. However, the EMG activity was only measured in five of the twelve participants due to lack of time. With such small numbers it is hard to draw definite conclusions regarding the relationship between the EMG activity and AMS. Furthermore, there was no significant increase in the EMG activity in one of the AMS measures (eve at 120°/s) yet there was still an increase in torque production. The EMG signal would be produced if the knee was stable and the hamstring muscles were acting isometrically but this would have no direct impact on the amount of torque produced. In order for the participants to be positioned with the knee flexed at 10° whilst performing the inv and eve test it was necessary for them to be sat on a separate bench. For the hamstrings or quadriceps to be recruited there would need to be some movement at the knee. The design of the knee support for the Cybex Norm allows the knee to be completely fixed so the muscles acting across the ankle can be isolated. This is necessary as the design of the chair and relative position to the dynamometer means it is not possible to test inv or eve with the knee at 0° without excessive PF. One of the major advantages of the Cybex Norm is the fixed chair and dynamometer 'in line' design which is considered the industry standard (Whimpenny, 2010). Altering this by using a stand-alone treatment couch could affect the stability of the leg as the purpose built knee and hip restraints could not be used and so peak torque values produced may be compromised. The effect of using the added bench for testing with the knee flexed to 10° and the Cybex chair for testing with 70° knee flexion is not commented on by either Lentell (1988) or van Cingel et al. (2009) but further investigation would reveal if this contributed to the difference AMS between the degrees of knee flexion. Whilst it is clear that Lentell (1988) produced a statistically significant difference in peak torque values it is not clear if the differences were clinically significant. If a Cohen's d test were performed then the effect size of the difference in torque could be assessed; however, this was not provided in the paper and is not possible to calculate with the data given. Nevertheless, the use of additional equipment including a separate bench adds another extraneous variable which should be avoided.

As the discussion above suggests the literature is unclear as to whether altering knee angle will significantly affect all measures of AMS. To that end, Chapter 6 describes an experiment using the Cybex Norm to compare the effect of altering the angle at the knee on the eight measures of AMS discussed in this thesis, including the use of a bench to allow measurement of inv and eve with 10° knee flexion. The results of this experiment indicated a significantly greater concentric and eccentric PF AMS peak torque was produced with the participant in long sitting with the knee fixed at 10°. To the author's knowledge this experiment has not been published previously and so it was not possible to compare these findings. It was observed through the testing that the participants were able to push back against the chair's backrest to generate extra force with the knee fixed at 10°. With the knee fixed between 80° and 110° this was prevented from happening by the knee support. It was concluded that this was the reason for the higher peak torque produced with the knee fixed at 10° and therefore PF and DF AMS testing should be undertaken with the knee flexed between 80° and 110°.

The results also demonstrated that fixing the knee at 10° produces significantly lower concentric inv and eve as well as eccentric eve compared to that produced when the knee is fixed between 80° and 110°. These results are in agreement with the data produced by Lentell (1988); however, the Cohen's d value indicates that the effect size is not large which suggests that the size if the difference between the values may not be clinically relevant. The paired sample t-test described in Chapter 6 also indicates that there is a significant correlation between the two knee angle conditions (10° and 80° – 110°) in concentric and eccentric inv and eve. In the production of reference values it could be argued that changes in inv and eve AMS would be apparent as long as the reference value was produced with the knee fixed at the same angle as the subsequent test. Furthermore, if PF and DF are tested with the knee fixed in a flexed position, it would be more efficient to test inv and eve in the same manor.

It is clear that any meta-analysis or production of reference values should consider the degree of knee flexion used. Based on the results of the experiment described in Chapter 6 and the observations made in its undertaking it is recommended that PF, DF, inv and eve testing should be performed with the knee fixed between 80° and 110°. It is acknowledged that this may allow for recruitment of the hamstrings resulting in elevated inv and eve torque results. However, the question of the clinical relevance of these elevated results coupled with the added time needed to participate in the experiment outweigh potential errors. Furthermore, the evidence suggests that testing PF with the knee at 10° produces an artificially high results. As testing both PF and DF, and inv and eve with the knee fixed at the same angle would further reduce the time needed to perform the experiment then both PF and DF, and inv and eve should be tested with the knee fixed between 80° and 110°.

4.1.3 Warm up procedure

Several of the papers identified in Chapter 2 described the warm up procedure used prior to exercise; these can be split into 3 distinct sub categories, cardiovascular warm up, stretching and familiarisation.

4.1.3.1 Cardiovascular warm up

A number of the papers identified in Chapter 2 described a cardiovascular warm up. For example the participants studied by S. Eyigor et al. (2008) and Sibel Eyigor, Karapolat, and Durmaz (2007) ran on a treadmill whereas the participants studied by Gopalakrishnan et al. (2010) and Xu et al. (2006) warmed up on a cycle ergometer. For some the rationale for a cardiovascular warm up is that exercise would increase the muscle temperature and so improve the neuromuscular function and performance (McArdle, Katch, & Katch, 2007). A search of the literature found no research pertaining to the effect of a warm up on the measurement of AMS. However, when examining reliability of isokinetic strength measurements of the elbow and knee, Madsen (1996) found that using a cardiovascular warm up had no effect on peak torque measurements. These experiments indicate a warm up would not improve the results; however, it could still be necessary in terms of injury prevention. Soligard et al (2008) examined the effect of a comprehensive warm up programme including 10 minutes of running exercises and 10 minutes of plyometric and strength exercises on the incidence of injury in 2540 young female football players. Their results indicated no significant difference in match or training injury rate between warm up and control groups. Therefore, as there is increased control in the ankle movements used when testing AMS compared to those used in football, it can be concluded that a cardiovascular warm up is unlikely to prevent injury when testing AMS using the Cybex Norm. As the research presented here indicates a cardiovascular warm up would not improve performance or prevent injury, this type of warm up is not recommended here.

4.1.3.2 Stretching

Five of the papers identified in Chapter 2 used stretching as part of the warm up (Gerodimos, Manou, Stavropoulos, Kellis, & Kellis, 2006; Keles, Sekir, Gur, & Akova, 2014; Sekir et al., 2007; Sekir et al., 2008; Y. Yildiz et al., 2003). However, a review on stretching and its effect on performance by McHugh and Cosgrave (2010) stated there is an acute loss of strength after a relaxed muscle has been stretched. This conclusion supports the ankle specific research by Rosenbaum and Hennig (1995) and Fowles and Sale (1997) both of whom demonstrated that static stretching prior to testing significantly reduced PF peak torque production. The rationale for stretching prior to exercise is to reduce injury, however, systematic reviews by Herbert and Gabriel (2002) and Tortora and Derrickson (2008) found that there was no evidence that stretching prior to exercise did reduce injury. Therefore, it can be concluded that stretching prior to strength testing would be detrimental to performance and as such is not recommended here.

4.1.3.3 Familiarisation

If the participant is not familiar with the equipment then it is possible that they will not achieve peak torque due to poor technique. For example, Du Toit, Buys, Venter, and Olivier (2004) demonstrated that a familiarisation session was warranted when they tested the isokinetic strength of the neck musculature in eighty-one teenagers. They found that the peak torque was increased in the second and third session compared to the first session. They also found a strong correlation between the results of the second and third sessions but not between the first and second. This conclusion is also reflected in the ankle specific literature as fifty-one of the sixty papers identified in Chapter 2 use familiarisation sessions which involve sub-maximal repetitions of the movement involved prior to the testing.

In conclusion, eight of the papers identified in Chapter 2 did not state whether or not warm up exercises were performed and only one of these papers said a warm up was not performed (Høiness, Glott, & Ingjer, 2003). In justifying this they cited the work of Madsen (1996) who found that using a warm up had no effect on peak torque measurements as previously discussed. The evidence presented here suggests familiarisation and stretching as part of a warm up both have an effect on peak torque production and so should be considered when using a meta-analysis to produce reference values. Based on this evidence it is recommended here that a familiarisation session is used but not a cardiovascular or stretching based warm up.

4.1.4 Contraction type and speed

The type of muscle contraction measured in an experiment will affect the amount of torque generated. For example, Keles et al. (2014) demonstrated that eccentric DF and eve were greater than concentric DF and eve. Sekir et al. (2007) and Sekir et al. (2008) provided a comparison of concentric and eccentric muscle strength in inv and eve and concluded that an eccentric contraction produces greater torque than a concentric contraction. This is an important point when considering the implications of published papers. For example, Urguden et al (2010) and van Cingel et al (2009) both measured inv and eve strength; however, neither paper stated contraction type which limits the usefulness of the conclusions drawn. The aim for van Cingel et al (2009) was to examine test-retest reliability of ankle inv and eve testing and they concluded that the test was reliable. However, without stating whether the test was concentric or eccentric, it is difficult to justify the use of this protocol or equipment based on this experiment only. The aim for Urguden et al (2010) was to examine the effectiveness of a rehabilitation programme in reversing muscle atrophy, proprioceptive loss and slowing of the muscle reflex time after an ankle sprain. Without knowing whether concentric or eccentric measurements were taken it is not possible to compare the results of this experiment with others which have assessed rehabilitation programmes in this way. Similarly nine of the thirty-one papers that measured PF and DF using the Cybex Norm did not state whether concentric or eccentric contractions were used. Thus, when producing reference values for AMS it is recommended that both concentric and eccentric measurements are taken as both are clinically relevant.

The speed at which the muscle contracts will also affect the outcome measures in terms of the peak torque. Concentrically, faster contraction speeds produce lower peak torque values when compared to slower contraction speeds, conversely slower eccentric speeds produce lower peak torque compared to faster speeds. This is explained schematically in Figure 4-1. This was demonstrated in a paper by Schulze et al (2002) who measured concentric and eccentric PF at 30°, 60°, 120°, 180°, 240° and 300°sec^{-1}. They found that peak torque decreased with each increase in velocity. This makes it impossible to generate reference values by pooling data from papers which have tested at different speeds. As with the contraction type, any method in a paper which investigates a specific population should measure at the appropriate speed. For example Li, Xu, & Hong (2009) examined the effect of practicing Tai Chi on muscle strength in an elderly population. Tai Chi consists of slow controlled movement, to reflect this the strength measurements were taken at 30°/s. Conversely, Behrens et al (2010) investigated a rehabilitation programme for short track speed skaters after an ankle sprain. To reflect the high speed of the contractions involved short track speed skating them muscle strength tests were performed at 240°/s. However, many activities may utilise a range of contraction speeds in the entirety of that task.

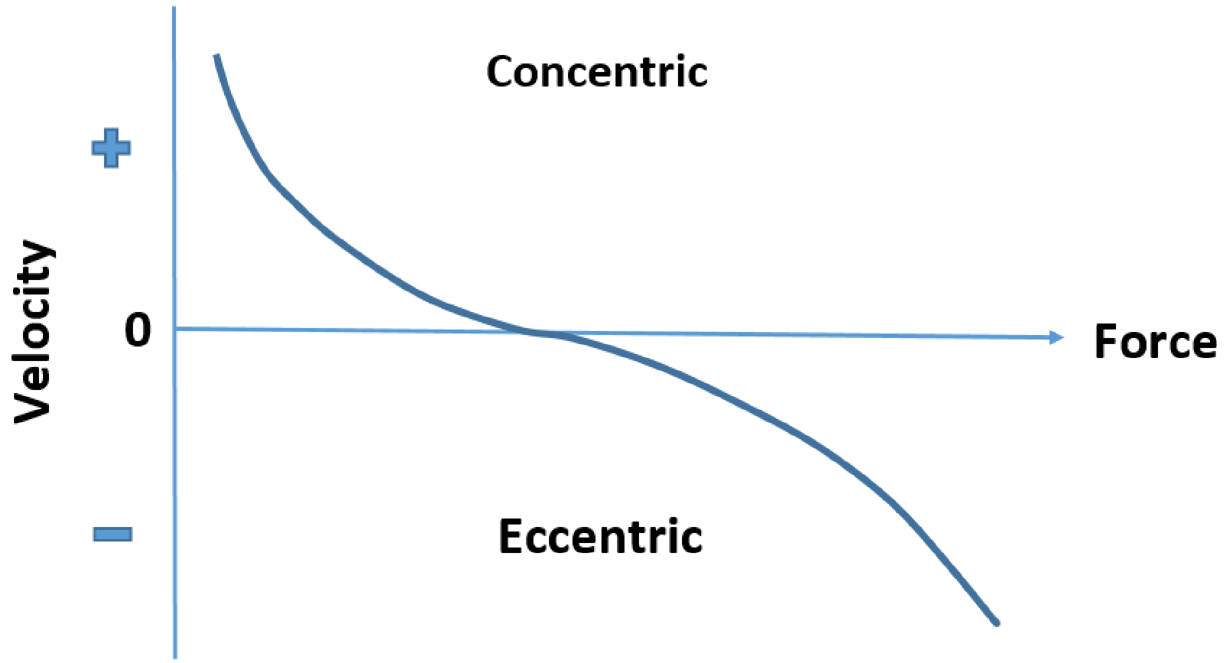


Figure 4-1 A schematic of the relationship between velocity and the muscle force generated.

Of the papers identified in Chapter 2 the most commonly tested speed was 60°/s for PF and DF measurements and 120°/s for inv and eve. Whilst these represent an arbitrary speed for testing, research suggests they are reflective of common clinical practice and as such can be compared to other studies. Thus, these testing speeds are recommended here.

4.1.5 The number of sets and repetitions used

When measuring peak torque it is important to ensure that participants are given the opportunity to perform maximally. If participants were given just one attempt at achieving peak torque using an isokinetic dynamometer it is unlikely the results would be reliable as without practice the movement can be unfamiliar as previously discussed. Equally fatigue has been shown to alter muscle strength (Forestier, Teasdale, & Nougier, 2002) so multiple attempts at achieving peak torque at one speed or movement type could reduce peak torque achieved in subsequent tests. Of the experiments described in Appendix 3, one set of three or five repetitions were the most common testing pattern used. When testing PF and DF on the Cybex Norm Laughlin et al (2009) showed both concentric and eccentric movements to be reliable using one set of five repetitions as determined by a repeated measures analysis of variance (ANOVA) test. However, the statistical analysis showed that concentric DF had a lower intraclass correlation coefficient (ICC) score than the other measures. The ICC is a method of statistical analysis which quantifies the relative consistency of results, thus indicating the reliability of the measurement (Weir, 2005). The low ICC score for concentric DF suggests low reliability. Based on the results presented there would have to be an 18.4% difference in the peak torque results to be 95% confident that the results were due to strength changes and not measurement error. Laughlin et al (2009) concluded that this anomaly was due to the lack of variation in DF strength between subjects. van Cingel et al. (2009) found the highest reproducibility for inv and eve testing in terms of high ICC and small standard error of measurement (SEM) when calculations were based on peak torque measurements determined by three sets of three repetitions, compared to a single set of three repetitions. The SEM is an indication of expected measurement 'noise'; a small SEM score means a result is very precise (Weir, 2005). The number of sets and repetitions used should also be considered when analysing papers in terms of a meta-analysis or producing reference values. It is common practice to include a period of recovery time between sets. van Cingel et al. (2009) allowed 30 seconds between sets and 5 minutes between speeds. As a protocol using three sets of three repetitions with 30 seconds rest between sets has been shown to be reliable and precise, these parameters recommended for use here. ICC and SEM scores will be discussed in further detail in the next chapter.

4.1.6 Foot dominance

There is conflicting evidence regarding the effect of limb dominance on the level of PF and DF AMS. Some evidence suggests that there is no difference between dominant and non-dominant strength at the ankle in terms of PF and DF peak torque (Ersoz et al., 2009; Konradsen et al., 1998; Leslie et al., 1990 ; So, Siu, Chan, Chin, & Li, 1994). Whereas Theoharopoulos and Tsitskaris (2000) found a significant difference between dominant and non-dominant PF peak torque at 60°/s in basketball players. Özçaldiran and Durmaz (2008) also found a significant difference between left and right median DF at 30°/s in runners. However, they found no such difference in PF at 30°/s or in PF or DF at 120°/s. In swimmers they found no significance difference between left and right PF and DF AMS at either 30°/s or 120°/s. Both Özçaldiran and Durmaz (2008) and Theoharopoulos and Tsitskaris (2000) found, in instances where there were significant differences between left and right, the non-dominant side was significantly stronger. Each paper concluded that this was a result of the activities undertaken by the participants. For example, Theoharopoulos and Tsitskaris

(2000) concluded that the non-dominant PF muscles were stronger as basketball players jump from the opposite leg to the dominant hand with which they release the ball. Thus demonstrating increased use of the PF muscles increases the torque capabilities. Similarly, Özçaldiran and Durmaz (2008) concluded that the non-dominant DF muscles are stronger in elite sprinters as these bear most of the body mass when the sprinter is in a starting position. Again increased use of the muscles increases the torque capabilities. Theoharopoulos and Tsitskaris (2000) stated that no differences in PF or DF peak torque were evident between dominant and non-dominant ankles in sprint swimmers due to swimming being a symmetrical sport.

In terms of inv and eve peak torque the limited literature that is available suggests that there is no difference between dominant and non-dominant sides. Of all of the papers that have used the Cybex Norm to measure inv and eve muscle strength only van Cingel et al (2009) measured strength in both ankles in healthy volunteers. Unfortunately a dominant vs. non-dominant comparison was not made. However, by using the supplied data to calculate the confidence intervals (CI) it can be inferred that there is no significant difference for males or females between inv or eve peak in dominant and non-dominant ankles at 30°/s or 120°/s (see Appendix 4 for an explanation of this calculation). This inference is supported by papers in the literature; for example, Lin et al (2009) concluded there were no differences in inv nor eve peak torque between dominant and non-dominant ankles when testing concentric strength at 30°/s and 120°/s using a Biodex 3 dynamometer. Similarly, Konradsen et al (1998) demonstrated no difference in isometric eve between left and right ankles 6 weeks post unilateral ankle injury. They assumed peak torque in the contra lateral ankle was the same as the involved ankle pre-injury based on unpublished data cited in the paper.

Of the papers identified in the previous chapter, only eight did not identify whether the left or the right ankle was used. However, none of the papers made a direct comparison between left and right AMS. The suggestion that there is a difference in specific populations would contraindicate the use of both left and right data in a meta-analysis. It is recommended here that the dominant ankle is used for testing. In a normal population, based on the evidence presented here, a reference value based on the dominant ankle data would be relevant to both ankles. In a specific population which may have stronger ankles on one side a comparison could be made to normal dominant ankles.

There are several ways of determining which limb is dominant, for example Aadahl and Jørgensen (2003) used four manipulative tests to identify limb dominance when examining limb dominance and type of task. The participants were asked to kick a ball, step on an insect, write a word with the foot, and take a step forwards. The majority of the papers identified in Chapter 2, where the method of identifying the dominant leg was stated, used the kick ball test; Aadahl and Jørgensen (2003) found that 90% of their participants (the same percentage that are right handed) used the right foot for this task. Based on this evidence the kick ball test is recommended for use here in order to determine foot dominance.

4.1.7 Feedback and encouragement

The screen of the Cybex Norm can display torque readings as they happen. This can be used as feedback for the participant to try and improve on the last repetition and encourage them to improve their score. Verbal feedback may also encourage a greater peak torque; however, different people respond differently to verbal encouragement in terms of peak torque production (Kannus, 1994). Therefore, standardising verbal feedback so the participants are encouraged to the same extent is impossible. Some of the papers described in the previous chapter used feedback where others did not, many papers did not state whether feedback was used or not. As Kannus (1994) demonstrated the use of feedback can affect AMS measures in some people it should be considered when conducting a meta-analysis. Based on these results it is recommended here that feedback is not used.

4.1.8 The Population tested

It is likely that the demographics of the population tested will affect the AMS peak torque produced. As such, this should be considered when performing a meta-analysis or producing reference values. Based on an analysis of the population demographics of the papers identified in Chapter 2, as well as application of biomechanical principles, the following have been identified here as potential independent variables affecting AMS: gender, height, mass, age, and shoe size. The literature relating to these variables and reasons for their inclusion will be discussed here. A review of the literature revealed little data on the relationship between anthropological measures and AMS hence a large proportion of the arguments put forward here are based on the findings of Danneskiold-Samsøe et al. (2009) and Harbo et al. (2011). Both of these studies tested muscle strength in large numbers of participants from a general population (189 and 178 respectively) and so could examine the relationship between anthropometric variables and strength. These papers are limited in that while they measured strength across multiple joints, in terms of AMS, each paper only measured concentric PF and DF. Where possible other papers have been cited to inform on other AMS measures.

4.1.8.1 Gender

Whilst it is accepted that males are generally physically stronger than females a search of the literature suggested there are a limited number of papers which discuss the differences in AMS between genders. The experimental population of Danneskiold-Samsøe et al. (2009) consisted of sixty-three males and 126 females. They concluded that women have lower muscle strength than men in the upper limb (shoulder, elbow, wrist and grip strength), trunk and lower limb (hip, knee and concentric PF and DF). This conclusion was supported by Harbo et al. (2011) who also found that males were stronger than females in the shoulder, elbow, wrist, hip, knee and ankle (concentric PF and DF) when they compared ninety-three males and eighty-five females. Results of a literature search for a comparison of inv and eve strength between males and females was limited to one paper. Ersoz et al. (2009) found no significant difference in the average eve to inv ratio between forty-seven females and thirty-two males. However, the actual eve and inv strength scores were not given and the ratio data is not enough to assume that there is no difference in strength between genders. If results indicated twice the strength in one gender compared to the other in both inv and eve the strength ratios would be the same for both genders.

Appendix 2 describes the experimental populations in all of the papers which used the Cybex Norm to measure AMS; none of these compared male and female strength. Based on the conclusions of Danneskiold-Samsøe et al. (2009), Harbo et al. (2011) and conclusions of the general literature that males are stronger than females (McArdle et al., 2007), it could be assumed that males are stronger than females in all ankle strength measures, not just concentric PF and DF. This may be the reason that all but one of the papers in Appendix 3 which tested both genders used approximately equal numbers of males and females. Collado et al. (2010) is the exception as within their experimental population there was an imbalance in genders between experimental and control groups (three women and six men in the experimental group compared to eight women and two men in the control group) when comparing concentric and eccentric training in rehabilitation of lateral ankle sprains. However, the measure of the efficacy of the intervention was a comparison of healthy and injured ankles in the same individual, thus, the gender ratios within the groups were not an issue.

Although there is evidence of a difference in concentric PF and DF between genders, this area requires further investigation to complete the data. As such, any meta-analysis should be gender specific and any investigation into AMS using the Cybex Norm should examine gender differences in all eight measures of AMS.

4.1.8.2 Mass

When discussing AMS in particular it is reasonable to assume that heavier individuals have greater strength as this would be necessary to support and move a greater body mass. This assertion is supported by Winegard, Hicks, Sale, and Vandervoort (1996). They performed a longitudinal study over 12 years and found that a decline in ankle strength with age was related to loss in muscle mass which in turn contributed towards an overall drop in body mass in twenty-two older participants. Harbo et al. (2011) suggested that body mass was a contributing factor in muscle strength. They produced thirty-six prediction models for isometric and isokinetic muscle strength for different movements around six different joints including PF and DF. Mass was a significant predictor of muscle strength in twenty-seven out of the thirty-six models produced. However, they do not state in which of twenty-seven models mass is a predicting factor. Thus, their evidence of the extent to which mass predicts PF and DF is not clear. Danneskiold-Samsøe et al. (2009) concluded that female but not male 'lower extremity' muscle strength (a combination of measured strength in the hip, knee and ankle) was dependent upon mass, thus, it is not possible to draw specific conclusions from their data regarding the relationship between ankle strength and mass.

The relationship between AMS and mass is complicated by the relationship between mass and gender. Janssen, Heymsfield, Wang, and Ross (2000) assessed the anthropometric characteristics of 268 males and 200 females and found males to be significantly heavier than females ($P<0.01$). According to UK government statistics the average English female weighs 70.2kg whereas the average English male weighs 83.6kg (Matheson, 2010). Therefore, the variation in AMS between genders may be due to differences in mass. Due to the limited nature of the current evidence concerning the relationship between AMS and mass, any investigation into reference values for AMS should include this variable as well as considering the relationship between mass and gender. Any meta-analysis performed would also need to control for these inter-relationships.

4.1.8.3 Height

Research by Harbo et al. (2011) suggested that strength increases with height. Their data showed that whilst height did contribute to the variation in muscle strength, statistical significance of this contribution was only demonstrated in thirteen out of the thirty-six models previously discussed. They do not state which thirteen models include height so it is not clear if height was a significant predictor of PF or DF specifically. Danneskiold-Samsøe et al. (2009) did not find a significant correlation between 'lower extremity' strength and height, but again, as the ankle data was combined with other data, it is not possible to draw conclusions regarding the specific relationship between ankle strength and height. They also suggested this lack of relationship may be due to the lack of variation in height within the gender groups. None of the papers described in Appendix 3 which have used the Cybex Norm to measure AMS have examined the relationship between height and AMS and the relationship is not clear from the wider literature. This is, therefore, an area which requires further investigation in terms of relevance to reference values and inclusion of papers in a meta-analysis.

4.1.8.4 Age

Both Danneskiold-Samsøe et al. (2009) and Harbo et al. (2011) concluded that general muscle strength declines with age. However, the data they presented indicated that the decline varied between muscle groups and was not uniform across ages. Danneskiold-Samsøe et al. (2009) divided their population into age groups each spanning a decade. They found that general muscle strength fell in a linear fashion from the 20-29 years age group to the 70-79 years age group in males, whereas in females the muscle strength remained constant between 20 and 40 and did not start to decline until the 40-49 years age group. The decline between 40 and 75 years was between 48% and 92% depending on the muscle group analysed. With specific reference to AMS there was a decline in both male and female values, however, in both males and females the decline in concentric PF did not start until 60-69 year age group. Male concentric DF strength started to decline from the 50-59 years age group and female concentric DF strength only showed decline from the 70-79 years age group. Harbo et al. (2011) also split the experimental population into age groups and found that age was a significant predictor of strength for twenty-four of the thirty-six muscle actions measured; however, the paper does not state which muscle actions these are. Buckley, Cooper, Maganaris, and Reeves (2013) compared eccentric PF between fifteen older adults (75±3 years) and seventeen younger adults (25±4 years) and found the younger adults to be significantly stronger. S. Kim, Lockhart, and Nam (2010) compared fourteen younger (25±3 years), fourteen middle-aged (41±3 years) and fourteen older individuals (70±3 years). They found a significant difference in concentric PF and DF at 30°/s, 60°/s and 120°/s between the younger and older groups in agreement with the research by Danneskiold-Samsøe et al. (2009). However, contrary to the data presented by Danneskiold-Samsøe et al. (2009), they also found a significant difference between the younger and middle age groups in PF but not DF at 30°/s and in DF but not PF at 60°/s. No significant differences were found in any of the AMS measures between the middle age group and the older group. The differing results from these two studies may be the result of differences in equipment and methods. Danneskiold-Samsøe et al. (2009) used a Lido Active dynamometer to measure strength at 15°/s, 30°/s and 45°/s whereas S. Kim et al. (2010) used the Biodex System 3 to measure muscle strength at 30°/s, 60°/s and 120°/s. As previously discussed both speed of contraction and type of equipment will affect the peak torque produced. Moreover, where Danneskiold-Samsøe et al. (2009) used discrete single gender groups spanning a decade, S. Kim et al. (2010) used a broader age range per group and the groups were mixed gender. As age and gender also affect AMS these too could be the reason for the discrepancy between results.

All of the papers which have used the Cybex Norm to measure inv and eve AMS are shown in Appendix 3; however, none compare inv and eve AMS between age groups. A search of the wider literature revealed little data on the differences between age groups in concentric or eccentric inv and eve. Spink, Fotoohabadi, and Menz (2010) found a significant difference in concentric PF, DF, inv and eve when comparing younger (23.2±4.3 years) and older (77.1±5.7 years) populations with the younger populations being between 24% and 37% stronger. As this and the evidence presented in the previous section demonstrate a relationship between age and AMS, any meta-analysis should control for age and any reference values produced should be age group specific.

Age is also related to height and mass. In a longitudinal study of data from 185,192 individuals over a period of 20 years Peter, Fromm, Klenk, Concin, and Nagel (2014) determined that mass increased with age until the age of 70 when it started to decrease and height increased between the ages of 20 and 35 and then started to decrease. They explained the increase in mass as an increase in fat mass whereas a loss of fat free mass drove loss of mass in the over 70 age ranges. They had no explanation for the initial increase in height; however, this does illustrate that the relationship between AMS and age is complex and may be influenced by height and mass. This complex relationship adds to the problems of undertaking a meta-analysis and the production of reference values for AMS.

4.1.8.5 Shoe size

The setup of the Cybex Norm necessitates the identification of the axis of movement about which the joint moves, in the case of PF and DF this is commonly taken as the lateral malleolus (Dehail et al., 2007; Frasson, Rassier, Herzog, & Vaz, 2007; Hamill & Knutzen, 1995). When testing PF the foot is secured to the footplate with two Velcro® straps and force is exerted through the metatarsal heads. When testing DF, force is exerted through the dorsum of the foot. Torque is a function of the force multiplied by the distance from the axis of motion at which it is applied (Tortora & Derrickson, 2008) A greater foot size would increase the distance of force application from the axis of movement, which results in a larger lever arm with which to produce torque. It therefore follows that larger feet would give greater PF and DF peak torque if all other variables remained constant. None of the papers produced in the previous chapter indicated the shoe size of the participants, thus, further investigation is needed into the influence of shoe size on AMS peak torque production.

The evidence presented here demonstrates that variations in the experimental population demographics can influence certain measures of AMS. It also demonstrates that the literature concerning the relationship between anthropometric measurements and AMS is not complete. While there are a number of research papers which have examined the role of height, mass, age and gender in relation to concentric and eccentric PF and DF, the papers identified in Appendix 3 indicate that there is no research to relate the anthropometric measurements and concentric and eccentric inv and eve using the Cybex Norm. A search for papers including other isokinetic dynamometers suggested that this conclusion is indicative of the literature as a whole. To the author's knowledge, up to August 2015, the role of shoe size in any measure of AMS has not been investigated. This further complicates generation of reference values for AMS based on a meta-analysis of the current literature.

4.2 Analysis of the collected data

Once the AMS data had been collected using a method sympathetic to the above methodological variable arguments (see Chapter 4 for a detailed explanation of this method) the data was analysed to determine the relationship between AMS and the anthropometric variables measured. This was undertaken with a view to producing reference values. Possible ways of achieving reference values from the collected data will be discussed in this section.

4.2.1 Integrity of the data

Prior to analysis of the data it is necessary to assess the robustness of the data. Collection of multiple sets of peak torque repetitions enabled the calculation of the Coefficient of Variance (COV). The COV is the ratio of the standard deviation (SD) to the mean (Abdi, 2010). A low COV means the torque produced in each of the individual reps are closely matched; if peak torque produced in each repetition was the same COV = 0. A high COV indicates a large variation in the peak torque produced between repetitions. This can suggest unfamiliarity with the equipment and so maximal peak torque may not be achieved due to poor technique (Whimpenny, 2000). Mean results from experimentation may be skewed by outlying results so using a 20% threshold or COV of 0.2 is recommended to maintain the integrity of the data (Whimpenny, 2000).

4.2.2 Calculating reference values

A common way to achieve a reference value from a data set is to take the mean average. If the data, in this case AMS, has been taken from individuals with normal ankle strength then the average value ± SD could be taken as the normal range. This was the method employed by Lategan (2011) when producing reference values for muscle strength across a number of joints including the ankle using the Cybex II. This method assumes that individuals have normal ankle strength which is controlled for by a medical questionnaire as this would exclude individuals with conditions that may affect ankle function. However, Lategan (2011) examined 438 males aged 19.06±1.86 years. As a consequence any reference values based on the mean peak torque of the data would be specific to males aged 19 years as both age and gender affect AMS. For a reference value to have a wider clinical relevence it should be produced from a mixed gender population with a wider anthropometric range. See section 6.1 for a comparison of reference values produced by different papers.

The data collected for this thesis and presented in Chapter 5 describes the mean average ± SD calculated from a mixed gender population aged between 18 and 59 years old. This mean average reference range was validated by comparing it with the results of a validation group. It was found that only three of the eight measured values of AMS in the validation group were within normal range (see Chapter 5 for details of results and the validation process). It was concluded that this discrepancy was the result of variations in the population demographics between the group used to generate the reference values and the validation group. As such further analysis was required to determine a reference value which considers these anthropometric variables.

Danneskiold-Samsøe et al. (2009) generated reference data using a Lido Active isokinetic dynamometer from a population of 128 males and 296 females aged between 20 and 80 years. As in the paper by Lategan (2011) the mean (±SD) peak torque was calculated; however, this data was then grouped by gender and further split into six age groups each spanning a decade. As reference values were generated for each gender in each of the age groups, both age and gender were controlled for. This did, however, result in lower numbers in each of the groups (between nine and twenty-three). These low numbers may compromise the external validity of the reference values. Furthermore, there was no consideration of mass, height and shoe size which as previously discussed may affect AMS, thus altering the reference values produced.

As this thesis is concerned with eight measures of AMS spanning both genders and six age groups, using a similar method to Danneskiold-Samsøe et al. (2009) would result in the production of ninety-six different reference values. This would not include consideration of height, mass and shoe size which, as previously discussed, may alter AMS outcome measures. However, Harbo et al. (2011) suggested a reference equation for each measure of AMS which could be calculated from a regression analysis using independent variables that predict muscle strength. They used a Biodex System 3 dynamometer to measure muscle strength in ninety-three male and eighty-five female participants aged between 15 and 83 years. Using this data and the independent variables of height, mass, age and gender, they performed a linear regression analysis from which predictive equations were produced. This method has larger potential for application than that of Danneskiold-Samsøe et al. (2009) as it allows anthropometric variables to be taken into consideration. However, a linear regression analysis using all of the independent variables measured may include variables which do not affect the dependent variable. For example Harbo et al. (2011) produced thirty-six equations based on a linear regression analysis, using age, height and mass as independent variables, for muscle strength around various joints in the body. They found that age was significantly related to muscle strength in twenty-four of the thirty-six equations. However, they did not state which twenty-four. Each of the equations they presented included all three independent variables. As such it would not be possible to say which equation included non-significant variables that could reduce the accuracy of the prediction from the equation.

A stepwise linear regression analysis would identify which of the anthropometric variables significantly contribute to each of the eight AMS measures being tested. Only the significantly predictive variables would be used in the individual equations, thus improving the accuracy of the reference value. Based on the arguments presented in this chapter a stepwise linear regression analysis is recommended for use here. Details of this will be discussed further in the next chapter.

4.3 Summary

This chapter has described the eight key methodological variables in the measurement of AMS. The evidence presented here suggests if a meaningful comparison of results between experiments is to be achieved then standardisation of the variables is necessary. It is clear from the discussion above that the highlighted variables will influence some AMS outcome measures. However, a lack of research in some areas of AMS measurement means that the extent of this influence is not clear. Furthermore variability between the methods used means determination of reference values by meta-analysis is not possible. Chapter 5 will describe and assess a method for the production of reference values for PF, DF, inv and eve based on the arguments put forward in this chapter. It will also describe a stepwise linear regression analysis method which will identify the anthropometric variables that contribute to the eight AMS measures being examined.

Chapter 5

General method of data collection

5. General method of AMS data collection

5.1 Introduction

Chapter 4 identified and described eight variables common to research studies that used the Cybex Norm isokinetic dynamometer to measure AMS. Alterations in the variables used were discussed in terms of the physiological consequences of applying such constraints. A comparison of statistical analysis methods was also presented and a stepwise linear regression analysis was recommended for the production of predictive equations for AMS. Based on the findings of Chapter 4 this chapter will propose and test a protocol for AMS measurement using the Cybex Norm and will describe the statistical methods used to analyse the collected data. Specifically the following research aims will be explored and empirically tested using the proposed protocol:

a. As there are a number of variables which need to be defined when measuring AMS, once the systematic review was complete, the first aim of this thesis is to develop a protocol for measuring AMS with each variable justified (Chapter 5). This includes determining the effect of altering the angle at which the knee is fixed on AMS (Chapter 6).
b. As this protocol is to be used to take measurements of AMS from which reference values would be generated, the second objective is to ensure the protocol and the Cybex Norm are robust using a test re-test experimental design. (Chapter 7).
c. Using the justified and reliable protocol described in this chapter, the main aim of this thesis is to determine reference values for AMS collecting data and using a linear regression analysis to produce reference value equations (Chapter 8).
d. Previous research has indicated that there is variation in strength with variation in different anthropometric measurements, for example height, weight, age and gender. In the production of reference values knowledge of the factors which affect AMS are crucial. Thus, the data collected will also be used to explore a fourth aim, the effect of variations in anthropometric measurements on AMS (Chapter 8).
e. Validated reference equations for AMS could have a range of clinical, rehabilitation and sporting applications. The fifth aim of this thesis is to demonstrate an application of the validated reference equations. (Chapter 9).

5.2 Ethical considerations

Ethical approval for this experimentation was given by the ethics panel in the School of Human and Health Sciences at the University of Huddersfield on 11th November 2010. The main ethical considerations of beneficence and non-maleficence were protecting the participants from harm during testing. To minimise risk to the participants the equipment (Cybex Norm) was serviced and calibrated in accordance with the manufacturers guidelines. A risk assessment was produced to ensure all reasonable precautions were taken when using the equipment and the laboratory (see Appendix 5). A medical questionnaire designed to demonstrate fitness to proceed (Appendix 7) was completed and signed by each participant. If the answers to any of the questions raised doubt as to the eligibility of the participant they were not permitted to undertake the testing phase. To further reduce risk of injury the participants were instructed in the appropriate use of the equipment and sub-maximal familiarisation tests were performed for each of the eight movements tested.

The participants were informed of the testing procedure and the rationale behind the experiment. Each person was given an opportunity to ask questions prior to and throughout the testing. Following this a consent form approved by the School Ethics Committee was signed by each participant (Appendix 8). The privacy of the participants was ensured by referring to them by participant number within the collected data. All data was kept in a password protected computer folder. The participants were assured of the ability to withdraw from the study at any point if they so desired.

5.3 Participant Recruitment

The research population consisted of a convenience sample of staff and students at the University of Huddersfield who were asked by e-mail and via posters (see Appendix 6) to participate in the experiment. The eligibility of each participant was determined by a questionnaire completed prior to commencing the study (see Appendix 6) with the intention of ensuring the safety of the participants as well as the validity of the data gathered.

5.4 Participant questionnaire

The participant questionnaire was split into two sections. The first section was concerned with the participant’s anthropometric measurements and the second section with their medical history.

5.4.1 Anthropometric measurements

The questionnaire (Appendix 7) required the participant to state their gender, age, height mass, shoe size and limb dominance. As the evidence for strength discrepancies between dominant and non-dominant ankles is not definitive (see section 3.2.6) the dominant ankle was tested as determined by the participant kicking a ball with the foot used deemed to be the dominant one (W.-H. Lin et al., 2009; Munn et al., 2003; Sekir et al., 2008).

5.4.2 Medical history

Obtaining the patient's medical history was necessary as there are a number of illnesses and injuries that could be exacerbated by the test or impair torque production as discussed in Chapter 1 (sections 1.2.2 and 1.2.3). One of the strongest predictors of future injury to the ankle is previous injury (Brinkman & Evans, 2011). Hence, previous injury may affect strength and so the amount of peak torque produced may be reduced, thus, reference values based on these measurements would be inaccurate. It is therefore logical to ascertain if participants have previously sustained ankle injuries. However, a systematic review by van Rijn et al (2008) found full recovery from acute ankle sprain (defined as torn or partially torn ankle ligaments) was reported by between 36% and 85% of patients after 3 years. They also found three different definitions of recovery used within the literature. As the literature is not clear on how long an individual takes to fully recover from ankle injury and there is no consistent definition of 'fully recovered', the participants within this study were asked if they had any ankle pain, injury or other impairment that affects every day function. They were also asked if they had ever consulted a health professional regarding an ankle injury. Answering yes to either of these questions would render the individual ineligible to participate.

Numerous papers have discussed the deleterious effect of illness on muscle strength. For example in a study of thirty-six type II diabetic patients Andersen et al (2004) concluded ankle weakness may exist in this population due to peripheral neuropathy. Neuromuscular disorders such as Charcot-Marie-Tooth disease, by definition, affect muscle strength (Rose, Burns, & North, 2010) and thus, individuals with such disorders could not be considered part of a 'normal' population in terms of ankle strength. Durmus et al. (2010) observed decreased lower limb muscle strength in patients with Parkinsons disease and this correlated with number of falls. Any disease which affects the muscles, bones or nervous system may have an effect on peak muscle torque measurements across the ankle. Questions 4 – 7 of the questionnaire (see Appendix 7) dealt with these disorders and answering yes to any of these questions indicated the individual was ineligible for the study.

The final question of this section of the questionnaire referred to lower back pain. It is possible that an individual suffering from lower back pain could exacerbate the problem by performing ankle strength tests. Because of this anyone with pain in the lower back that affects every day movement was also considered ineligible.

5.5 Test Procedure

The dominant ankle was tested, as determined by asking the participant to kick a ball; the foot used was assumed to be the dominant one. (W.-H. Lin et al., 2009; Munn et al., 2003; Sekir et al., 2008). The participants were seated in the dynamometer chair and strapped in to minimise movement of the upper body. The dominant foot was strapped in to the footplate using Velcro® straps and the thigh stabiliser tube and pad were used to support and prevent movement of the knee in accordance with the manufacturer's instructions. The knee angle was fixed between 80° and 110° (Sekir et al., 2007; Urguden et al., 2010; Yavuz Yildiz et al., 2007). Prior to the PF and DF testing the axis of rotation of the dynamometer arm was aligned with the participant's lateral malleolus (Frasson et al., 2007, Dehail et al., 2007). Due to the construction of the Cybex Norm foot plate it is not possible to align both the medial and lateral malleolus of the ankle with the axis of motion of the dynamometer arm. As such there may be some variation in the participant position and so the torque produced between torque measurements produced by the Cybex and those produced by other machines where this is possible. Prior to measurement of inversion and eversion the axis of motion of the dynamometer arm was aligned with an approximation of the anterioposterior axis of motion of the ankle. This was determined by observation of movement of the ankle about the anterioposterior axis.

5.5.1 Warm Up

The test was performed on a Cybex Norm isokinetic dynamometer (Phoenix Healthcare, Nottingham, UK). To familiarise the participants with the equipment full instructions were given on its use and each participant performed five sub-maximal repetitions concentrically and eccentrically at 120°/s in inv and eve and at 60°/s in PF and DF (Du Toit et al., 2004; Gopalakrishnan et al., 2010; Muller et al., 2007; Patterson & Ferguson, 2010).

5.5.2 Testing inversion and eversion strength

The following was the method used to test inv and eve strength. Each point in the method is based on the discussion presented in Chapter 3. The numbers in brackets refer to the section in which the particular item was discussed.

- Familiarisation: five sub-maximal reciprocal repetitions of concentric inv and eve at 120°/s (3.2.3).
- Three sets of three maximal repetitions (3.2.5) of reciprocal concentric inv and eve at 120°/s (3.2.4) should be performed with 30 seconds rest between sets (3.2.5).
- Sixty seconds rest were allowed between concentric and eccentric testing (3.2.5).
- Familiarisation: five sub-maximal reciprocal repetitions of eccentric inv and eve at 120°/s (3.2.3).
- Three sets of three maximal repetitions (3.2.5) of reciprocal eccentric inv and eve at 120°/s (3.2.4) were performed with 30 seconds rest between sets (3.2.5).
- Five minutes rest between inv and eve testing and PF and DF testing were allowed (3.2.5).

5.5.3 Testing plantar flexion and dorsiflexion strength

- Familiarisation: five sub-maximal reciprocal repetitions of concentric PF and DF 60°/s (3.2.3).
- Three sets of three maximal repetitions (3.2.5) of reciprocal concentric PF and DF at 60°/s (3.2.4) were performed with 30 seconds rest between sets (3.2.5).
- Sixty seconds rest between concentric and eccentric testing was allowed (3.2.5).
- Familiarisation: five sub-maximal reciprocal repetitions of eccentric PF and DF 60°/s (3.2.3).
- Three sets of three maximal repetitions (3.2.5) of reciprocal eccentric PF and DF at 60°/s (3.2.4) were performed with 30 seconds rest between sets (3.2.5).

5.6 Analysis of the results

All statistical analysis was carried out using SPSS software package version 20. The COV of each set of three repetitions was calculated by the Cybex Norm software. Data from sets which produced a COV of greater than 0.2 were discarded. Peak torque for each of the eight measures of AMS being concentric and eccentric PF, DF, inv and eve, was taken as the highest torque achieved on any single repetition throughout the ROM.

5.7 Pilot Study

Prior to testing a large population a pilot study to test AMS using the method detailed above was undertaken to answer the following questions:

1. Are the inclusion and exclusion criteria sufficient to include eligible individuals whilst protecting potentially vulnerable individuals?
2. Is there a fatigue effect dependant on the experimental order?
3. Is it possible to consistently achieve a COV of less than 0.2 for all ankle strength experiments performed?
4. How long will the whole experiment take per participant?
5. Are there any other factors which have not been considered in the methodology which may affect the safety and dignity of the participants or the accuracy of the data collected?

5.7.1 Subjects

Participants were recruited as a convenience sample of staff and students of the University of Huddersfield between 20th November and 12th December 2010. The purpose of the experiment was explained and twenty participants, eight male and twelve female, were recruited. Volunteers were assessed for eligibility by use of a medical questionnaire (Appendix 7) and informed consent was obtained (Appendix 8). Table 5-1 shows the anthropometric data for the population tested.

Table 5-1

Pilot study participant demographics

Gender		Minimum	Maximum	Mean	Std. Deviation
Female (n=12)	Height	157	173	164.83	5.39
	Mass	57	104	70.56	13.70
	Age	22	54	41.25	9.42
	Footsize	4	7	5.92	1.18
Male (n=8)	Height	169	190	181.88	8.17
	Mass	62	110	84.73	14.09
	Age	20	38	23.88	5.82
	Footsize	8	12	10.12	1.36

Note Height is measured in cm, mass in kg, age in years and foot size is UK standard

5.7.2 Test procedure and data analysis

AMS testing was carried out according to the protocol previously described in section 5.5 on a Cybex Norm isokinetic dynamometer. Statistical analysis was carried out using SPSS version 20. A Shapiro-Wilk test was carried out to determine if the collected data was normally distributed, based on the results of this test either a one way repeated measures test was performed or a Friedman's test was performed to assess the effect of test order on AMS peak torque production.

5.7.3 Results

Table 5-2 shows the mean AMS peak torque values and SD for the whole population tested and males and females individually.

Table 5-2

Mean AMS peak torque values of the pilot population as a whole and split by gender.

Gender		Minimum	Maximum	Mean	Std. Deviation
female	PFcon	26	65	40.67	10.96
	DFcon	9	14	11.75	1.71
	PFecc	26	168	96.00	42.37
	DFecc	23	41	28.67	5.53
	Invcon	14	28	17.42	4.12
	Evecon	9	20	15.42	3.53
	Invecc	15	33	22.45	5.11
	Eveecc	16	34	26.83	5.95
Male	PFcon	33	96	76.00	21.99
	DFcon	12	31	22.25	6.67
	PFecc	38	188	139.67	57.18
	DFecc	22	79	47.38	21.17
	Invcon	14	33	21.88	5.84
	Evecon	14	41	21.25	8.50
	Invecc	12	54	34.00	12.47
	Eveecc	12	46	30.75	10.40
Combined	PFcon	26	96	54.80	23.73
	DFcon	9	31	15.95	6.78
	PFecc	26	188	113.47	51.81
	DFecc	22	79	36.15	16.47
	Invcon	14	33	19.20	5.24
	Evecon	9	41	17.75	6.51
	Invecc	12	54	27.32	10.45
	Eveecc	12	46	28.40	8.02

Note PF = plantar flexion; DF = dorsiflexion; inv = inversion; eve = eversion; con = concentric; ecc = eccentric
All torque values are in Nm.

5.7.3.1 Coefficients of variance

Twenty participants performed each of the eight ankle movements, concentric and eccentric PF, DF, inv and eve. Of these 160 movements performed, 154 produced at least one set with a COV of less than or equal to 0.2. The six movements where the COV was greater than 0.2 included five eccentric PF movements and one eccentric inv movement.

5.7.3.2 Test order

A Shapiro-Wilk test was carried out to determine if the collected data was normally distributed. The results of this test indicated that eccentric PF, inv and eve were normally distributed and the rest of the measures were not normally distributed. To analyse any differences in test order a one-way repeated measures analysis of variance was used for the normally distributed data and a Friedman's test was used for the data which was not normally distributed. Because of the reduced number of people who did not achieve a reliable reading for PFecc it was not possible to determine the effect of the test order on that measurement.

Parametric tests

The means and SD are presented in Table 5-3. In terms of eccentric inv Wilks' Lambda = 0.04, F(3,1) = 7.34, *P* = 0.264, for eccentric eve Wilks' Lambda < 0.001, F(3,1) = 1025.65, *P* = 0.02, multivariate partial squared = 1.00.

Table 5-3

Means and SD of the AMS measures in each of the four orders

	Mean	Std. Deviation	N
Invecc1	34.50	5.26	4
Invecc2	19.75	9.29	4
Invecc3	27.50	8.02	4
Invecc4	35.25	13.30	4
Eveecc1	37.00	6.83	4
Eveecc2	20.25	8.26	4
Eveecc3	29.75	6.02	4
Eveecc4	29.25	4.57	4

Note Inv- = inversion; Eve = eversion; ecc = eccentric;
Test orders:1 PFDF ecc PFDF con inv eve ecc inv eve con
2: PFDF con PFDF ecc inv eve con inv eve ecc
3: inv eve ecc inv eve con PFDF ecc PFDF con
4: inv eve con inv eve ecc PFDF con PFDF ecc

These results suggest that test order has no effect on eccentric inv but does have an effect on eccentric eve.

Non-parametric tests

Table 5-4

The results of the Friedmans test analysing the variance in AMS with test order.

	PFcon	DFcon	DFecc	Invcon	Evecon
N	4	4	4	4	4
Chi-Square	6.60	5.31	6.69	2.92	4.89
df	3	3	3	3	3
Asymp. Sig.	0.09	0.15	0.08	0.40	0.18

Note PF = plantar flexion; DF = dorsiflexion; inv = inversion; eve = eversion; con = concentric; ecc = eccentric.

The results of the Friedmans analysis (Table 5-4) indicate there is no effect on AMS production with changing test order.

5.7.4 Discussion

5.7.4.1 Comparison to existing reference values

The mean values shown in Table 5-2 have large SD values associated with them. This indicates there are a large range of measured values. Some, but not all, of the values are reduced when the results are split by gender. This suggests that some, but not all, of the AMS measures are influenced by gender. Other factors, not controlled for here, such as height, mass, age and shoe size are also likely to affect the AMS values as previously discussed and as such these could explain the size of the SD. Use of a stepwise linear regression analysis would take these variables into account; however, this is not appropriate here due to the low numbers tested.

The concentric PF and DF values presented here are lower than the reference values published by Danneskiold-Samsøe et al. (2009); however, the speed at which they tested was also lower (45°/s compared to 60°/s here). As previously discussed, increasing the speed of the contraction results in a lower peak torque, thus, results from this pilot study would be expected to be lower. The values for PF con and DF con shown in Table 5-2 are also lower than Harbo et al. (2011) who tested at the same speed. As discussed in section 2.3.1, there is evidence to suggest peak torque readings can differ between machines and as such the differences here could be the result of using Biodex System 3 isokinetic dynamometer rather than the Cybex Norm. van Cingel et al. (2009) tested inv and eve at the same speed as this pilot study also using the Cybex Norm. They found their results to be higher than the results presented here particularly in the females (21.39Nm inv and 22.46Nm eve compared to 17.42Nm inv and 15.42Nm eve presented here). However, there were a number of differences in protocol between the papers. There was a difference in average age between the populations tested (28.6 years compared to 41.2 years presented here) which may account for the differences. van Cingel et al. (2009) also tested inv and eve with the leg in full extension necessitating the use of a separate bench rather than the in-line Cybex chair. All of these factors could have contributed to the differences in inv and eve values. It can be concluded that variation between the data presented here and that of the published reference values is due to differences between the data collection methods, populations and equipment used. This supports the assertion that that reference values for the Cybex Norm, produced using a standardised protocol are worthy of investigation.

5.7.4.2 Coefficients of variance

The results indicated that 154 out of 160 movements achieved a COV of less than 0.2. This suggests that there was a high level of consistency across the three results. Based on these results it can be concluded the 0.2 threshold level recommended by Whimpenny (2000) are achievable in all eight measures of AMS.

5.7.4.3 Test order

The data presented in section 5.7.3.2 suggests that the order in which the tests are taken has an effect on eccentric Eve only. Thus, it is recommended that the order in which the tests are taken in the main experiment are randomised.

5.7.5 Conclusions drawn from pilot study

Based on the results and conclusions drawn from pilot study the following observations and recommendations were made:

1.The inclusion and exclusion criteria were generally sufficient to include eligible individuals whilst protecting potentially vulnerable individuals. Two exceptions were noted:

a. One participant reported they could have produced greater torque had they not been running the previous evening. To control this variable a sentence will be added to the information document 'no strenuous physical activity 24 hours prior to testing' to avoid post exercise fatigue affecting results.

b. Question 6 of section 1 should be changed to 'Do you currently have any back pain or are you suffering from a lower back injury that affects every day movement?' thus allowing individuals with historical back pain but no current symptoms to participate.

2.Each of the participants was asked if their muscles felt fatigued after each movement type performed. None of the participants indicated that they were fatigued; however, the statistical analysis indicated varying test order altered the amount of AMS produced. To avoid any order bias which may occur, the order in which the tests are taken will be randomised across the experiment using the following sequences:

a. Eccentric PF and DF / concentric PF and DF / eccentric inv and eve / concentric inv and eve
b. Concentric PF and DF / eccentric PF and DF / concentric inv and eve / eccentric inv and eve
c. Eccentric inv and eve / concentric inv and eve / eccentric PF and DF / concentric PF and DF
d. Concentric inv and eve / eccentric inv and eve / concentric PF and DF / eccentric PF and DF

The first participant will follow sequence a; the second participant sequence b etc. The order in which a particular participant took the tests will be recorded on a randomisation chart (Appendix 9).

3.The majority of the participants achieved a COV of less than 0.2 for all of the movement types, so this is accepted as an achievable level. Where participants are not able to score below the 0.2 threshold the data from that particular measure will be discarded.

4.The test takes approximately 30 minutes per participant. This could be reduced with familiarity with the testing process. This is an acceptable amount of time to allow the principle researcher to test sufficient numbers for the statistical analysis (111 participants as described in section 4.3) over a 2 year period.

5.Several other minor alterations were identified from the pilot study. These were:

a. The questionnaire should be included with the recruitment e-mail as this will reduce the number of e-mails that need to be sent.
b. The questionnaire should include participant number on each sheet to help ensure the anonymity of the participants

c. Participant number should be used instead of name to identify individuals within the Cybex Norm software to further ensure the anonymity of the participants.

5.8 Standardised Protocol

The following is a summary of the protocol based on the papers found in Chapter 3 and modified based on the results and experience of the pilot study.

- The dominant ankle should be tested unshod in a supine position with the knee flexed between 80° and 110°
- The following test order should be randomised to avoid order bias.
- Familiarisation: five sub-maximal, reciprocal, concentric inv and eve repetitions at 120°/s.
- Three sets of three repetitions maximal reciprocal concentric inv and eve at 120°/s should be performed with 30 seconds rest between sets.
- Sixty seconds rest should be allowed between concentric and eccentric testing.
- Familiarisation: five sub-maximal, reciprocal, eccentric inv and eve repetitions at 120°/s.
- Three sets of three repetitions maximal reciprocal eccentric inv and eve at 120°/s should be performed with 30 seconds rest between sets.
- Five minutes rest between inv and eve testing and PF and DF testing should be allowed.

- Familiarisation: five sub-maximal, reciprocal, eccentric PF and DF repetitions at 60°/s
- Three sets of three repetitions maximal reciprocal concentric PF and DF at 60°/s should be performed with 30 seconds rest between sets.
- Sixty seconds rest between concentric and eccentric testing should be allowed
- Familiarisation: five sub-maximal, reciprocal, eccentric PF and DF repetitions at 60°/s
- Three sets of three repetitions maximal reciprocal eccentric PF and DF at 60°/s should be performed with 30 seconds rest between sets.

Chapter 6

The effect of knee angle on AMS production

6. An experiment examining the effect of knee angle on AMS peak torque production

6.1 Introduction

Research has shown that altering the angle at which the knee is fixed will alter the amount of torque produced at the ankle. Wakahara et al. (2009) demonstrated a significant increase in eccentric PF force when changing the knee angle from 0° to 90° flexion using the CON-TREX dynamometer. Lentell (1988) found that changing the knee angle from 10° to 70° resulted in a significant increase in concentric inv and eve using a Cybex II dynamometer. A search of the literature indicated that similar experiments had not been performed for eccentric inv or eve, or for concentric or eccentric DF or concentric PF. Appendix 3 indicates that testing ankle strength with the knee held at 80-110° is common clinical practice for testing inv and eve strength. Analysis of the papers which have tested PF and DF strength using the Cybex Norm have suggests holding the knee in a fully extended position or between 80° and 110° is also common clinical practice. As discussed in section 3.2.2, a fully extended knee may artificially inflate eccentric PF whilst preventing the full ROM. Therefore, the aim of this experiment is to determine the effect of altering the knee angle between 10° and 80°-110° on concentric and eccentric PF, DF, inv and eve using the Cybex Norm isokinetic dynamometer.

6.2 Method

The participant recruitment method used and ethical considerations are outlined in sections 5.2 and 5.3 respectively. Participants were asked to attend the laboratory on one occasion for approximately 1 hour. A participant questionnaire was completed (see section 5.4), full instruction on the use of the Cybex Norm was given and the participants were asked to complete a familiarisation protocol (see section 5.5.1). The participants were then tested using the protocol detailed in section 5.8, with the following modifications:

- The right ankle was tested unshod in a supine position with the knee flexed either between 80° and 110° or 10°. The initial testing angle alternated between participants with the other angle being tested straight afterwards.

The order of the AMS testing was randomised according to Table 6-1.

Table 6-1

Randomisation table showing the order in which AMS was tested.

Movement type				Participant number	
PFDF ecc	PFDF con	inv eve ecc	inv eve con	1	9
inv eve ecc	inv eve con	PFDF ecc	PFDF con	2	10
PFDF ecc	PFDF con	inv eve con	inv eve ecc	3	-
inv eve con	inv eve ecc	PFDF ecc	PFDF con	4	-
PFDF con	PFDF ecc	inv eve ecc	inv eve con	5	-
inv eve ecc	inv eve con	PFDF con	PFDF ecc	6	-
PFDF con	PFDF ecc	inv eve con	inv eve ecc	7	-
inv eve con	inv eve ecc	PFDF con	PFDF ecc	8	-

Note PF = plantar flexion; DF = dorsiflexion; Inv = inversion; Eve = eversion; con = concentric; ecc = eccentric.

Statistical analysis was performed using statistical software SPSS (version 20). Where data was normally distributed, a paired samples t-test assessed the differences between the eight AMS peak torque values produced in the first and second tests. Where the data is not normally distributed a Wilcoxon Signed Ranks test was performed to assess any differences.. $P < 0.05$ was considered statistically significant. The Cohen's d value indicates the size effect of the difference between the measured torque values where there is a significant difference. < 0.2 indicates no effect, 0.2 - 0.4 indicates small effect; 0.5 - 0.8 indicates an intermediate effect; > 0.8 indicates a large effect.

6.3 Results

Ten participants were tested, five males and five females. The participant demographics are described in Table 6-2.

Table 6-2

Demographics of the experimental population

	Minimum	Maximum	Mean	Std. Deviation
height	153.00	177.00	164.60	8.38
mass	56.00	111.70	78.08	16.54
age	34	54	45.30	6.73

Note Height is measured in cm, mass in kg and age in years.

6.3.1 Normality of the Data

A Shipiro-Wilk test for normality was performed on the data.

Table 6-3

The results of a Shapiro-Wilk test of normality on both sets of data

	Shapiro-Wilk		
	Statistic	df	Sig.
PFcon80	0.83	10	0.04
PFcon10	0.85	10	0.06
DFcon80	0.87	10	0.10
DFcon10	0.91	10	0.25
PFecc80	0.93	10	0.44
PFecc10	0.97	10	0.84
DFecc80	0.88	10	0.12
DFecc10	0.80	10	0.01
Invcon80	0.98	10	0.98
Invcon10	0.88	10	0.13
Evecon80	0.89	10	0.16
Evecon10	0.96	10	0.76
Invecc80	0.81	10	0.02
Invecc10	0.97	10	0.85
Eveecc80	0.83	10	0.04
Eveecc10	0.96	10	0.81

Note PF = plantar flexion; DF = dorsiflexion; Inv = inversion; Eve = eversion; con = concentric; ecc = eccentric. 80 =80°-110°; 10=10°. Peak torque is measured in Nm. Normality of distribution assumed if $P > 0.05$

The results indicated that the data was normally distributed in all measures apart from concentric PF ($P = 0.04$), eccentric inv ($P = 0.02$) and eve ($P = 0.04$) with the knee flexed at 80°-110° and eccentric DF ($P = 0.01$) with the knee flexed to 10°. See Table 6-3 for detail of the analysis. The normally distributed data and the data that was not normally distributed was analysed separately.

6.3.2 Non-parametric data

The non-parametric data with means and medians are displayed in Table 6-4. The results of the Wilcoxon signed rank test are displayed in Table 6-5. These indicate that there is an decrease in concentric PF between knee flexion at 10° (median 48Nm) and knee flexion at 80°-110° (median 44Nm); (z = -2.55, P = 0.01) and the effect size was large (R = -0.81). The table also indicates a significant increase in eccentric eve between knee flexion at 10° (median 22.5Nm) and knee flexion at 80°-110° (median 23Nm); (z = 2.14, P = 0.03) and but the effect size was intermediate (R = 0.68).

Table 6-4

The mean and median results from the non-parametric data.

	N	Mean	Std. Deviation	Minimum	Maximum	Percentiles 25th	Percentiles 50th (Median)	Percentiles 75th
PFcon80	10	48.20	16.84	27.00	81.00	37.75	44.00	54.00
PFcon10	10	55.60	19.41	31.00	95.00	45.00	48.00	67.25
DFecc80	10	33.50	15.36	16.00	67.00	23.50	26.50	45.50
DFecc10	10	33.00	13.33	22.00	66.00	22.75	29.00	38.25
Invecc80	10	22.20	8.19	15.00	41.00	16.00	19.50	27.75
Invecc10	10	19.90	6.01	11.00	31.00	15.50	19.00	24.75
Eveecc80	10	26.00	8.98	15.00	42.00	21.25	23.00	32.75
Eveecc10	10	21.30	6.65	8.00	33.00	17.50	22.50	24.50

Note PF = plantar flexion; DF = dorsiflexion; Inv = inversion; Eve = eversion; con = concentric; ecc = eccentric. 80 =80°-110°; 10=10°. Peak torque is measured in Nm.

Table 6-5

The results of the Wilcoxon test to determine the effect of knee angle on AMS

	PFcon10 - PFcon80	DFecc10 - DFecc80	Invecc10 - Invecc80	Eveecc10 - Eveecc80
Z	-2.55	-0.06	-1.54	2.14
Asymp. Sig. (2-tailed)	0.01	0.95	0.12	0.03
R	-0.81	-0.02	-0.49	0.68

Note PF = plantar flexion; DF = dorsiflexion; Inv = inversion; Eve = eversion; con = concentric; ecc = eccentric. 80 =80°-110°; 10=10°. Peak torque is measured in Nm.

To provide a correlation analysis for the non-parametric data a Spearman's rho test was used. The results of this analysis are displayed in Table 6-6.

Table 6-6

The results of a Spearman's rho correlation test examining differences in AMS with knee angle

		PFcon80	DFecc80	Invecc80	Eveecc80
PFcon10	Correlation Coefficient	0.52	-	-	-
	Sig. (2-tailed)	0.13	-	-	-
DFecc10	Correlation Coefficient	-	0.95	-	-
	Sig. (2-tailed)	-	0.00	-	-
Invecc10	Correlation Coefficient	-	-	0.85	-
	Sig. (2-tailed)	-	-	0.00	-
Eveecc10	Correlation Coefficient	-	-	-	0.65
	Sig. (2-tailed)	-	-	-	0.04

Note PF = plantar flexion; DF = dorsiflexion; inv = inversion; eve = eversion; con = concentric; ecc = eccentric; 10 = knee flexed to 10°; 80 = knee flexed between 80° and 110°

The results displayed in Table 6-6 indicate that there was a significant correlation between eccentric inv, eve and DF AMS measures with the knee flexed at 10° and between 80° and 110°. There was no correlation between concentric PF measures. This data is represented graphically in Figure 6-1 through to Figure 6-4.

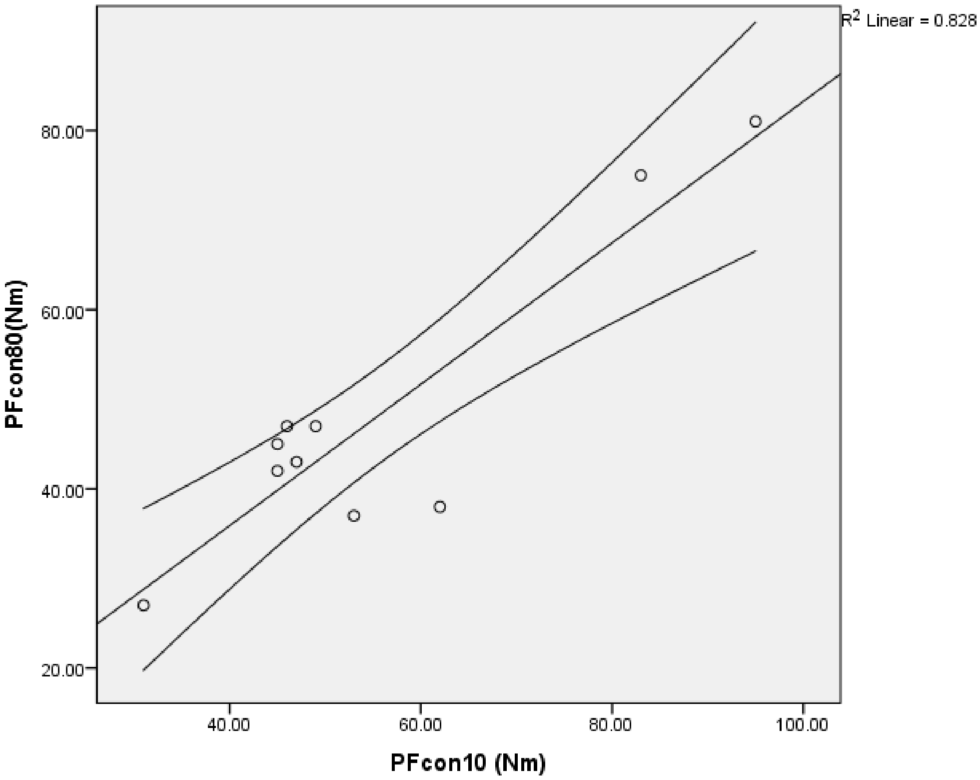


*Figure 6-1 A s*catterplot representing the relationship between concentric PF measures when the knee is flexed to 10° and between 80° and 110°. PF = plantar flexion; con = concentric; 80 = knee flexed between 80° and 110°; 10 knee flexed to 10°.

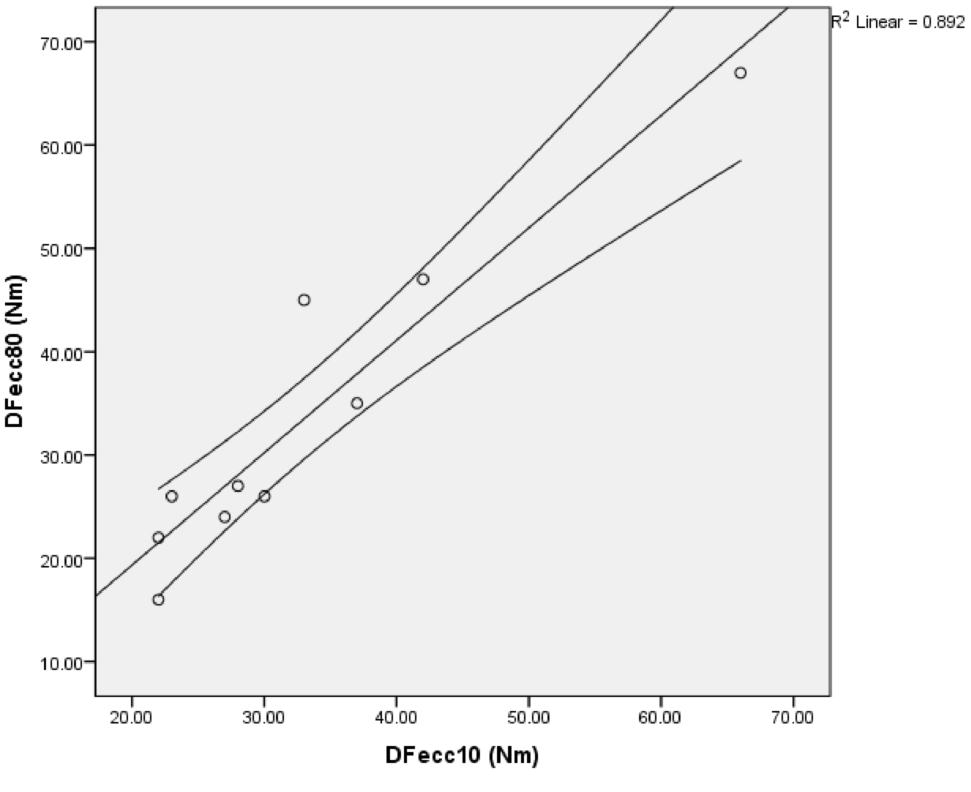


Figure 6-2 A scatterplot representing the relationship between eccentric DF measures when the knee is flexed to 10° and between 80° and 110°. DF = dorsiflexion; ecc = eccentric; 80 = knee flexed between 80° and 110°; 10 knee flexed to 10°.

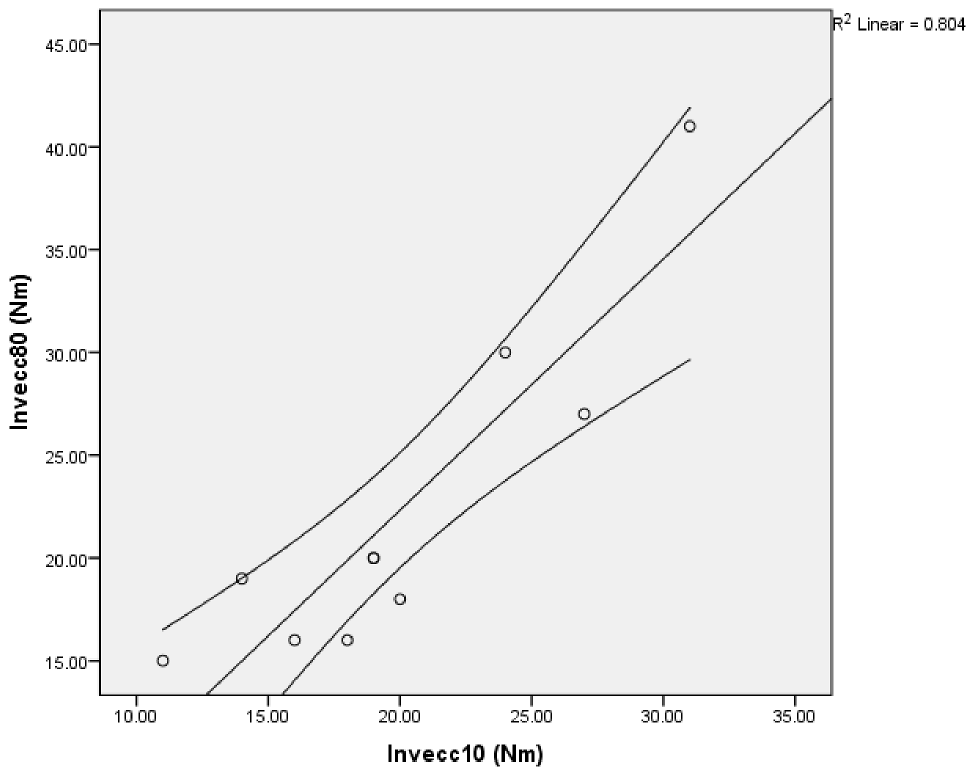


Figure 6-3 A scatterplot representing the relationship between eccentric inversion measures when the knee is flexed to 10° and between 80° and 110°. Inv = inversion; ecc = eccentric; 80 = knee flexed between 80° and 110°; 10 knee flexed to 10°.

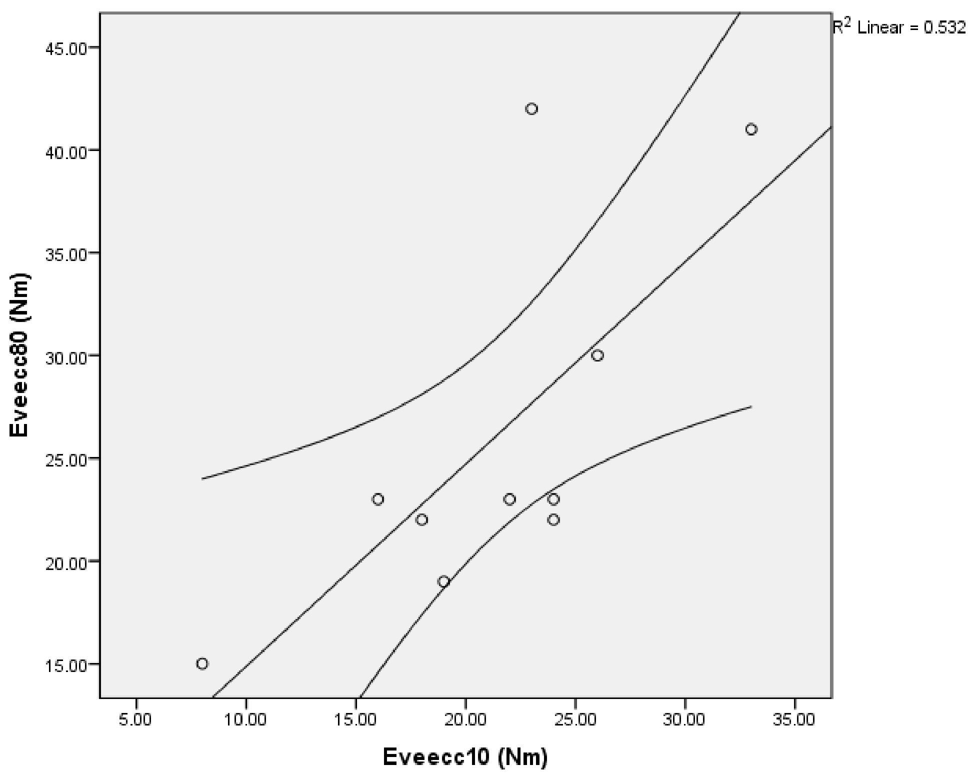


Figure 6-4 A scatterplot representing the relationship between eccentric eversion measures when the knee is flexed to 10° and between 80° and 110°. Eve = eversion; ecc = eccentric; 80 = knee flexed between 80° and 110°; 10 knee flexed to 10°.

6.3.2 Parametric data

The mean average peak torque for each of the eight measured AMS movements in both knee angle conditions are shown in Table 6-7 and are represented in Figure 6-5 and Figure 6-6.

Table 6-7

The mean average results and t-test statistics for the peak torque achieved in both knee angle conditions in each of the normally distributed AMS measures.

	Min	Max	Mean	Std. Deviation	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)	Cohen's d
					Lower	Upper				
DFcon80	8	27	14.60	6.62	-0.98	1.98	0.76	9	0.46	-
DFcon10	7	28	14.10	6.67						
PFecc80	35	104	72.60	23.87	-39.98	-1.02	-2.38	9	0.04	0.77
PFecc10	47	151	93.10	29.09						
Invcon80	9	28	17.70	5.44	0.64	5.36	2.88	9	0.02	0.66
Invcon10	11	22	14.70	3.50						
Evecon80	11	26	16.60	5.04	0.60	5.20	2.85	9	0.02	0.67
Evecon10	8	19	13.70	3.47						

Note PF = plantar flexion; DF = dorsiflexion; Inv = inversion; Eve = eversion; con = concentric; ecc = eccentric. 80 =80°-110°; 10=10°. Peak torque is measured in Nm.

The results of the paired samples t-test displayed in Table 6-7 are also shown in Figure 6-5 and Figure 6-6. These indicate that concentric and eccentric PF is significantly less ($P < 0.05$) when the knee is fixed between 80° and 110° compared to fixing the knee at 10°. Changing the angle of the knee had no effect on the amount of concentric DF peak torque produced. When the knee was fixed between 80° and 110° there was significantly greater ($P < 0.05$) concentric inv. The Cohen's d values shown in Table 6-7 indicate that the effect size of the statistically significant differences was intermediate.

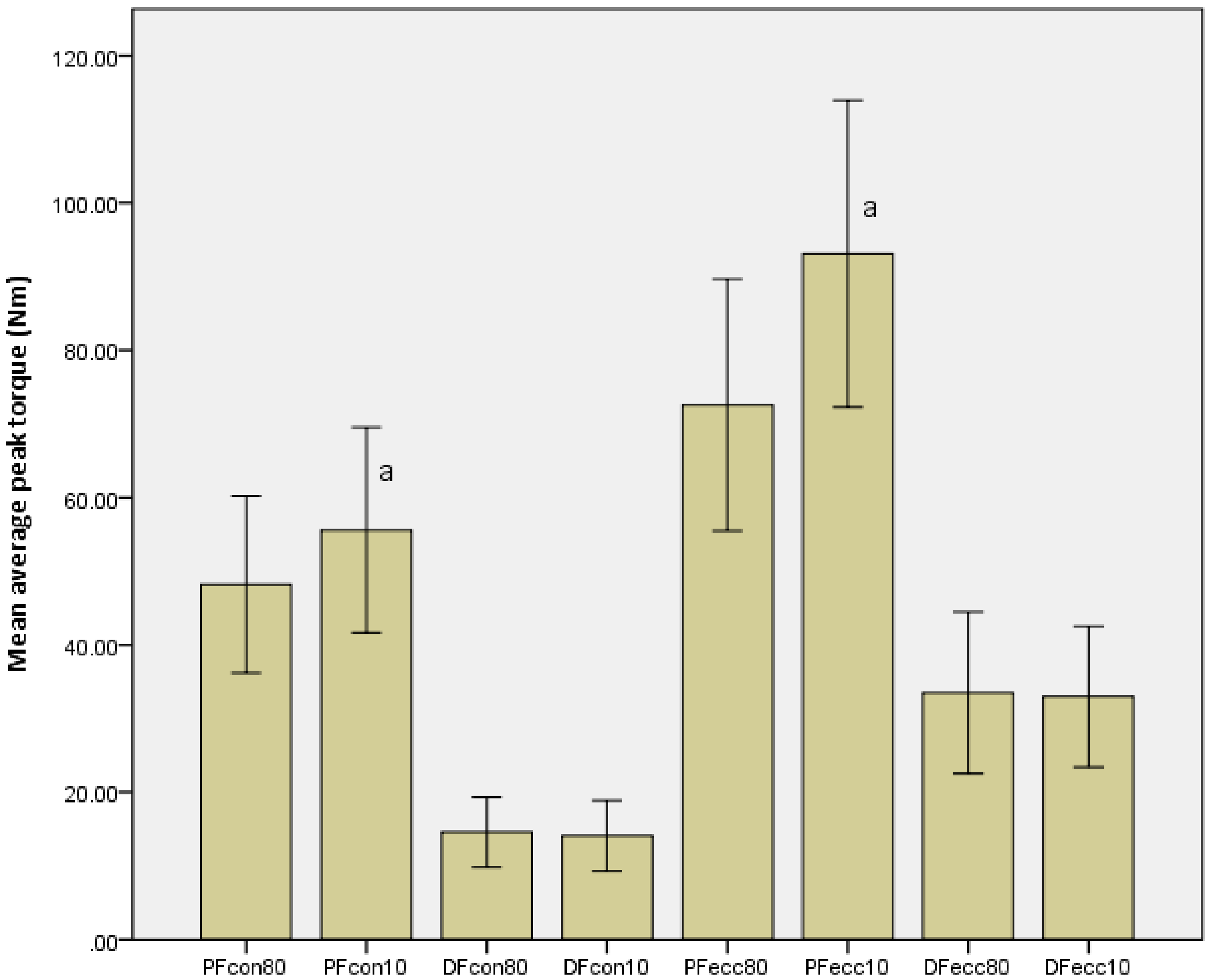


Figure 6-5 A graph comparing concentric and eccentric peak torque produced in each of the knee angle conditions. PF = plantar flexion; DF = dorsiflexion; Inv = inversion; Eve = eversion; con = concentric; ecc = eccentric. 80 = knee flexed between 80°-110°; 10 = knee flexed to 10° a=significantly greater than the 80°-110° condition. Error bars represent the 95% CI.

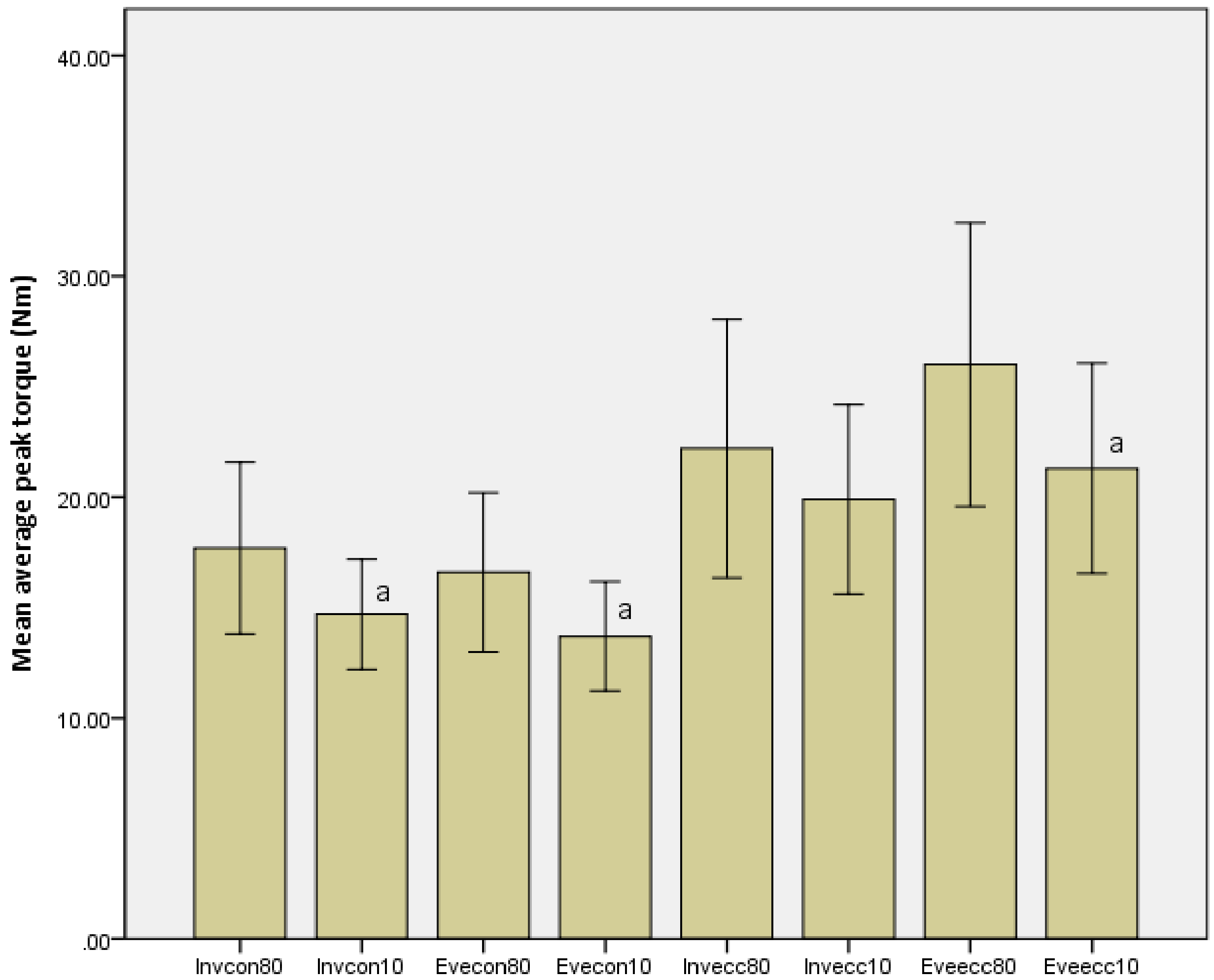


Figure 6-6 A graph comparing concentric and eccentric peak torque produced in each of the knee angle conditions. Inv = Inversion; Eve = eversion; con = concentric; ecc = eccentric; 80 = knee flexed between 80°-110°; 10 = knee flexed to 10°. a = significantly less than the 80°-110° condition. Error bars represent 95% CI.

Table 6-8 shows the results of a Pearson's correlation test comparing the peak torque produced at the two different knee angles.

Table 6-8

Results of a Pearson's correlation test between knee angle conditions.

	Correlation	Sig.
PFecc80 & PFecc10	0.49	0.16
DFcon80 & DFcon10	0.95	0.00
Invcon80 & Invcon10	0.81	0.00
Evecon80 & Evecon10	0.78	0.01

Note: PF = plantar flexion; DF = dorsiflexion; inv = inversion; eve = eversion; con = concentric; ecc = eccentric. 80 = knee flexed between 80° and 110°; 10 = knee flexed to 10°

There was a significant correlation between peak torque produced at each knee angle concentric DF, inv and eve. There was no significant correlation between eccentric PF taken with the knee fixed at 10° and at 80°-110°. These data are represented graphically in Figure 6-7 through to Figure 6-10.

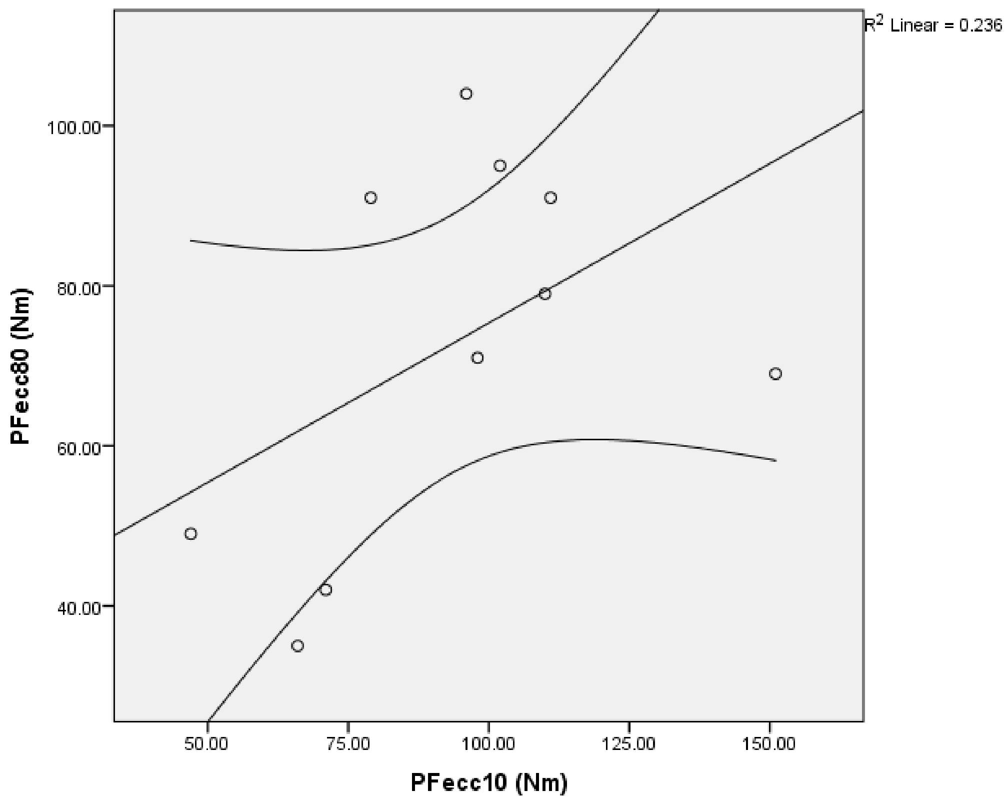


*Figure 6-7 A s*catterplot representing the relationship between eccentric PF measures when the knee is flexed to 10° and between 80° and 110°. PF = plantar flexion; ecc = eccentric; 80 = knee flexed between 80° and 110°; 10 = knee flexed to 10°.

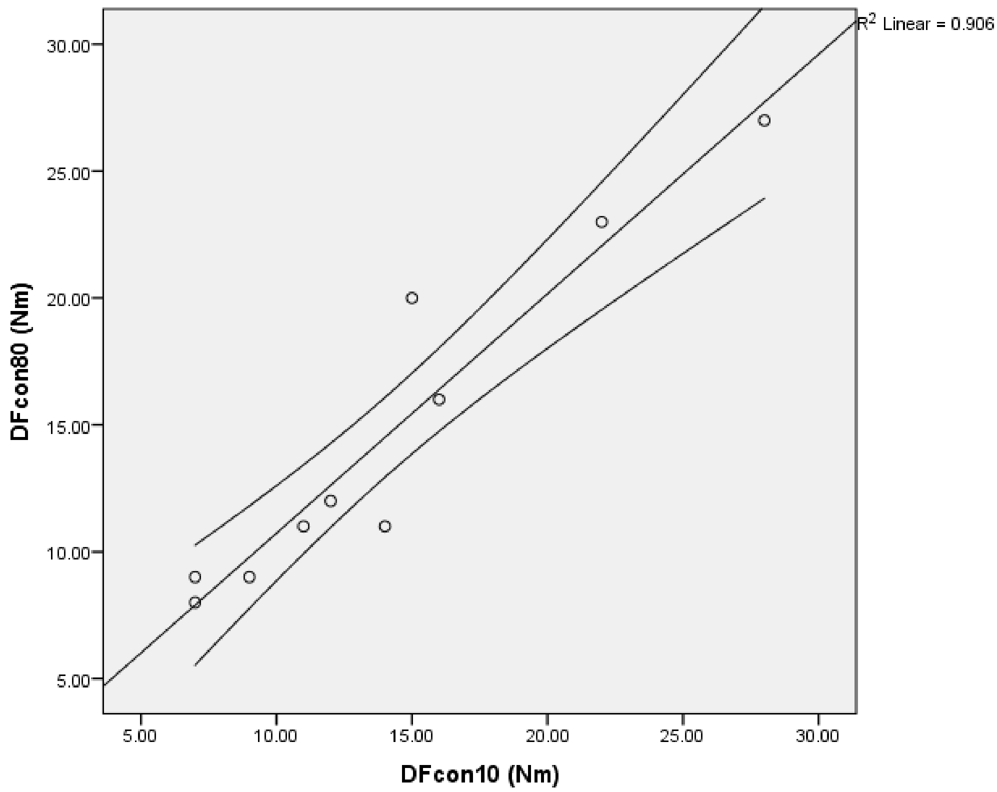


*Figure 6-8 A s*catterplot representing the relationship between concentric DF measures when the knee is flexed to 10° and between 80° and 110°. DF = dorsiflexion; con = concentric; 80 = knee flexed between 80° and 110°; 10 = knee flexed to 10°.

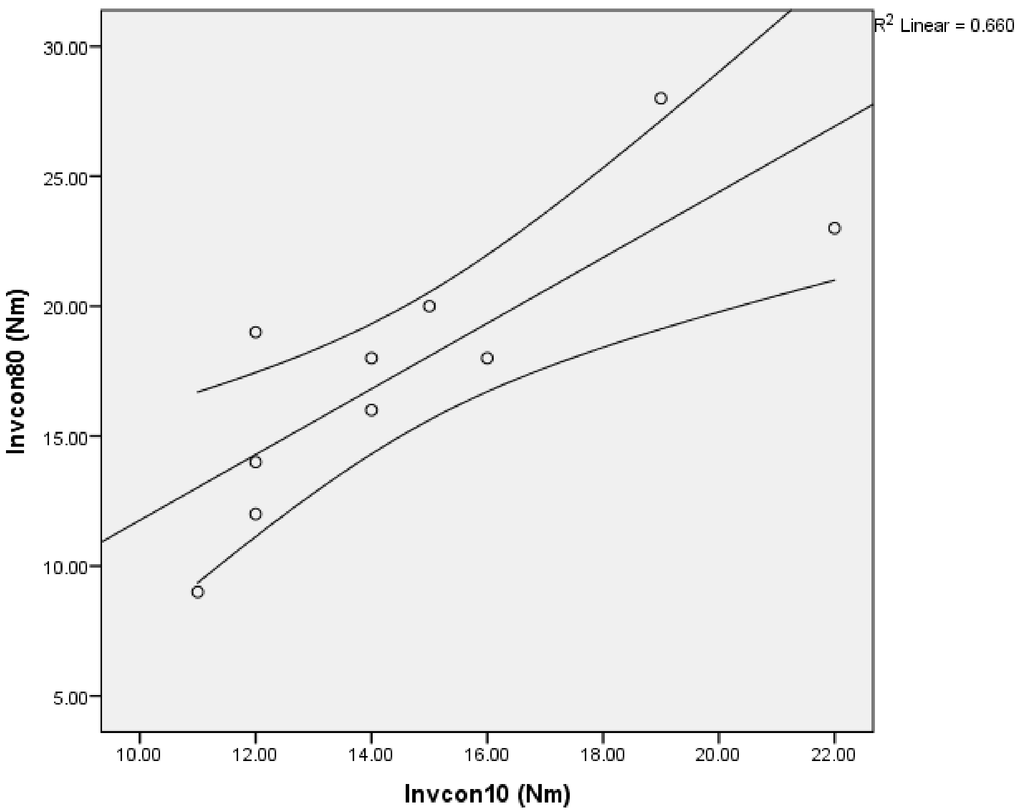


*Figure 6-9 A s*catterplot representing the relationship between concentric inv measures when the knee is flexed to 10° and between 80° and 110°. Inv = inversion; con = concentric; 80 = knee flexed between 80° and 110°; 10 = knee flexed to 10°.

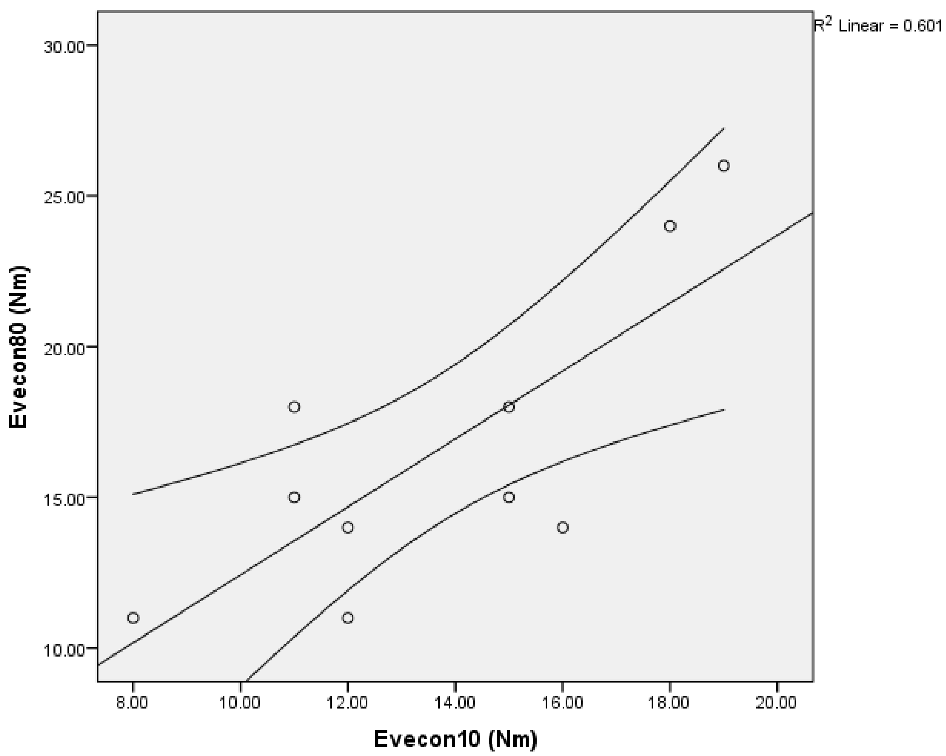


*Figure 6-10 A s*catterplot representing the relationship between concentric eve measures when the knee is flexed to 10° and between 80° and 110°. Eve = eversion; con = concentric; 80 = knee flexed between 80° and 110°; 10 = knee flexed to 10°.

6.4 Discussion

The results described here indicate that there is a significantly less inv and eve peak torque generated with the leg fixed at 10° compared to when the leg is fixed between 80° and 110°. These results are in agreement with the conclusions of Lentell (1988). However, the Cohen's d and R values bring into question the clinical significance of the differences. A large effect size would indicate that the differences between the torque values are clinically relevant; however, as the effect size is only intermediate this may not be the case. Furthermore, it is not possible to calculate the effect size from the data presented by Lentell (1988) and so it is not possible to comment on the relevance of the differences they described. From observing the experimental procedure it was concluded that use of a bench to raise the participant to sufficient height for testing added possible variation in terms of participant movement during the test. This movement was not apparent when using the Cybex Norm chair due to the use of the purpose built supports and restraints. This may detract from the reliability of the results; furthermore, movement of the participant from the Cybex Norm chair to the bench and back significantly increased the amount of time needed for the testing.

The PF measurements presented here also showed a significant increase in peak torque produced with the leg fixed at 10° compared to fixing the leg at between 80° and 110°. Both the R value for concentric PF ($R = 0.81$) the effect size for eccentric PF ($d = 0.77$) suggests a large effect size meaning that this result may have greater clinical relevance. After observing the participants during the testing procedure it was suggested that the increase in peak torque produced with the leg fixed at 10° maybe a result of the transfer of force through the knee and hip to the chair back. This conclusion would explain why there was no difference between knee angle conditions when testing DF strength. As the DF movement pulls the foot towards the chair back there is no transfer of force towards the chair, thus, no difference in the results. It Is also possible that the increase in concentric PF peak torque when the knee is flexed to 10° compare to 80°-110° may also be due to 'active insufficiency' of the gastrocnemius whereby the motor neurone activation is reduced when the knee is flexed to 80°-110° due to the shortened fascicle length (Kennedy & Cresswell, 2001). The reduced input from gastrocnemius as a result of knee flexion is an acknowledged limitation of the protocol used here, however, due to the time constraints of the PhD process the measurement of peak torque with the leg fixed between 80° and 110° is recommended. This is more efficient in terms of time spent testing for the participants and is the only realistic option in terms of measuring inv and eve using the Cybex Norm.

6.5 Conclusion

Based on the results of this experiment as well as the observations made in its undertaking, it is recommended that PF, DF, inv and eve testing should be performed with the knee fixed between 80° and 110°. It is acknowledged that this may allow for recruitment of other muscle groups resulting in elevated inv and eve torque results. However, the question of the clinical relevance of these elevated results coupled with the added time needed to participate in the experiment outweigh potential errors. Furthermore, the evidence suggests that testing PF with the knee at 10° produces higher results, in part due to the inhibition of the gastrocnemius in knee flexion. If these factors are understood and acknowledged then the angle at which the knee is flexed is not an issue providing the angle is clearly stated in the protocol and any comparative measures use the same protocol. As testing both PF and DF, and inv and eve with the knee fixed at the same angle would further reduce the time needed to perform the experiment then both PF and DF, and inv and eve should be tested with the knee fixed between 80° and 110°.

Chapter 7

Reliability of the Protocol

7. Reliability of the protocol

7.1 Introduction

In order to produce valid reference range equations it is necessary to use a reliable protocol. To ascertain the reliability of the protocol described in Chapter 5 a test-retest experiment was carried out

7.2 Method

Eighteen healthy participants were recruited via e-mail from a convenience sample of University staff and students. They attended the laboratory on two different occasions ranging from two to six days between visits. On the first visit a medical questionnaire was completed and written informed consent was obtained from all subjects (see Appendix 7 and Appendix 8). Exclusion criteria included a history of ankle problems or any known neurological or musculoskeletal problems which may affect AMS. The participants were asked to avoid strenuous exercise for 24 hours prior to each visit. Ethical approval was obtained from the University's Research Ethics Committee on 11th November 2010.

On each visit the participants undertook the AMS testing according to the protocol described in Chapter 5. The order in which the test were taken were randomised across the participants; however, each participant performed the test in the same order on the first and second visit to avoid test order bias. Statistical analysis was performed using statistical software SPSS (version 20). As the Shapiro-Wilk test was used to determine the normaility of the distribution of the data. Significance levels were set at $P = 0.05$.

The ICC used by van Cingel et al. (2009), Laughlin et al. (2009) and Taskiran, Özdogan, Sepici, and Meray (2013) indicated the percentage of the observed score variance attributable to true score variance (based on between subject variance) and error variance (biological variance, equipment variance, tester and participant error). The ICC here was calculated using a two-way mixed effects model with type consistency to demonstrate the reliability of the data. The SEM used by van Cingel et al. (2009) and Laughlin et al. (2009) gave an indication of expected measurement 'noise' (this figure has the same units as the measurement and gives an indication of the expected variation from the mean from trial to trial (Weir, 2005)). The calculation used was as follows: $SEM = SD \times \sqrt{(1 - ICC)}$; (Weir, 2005).

7.3 Results

Six males and eleven females were recruited for the experiment. See Table 7-1 for the participant demographics.

Table 7-1

Participant demographics

	Minimum	Maximum	Mean	Std. Deviation
Height	155.00	179.00	166.77	7.66
Weight	44.30	87.00	65.32	12.06
Age	20.00	66.00	40.65	14.75

Note Height is measured in cm, mass in kg and age in years.

A Shapiro-Wilk test of normality was performed to test the normality of the distribution of results (see Table 7-2).

Table 7-2
The results from a Shapiro-Wilk test of normality.

	Shapiro-Wilk		
	Statistic	df	Sig.
PFcon1	0.96	17	0.57
PFcon2	0.97	17	0.87
DFcon1	0.93	17	0.20
DFcon2	0.93	17	0.25
PFecc1	0.93	17	0.20
PFecc2	0.92	17	0.14
DFecc1	0.94	17	0.33
DFecc2	0.93	17	0.19
Invcon1	0.97	17	0.83
Invcon2	0.96	17	0.68
Evecon1	0.98	17	0.92
Evecon2	0.91	17	0.12
Invecc1	0.96	17	0.69
Invecc2	0.96	17	0.55
Eveecc1	0.89	17	0.05
Eveecc2	0.97	17	0.84

Note PF = plantar flexion; DF = dorsiflexion; inv = inversion; eve = eversion; con = concentric; ecc = eccentric. 1 = first test; 2 = second test.
Normality of distribution assumed if $P > 0.05$

The Shapiro-Wilk test, described in **Table 7-2**, indicated that all of the data was normally distributed, thus, a paired samples t-test was used to analyse the data.

Table 7-3

The results of a paired samples t-test comparing AMS peat torque between visits.

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
PFcon1 - PFcon2	3.31	6.76	1.69	-0.29	6.91	1.96	15	0.07
DFcon1 - DFcon2	-0.31	4.70	1.18	-2.82	2.19	-0.27	15	0.79
PFecc1 - PFecc2	6.69	19.91	4.98	-3.92	17.29	1.34	15	0.20
DFecc1 - DFecc2	1.19	8.57	2.14	-3.38	5.76	0.55	15	0.59
Invcon1 - Invcon2	0.75	2.86	0.72	-0.78	2.28	1.05	15	0.31
Evecon1 - Evecon2	-0.25	3.87	0.97	-2.31	1.81	-0.26	15	0.80
Invecc1 - Invecc2	2.00	4.07	1.02	-0.17	4.17	1.97	15	0.07
Eveecc1 - Eveecc2	0.00	6.86	1.72	-3.66	3.66	0.00	15	1.00

Note: PF = plantar flexion; DF = dorsiflexion; inv = inversion; eve = eversion.
All torque values measured in Nm

Table 7-4

The mean peak torque values for the first and second AMS tests with corresponding t-test significance values and intraclass correlation coefficient values.

		Test 1				Test 2				t-test *P* value	ICC value	SEM value (Nm)	SEM %
		Minimum	Maximum	mean	SD	Minimum	Maximum	mean	SD				
PF	concentric	19.00	125.00	51.93	25.44	18.00	113.00	48.63	23.20	0.07	0.98	3.45	6.65
	eccentric	31.00	142.00	76.56	37.56	22.00	184.00	69.88	44.32	0.20	0.94	9.21	12.02
DF	concentric	8.00	28.00	15.44	5.21	8.00	35.00	15.75	6.75	0.79	0.82	2.21	14.33
	eccentric	18.00	57.00	32.44	12.11	16.00	57.00	31.25	10.95	0.59	0.84	4.84	14.94
inv	concentric	7.00	41.00	18.75	8.17	7.00	33.00	18.00	7.37	0.31	0.97	1.42	7.57
	eccentric	8.00	45.00	24.31	10.91	11.00	45.00	22.31	9.17	0.07	0.96	2.18	8.97
eve	concentric	7.00	45.00	17.25	8.71	8.00	37.00	17.50	7.93	0.80	0.94	2.13	12.35
	eccentric	12.00	69.00	24.06	14.16	8.00	64.00	24.06	13.70	1.00	0.94	3.48	14.43

Note: PF = plantar flexion; DF = dorsiflexion; inv = inversion; eve = eversion. ICC = intraclass correlation coefficient; SEM = standard error of the mean.
All torque values measured in Nm

7.4 Discussion

The results of the paired samples t-test and the calculated ICC (Table 7-3 and Table 7-4) suggest that both the protocol presented here and the Cybex Norm isokinetic dynamometer are reliable tools for measuring AMS. The SEM measures indicates a range of measurement noise, consequences of which will be discussed here.

The paired samples t-test results shown in Table 7-3 indicated no significant difference between the first and second AMS measures ($P > 0.05$ in all cases). This is consistent with the data presented by Laughlin et al. (2009) who examined consistency of concentric and eccentric PF and DF measurements over three tests. Their protocol placed the participant in a prone position with the leg fully extended. However, Taskiran et al. (2013) reported that the participants found this position to be uncomfortable. If both positions produce reliable results it could be concluded that a supine seated position is preferable for reasons of participant comfort.

The ICC values for each of the AMS measurements showed high levels of reliability in all AMS measures (Table 7-4) which, combined with the t-test results suggest this protocol is a reliable when measuring AMS using the Cybex Norm. The AMS ICC results are similar to the results of Laughlin et al (2009) (see Appendix 10 for details of this comparison), apart from concentric DF which they found to be ICC = 0.67 compared to ICC = 0.82 found here. They concluded that the measurement of concentric DF was not reliable due to the low ICC score despite an ANOVA suggesting no significant difference between the three tests performed. It could be argued that the measurement was reliable as there was no significant difference between tests. The low variability in their test population may have led to low ICC scores whereas high variability could lead to high ICC scores irrespective of the test to test variation (Weir, 2005). Higher between-subject variability is likely here as a mixed gender population was used compared to an all-male population used by Laughlin et al. (2009) which may explain the higher ICC values presented here. This comparison of results also suggests the data presented here has greater external validity than that of Laughlin et al. (2009).

The concentric and eccentric AMS PF and DF SEM data presented here are higher than those of Laughlin et al. (2009) (Appendix 10). They performed a full familiarisation session a week prior to the actual testing. Furthermore they performed 5 submaximal and 3 maximal familiarisation tests at each visit. It could be argued that these extra familiarisation tests resulted in a greater understanding of the procedure which, in turn, would result in lower SEM scores. Adding an initial familiarisation visit may increase the SEM scores but the time constraints of this thesis meant this was not possible. However, as the t-test performed here showed no significant differences between the first and second tests and the ICC reliability scores were high the protocol here was deemed to be reliable.

The reproducibility of concentric inv and eve AMS was measured by van Cingel et al. (2009) was presented in terms of ICC. They found lower ICC values compared to those presented here which they suggested meant the protocol was reproducible (Appendix 10). However, no paired samples t-test or normality data was presented. One of the main differences between the two protocols is the use of a height adjustable treatment bench to achieve knee flexion of 10° during testing by van Cingel et al. (2009). Altering the angle of knee flexion can affect PF and DF strength (Möller, Lind, Styf, & Karlsson, 2005); adding a treatment bench to the equipment adds another variable which may reduce the reliability of the data and, hence the lower ICC scores. A paired samples t-test would be useful in supporting their claim of reliability of the test due to the lower ICC scores. The inv and eve AMS SEM scores calculated from the data presented by van Cingel et al. (2009) were higher than the data presented here (Table 7-4 and Appendix 10). This is a reflection of the SEM scores being a function of 1-ICC scores which were lower.

7.5 Summary

For any experiment, the use of a reliable protocol is essential for the robustness of the results. This chapter presented a protocol for the measurement of AMS derived from the discussion of the key variables described in Chapter 3. This protocol was modified as a result of the conclusions drawn from a pilot study and was then used on the Cybex Norm in a test-retest reliability experiment. The results and discussion presented in this chapter demonstrated the reliability of the protocol and Cybex Norm in measuring AMS in concentric and eccentric PF, DF, inv and eve. The protocol described in Chapter 5 was, therefore, used to test the main experimental population, the results and analysis of which will be presented in the next chapter.

Chapter 8

Determining AMS reference range equations

8. Determining AMS reference range equations

8.1 Introduction

A frame of reference is necessary in order to fully understand the implications of a measurement. A common method of achieving this frame of reference is the use of reference values, also referred to as normal or normative values. These values represent the expected score or measurement for a given set of circumstances. Chapter 4 presented a reliable protocol for the production of AMS peak torque values, based on an analysis of the methods used in the literature and the results of a pilot study. This chapter will describe the results of using that protocol to test a healthy population. The results of the AMS peak torque tests and subsequent statistical analysis of the data will also be described. The analysis will consider the individual relationships between the measured anthropometric variables and AMS. This will indicate how these relationships affect the average AMS measurement in a general population. This chapter will then describe a stepwise linear regression analysis which will include the anthropometric variables in producing a predictive model for each of the eight AMS measures: concentric and eccentric PF, DF, inv and eve.

8.2 Method

The general method for collection of AMS data was followed as described in Chapter 5. The following are additions to this method which are specific to this experiment:

8.2.1 Participants

The number of participants required was determined by the number of independent variables being considered in accordance with the calculation of Tabachnick and Fidell (2007): $N>50+8m$ where N is the number of participants and m is the number of independent variables. Five independent variables were studied (gender, age, height, mass and shoe size), thus, a minimum of ninety participants were required.

8.2.2 Statistical analysis

The aim of this experiment is to produce equations that will predict AMS reference ranges. 111 participants were tested and randomly divided into a reference group (n=100) and a validation group (n=11) by the SPSS software. Initially reference values were produced by taking the average of each of the eight AMS values measured in the reference group. The reference range was taken as between the upper and lower 95% CI. This range represents the values of AMS which can be considered normal. There are various ways of calculating the range, for example Danneskiold-Samsøe et al. (2009) produced mean values and expressed them ±SD. This can give a wide range of values which may not be clinically useful. Using the 95% CI produces a reference range which would be applicable to a clinical setting. This reference value and range was then validated by comparing it to the AMS values measured in the validation group. Reference values and ranges were considered valid if the AMS values measured in the validation group fell within the reference ranges.

The results of the validation process described above will be presented in Chapter 5. These results will indicate that only three of the eight AMS reference ranges were validated. It was concluded that this was due to differences in anthropometric measures between the reference and validation groups. For a full description and analysis of these results see section 5.4. To further explore the relationship between AMS and the anthropometric measures a Pearson's correlation test was used. The Pearson's correlation test was used to identify a relationship between the gathered AMS data and the individual anthropometric measures of gender, age, height, mass and shoe size used as independent variables. For each correlation test the significance was set at $P < 0.05$ and the strength of the correlation relationship was considered either small ($r = 0.10$ to 0.29), medium ($r = 0.30$ to 0.49) or large ($r = 0.50$ to 1.0); (Cohen, 1988).

As the literature suggests that variations in anthropometric variables can affect AMS, to determine which independent variables were significant in each of the eight AMS measures a stepwise linear regression analysis was performed. A stepwise linear regression analysis is a statistical tool which demonstrates how well a set of independent variables, in this case gender, mass, height, age and shoe size, are able to predict an outcome measure, AMS peak torque (Boduszek, 2015). The analysis process adds each of the independent variables in turn and assesses whether the resultant model gives a better prediction of the dependent variable, in this case AMS peak torque. From this analysis it is also possible to determine the relative extent to which each of the independent variables contribute to the variation in the outcome measure and how much of the variation can be predicted by linear regression model as a whole.

8.2.3 Assessing normality, collinearity and homoscedasticity of the data

Prior to the stepwise linear regression analysis a preliminary analysis was undertaken to ensure there was no violation of the assumptions of normality, collinearity and homoscedasticity. These tests are performed to ensure the robustness of the data (Boduszek, 2015). Assessing the normality of the data identifies any outlier which would reduce the predictive value of the equation. Normality of the distribution of the residual differences between predicted and obtained values of AMS were assessed by scatter plot. Any residuals greater than 3.3 or less than -3.3 were considered outliers were removed (Tabachnick & Fidell, 2007). Collinearity of the data assess the independent contribution to variation in the dependent variable of each of the independent variables. For example height and mass are related, taller people are generally heavier, and both affect AMS; this is termed collinearity. If both height and mass affect AMS it is necessary to separate the individual and combined effects. The collinearity tests were performed to determine the individual effects of each of the independent variables. If the results of the tests indicated possible collinearity then one or more of the independent variables were removed as the test showed they were not contributing to the model. Collinearity of the data was checked in three ways: if the Pearson's r value was greater than 0.9, the tolerance was less than 0.10 or the variance inflation factor (VIF) was greater than 10 then collinearity was indicated and as such the variable should be removed (Boduszek, 2015). Homoscedasticity refers to the consistency of variation of the predicted value from the measured value. The homoscedasticity of the data was assessed by using a normal P-P probability plot of the regression standardised residual. If the residuals plotted a diagonal line consistent with the predicted values then the data was accepted (Boduszek, 2015).

A stepwise linear regression analysis was performed for each of the eight AMS measures (concentric and eccentric PF, DF, inv and eve) to determine the level of influence of five predictive values (independent variables: height, mass, age, gender and shoe size) on AMS (the dependent variable). A predictive equation for each of the eight AMS measures was produced using the unstandardised co-efficients generated in the regression analysis. The analysis software produces an unstandardised coefficient for each of the independent variables. These are then multiplied by the independent variable (for example by height in cm or age in years). The resulting values are added to the constant generated in the regression analysis giving a predicted value for the individual aspect of AMS. A reference range would have greater clinical use. This range was defined as the mean of the predicted values ± the SD of the residuals (RSD) (Harbo et al., 2011). The strength of these equations was tested using and ANOVA test. This compares the variance in the predicted relationships and the actual relationships between AMS and the anthropometric variables. A significant result indicates little variation between the two. The adjusted R squared values for each of the equations were examined to determine the amount of AMS variance predicted by the equations in a wider population. The R squared value represents the extent to which the combined variation of the independent variables predicts the variation in the dependent variable i.e. AMS. The higher the value the greater the amount of variation predicted.

8.2.4 Validation of the equations

The resulting eight equations generated from the reference population were used to predict the eight measures of AMS in the validation population. The reference ranges used were the predicted measures of each of the eight AMS movements ± RSD (Harbo et al., 2011). The AMS reference ranges were considered valid if the validation set mean AMS fell within the reference range. To further validate the reference values a paired samples t-test was used to determine if there was a statistically significant difference between predicted and measured values.

8.2.5 Validity of Testing

The experimental design had internal validity in terms of the muscles being used as the body positioning and strapping on the equipment isolated the PF, DF, inv and eve movements and so the torque produced was a result of specific muscle contractions. This isolation is achieved by the use of Velcro® straps over the foot, a thigh support tube to fix the knee and a seatbelt which restrict the movement of the participant. The questionnaire removed anyone who had any skeletal or neuromuscular problems so the results would, in theory, be an accurate reflection of healthy muscle working. Other factors which could affect torque production such as foot size, mass, age, height and gender were all ascertained and the results were analysed in terms of these variables, thus controlling them. To ensure consistency of testing the same researcher performed all of the tests using the standardised protocol described here. As previously discussed the dynamometer was calibrated and serviced in accordance with the manufacturer's recommendations to ensure consistent measurement.

The experimental design had external validity as a large number of people were tested with a diverse range of anthropometric measures and as such the results can be applied to the population as a whole.

8.3 Results

AMS was tested in 111 participants (forty-nine males, sixty-two females). The participant demographics are shown in Table 8-1.

Table 8-1

Participant demographics

	Minimum	Maximum	Mean	Std. Deviation
Height	155.00	190.00	170.14	8.10
Mass	44.10	127.90	73.48	16.34
Age	19.00	59.00	37.08	11.40
Footsize	3.00	12.00	7.27	2.09

Note Height is measured in cm, mass in kg, age in years and shoe size is UK standard.

8.3.1 Integrity of the data

8.3.1.1 Coefficients of variance

Each participant produced three sets of three maximal reps for each of the eight movement types. The peak torque produced was accepted for a set if the COV was less than 0.2 or 20%; 111 participants were tested. Table 8-2 shows the number of scores registered per movement type.

Table 8-2

Number of scores registered per movement type.

Movement type		Scores registered
PF	concentric	110
	eccentric	101
DF	concentric	111
	eccentric	111
Inv	concentric	111
	eccentric	111
Eve	concentric	111
	eccentric	110

Note: PF = plantar flexion; DF = dorsiflexion; inv = inversion eve = eversion. Total number of tests = 111

The data in Table 8-2 demonstrates that the majority of the participants were able to demonstrate a high level of consistency over the three repetitions within each set. Ten participants were not able to achieve the required level of consistency on eccentric PF, one participant was not consistent in concentric PF and one in eccentric eve.

8.3.2 Mean average reference value

SPSS software was used to randomly split the data set of 111 into two groups: a reference set (n=100) and a validation set (n=11). The mean average of each of the eight measures of AMS taken from the reference set (fifty-five males, forty-five females) as described in Table 8-3, were used as reference values with the upper and lower 95% CI indicating the reference range. These values are shown in Table 8-4.

Table 8-3

Anthropometric descriptors of the reference set

	Minimum	Maximum	Mean	Std. Deviation
Height	155.00	188.00	170.43	7.83
Mass	44.10	127.90	73.93	16.49
Age	19.00	59.00	37.15	11.51
Footsize	3.50	12.00	7.35	2.04

Note Height is measured in cm, mass in kg, age in years and foot size is UK standard
N = 100

Table 8-4

Mean average and confidence intervals for eight AMS measures taken from the reference set

		Mean average	Lower CI	Upper CI
PF	Concentric	52.32	48.50	56.14
	Eccentric	85.51	78.26	92.76
DF	Concentric	18.05	16.84	19.26
	Eccentric	37.82	35.50	40.14
Inv	Concentric	19.09	17.77	20.41
	Eccentric	25.75	23.97	27.53
Eve	Concentric	18.36	17.21	19.51
	Eccentric	29.49	26.84	32.15

Note: PF = plantar flexion; DF = dorsiflexion; inv = inversion eve = eversion.
All torque measurements are in Nm.
n=100

To validate these reference values a comparison was made with the mean average of each of the eight AMS measures taken from the validation set (seven females and four males) described in Table 8-5.

Table 8-5

Anthropometric descriptors of the validation set

	Minimum	Maximum	Mean	Std. Deviation
Height	155.00	190.00	167.50	10.32
Mass	52.00	100.00	69.38	14.97
Age	20.00	48.00	36.45	10.80
Footsize	3.00	11.00	6.55	2.50

Note Height is measured in cm, mass in kg, age in years and foot size is UK standard
N = 11

The average AMS values for the validation group are shown in Table 8-6.

Table 8-6

Mean average of AMS values for the validation set

	Minimum	Maximum	Mean	Std. Deviation	Within normal range y/n
PFcon	22.00	91.00	56.60	22.92	N
DFcon	9.00	30.00	15.64	5.55	N
PFecc	27.00	138.00	94.13	40.58	N
DFecc	12.00	71.00	34.00	15.12	N
Invcon	8.00	30.00	19.18	7.00	Y
Evecon	9.00	26.00	17.27	5.62	Y
Invecc	9.00	41.00	24.18	10.18	Y
Eveecc	8.00	45.00	25.00	10.96	N

Note: PF = plantar flexion; DF = dorsiflexion; inv = inversion eve = eversion.
All torque measurements are in Nm.

Table 8-6 indicates three of the eight AMS measures from the validation group are within the reference range provided by the lower and upper CI described in Table 8-4. These were concentric and eccentric inv and eccentric eve. The remaining five measures of AMS, concentric and eccentric PF and DF and eccentric eve, were all outside of the reference range.

8.3.3 Relationship between anthropometric measures and muscle strength

This section will further analyse the relationship between the individual anthropometric variables and AMS to determine to what extent changes in these variables affect reference values. To maximise the statistical power of the tests data from 111 participants was used in the following analysis.

8.3.3.1 Gender

An independent samples t-test, described in Appendix 11, was performed to determine the relationship between gender and AMS. This analysis indicated a significant difference in strength between the genders (P < 0.01 and d > 0.8 in all cases apart from eccentric eve where P = 0.03 and d = 0.43); (Figure 8-1).

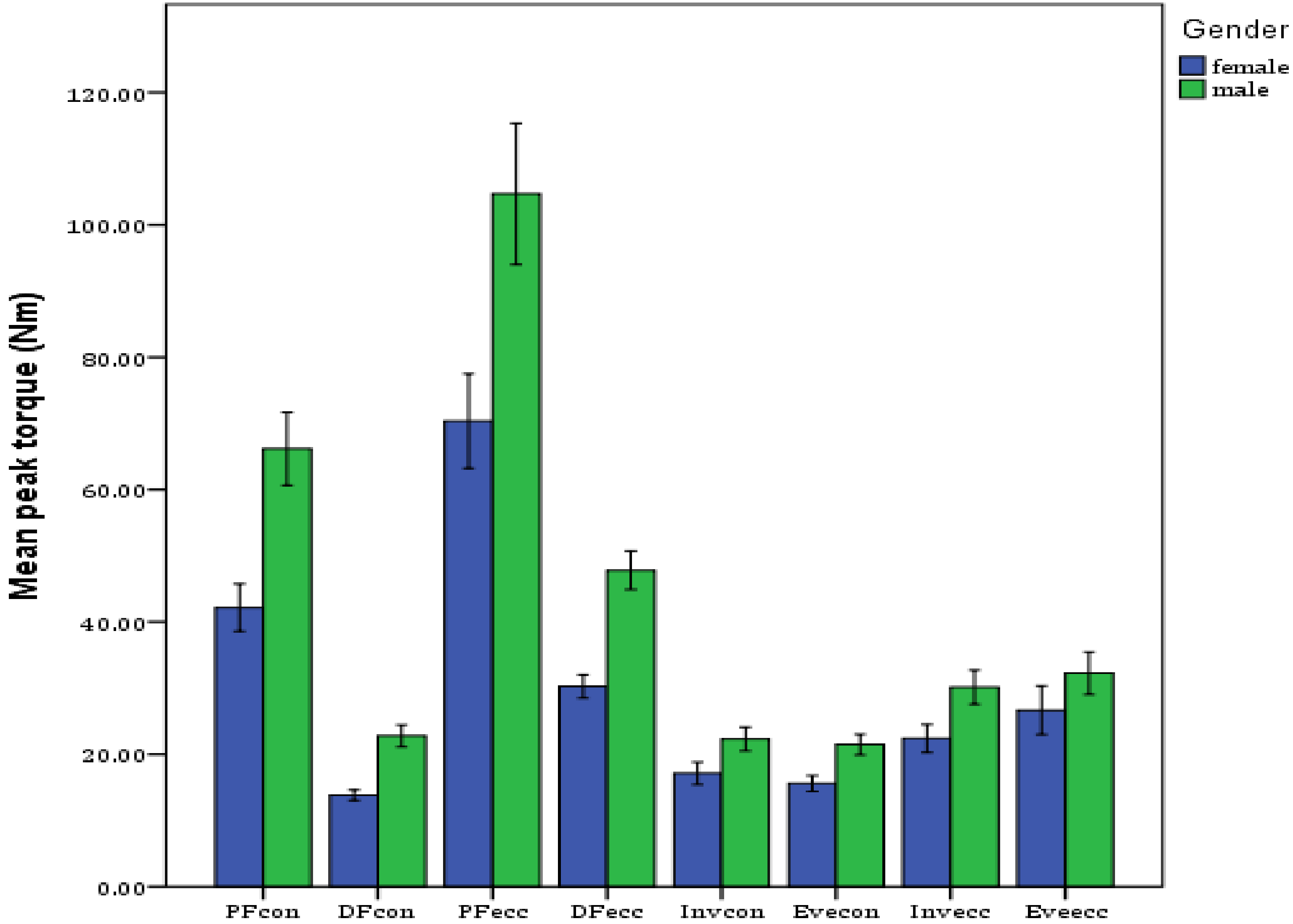


Figure 8-1 A graph comparing mean peak torque between genders for each of the eight measures of AMS. PF = plantar flexion; DF = dorsiflexion; Inv = inversion; Eve = eversion; con = concentric; ecc = eccentric. Error bars represent 95% CI.

8.3.3.2 Age

A Pearson's correlation test was performed to indicate if there was a possible relationship between age and AMS (Appendix 12). The results suggested no significant correlation ($P > 0.05$) between age and any of the eight measures of AMS. However, there was not an equal distribution of males and females across age groups (Appendix 13) which may skew the data as discussed previously. Further Pearson's correlation tests were performed on male and female groups; the results of which are shown in Table 8-7.

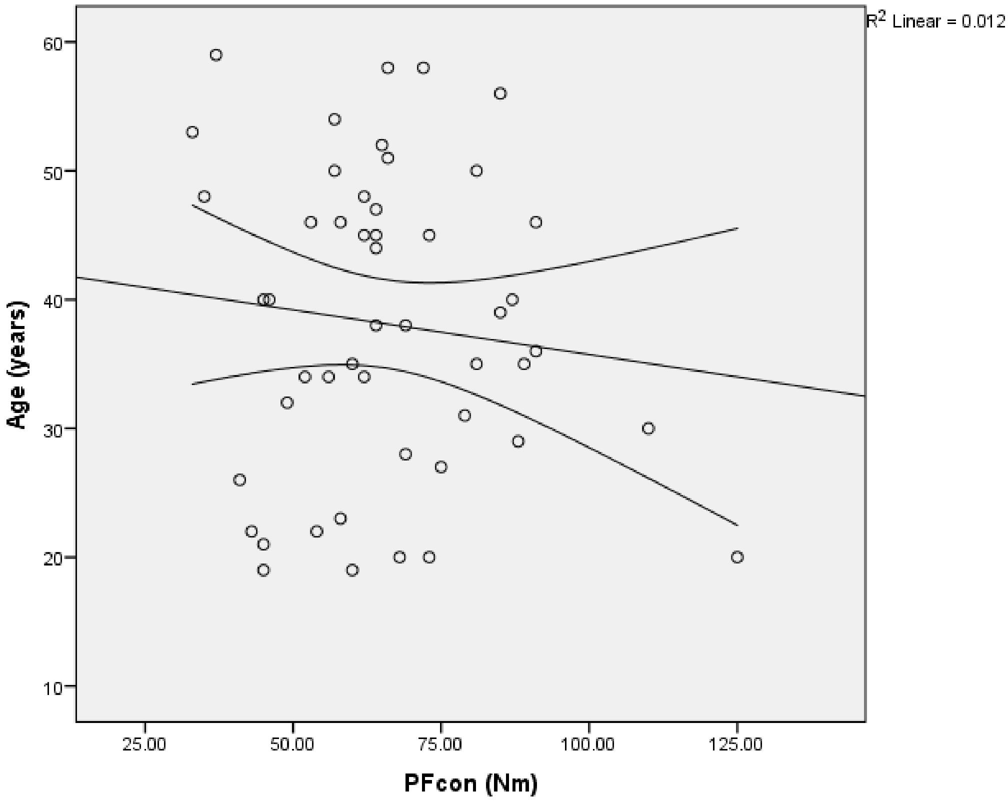
Table 8-7

Results of a Pearson's correlation test examining the gender specific relationship between age and AMS.

Gender		PFcon	DFcon	PFecc	DFecc	Invcon	Evecon	Invecc	Eveecc
Male	Pearson correlation	-0.11	-0.09	0.10	-0.02	-0.10	-0.21	-0.00	-0.16
	Significance (2-tailed)	0.46	0.56	0.52	0.90	0.50	0.15	0.98	0.27
Female	Pearson correlation	-0.26	-0.27	-0.14	-0.03	-0.15	-0.27	-0.05	-0.16
	Significance (2-tailed)	0.05	0.03	0.32	0.83	0.24	0.04	0.73	0.22

Note: PF = plantar flexion; DF = dorsiflexion; Inv = inversion; Eve = eversion; con = concentric; ecc = eccentric.

The data displayed in Table 8-7 indicates there is no significant correlation between age and AMS in any of the eight measures in the male population. There was a significant correlation in the female population between age and concentric PF, concentric DF and concentric eve ($P < 0.05$).



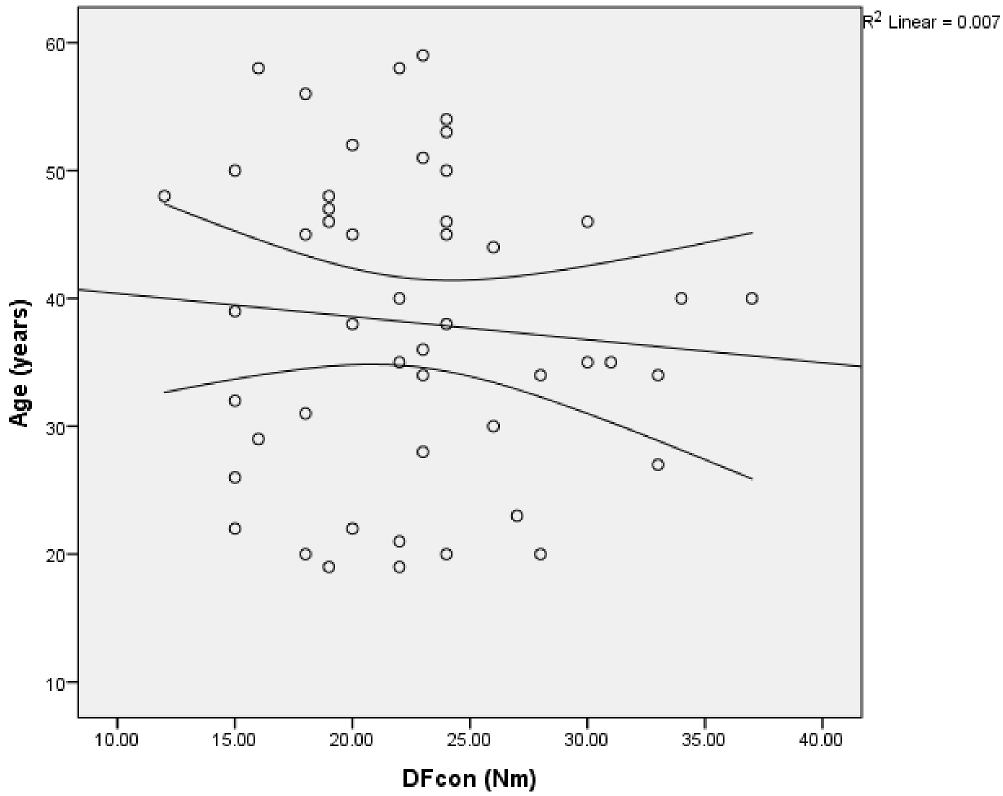
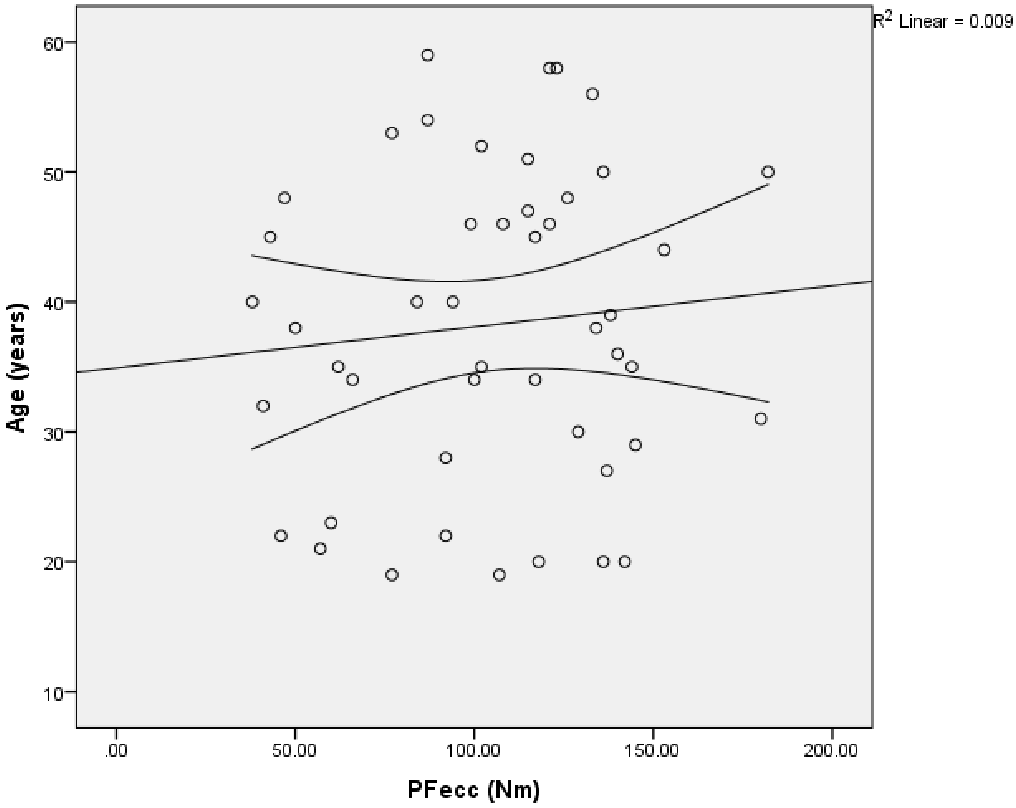


Figure 8-2 Scatterplots demonstrating the relationship in males between age and concentric PF and DF. The lines represent a linear line of best fit and 95% CI. PF = plantar flexion; DF = dorsiflexion; con = concentric



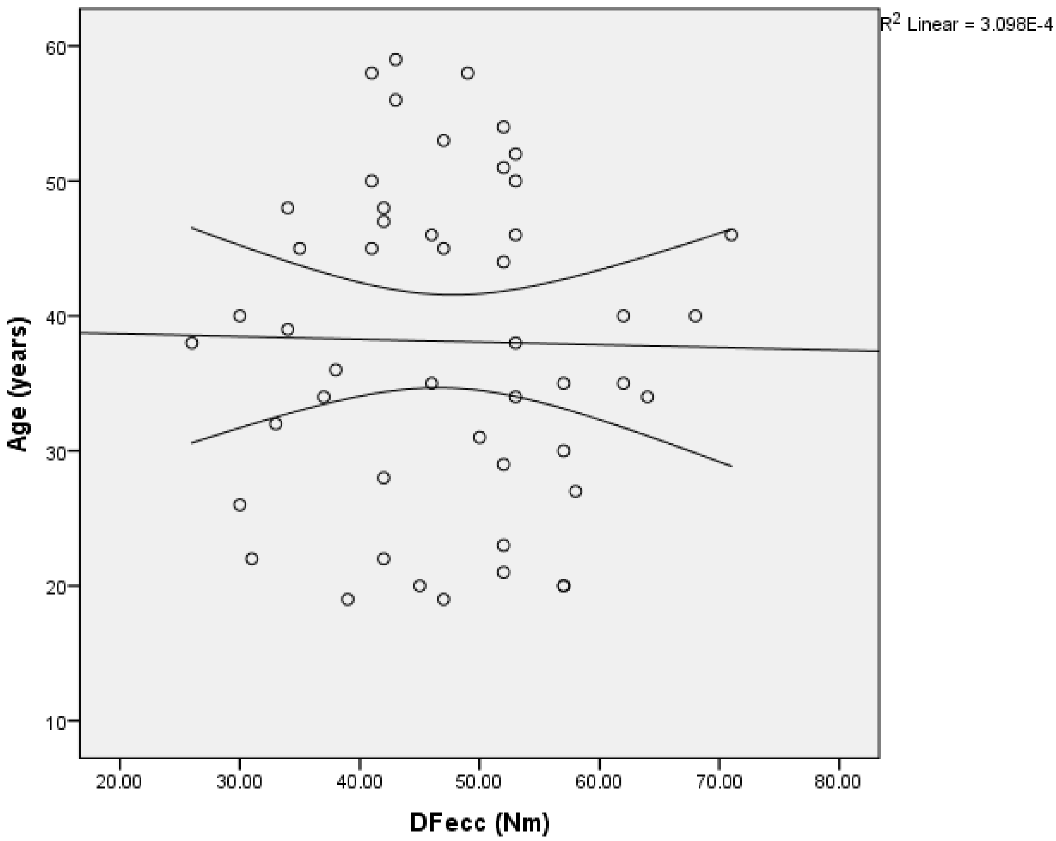


Figure 8-3 Scatterplots demonstrating the relationship in males between age and eccentric PF and DF. The lines represent a linear line of best fit and 95% CI. PF = plantar flexion; DF = dorsiflexion; ecc = eccentric.

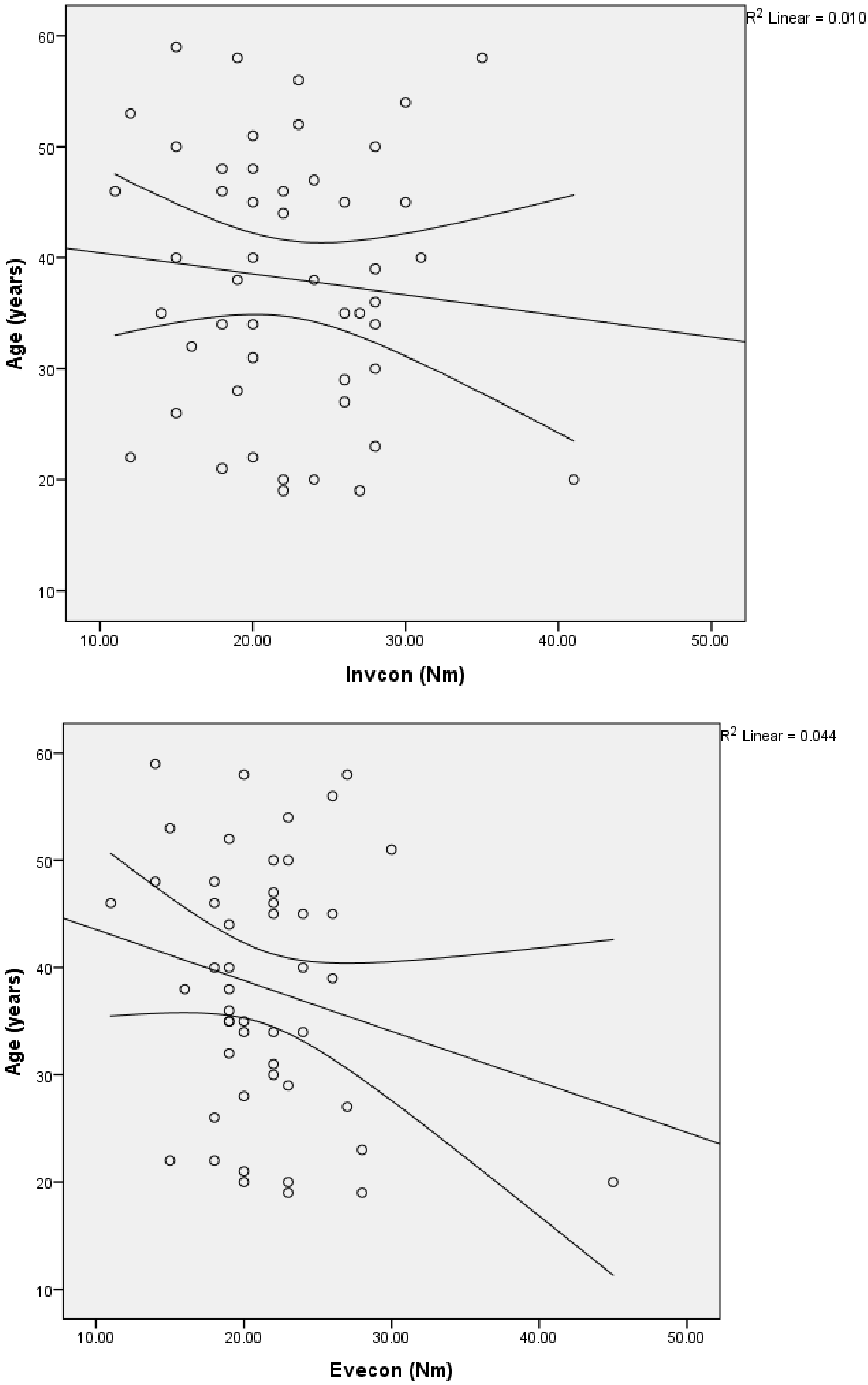
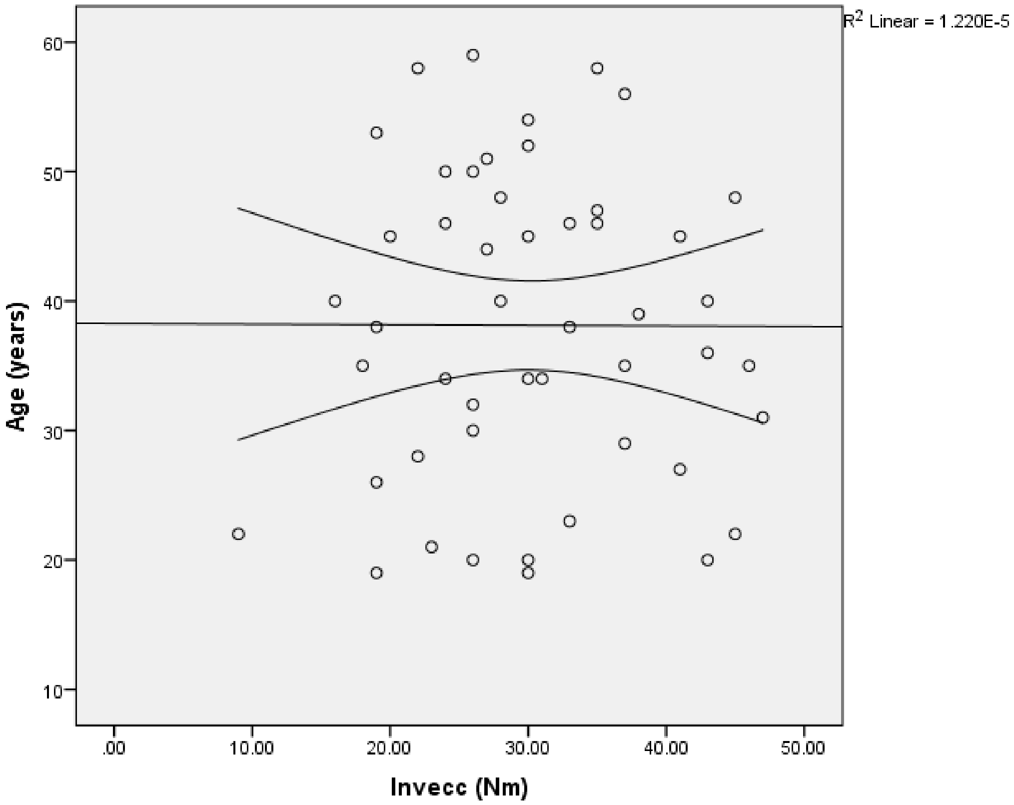


Figure 8-4 Scatterplots demonstrating the relationship in males between age and concentric inv and eve. The lines represent a linear line of best fit and 95% CI. Inv = inversion; eve = eversion; con = concentric



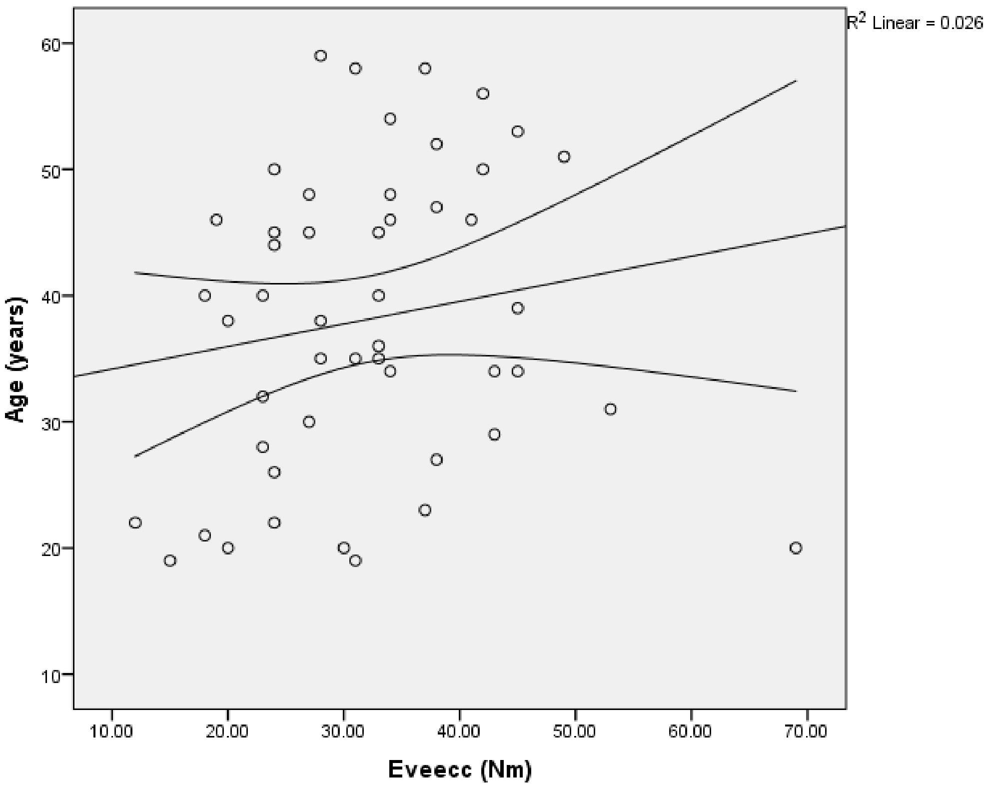


Figure 8-5 Scatterplots demonstrating the relationship in males between age and eccentric inv and eve. The lines represent a linear line of best fit and 95% CI. Inv = inversion; eve = eversion; ecc = eccentric.

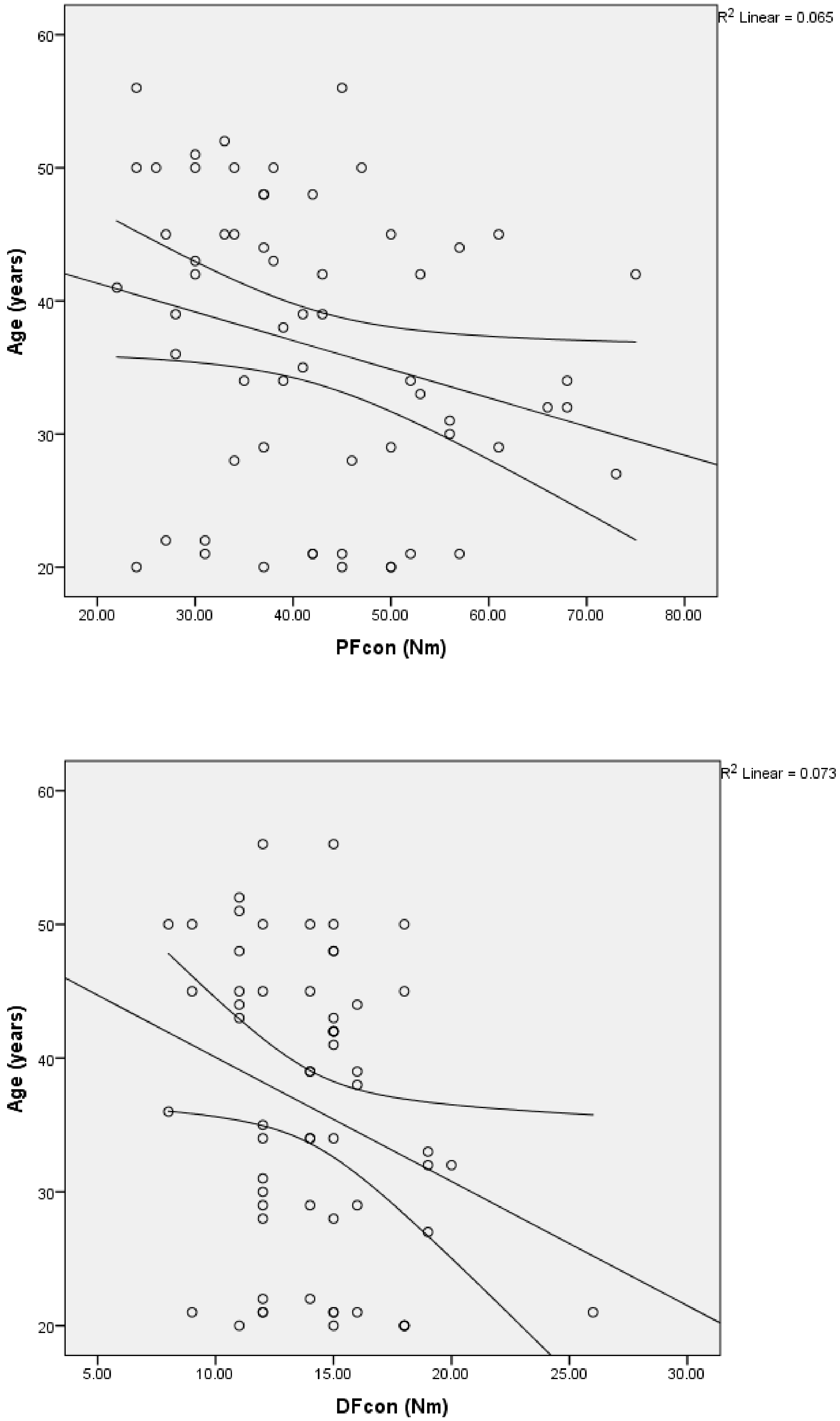
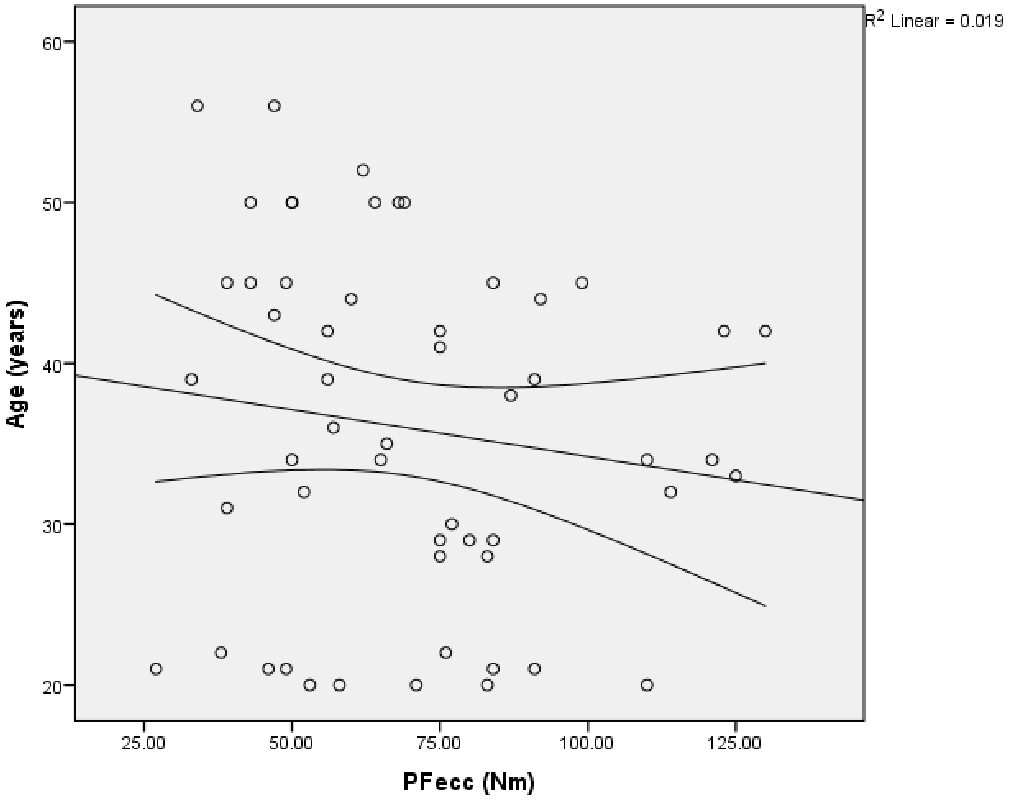


Figure 8-6 Scatterplots demonstrating the relationship in females between age and concentric PF and DF. The lines represent a linear line of best fit and 95% CI. PF = plantar flexion; DF = dorsiflexion; con = concentric



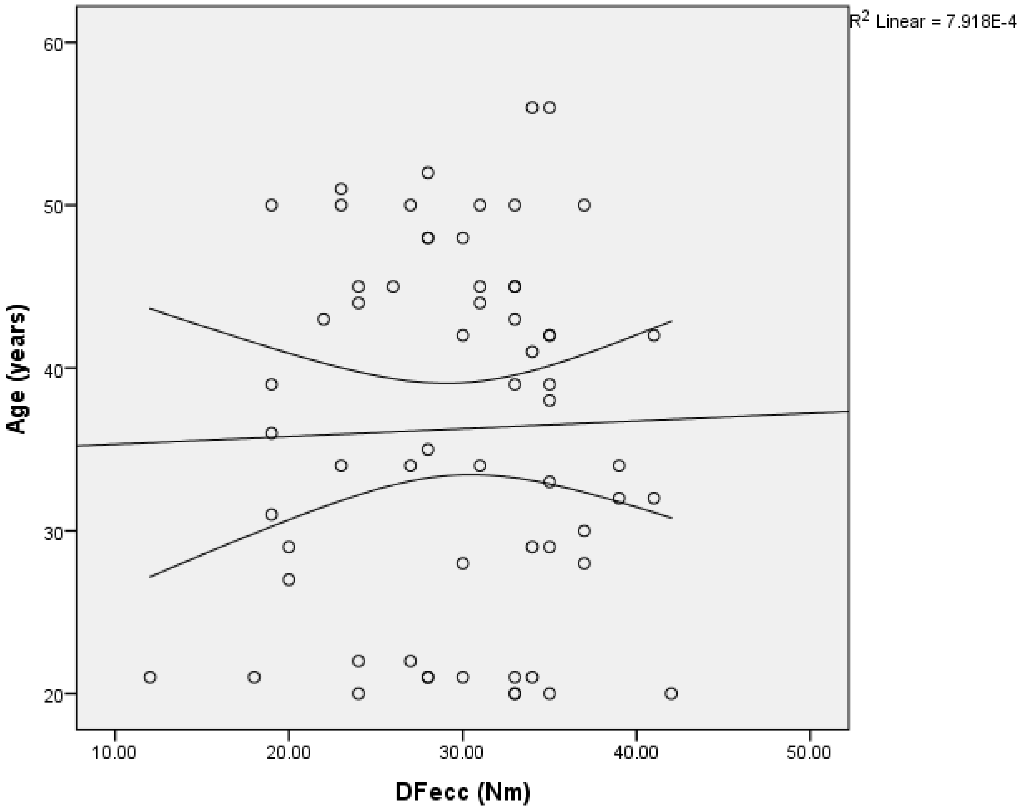


Figure 8-7 Scatterplots demonstrating the relationship in females between age and eccentric PF and DF. The lines represent a linear line of best fit and 95% CI. PF = plantar flexion; DF = dorsiflexion; ecc = eccentric.

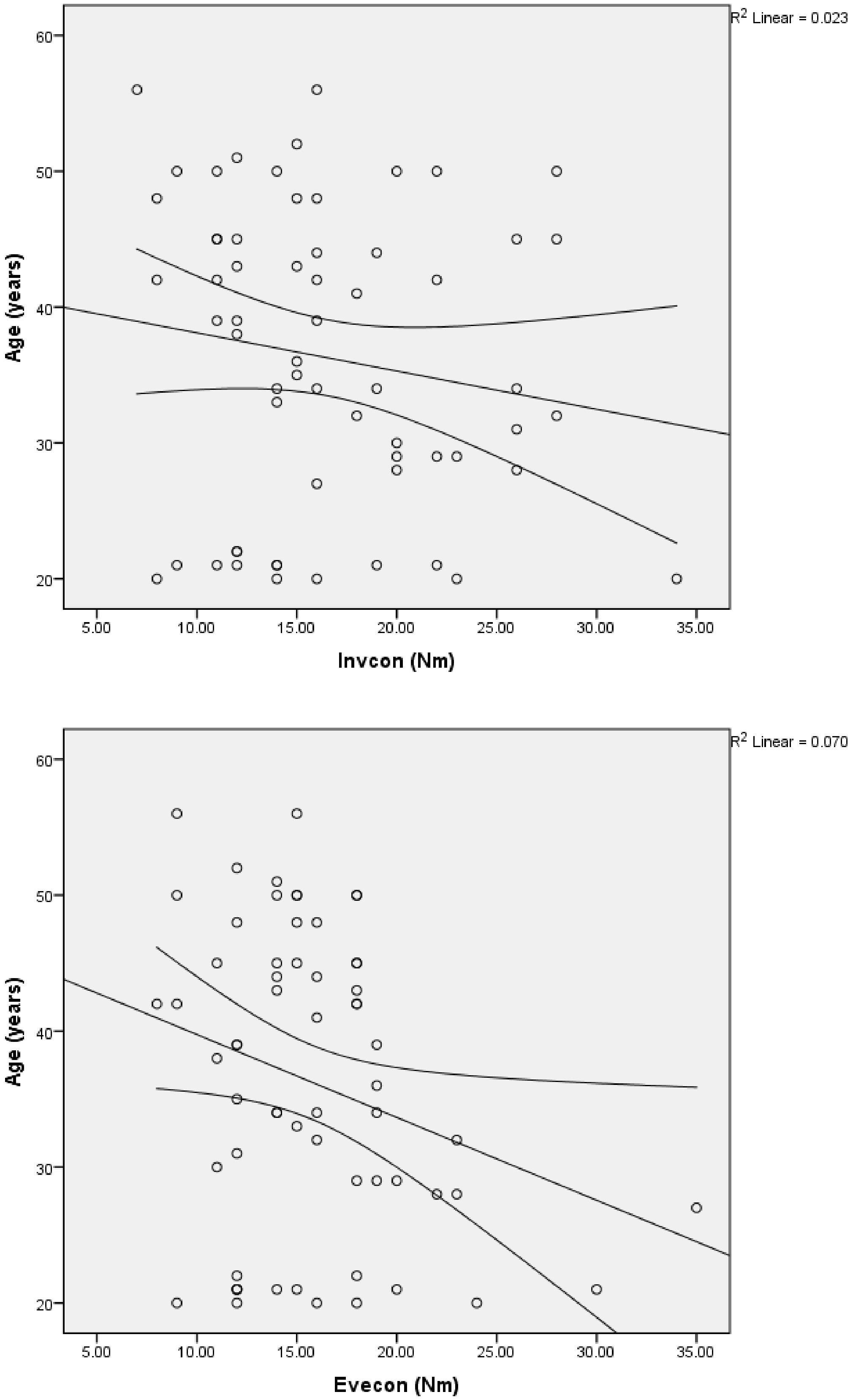


Figure 8-8 Scatterplots demonstrating the relationship in females between age and concentric inv and eve. The lines represent a linear line of best fit and 95% CI. Inv = inversion; eve = eversion; con = concentric

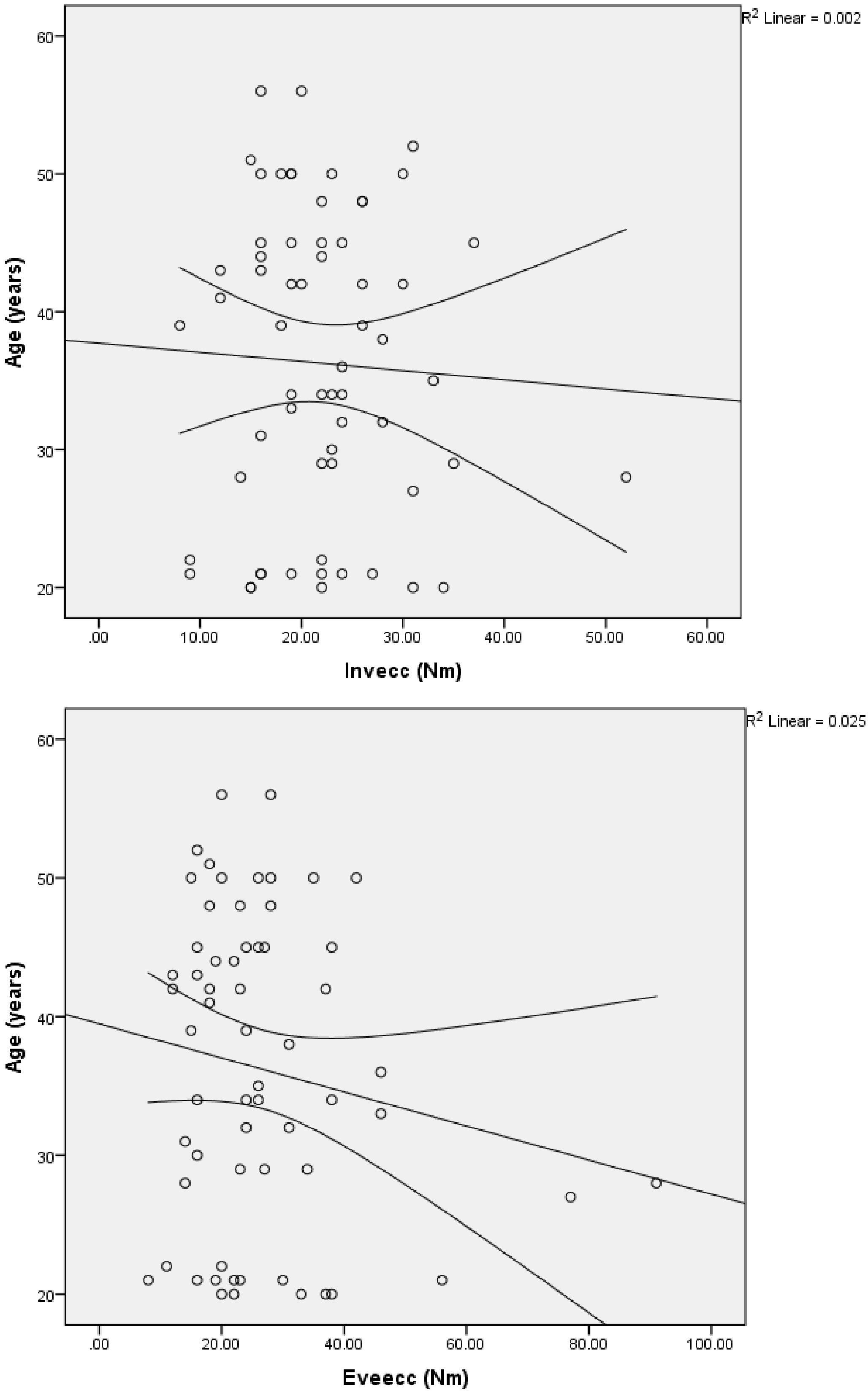


Figure 8-9 Scatterplots demonstrating the relationship in females between age and eccentric inv and eve. The lines represent a linear line of best fit and 95% CI. Inv = inversion; eve = eversion; ecc = eccentric

8.3.3.3 Mass

With the male and female AMS data taken together there was a significant correlation between mass and strength in all eight measures of AMS. ($P < 0.05$ in all cases see Appendix 14). The data presented in Appendix 11 indicated a significant difference in strength between the genders ($P < 0.01$ and $d > 0.8$ in all cases apart from eccentric eve where $P = 0.03$ and $d = 0.43$) and an independent samples t-test indicated that males were significantly heavier than females ($t(109) = -5.99$, $P < 0.01$, $d = -0.62$. (See Appendix 15). Any correlation between strength and mass may be due to the strength and gender interaction, thus, male and female data were analysed separately. In the female data there were significant correlations between mass and strength in concentric DF ($P = 0.04$), eccentric DF ($P < 0.01$) and concentric inv ($P = 0.02$) with a tendency towards significance in concentric PF ($P = 0.06$) and eccentric PF ($P = 0.07$). In the male data there were significant correlations between mass and strength in concentric DF ($P < 0.01$), eccentric DF ($P < 0.01$) and eccentric eve ($P = 0.02$). These data and the Pearson's r statistics are summarised in Table 8-8.

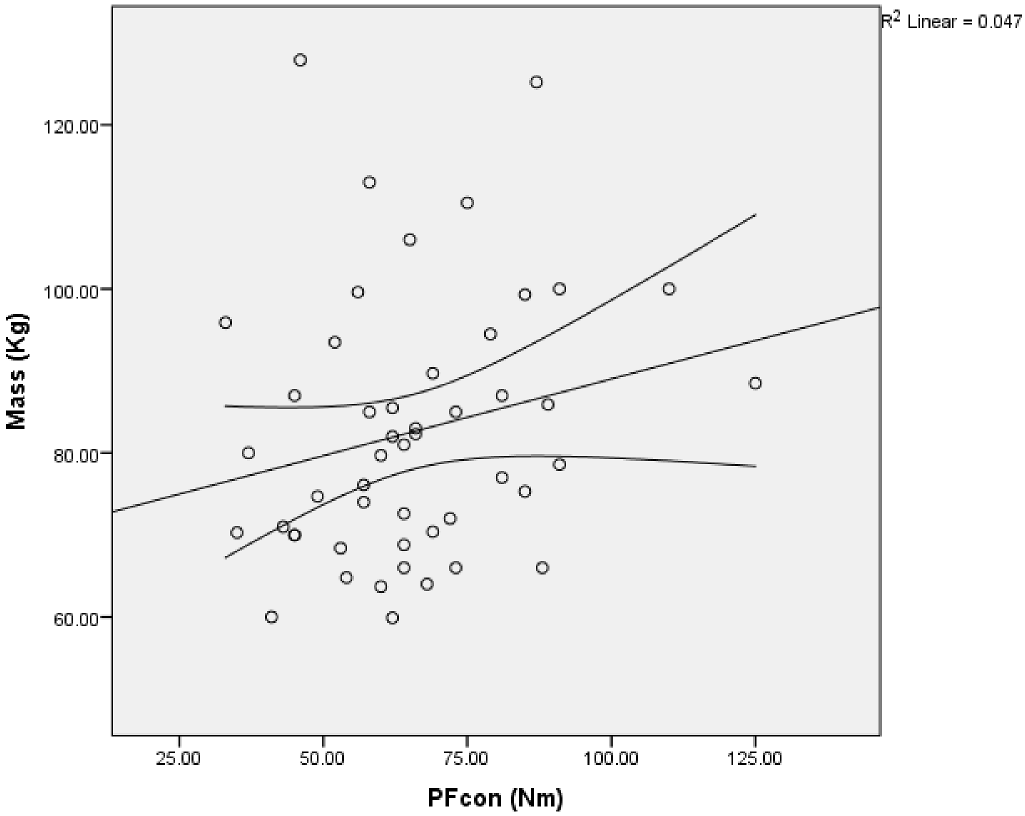
Table 8-8

The results of a Pearson's correlation analysis between AMS and mass in males and females

Gender		PFcon	DFcon	PFecc	DFecc	Invcon	Evecon	Invecc	Eveecc
Male	Pearson correlation	0.22	0.68	0.09	0.66	0.14	0.04	0.27	0.34
	Significance (2-tailed)	0.13	0.00	0.56	0.00	0.34	0.79	0.06	0.02
Female	Pearson correlation	0.24	0.27	0.25	0.38	0.29	0.16	0.14	0.01
	Significance (2-tailed)	0.06	0.04	0.07	0.00	0.02	0.22	0.28	0.93

Note PF = plantar flexion; DF = dorsiflexion; Inv = inversion; Eve = eversion; con = concentric; ecc = eccentric.

The correlations described in Table 8-8 are shown graphically in Figure 8-10 through to Figure 8-17.



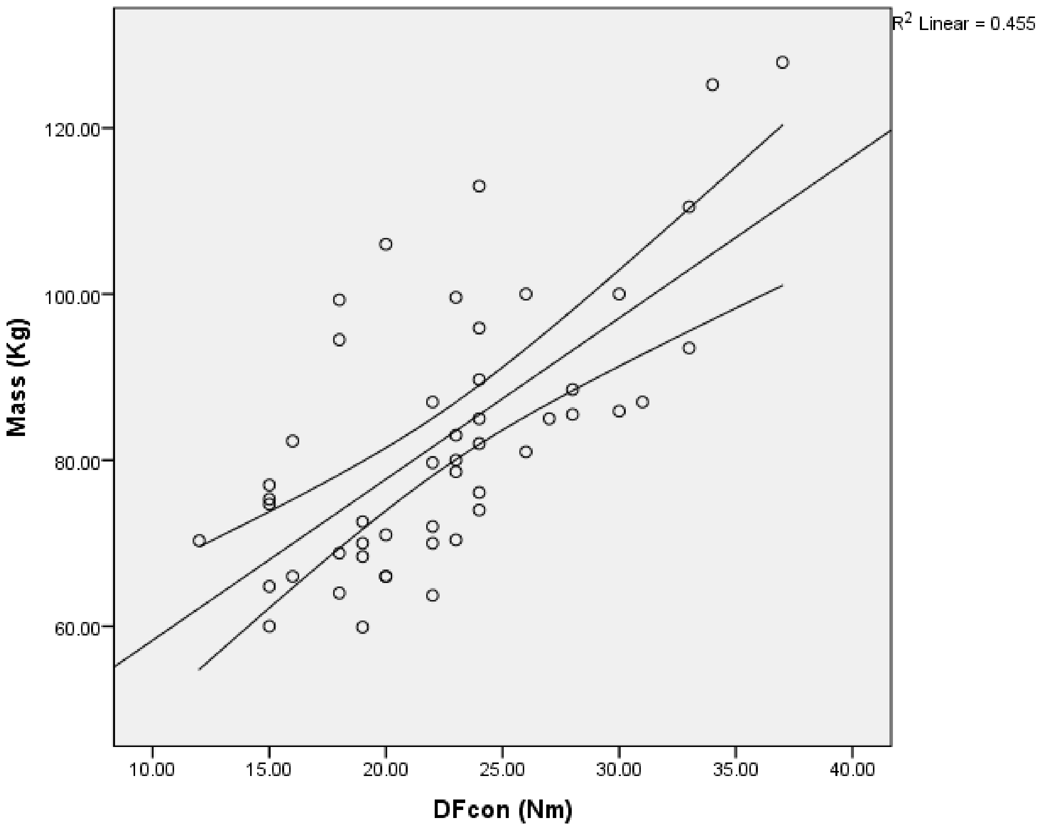
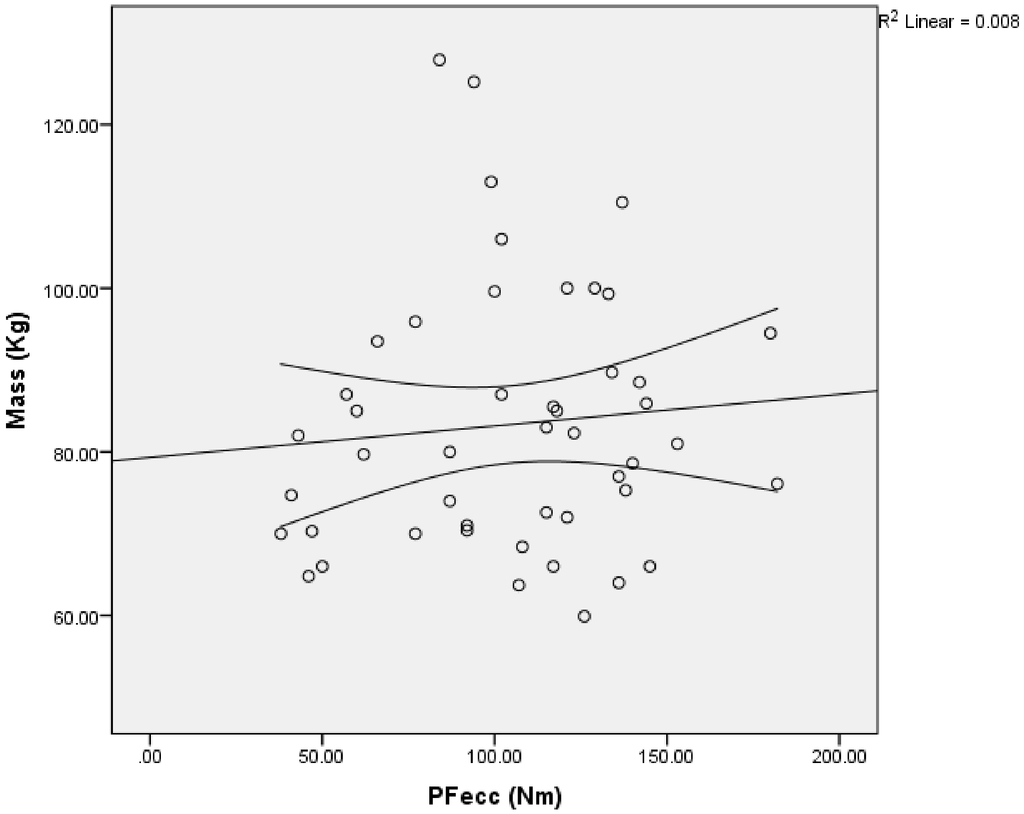


Figure 8-10 Scatterplots demonstrating the relationship in males between mass and concentric PF and DF. The lines represent a linear line of best fit and 95% CI. PF = plantar flexion; DF = dorsiflexion; con = concentric.



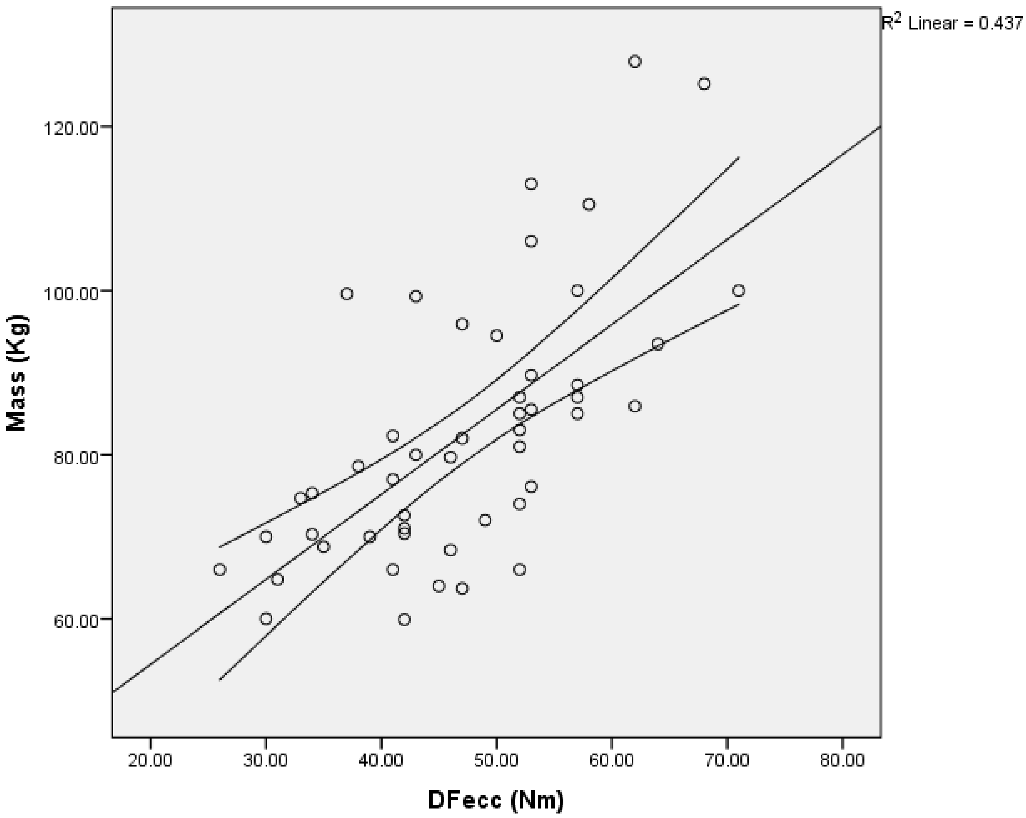
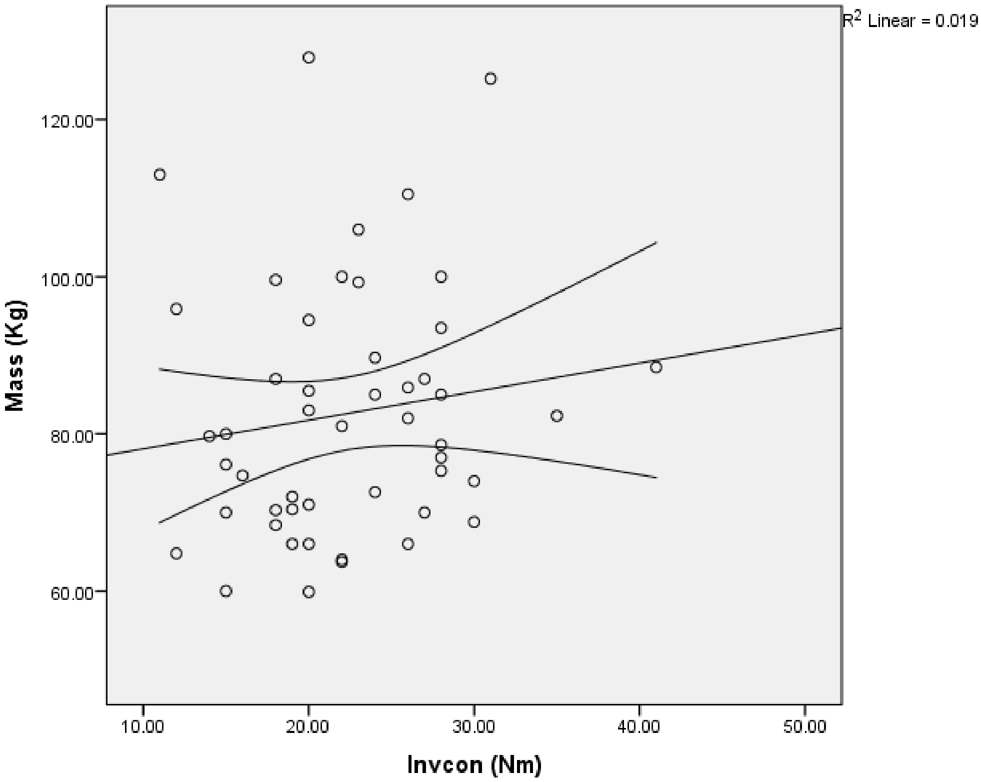


Figure 8-11 Scatterplots demonstrating the relationship in males between mass and eccentric PF and DF. The lines represent a linear line of best fit and 95% CI. PF = plantar flexion; DF = dorsiflexion; ecc = eccentric.



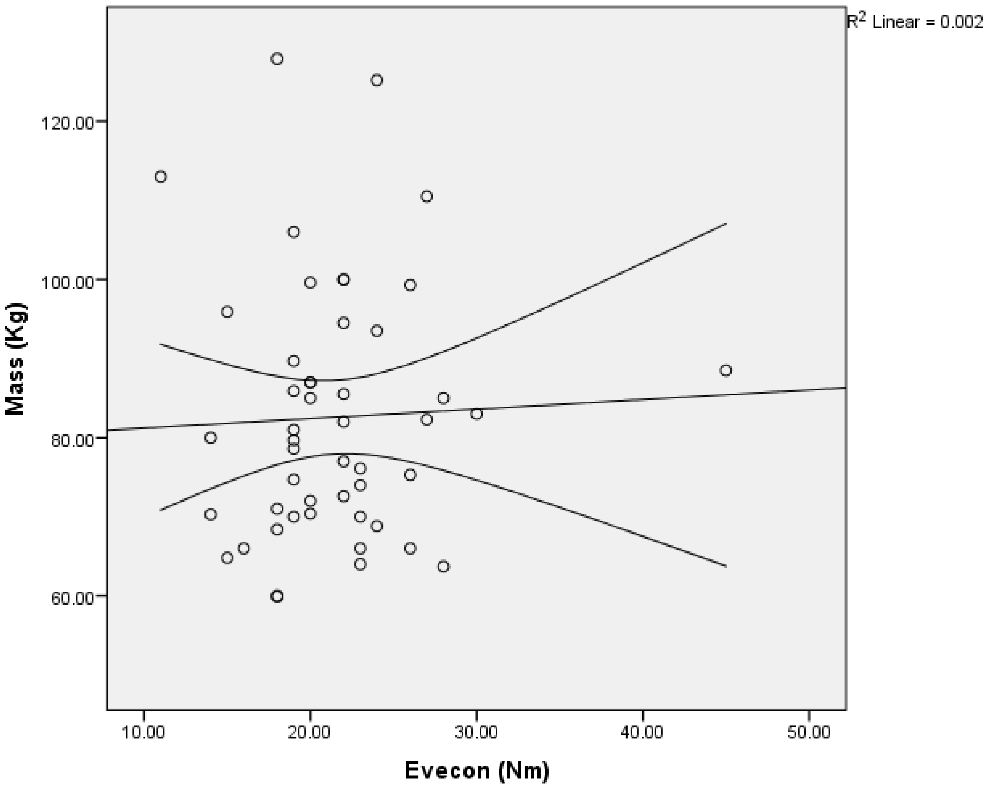


Figure 8-12 Scatterplots demonstrating the relationship in males between mass and concentric inv and eve. The lines represent a linear line of best fit and 95% CI. Inv = inversion; eve = eversion; con = concentric.

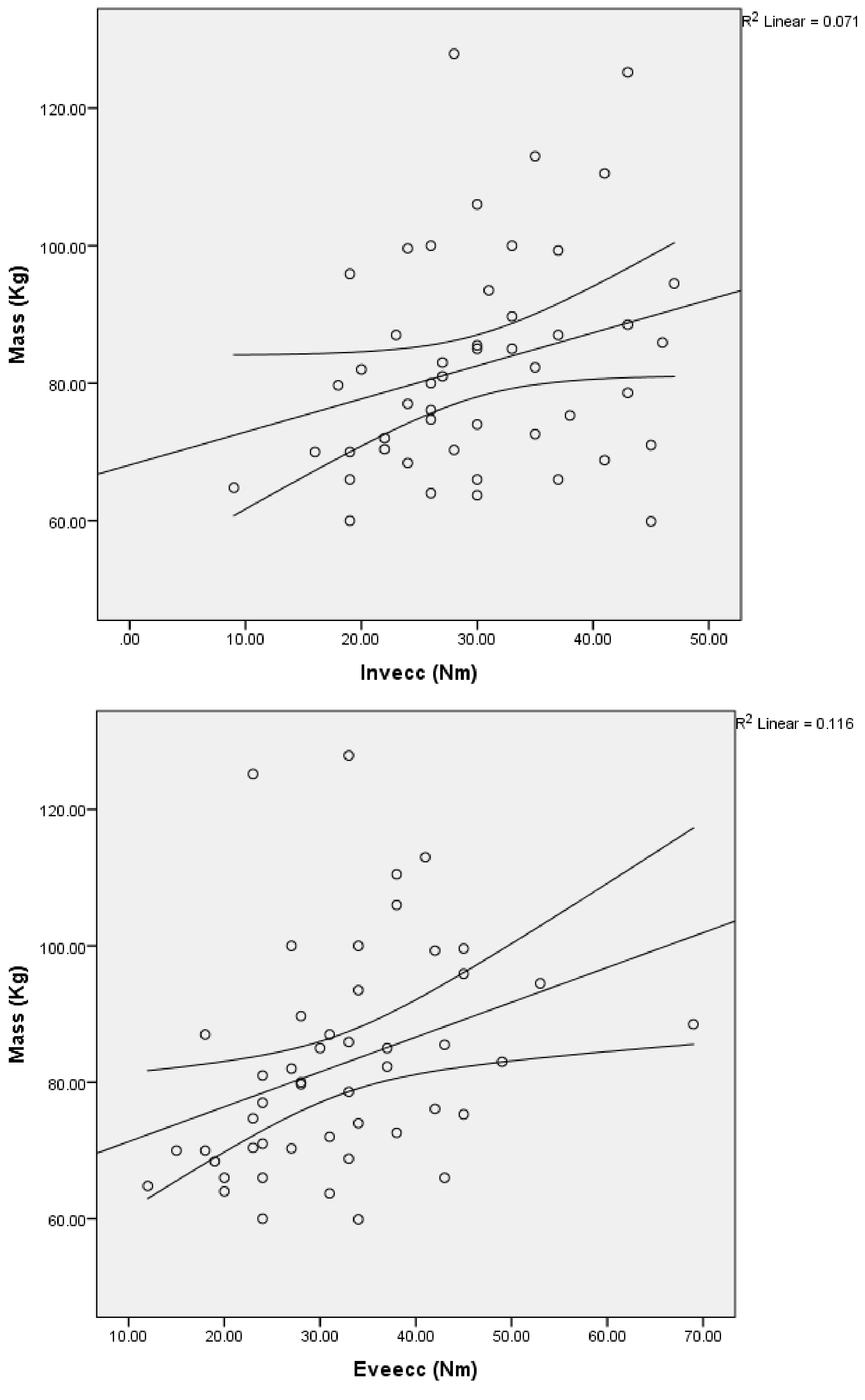
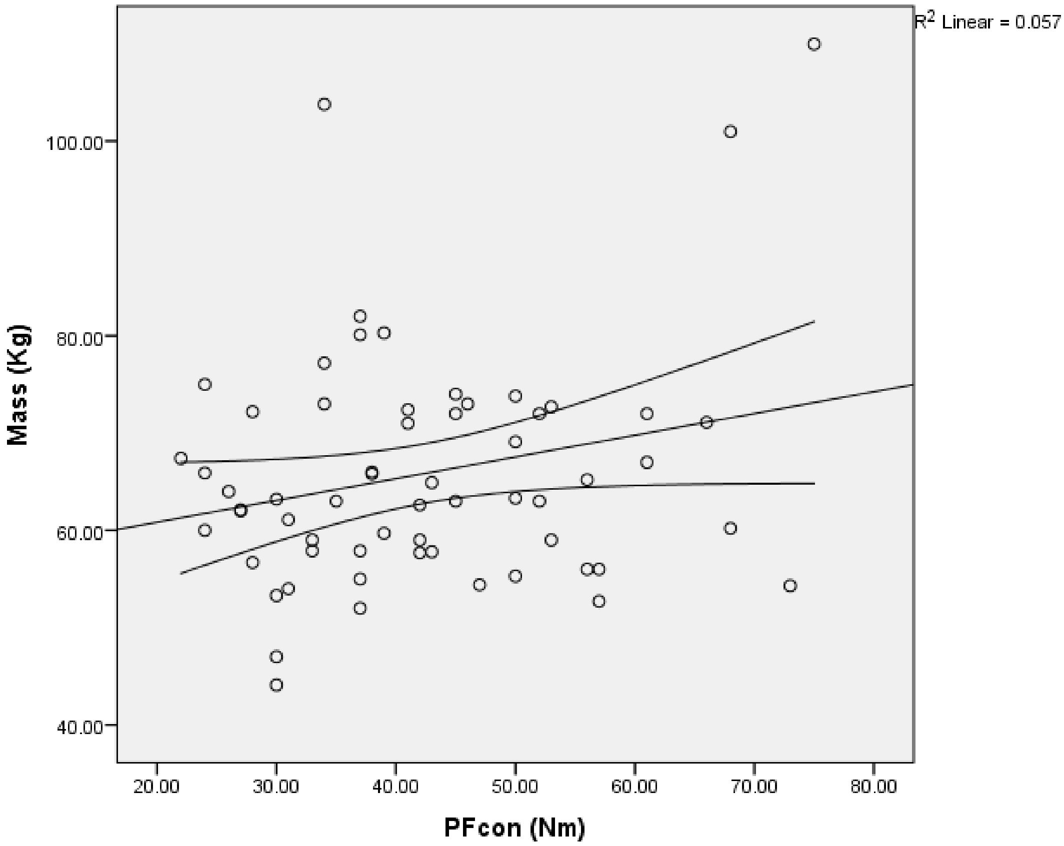


Figure 8-13 Scatterplots demonstrating the relationship in males between mass and eccentric inv and eve. The lines represent a linear line of best fit and 95% CI. Inv = inversion; eve = eversion; ecc = eccentric.



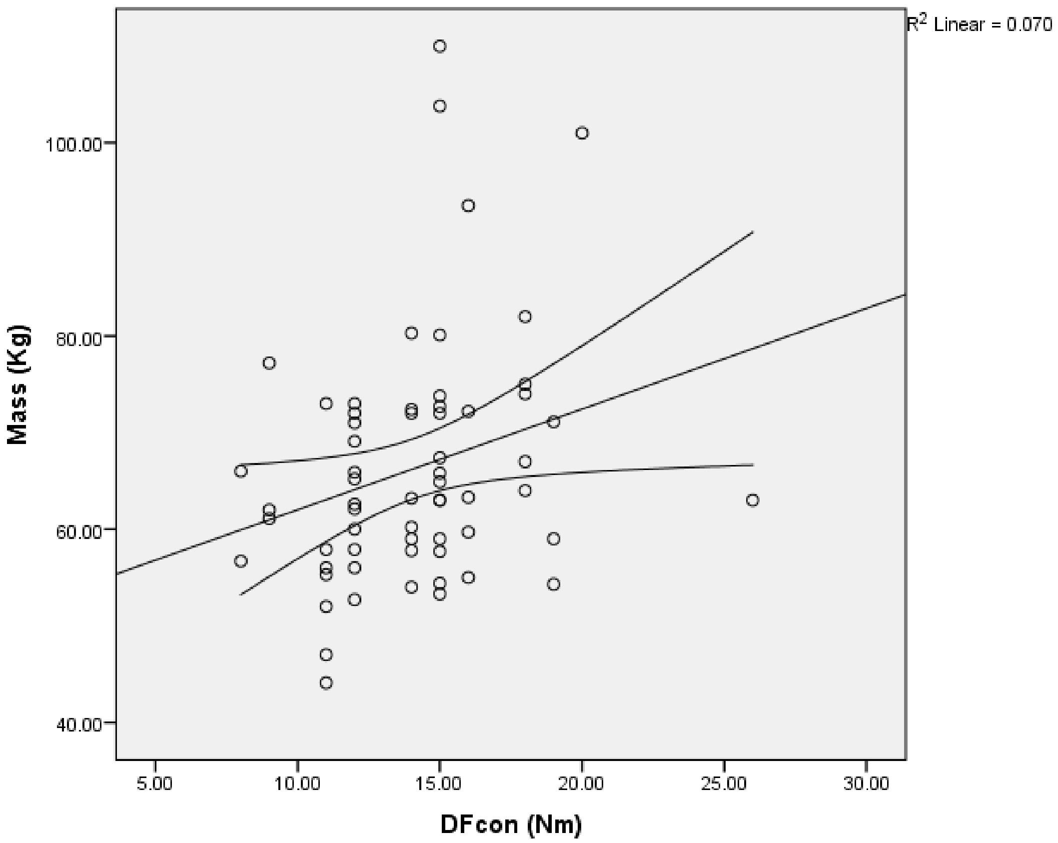
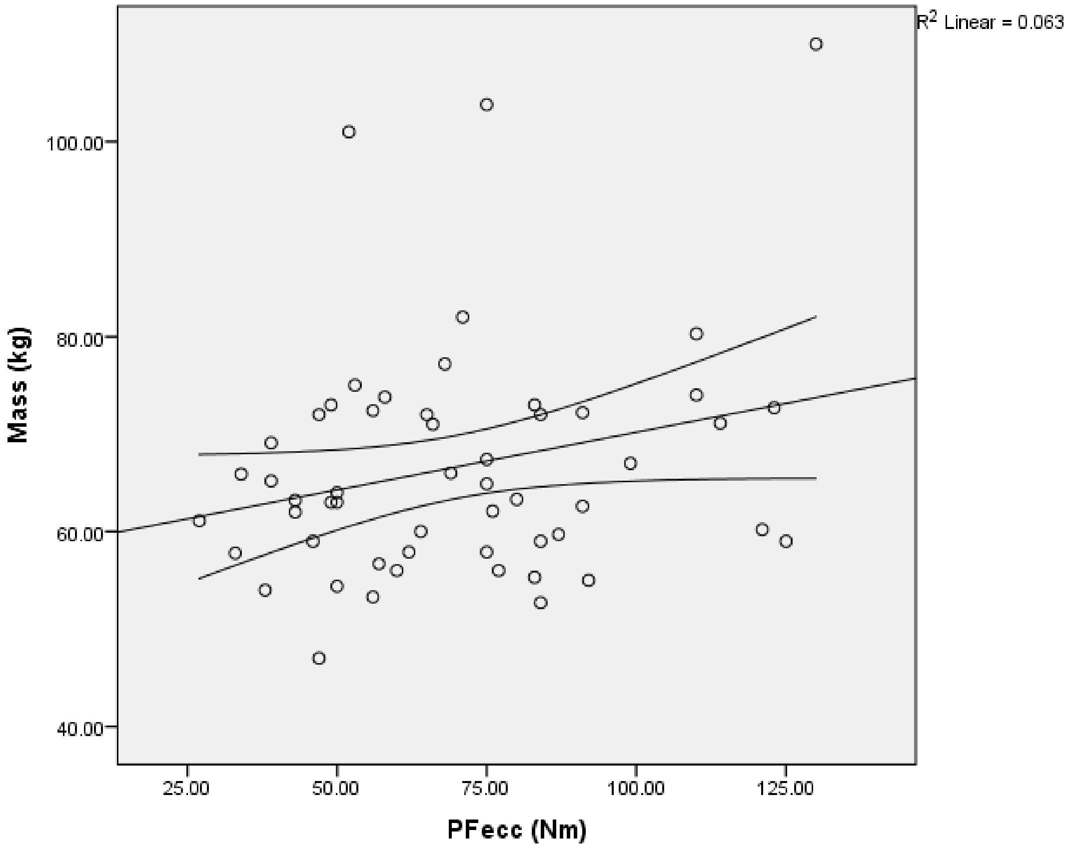


Figure 8-14 Scatterplots demonstrating the relationship in females between mass and concentric PF and DF. The lines represent a linear line of best fit and 95% CI. PF = plantar flexion; DF = dorsiflexion; con = concentric.



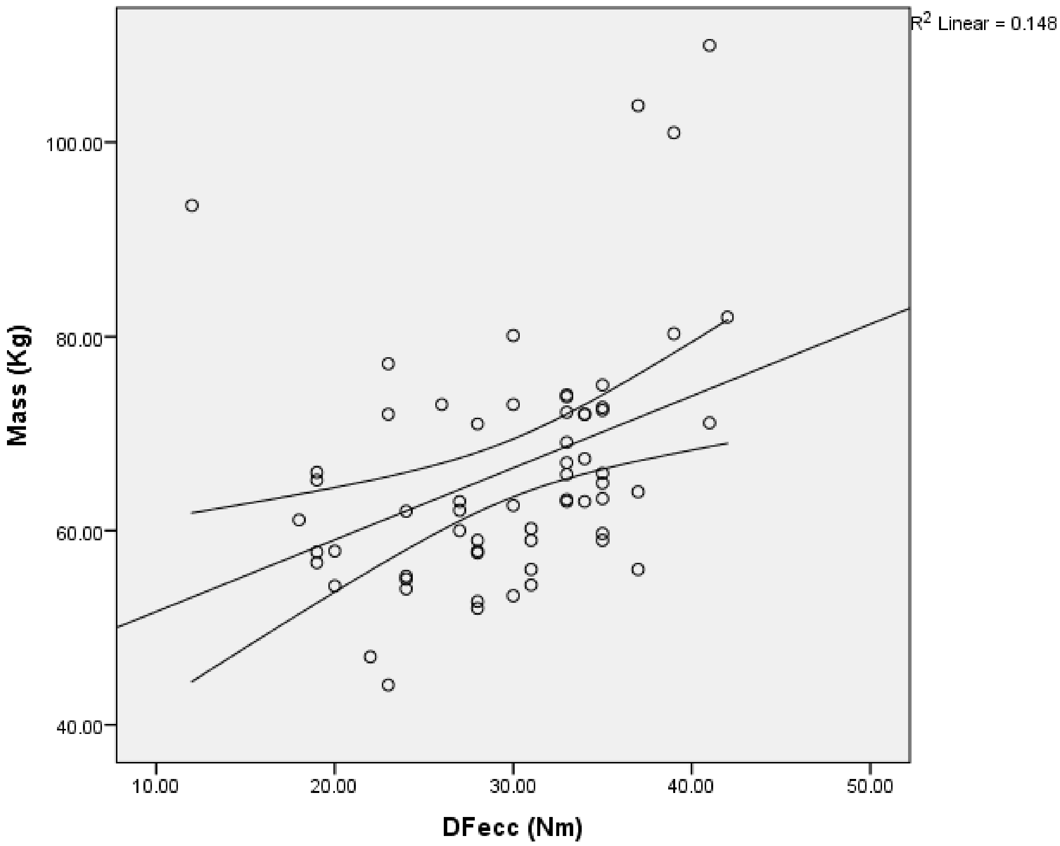
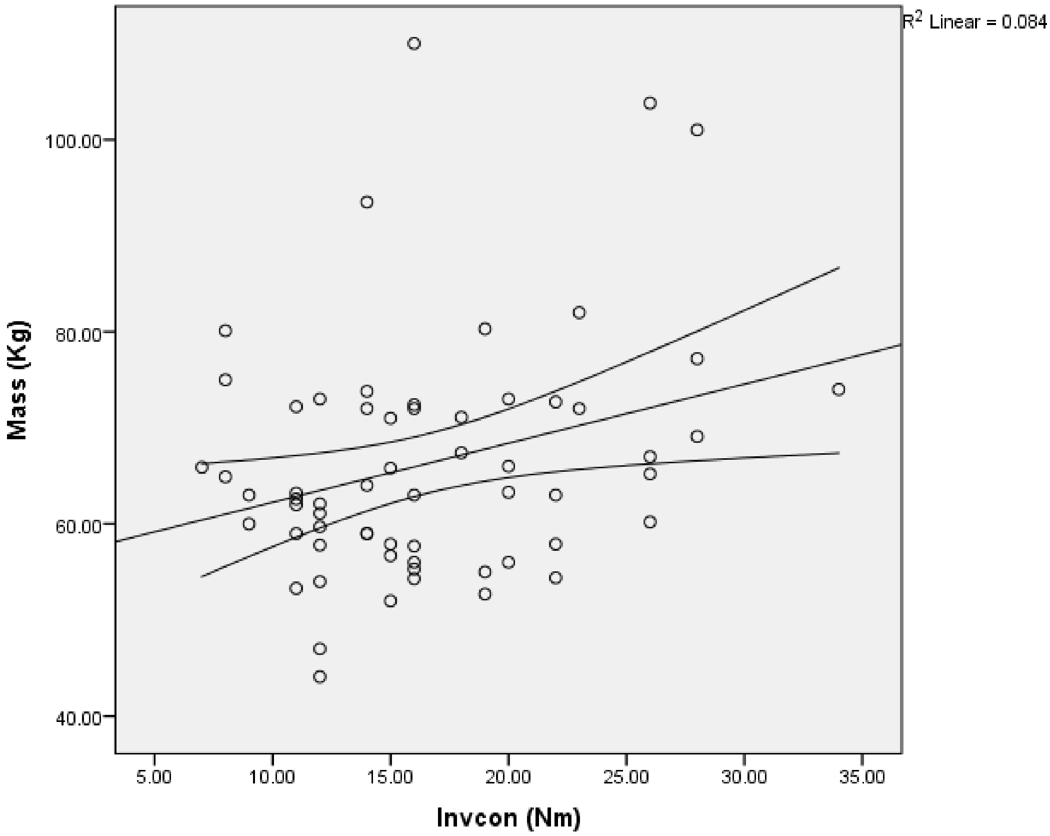


Figure 8-15 Scatterplots demonstrating the relationship in females between mass and eccentric PF and DF. The lines represent a linear line of best fit and 95% CI. PF = plantar flexion; DF = dorsiflexion; ecc = eccentric.



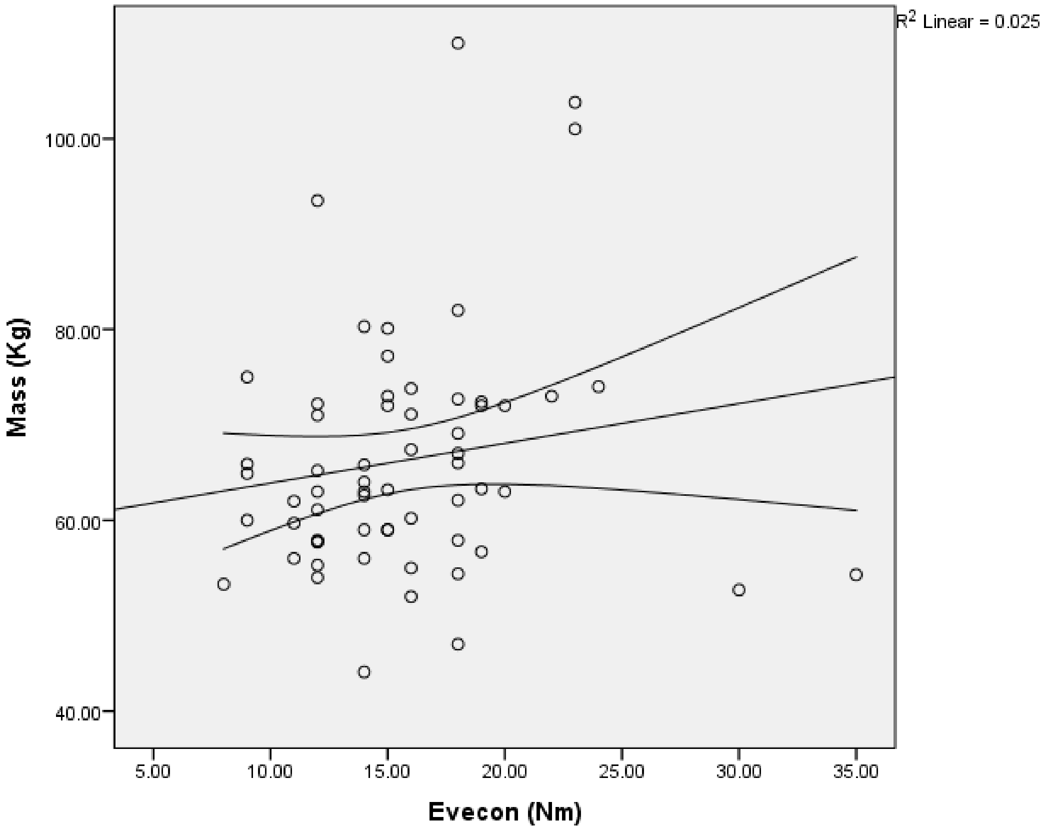
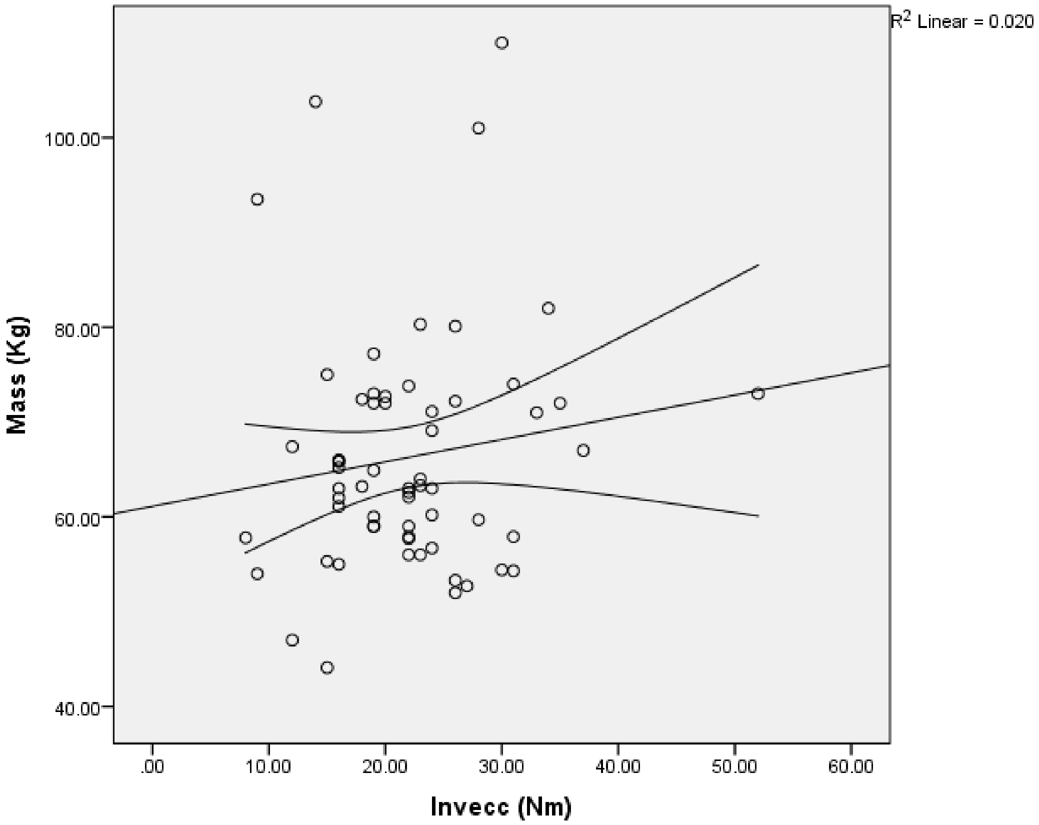


Figure 8-16 Scatterplots demonstrating the relationship in females between mass and concentric inv and eve. The lines represent a linear line of best fit and 95% CI. Inv = inversion; eve = eversion; con = concentric.



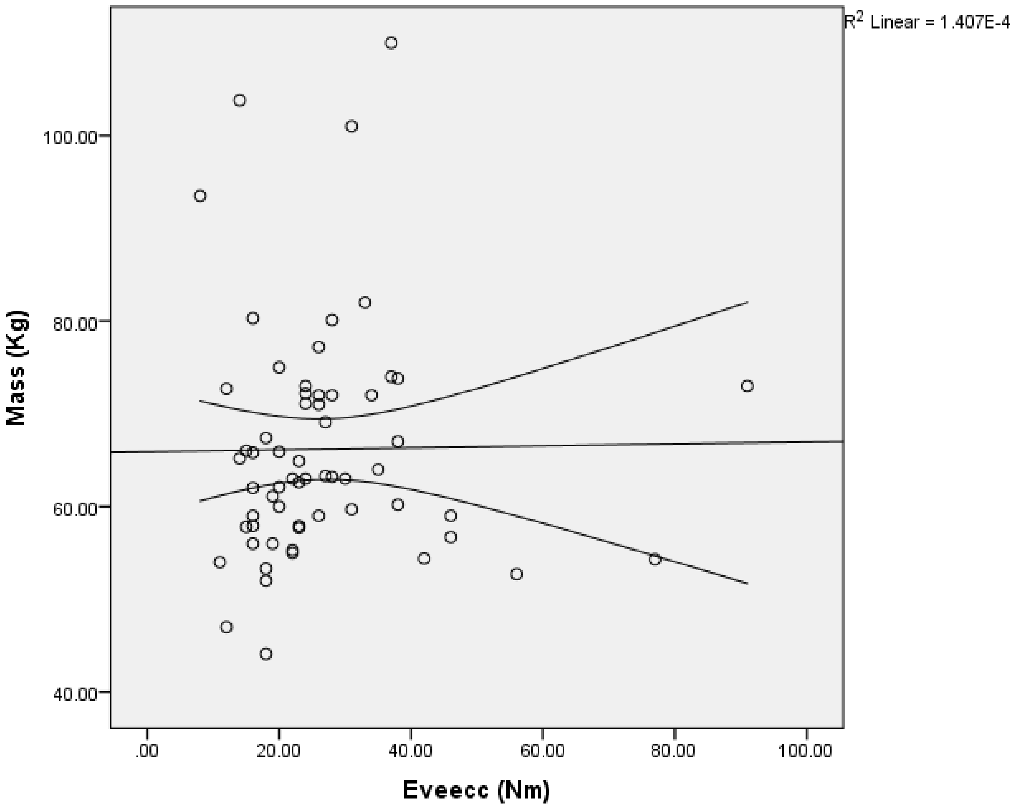


Figure 8-17 Scatterplots demonstrating the relationship in females between mass and eccentric inv and eve. The lines represent a linear line of best fit and 95% CI. Inv = inversion; eve = eversion; ecc = eccentric.

Comparing AMS between genders controlling for mass

To ascertain the effect of mass on differences in AMS between genders, independent samples t-tests comparing males and females in the same mass ranges (60-79.9kg (female n = 34, male n = 24) and 80-99.9kg (female n = 7, male n = 17)) were performed (Appendix 16 and Appendix 17). These indicated that in the 60-79.9kg range there was a significant difference between males and females in concentric and eccentric PF and DF ($P < 0.01$, $d > 0.8$) and in concentric inv ($t(56) = -2.61$, $P = 0.01$, $d = -0.71$) and eve ($t(56) = -5.48$, $P < 0.01$, $d = -1.47$) and eccentric inv ($t(56) = -2.39$, $P = 0.02$, $d = 0.63$). There was no significant difference in eccentric eve ($P = 0.83$) see Figure 8-18. In the 80-99.9kg mass range there was a significant difference between genders in concentric DF ($t(22) = -4.56$, $P < 0.01$, $d = -2.33$) and eccentric DF ($t(22) = -2.44$, $P < 0.01$, $d = -1.83$) as well as eccentric inv ($t(22) = -2.08$, $P = 0.05$, $d = -0.92$) and eccentric eve ($t(22) = -2.62$, $P = 0.02$, $d = -1.20$). There was a tendency towards a significant difference in concentric PF ($t(21) = -1.84$, $P = 0.08$, $d = -0.91$) and concentric eve ($t(22) = -1.92$, $P = 0.07$, $d = -0.95$); (Figure 8-19).

A paired samples t-test also indicated that there was a significant difference between male and female mass within the 60-79.9 kg mass group ($t(56) = -2.38$, $P = 0.02$). The magnitude of the difference between the means (mean difference = -3.56, 95% CI: -6.55 to – 0.57) was intermediate ($d = -0.62$). There was no significant difference between male and female mass in the 80-99.9kg mass category ($P = 0.34$).

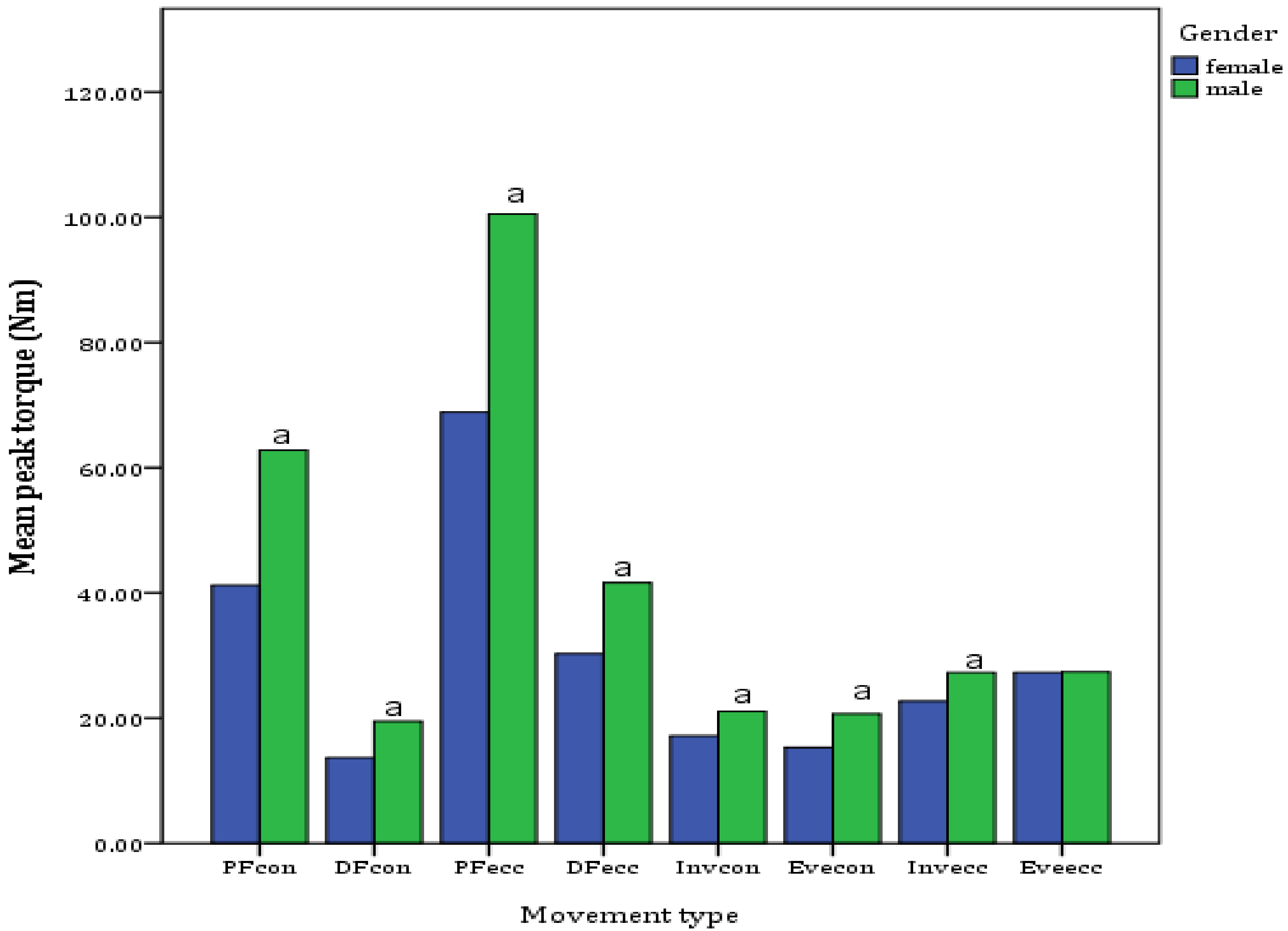


Figure 8-18 A graph showing the relationship in AMS between males and females in the 60-79.9kg mass group. PF = plantar flexion; DF = dorsiflexion; con = concentric; ecc = eccentric; Inv=inversion; Eve=eversion; con = concentric; ecc = eccentric. a=significantly different to female peak torque.

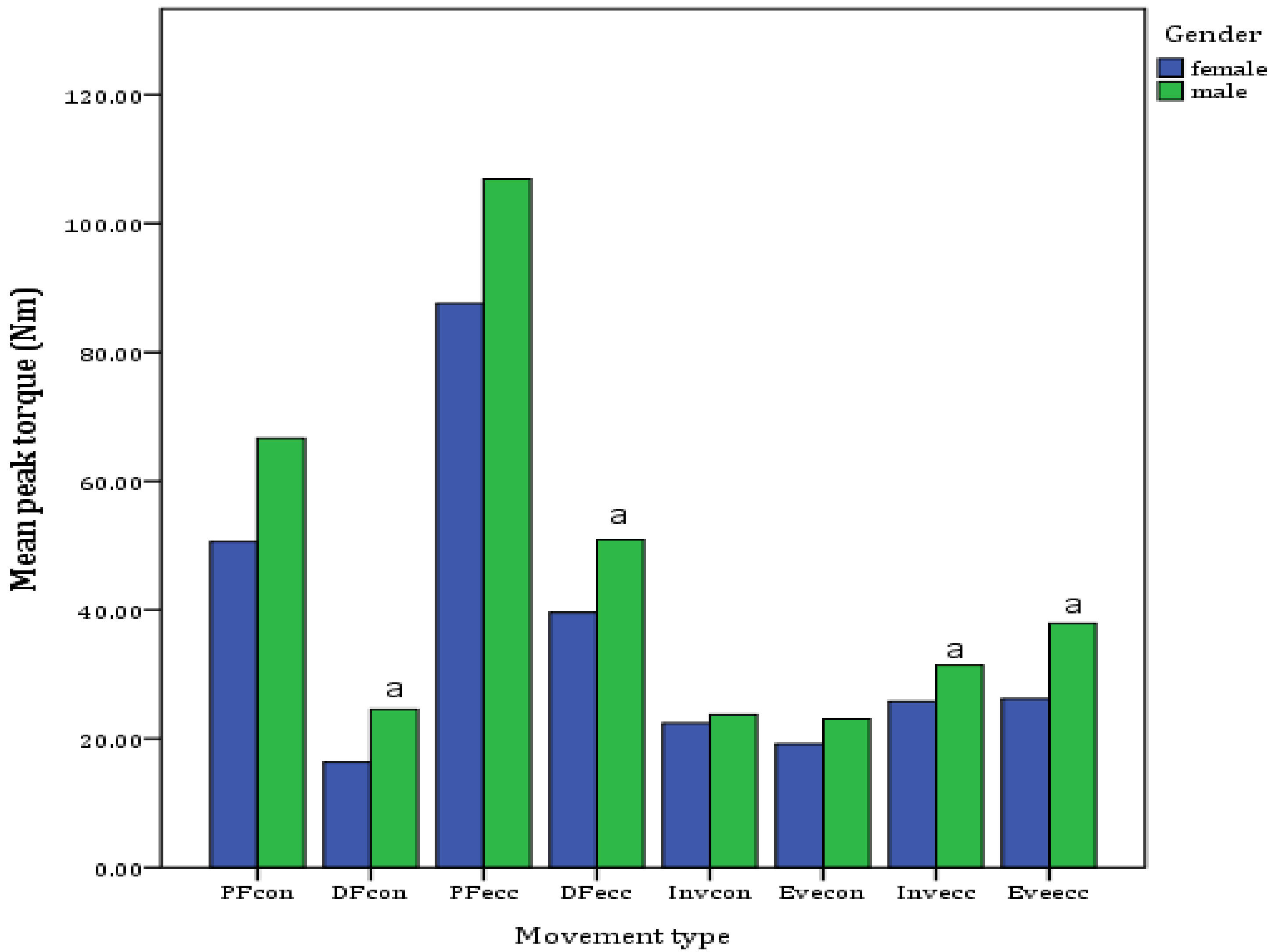


Figure 8-19 A graph showing the relationship in AMS between males and females in the 80-99.9kg mass group. PF = plantar flexion; DF = dorsiflexion; con = concentric; ecc = eccentric; Inv=inversion; Eve=eversion; con = concentric; ecc = eccentric. a=significantly different to female peak torque

8.3.3.4 Height

In the sample population a Pearson's correlation test indicated a relationship between height and AMS (P < 0.01 in all cases, see Appendix 18 for r values), however, an independent samples t-test indicated there was a significant difference in height between males and females (t(109) = -8.73, P < 0.01, d = -1.67); (Appendix 19). As discussed previously mean AMS is greater in males than in females, thus, a correlation would exist between height and AMS due to differences between genders. It is therefore necessary to analyse the interaction between height and strength in single gender groups. When the Pearson's correlation test was repeated for the single gender groups, for the males there was significant correlation between height and concentric and eccentric DF (P<0.01) and for the females there was a significant correlation between concentric and eccentric PD and DF (P<0.05). See Table 8-9 for significance and r values.

Table 8-9

Results of a Pearson's correlation analysis between height and the eight measures of AMS.

Gender		PFcon	DFcon	PFecc	DFecc	Invcon	Evecon	Invecc	Eveecc
Male	Pearson correlation	0.27	0.50	0.17	0.50	0.04	0.03	0.04	0.12
	Significance (2-tailed)	0.07	0.00	0.24	0.00	0.80	0.85	0.81	0.41
Female	Pearson correlation	0.28	0.32	0.33	0.46	0.05	-0.02	0.14	0.17
	Significance (2-tailed)	0.03	0.01	0.01	0.00	0.68	0.86	0.26	0.19

Note PF = plantar flexion; DF = dorsiflexion; Inv = inversion; Eve = eversion; con = concentric; ecc = eccentric.

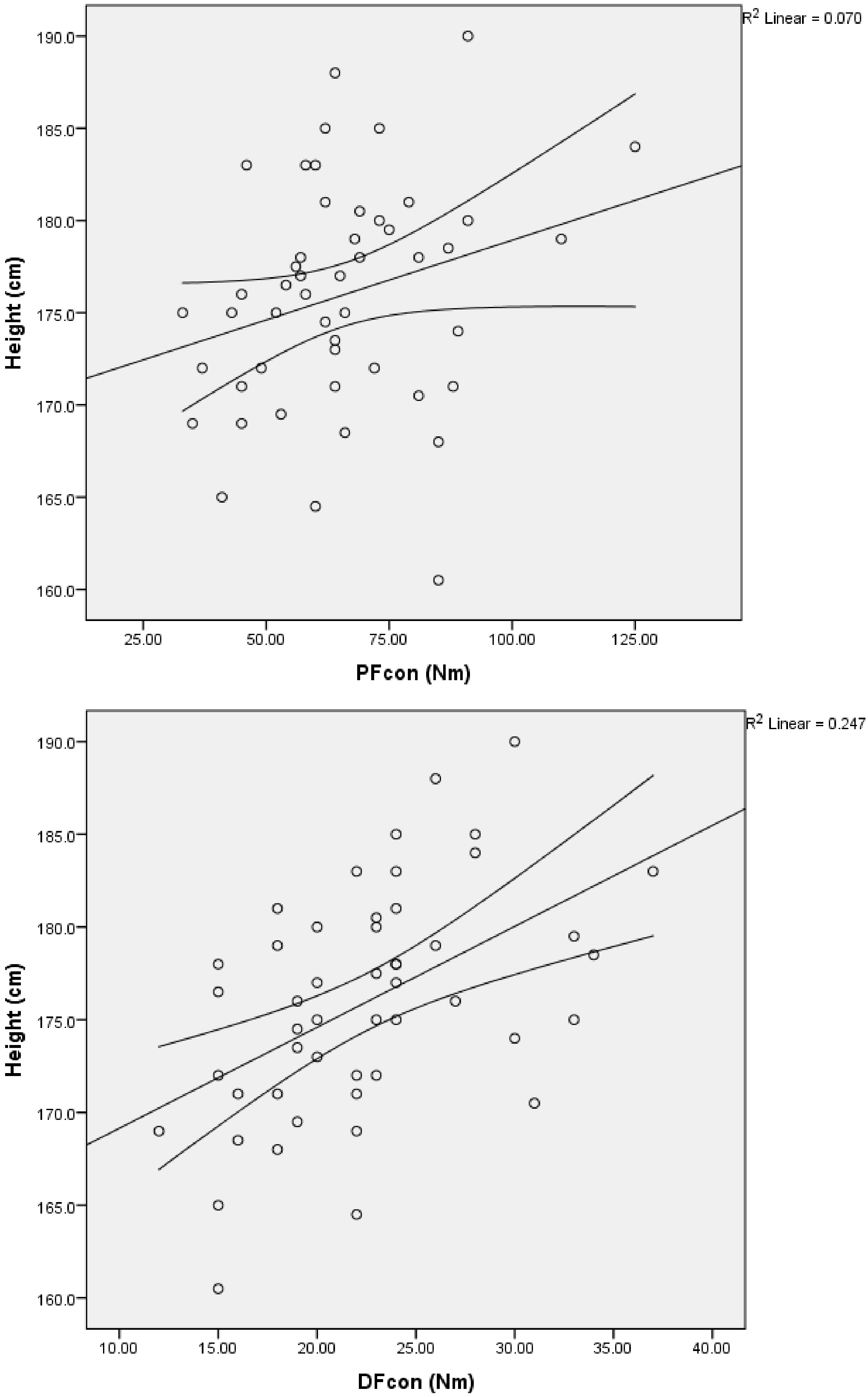


Figure 8-20 Scatterplots demonstrating the relationship in males between height and concentric PF and DF. The lines represent a linear line of best fit and 95% CI. PF = plantar flexion; DF = dorsiflexion; con = concentric.

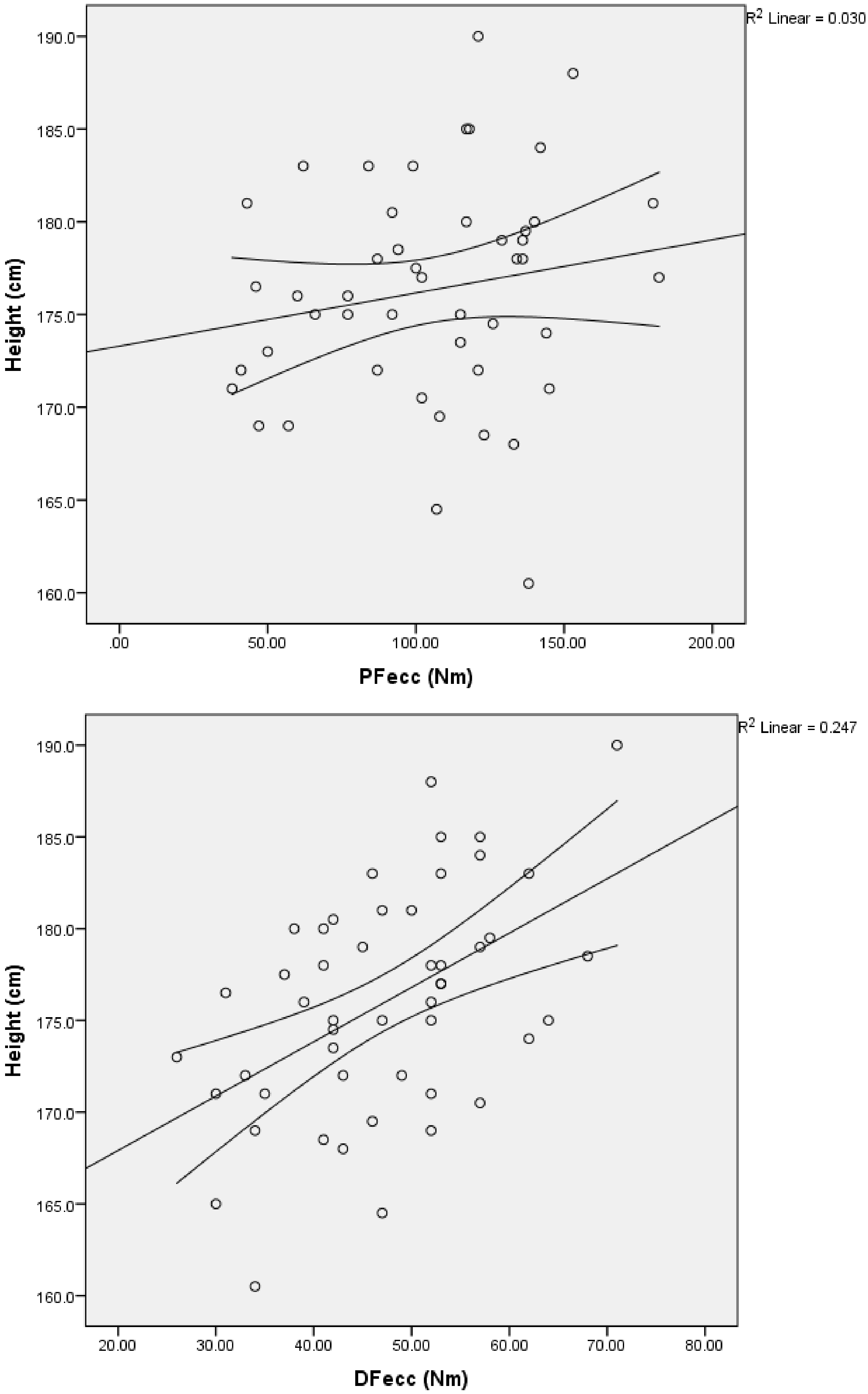


Figure 8-21 Scatterplots demonstrating the relationship in males between height and eccentric PF and DF. The lines represent a linear line of best fit and 95% CI. PF = plantar flexion; DF = dorsiflexion; con = concentric.

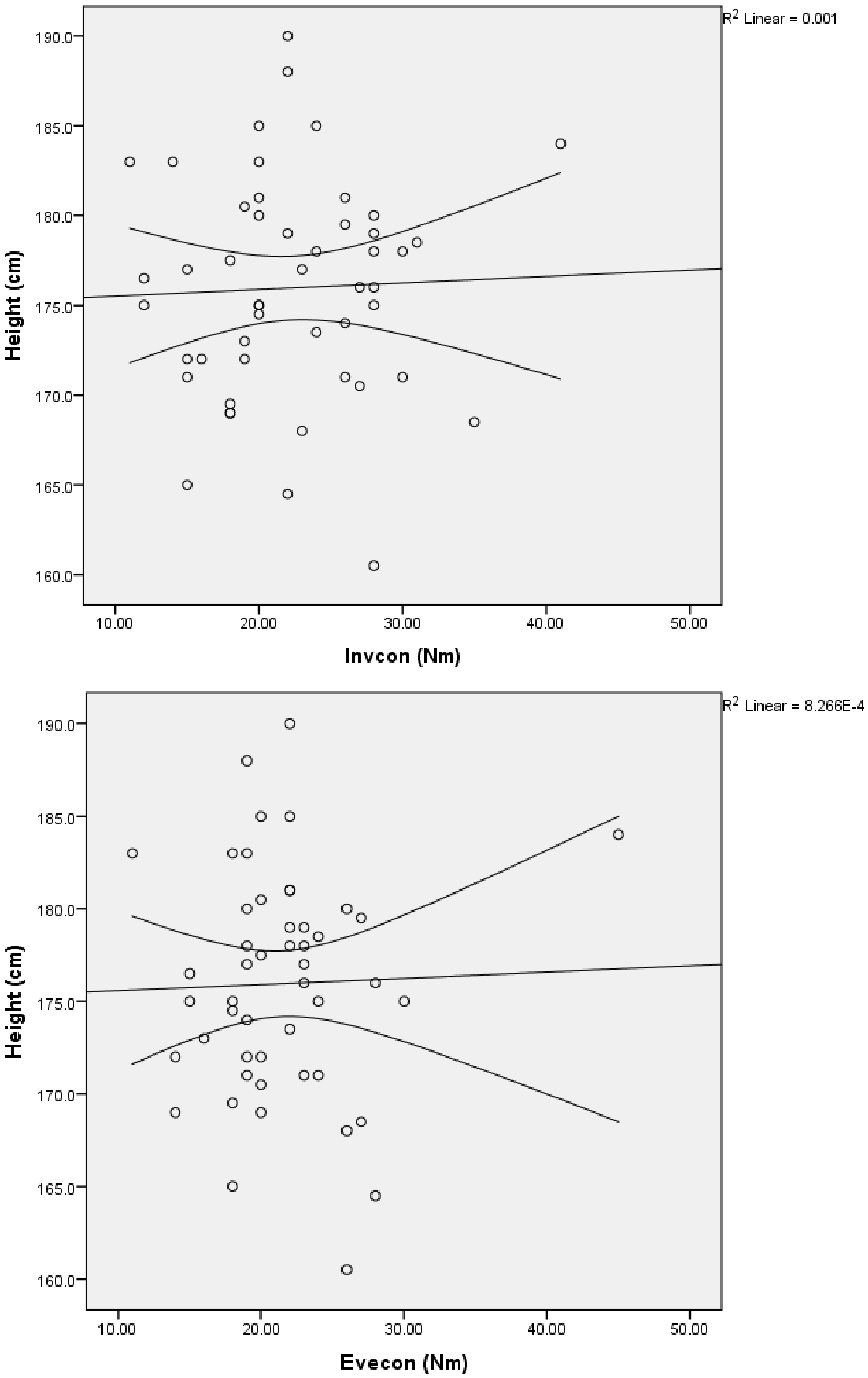
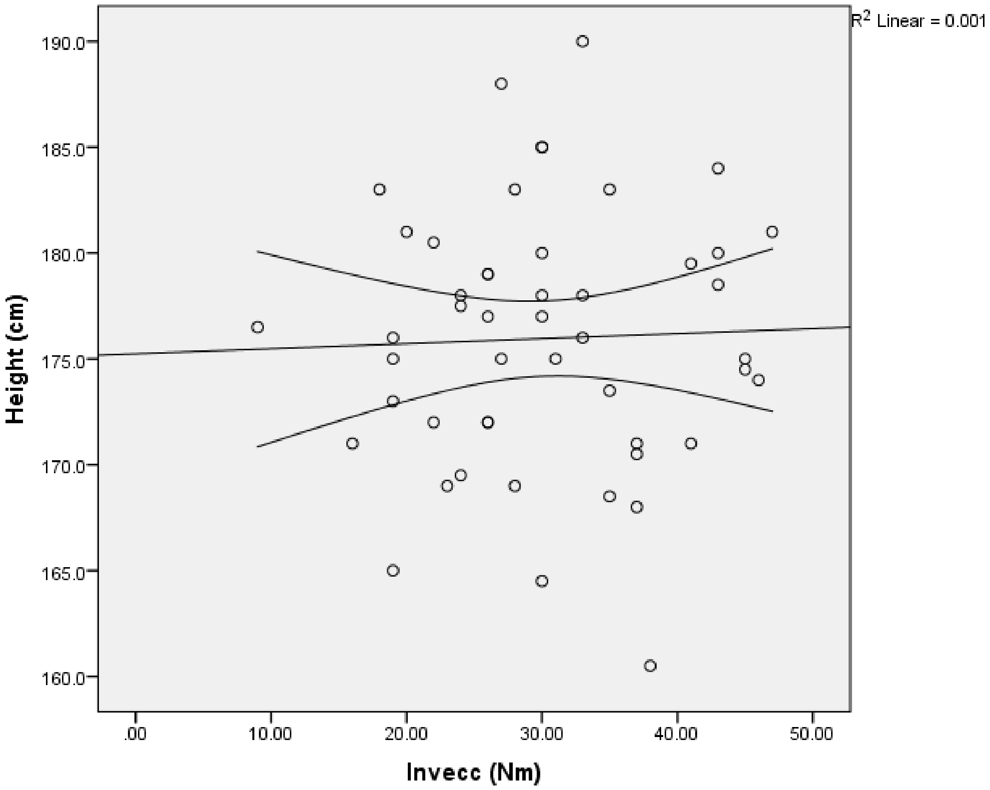


Figure 8-22 Scatterplots demonstrating the relationship in males between height and concentric inv and eve. The lines represent a linear line of best fit and 95% CI. Inv = inversion; eve = eversion.



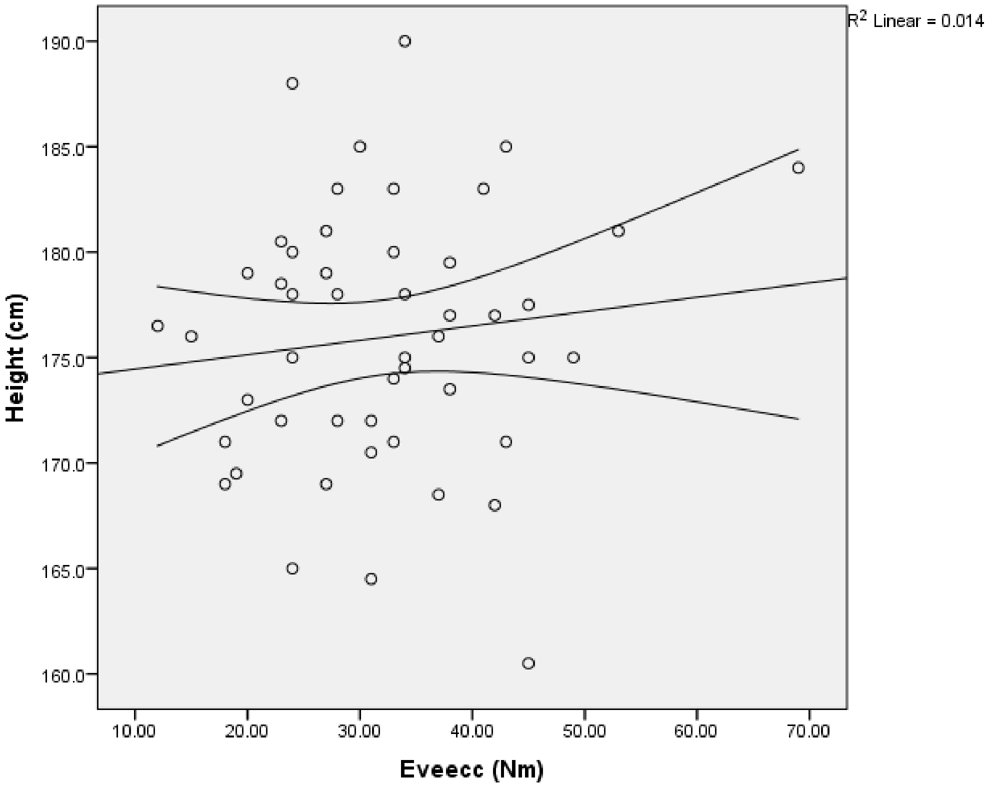


Figure 8-23 Scatterplots demonstrating the relationship in males between height and eccentric inv and eve. The lines represent a linear line of best fit and 95% CI. Inv = inversion; eve = eversion.

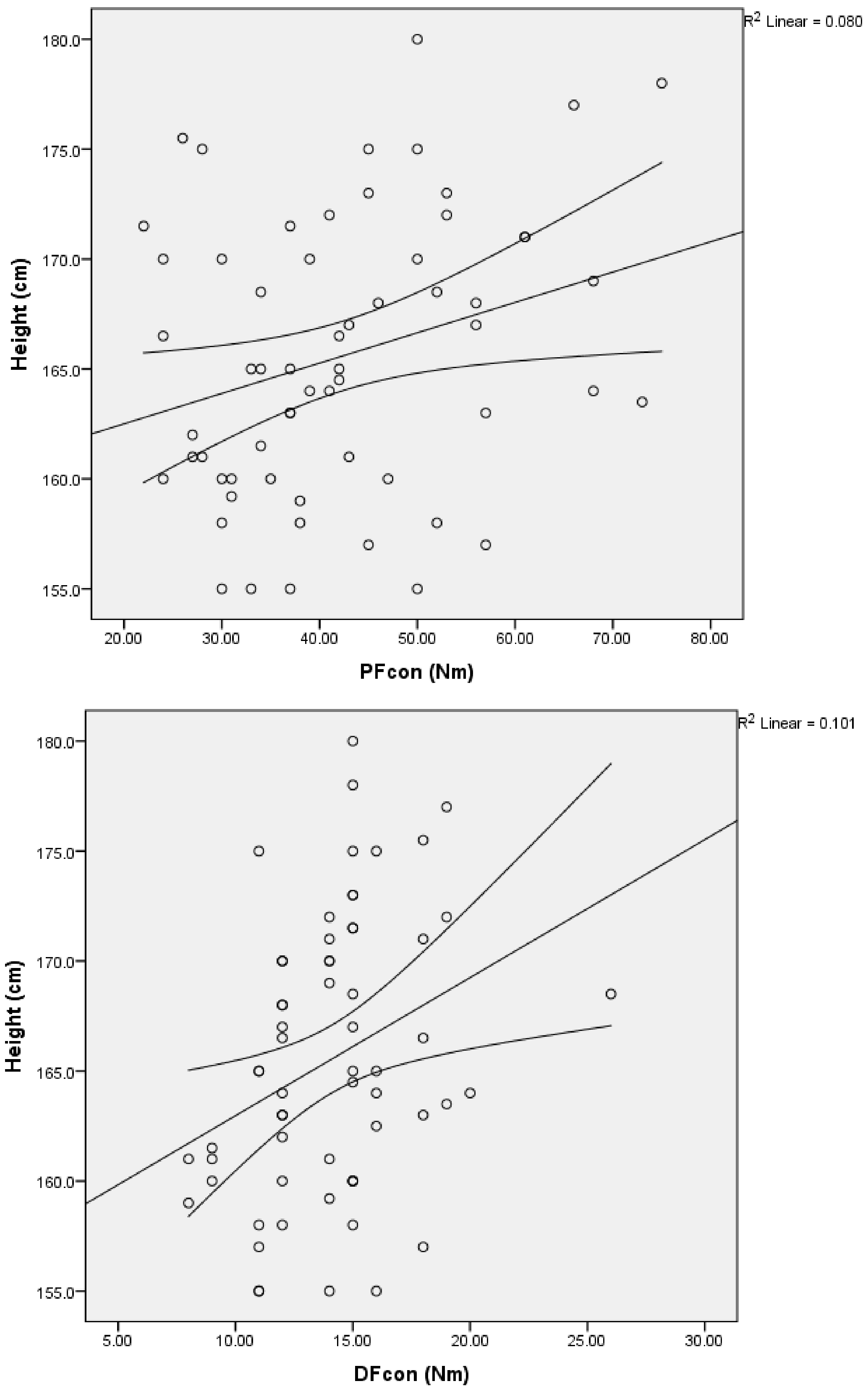
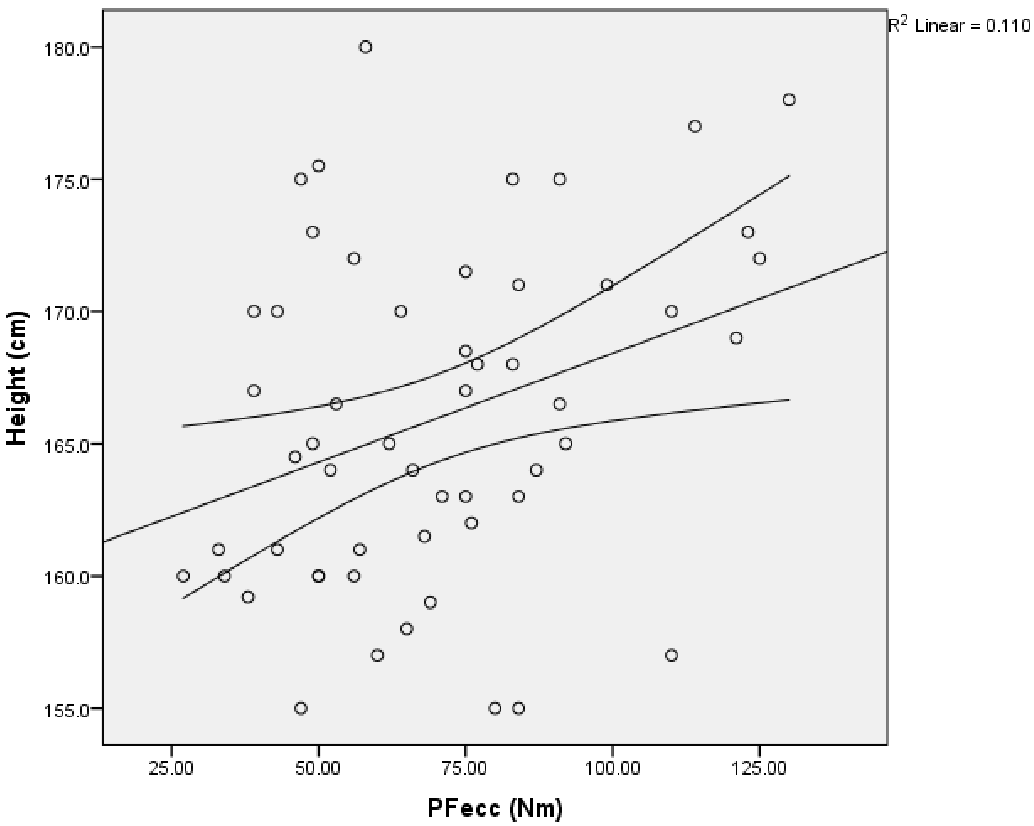


Figure 8-24 Scatterplots demonstrating the relationship in females between height and concentric PF and DF. The lines represent a linear line of best fit and 95% CI. PF = plantar flexion; DF = dorsiflexion; con = concentric.



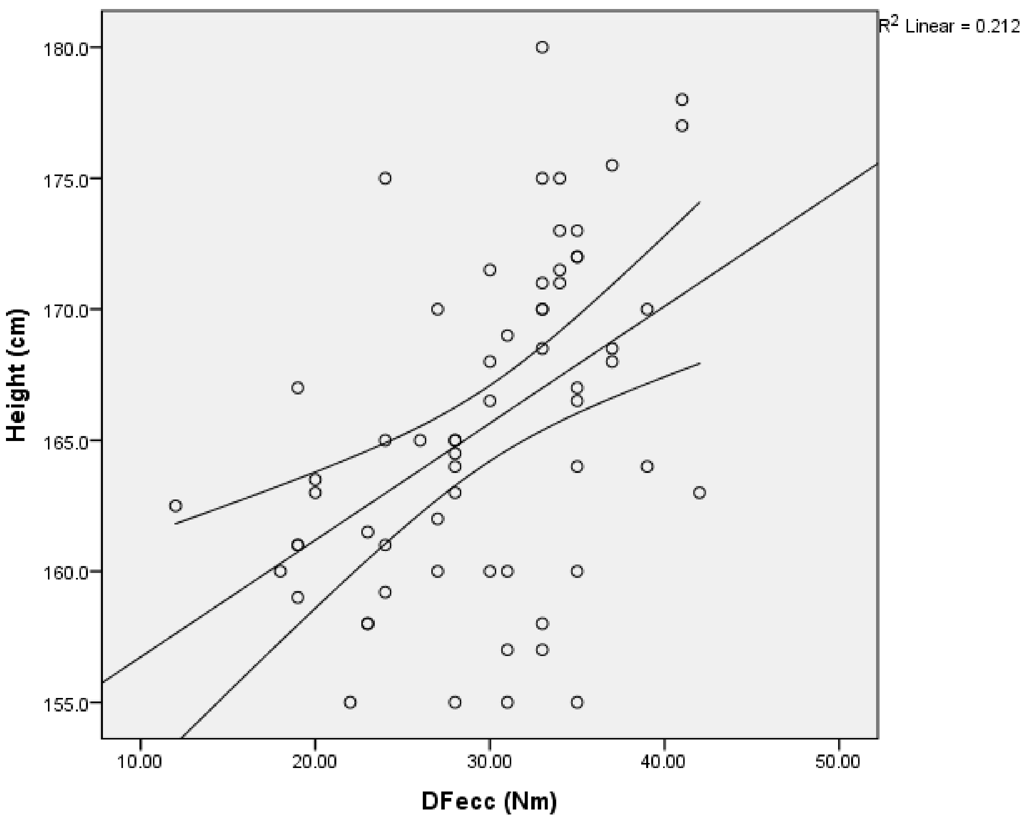
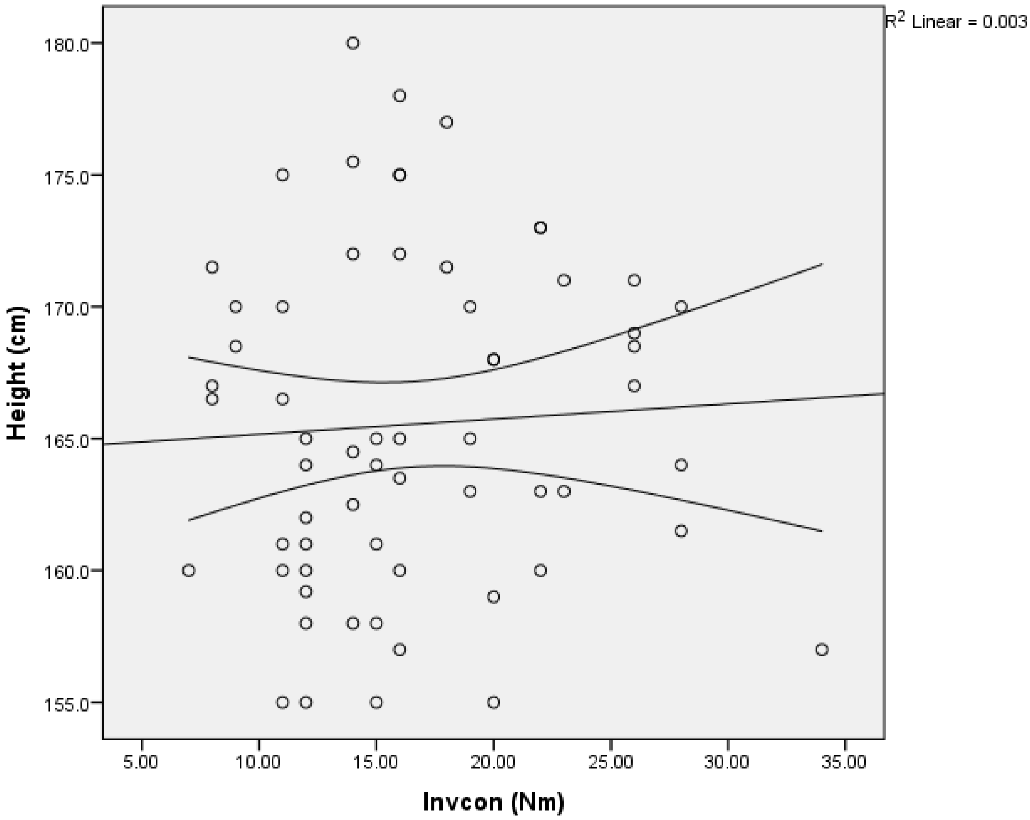


Figure 8-25 Scatterplots demonstrating the relationship in females between height and eccentric PF and DF. The lines represent a linear line of best fit and 95% CI. PF = plantar flexion; DF = dorsiflexion; con = concentric.



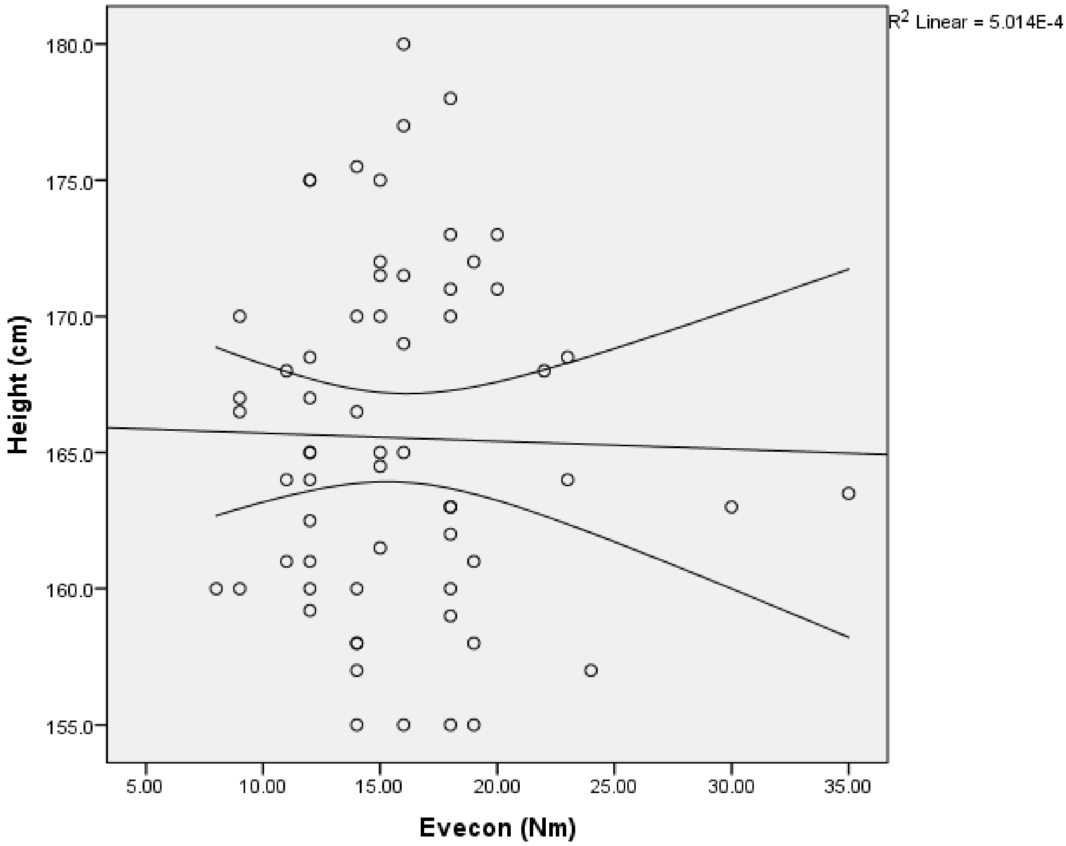


Figure 8-26 Scatterplots demonstrating the relationship in females between height and concentric inv and eve. The lines represent a linear line of best fit and 95% CI. Inv = inversion; eve = eversion.

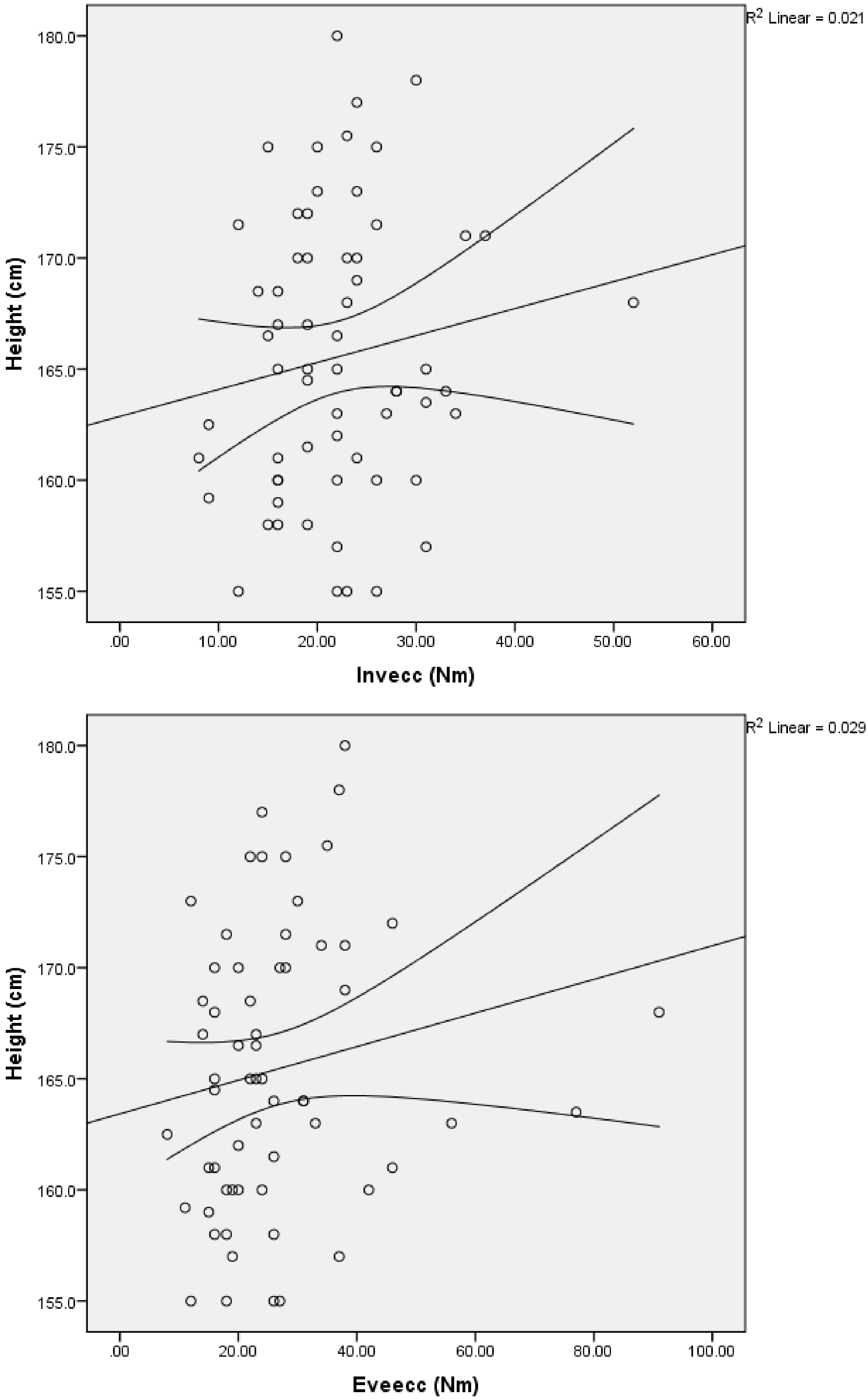


Figure 8-27 Scatterplots demonstrating the relationship in females between height and eccentric inv and eve. The lines represent a linear line of best fit and 95% CI. Inv = inversion; eve = eversion.

Comparing AMS between genders controlling for height

To ascertain the contribution of height towards variation in AMS between genders an independent samples t-test was performed examining the relationship between males and females in the same height categories: 165-169.9cm, 170-174.9cm and 175-179.9cm. Independent samples t-test showed no significant difference in height between males and females in the 165-169.9cm height group (Appendix 20), however, as the graph in Figure 8-28 shows there was significant difference between males and females in terms of eccentric DF ($t(17) = -3.51$, $P < 0.01$, $d = -1.59$) and concentric eve ($t(17) = -1.84$, $P = 0.01$, $d = -1.36$); (Appendix 21).

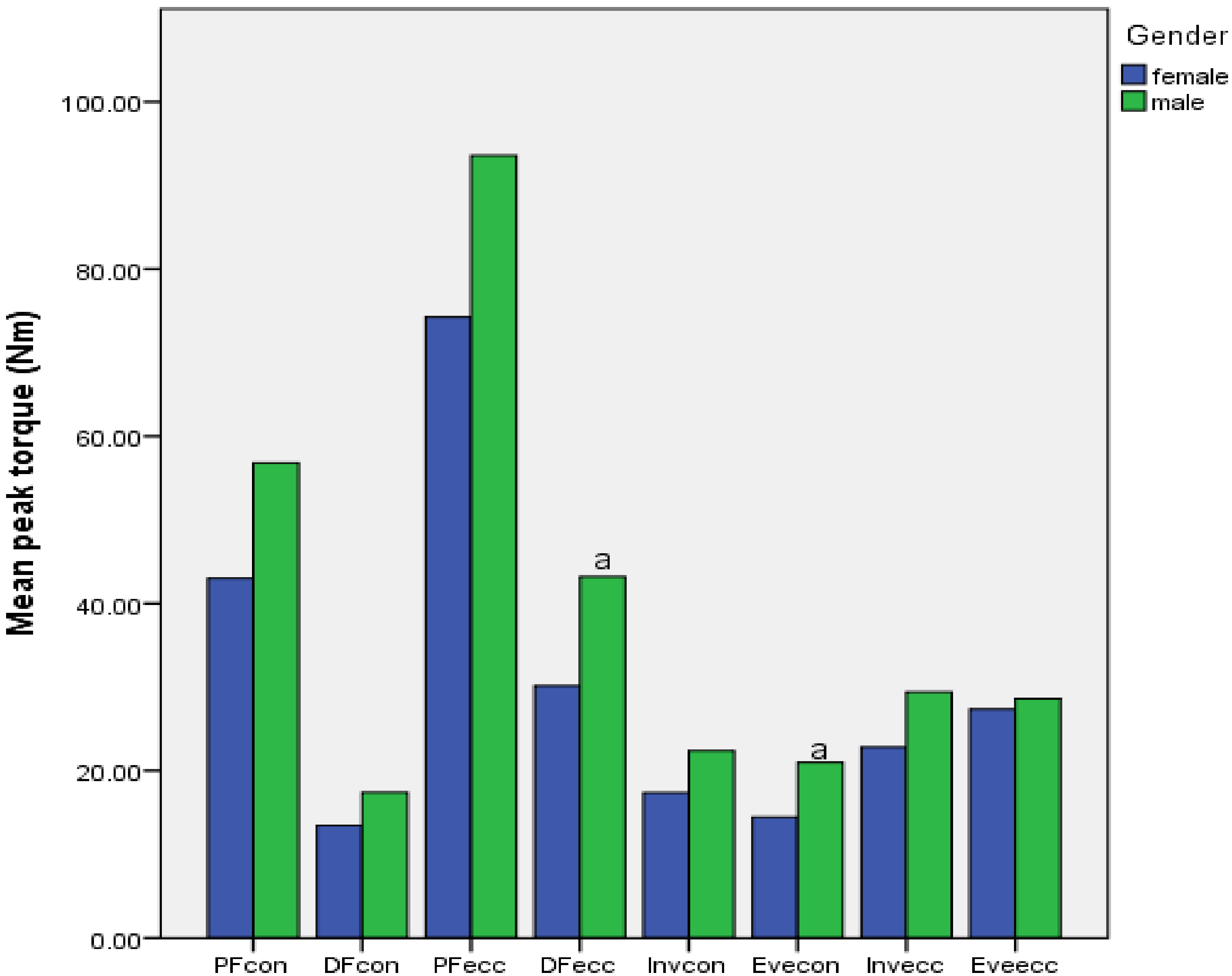


Figure 8-28 A graph comparing AMS between genders in the 165.0-169.9cm height group. PF=plantar flexion; DF=dorsiflexion; con=concentric; ecc=eccentric; a= significantly different to female average peak torque.

In the 170-174.9cm group there was a tendency towards significant difference between the genders in terms of height ($t(21) = -1.9$, $P = 0.07$, $d = -0.79$); (Appendix 22). *Figure 8-29* indicates there was a significant difference between genders in terms of concentric PF ($t(21) = -3.49$, $P = 0.02$, $d = -1.45$) and concentric DF ($t(21) = -4.11$, $P < 0.01$, $d = -1.69$), eccentric DF ($t(11.19) = -2.64$, $P = 0.02$, $d = -1.12$), concentric eve ($t(21) = -2.41$, $P = 0.03$, $d = -1.00$) and eccentric inv ($t(21) = -2.40$, $P = 0.03$, $d = -0.99$); (Appendix 23).

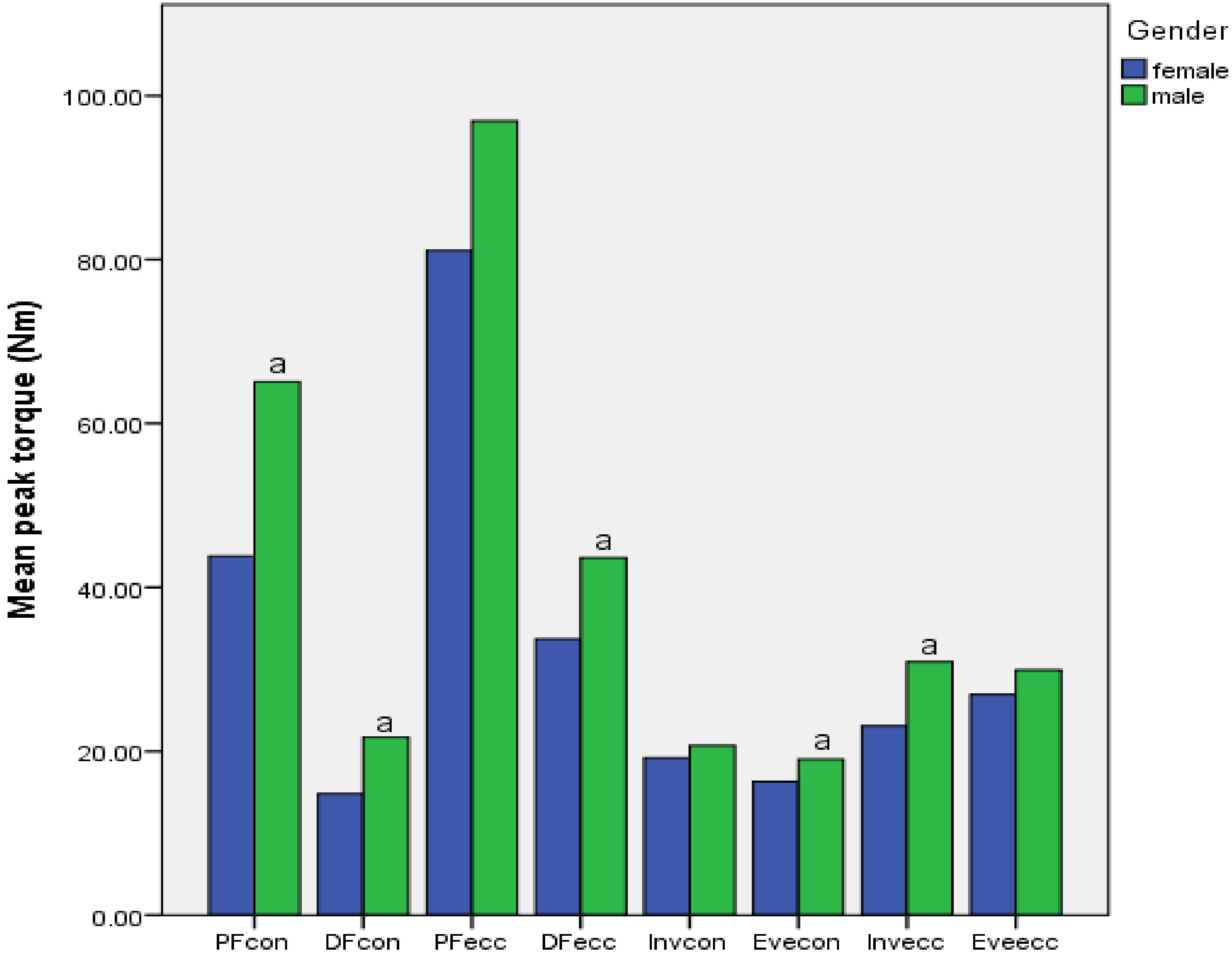


Figure 8-29 A graph comparing AMS between genders in the 170-174.9cm height group. PF=plantar flexion; DF=dorsiflexion; con=concentric; ecc=eccentric; a= significantly different to female average peak torque

There was no significant difference between genders in terms of height ($P = 0.12$) in the 175-179.9cm group (Appendix 24), however, as Figure 8-30 shows, in this group there was a significant difference between genders in terms of concentric DF ($t(21) = -3.23$, $P < 0.01$, $d = -1.76$), eccentric DF ($t(21) = -3.43$, $P < 0.01$, $d = -1.83$) and concentric inv ($t(21) = 13.06$, $P < 0.01$, $d = -1.71$) and concentric eve ($t(21) = -4.21$, $P < 0.001$, $d = -2.25$); (Appendix 25).

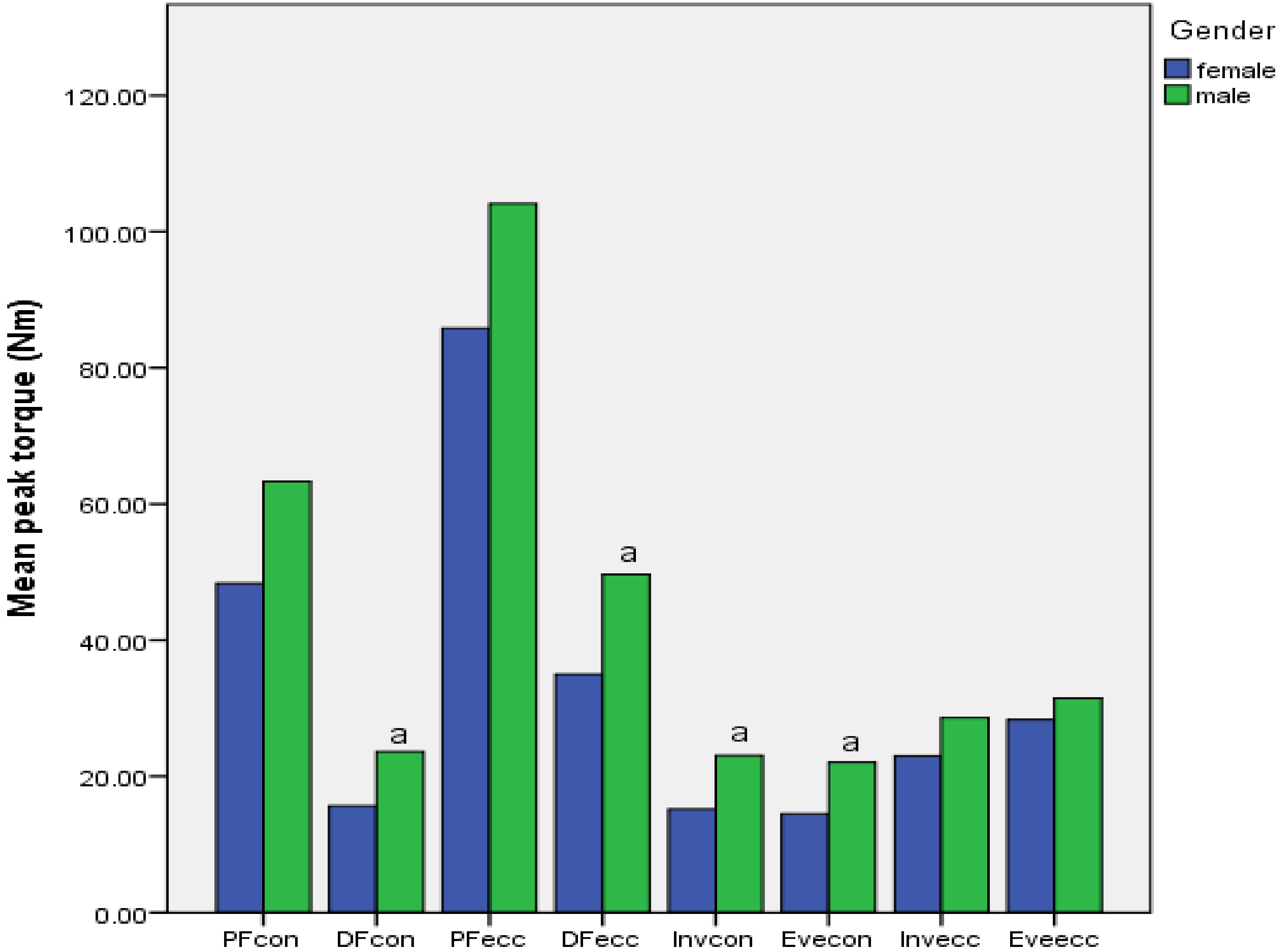


Figure 8-30 A graph comparing AMS between genders in the 175.0-179.9cm height group. PF=plantar flexion; DF=dorsiflexion; con=concentric; ecc=eccentric; a= significantly different to female average peak torque

8.3.3.5 Shoe size

A Pearson's correlation test indicated there was a significant correlation between shoe size and AMS ($P < 0.01$ in all cases apart from eccentric eve where $P = 0.02$); (Appendix 26). There was also a correlation between gender and shoe size ($r = 0.81$, $n = 100$, $P < 0.01$), therefore, it could be this interaction that is causing the correlation between shoe size and AMS. When the genders were split there were some significant correlations in measures of PF and DF strength in the female group and a tendency towards significant interactions in the male group. This data is summarised in Table 8-10.

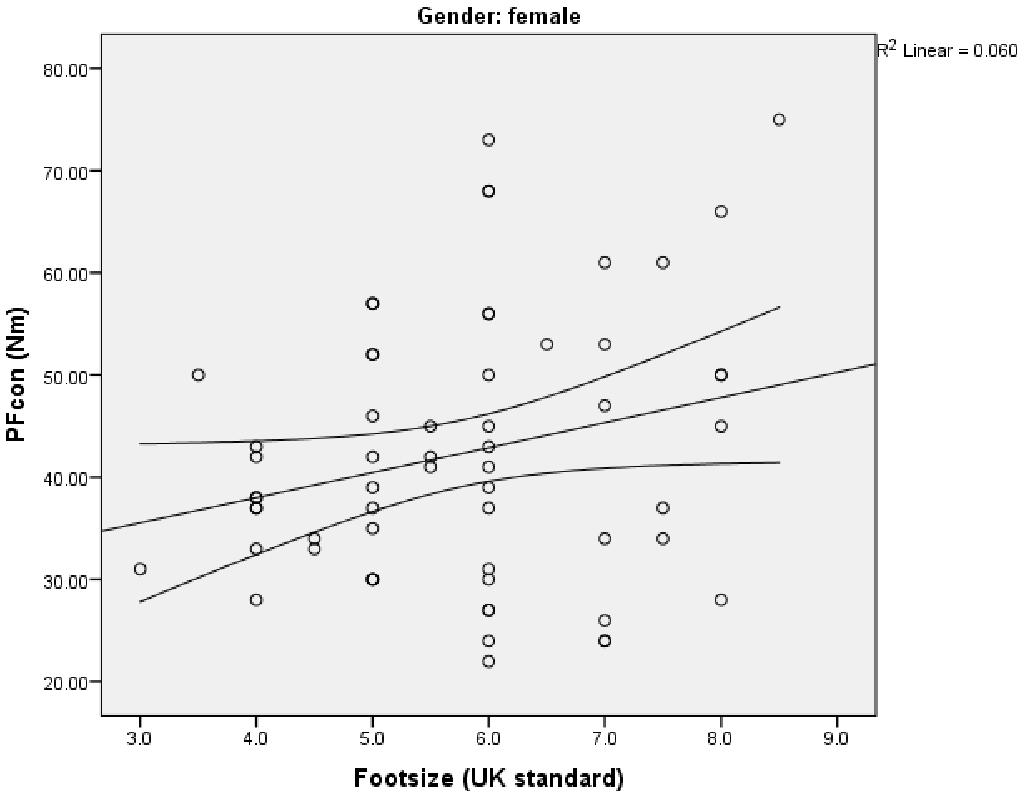
Table 8-10

A table summarising the results of a Pearson's correlation analysis between shoe size and AMS in males and females.

Gender		PFcon	DFcon	PFecc	DFecc	Invcon	Evecon	Invecc	Eveecc
Male	Pearson correlation	0.26	0.24	0.15	0.24	0.06	0.11	0.11	0.14
	Significance (2-tailed)	0.07	0.09	0.32	0.09	0.71	0.47	0.46	0.35
Female	Pearson correlation	0.25	0.28	0.26	0.40	0.05	0.02	0.09	0.09
	Significance (2-tailed)	0.06	0.03	0.06	0.00	0.72	0.90	0.50	0.48

Note: PF = plantar flexion; DF = dorsiflexion; inv = inversion; eve = eversion; con = concentric; ecc = eccentric

The results described in Table 8-10 are displayed graphically in ***Figure 8-31***through to ***Figure 8-38***



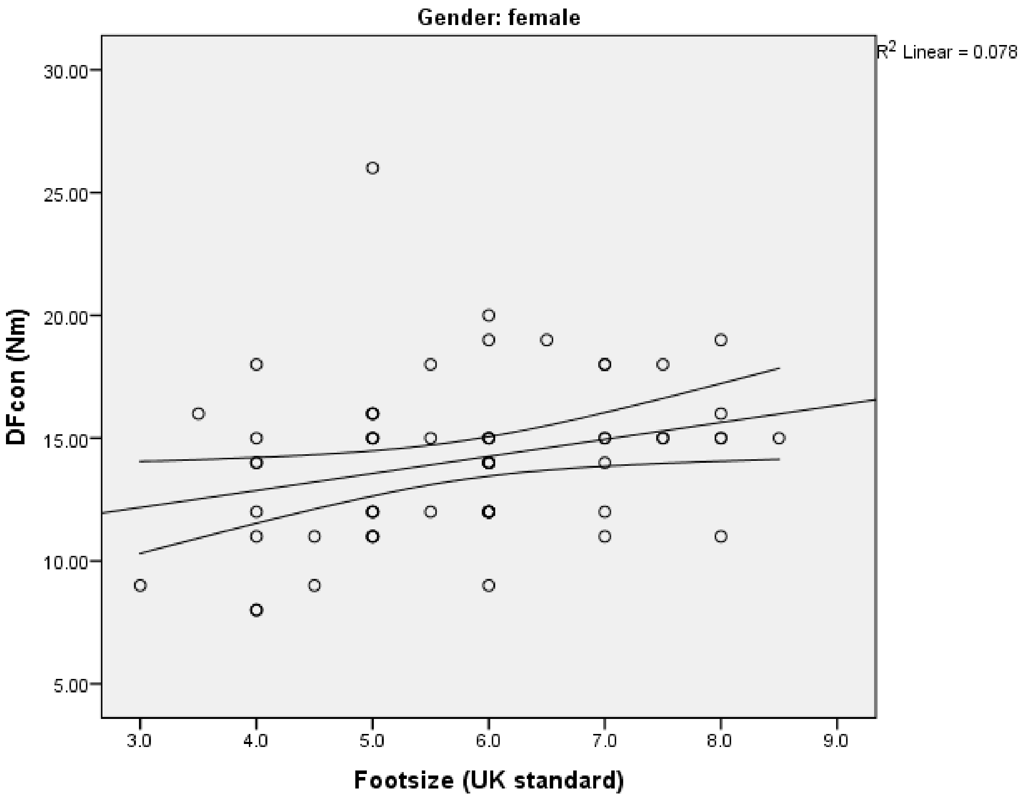
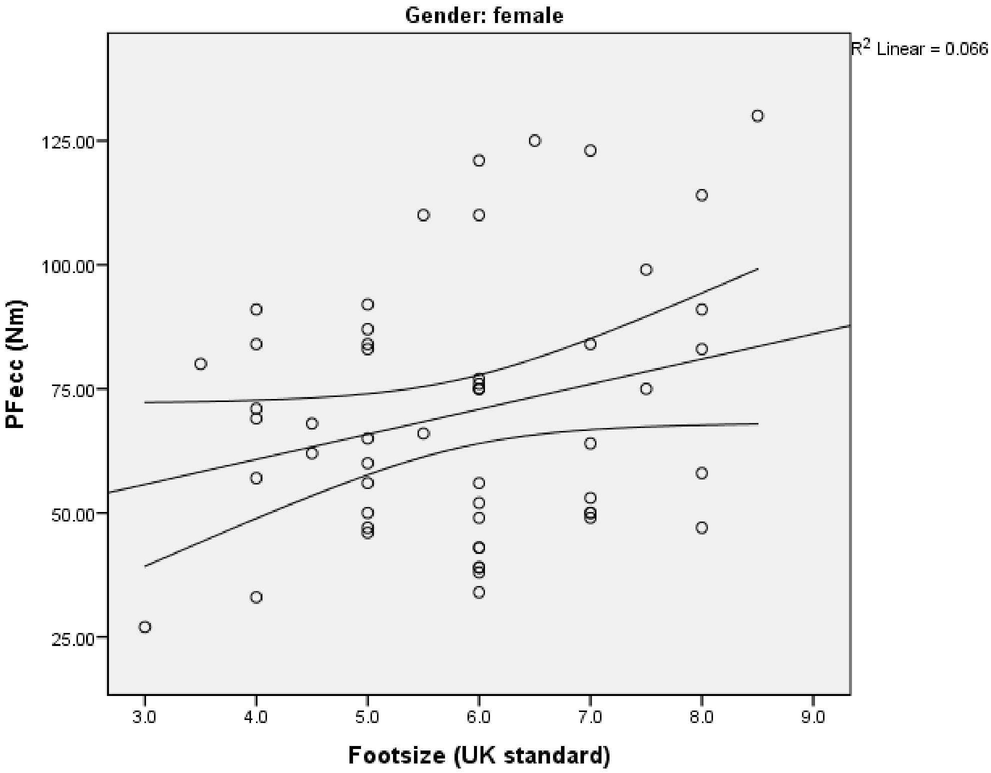


Figure 8-31 Scatterplots demonstrating the relationship in females between shoe size and concentric PF and DF. The lines represent a linear line of best fit and 95% CI. PF = plantar flexion; DF = dorsiflexion; con = concentric.



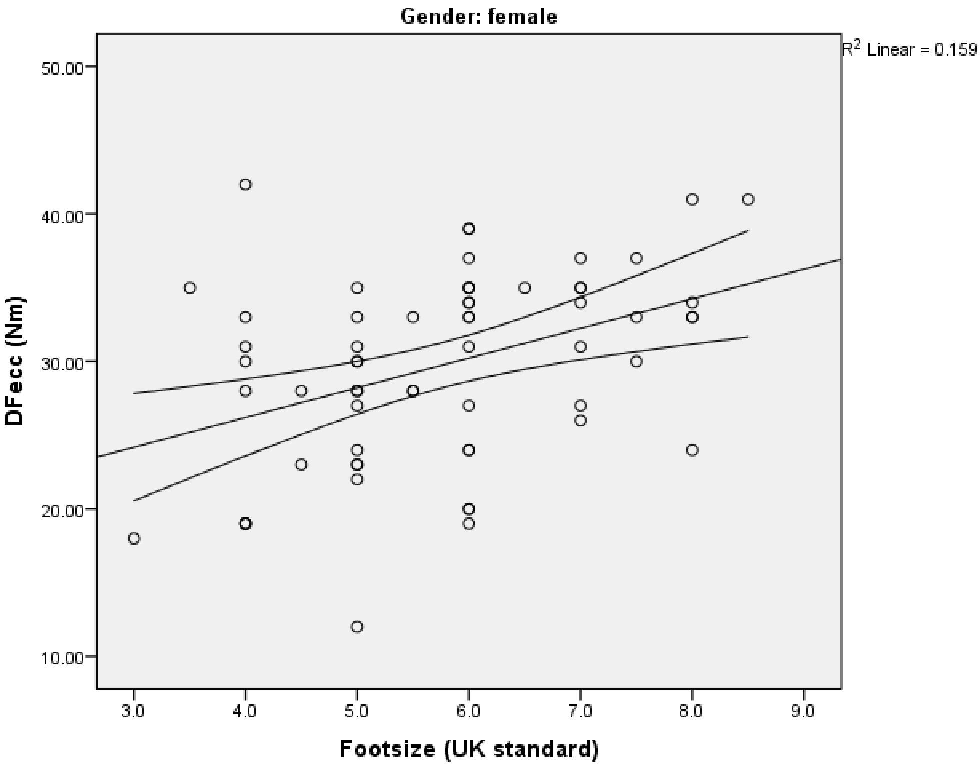
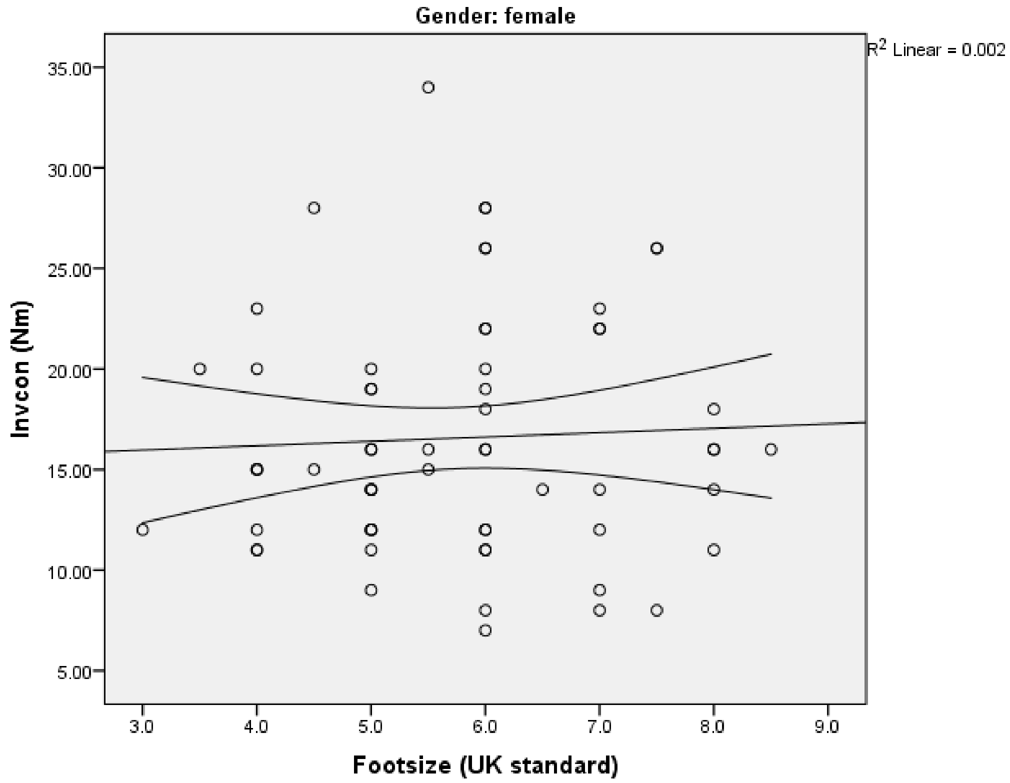


Figure 8-32 Scatterplots demonstrating the relationship in females between shoe size and eccentric PF and DF. The lines represent a linear line of best fit and 95% CI. PF = plantar flexion; DF = dorsiflexion; ecc = eccentric



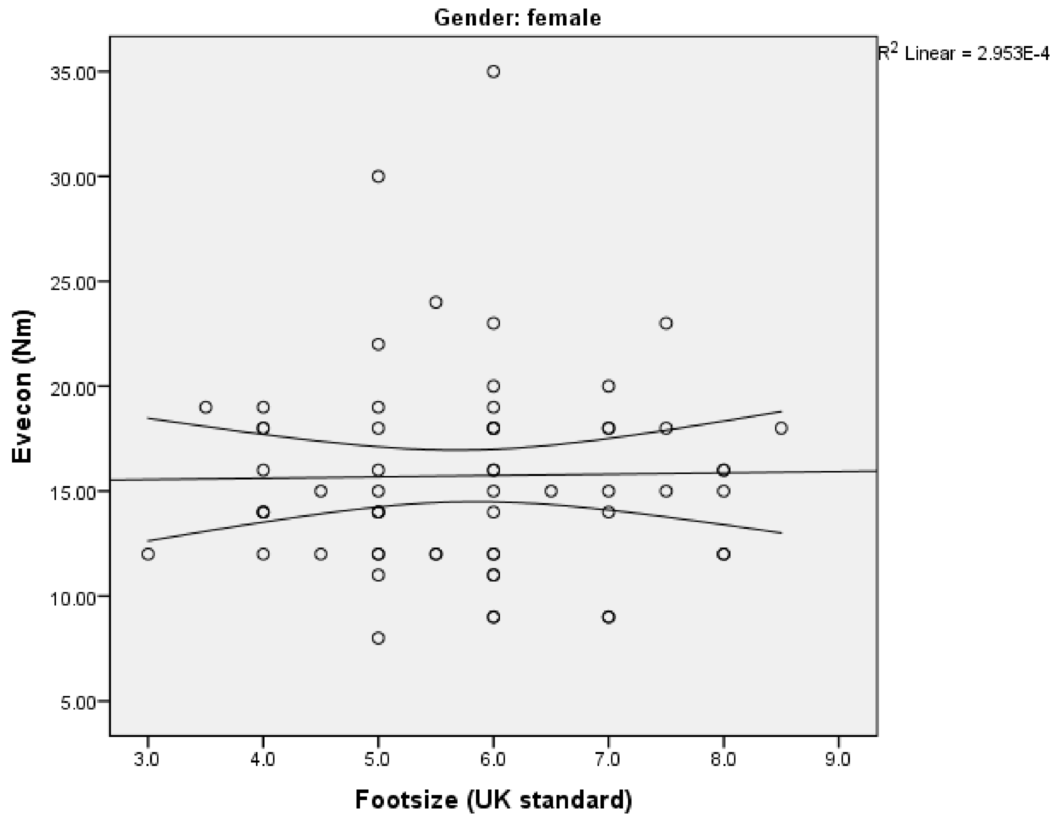
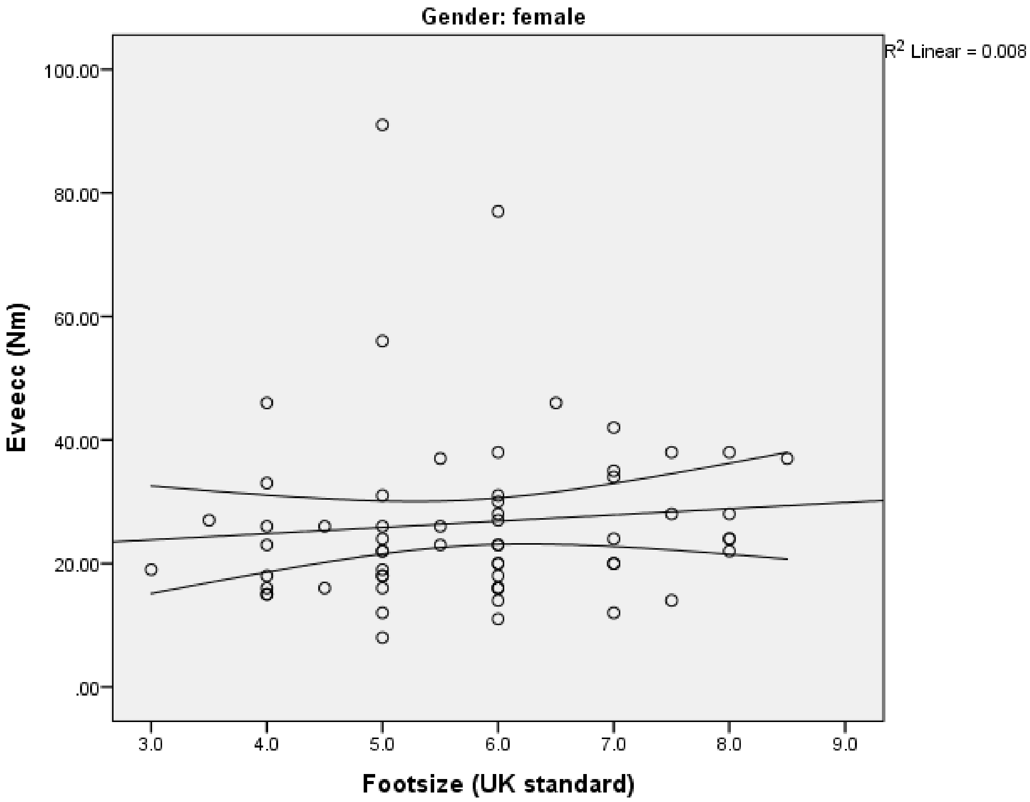


Figure 8-33 Scatterplots demonstrating the relationship in females between shoe size and concentric inv and eve. The lines represent a linear line of best fit and 95% Inv = inversion, eve = eversion; con = concentric;



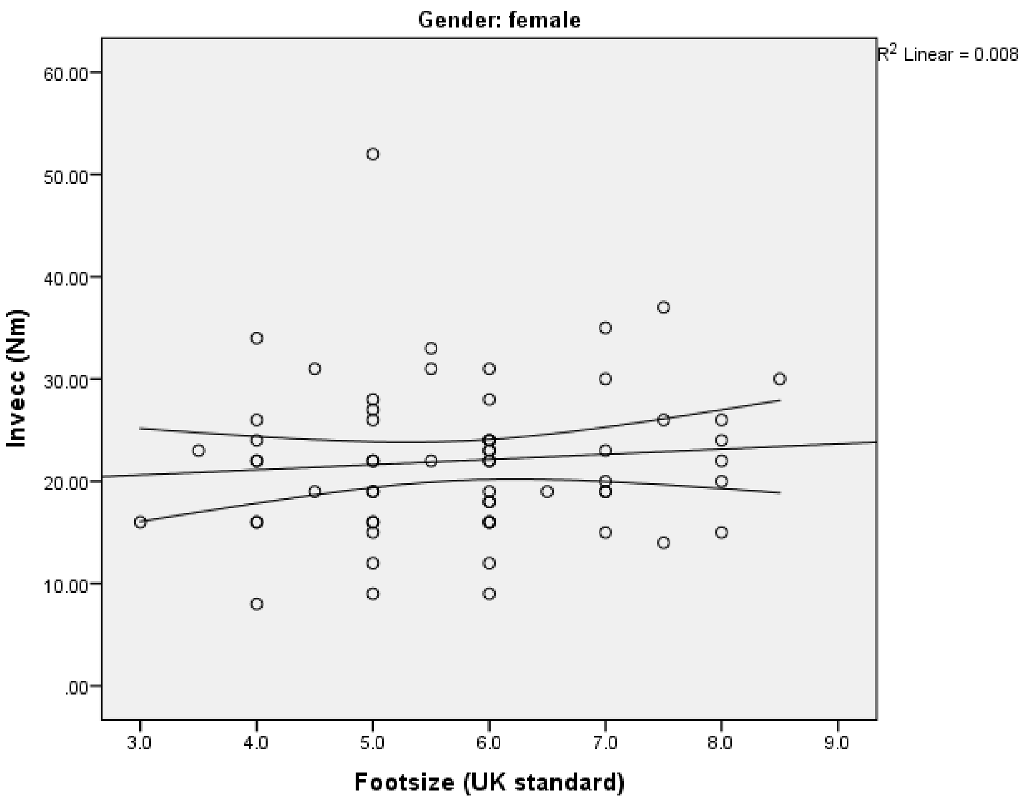
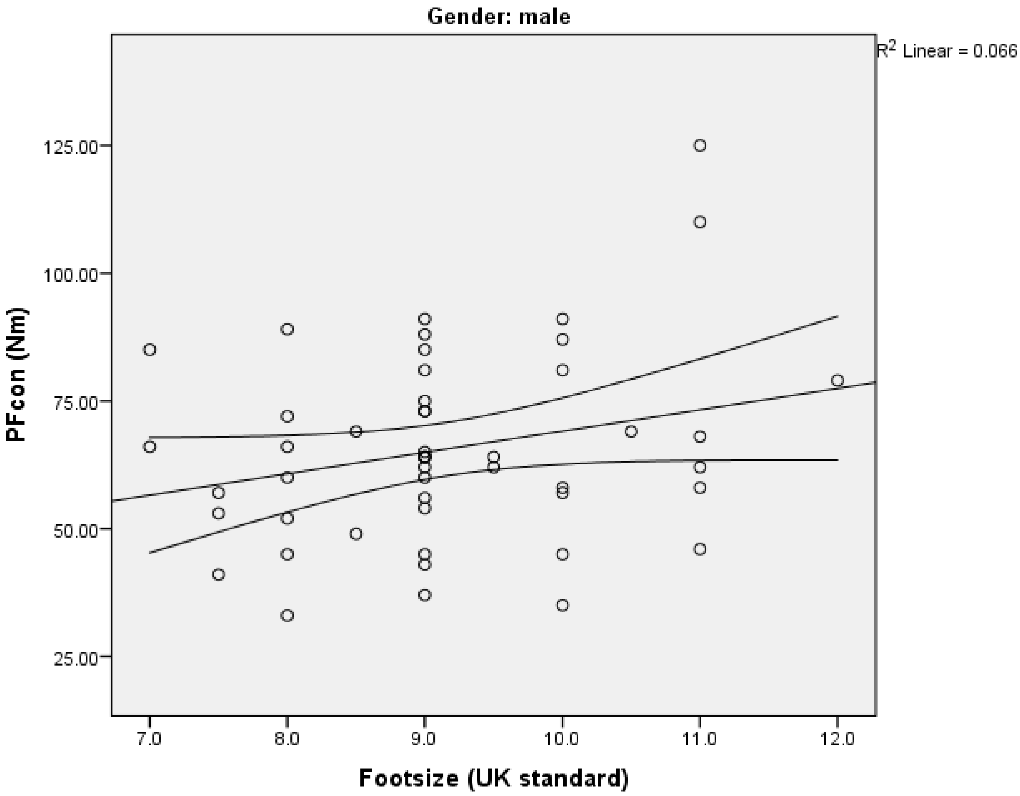


Figure 8-34 Scatterplots demonstrating the relationship in females between shoe size and eccentric inv and eve. The lines represent a linear line of best fit and 95% CI. Inv = inversion; eve = eversion; ecc = eccentric



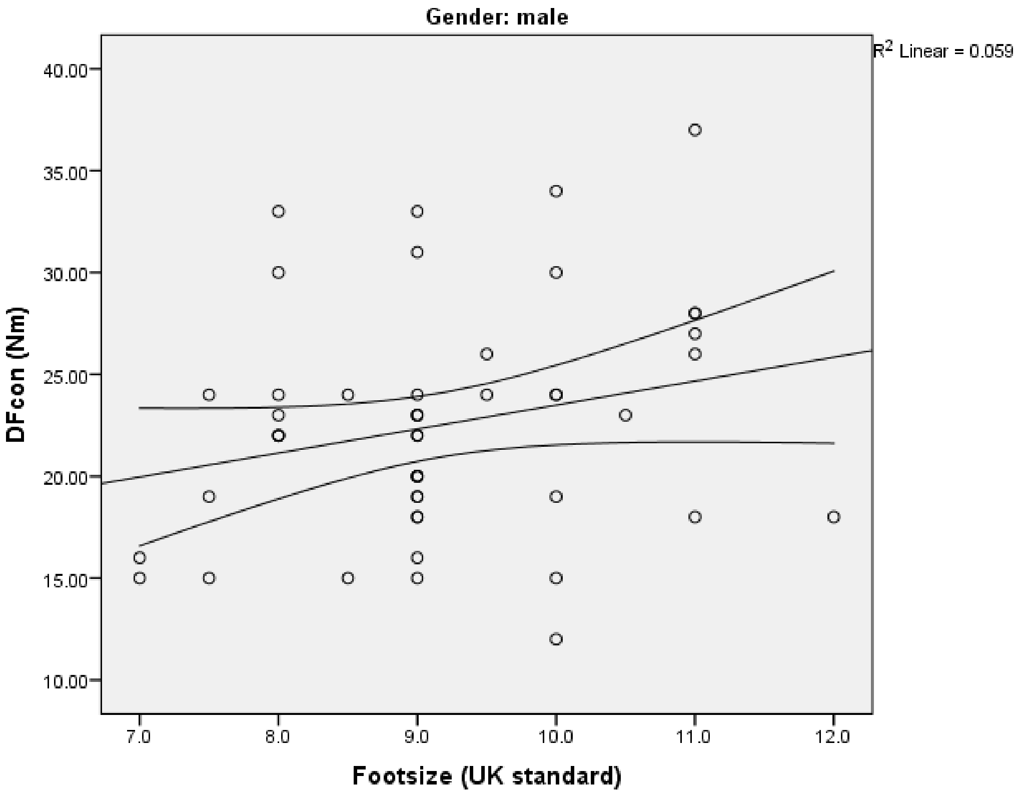
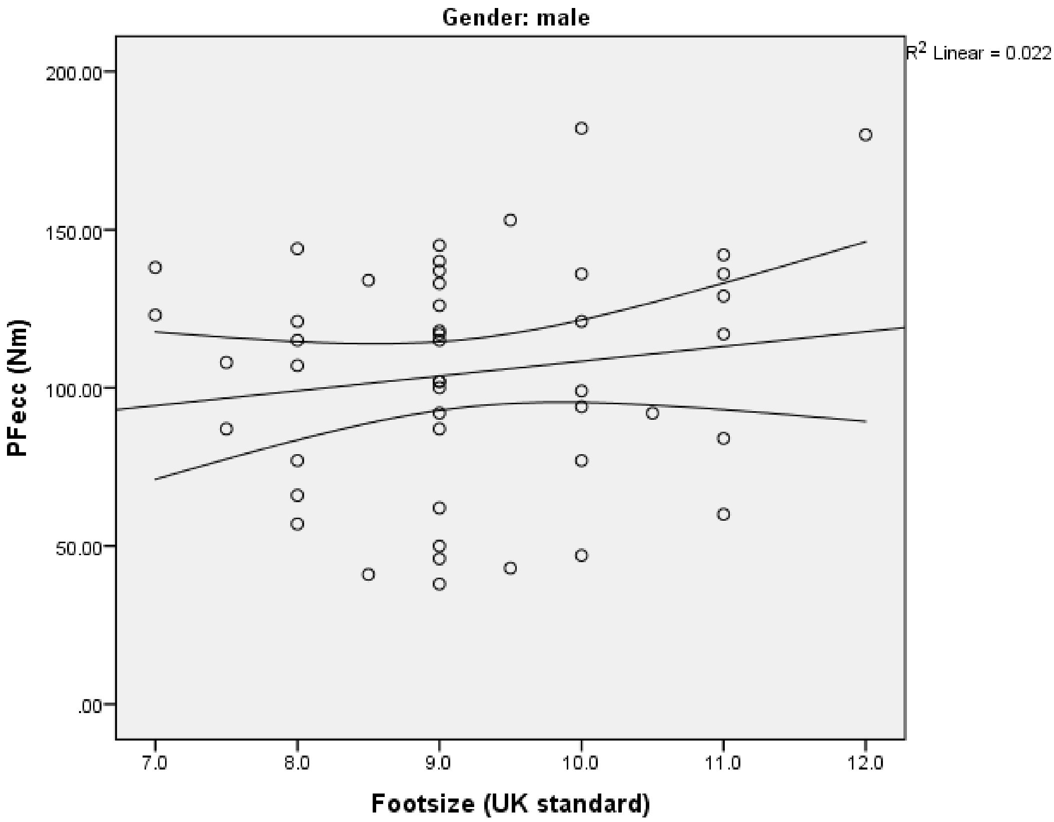


Figure 8-35 Scatterplots demonstrating the relationship in males between shoe size and concentric PF and DF. The lines represent a linear line of best fit and 95% CI. PF = plantar flexion; DF = dorsiflexion; con = concentric.



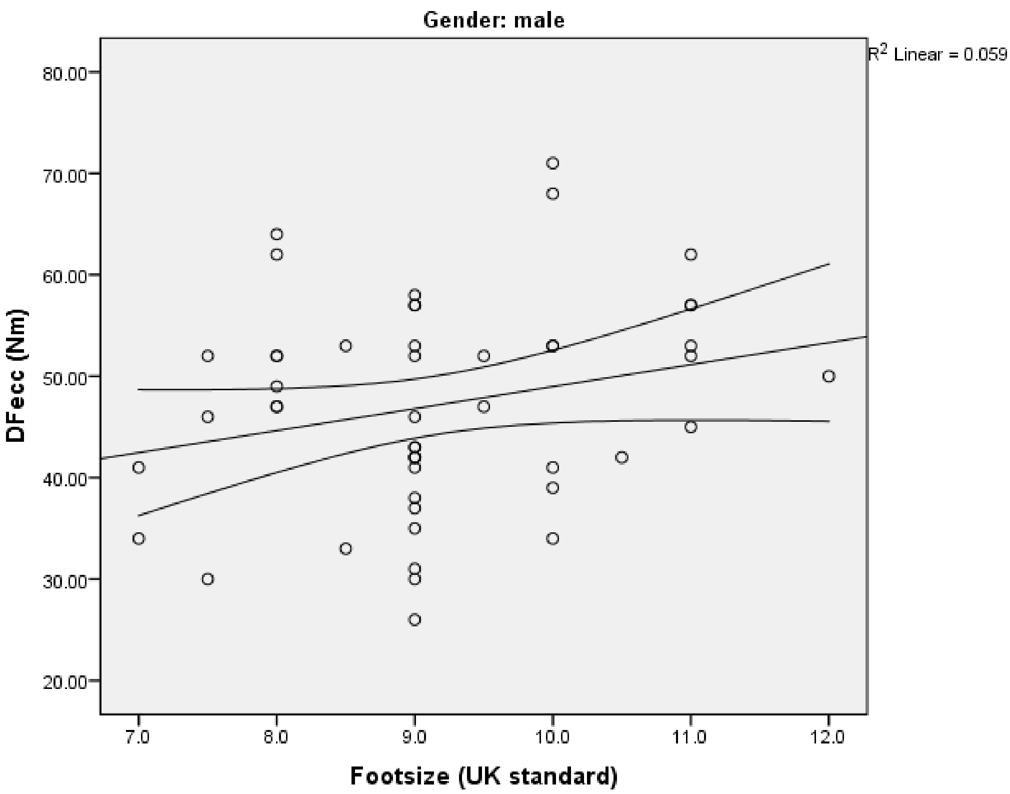
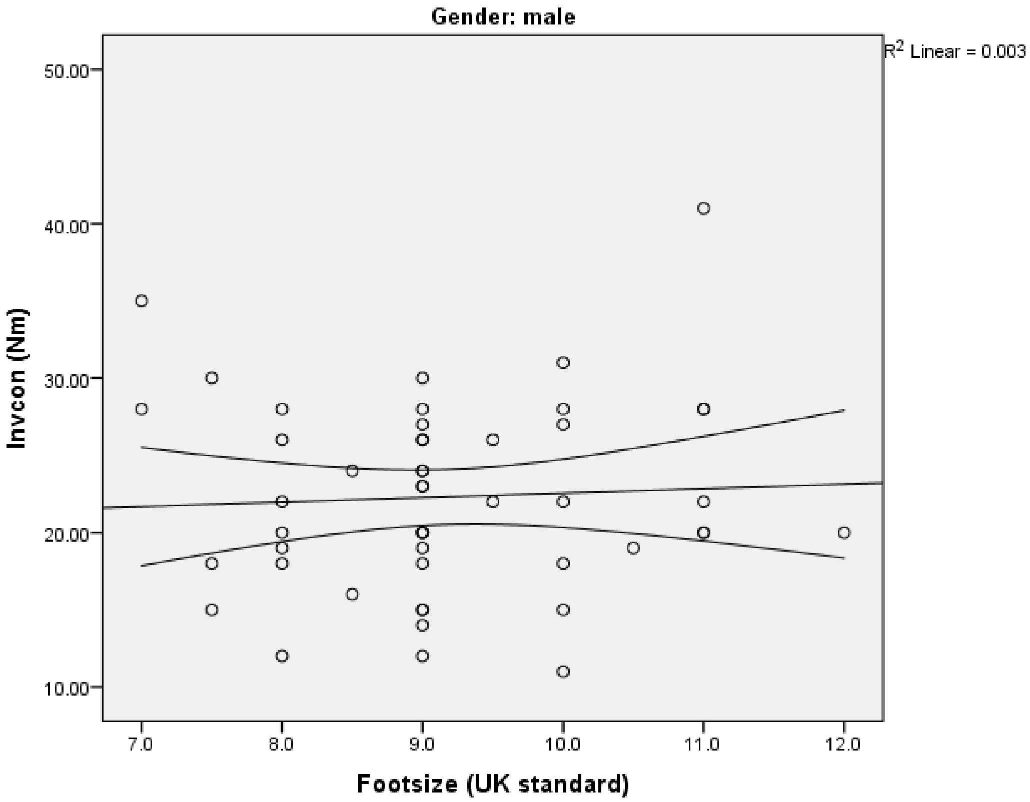


Figure 8-36 Scatterplots demonstrating the relationship in males between shoe size and eccentric PF and DF. The lines represent a linear line of best fit and 95% CI. PF = plantar flexion; DF = dorsiflexion; ecc = eccentric



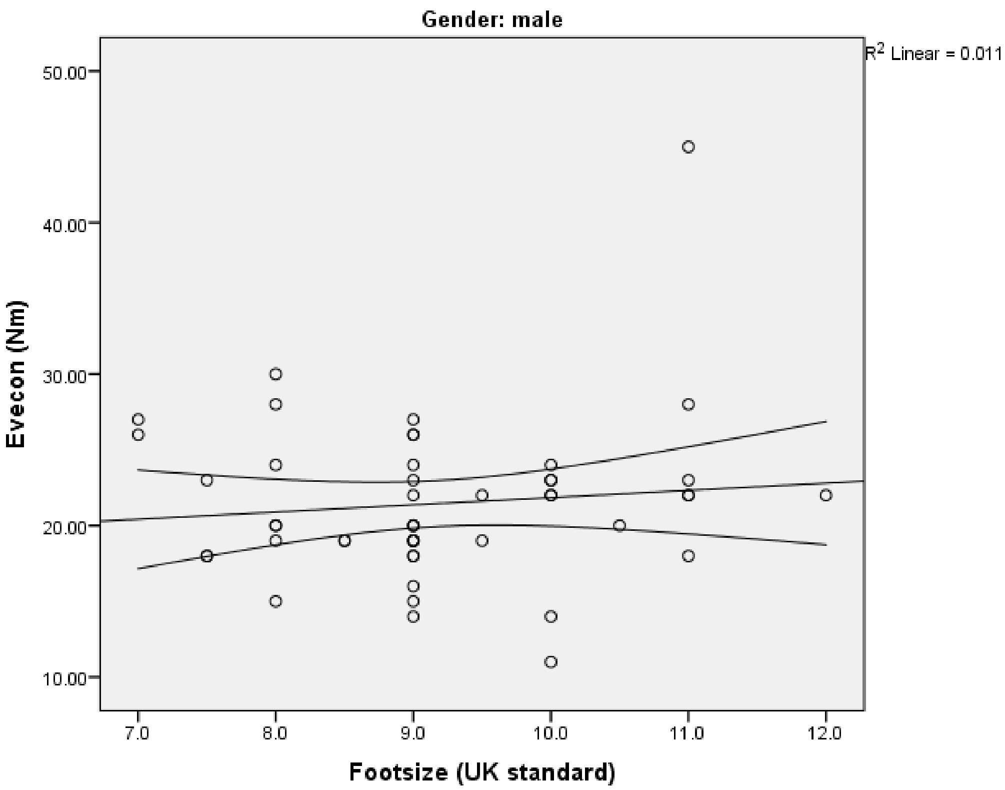
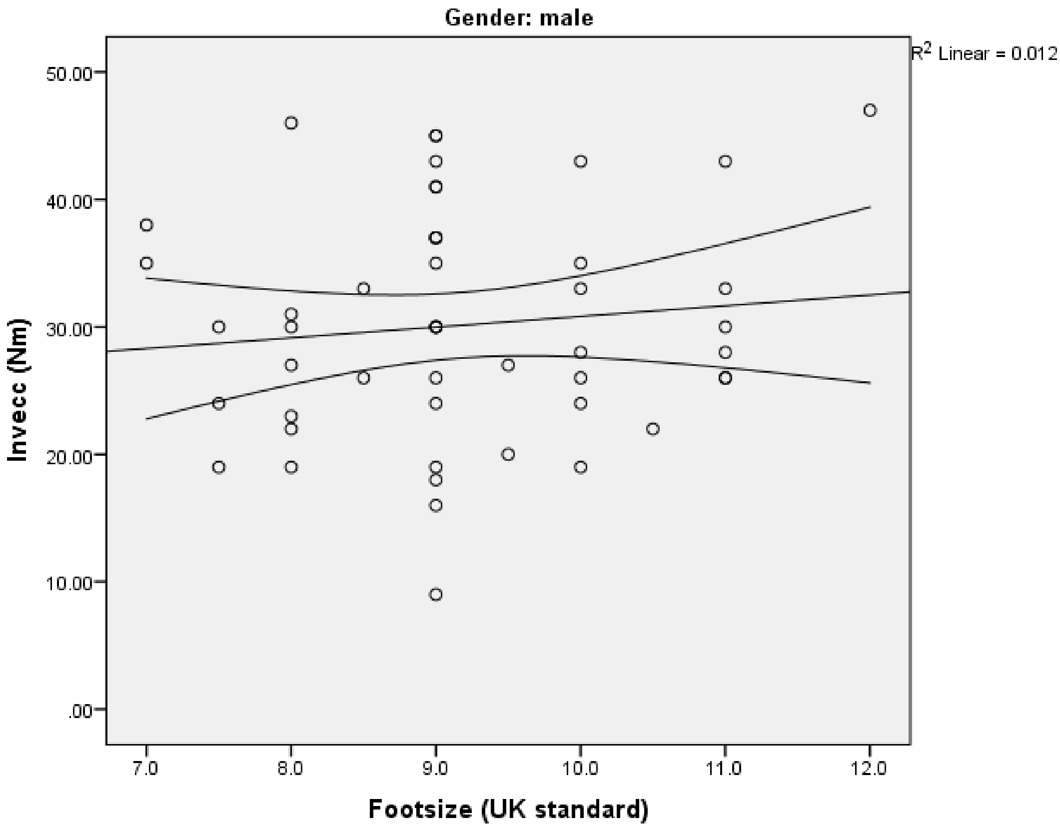


Figure 8-37 Scatterplots demonstrating the relationship in males between shoe size and concentric inv and eve. The lines represent a linear line of best fit and 95% Inv = inversion, eve = eversion; con = concentric;



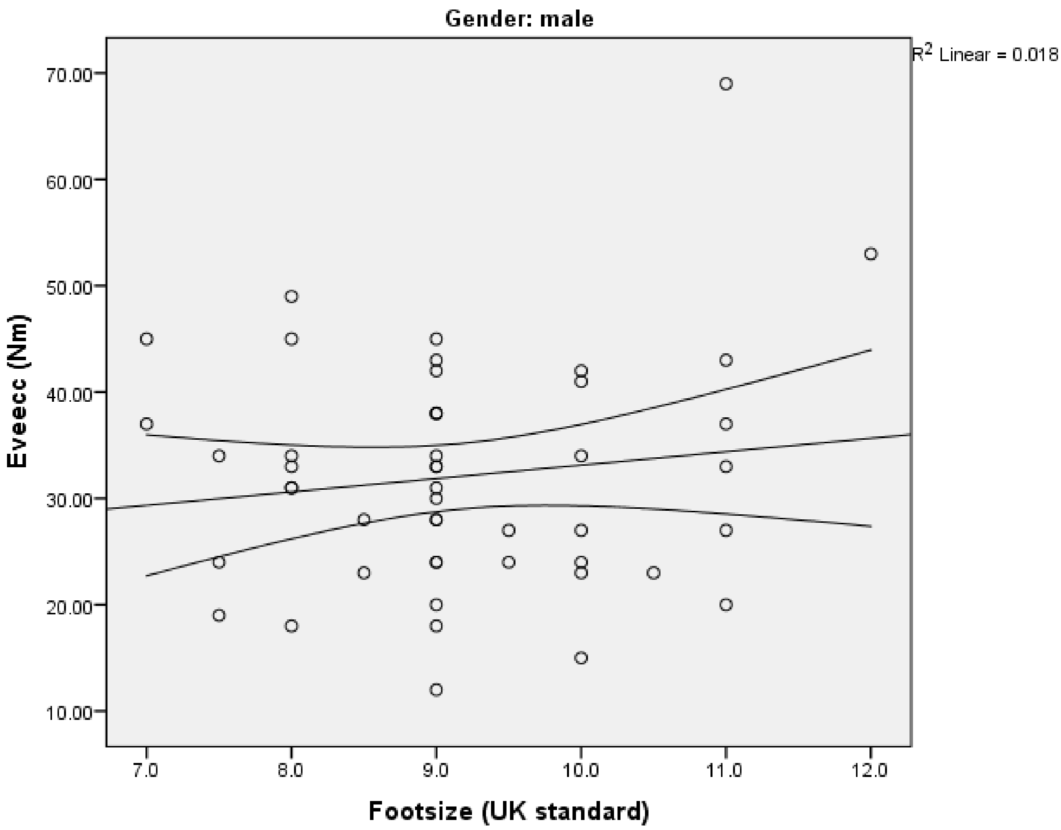


Figure 8-38 Scatterplots demonstrating the relationship in males between shoe size and eccentric inv and eve. The lines represent a linear line of best fit and 95% CI. Inv = inversion; eve = eversion; ecc = eccentric

8.3.4 Linear regression analysis

The results from the previous section demonstrate that the independent variables of gender, age, mass, height and shoe size interact with each other and with one or more measures of AMS. These relationships will be investigated in here using further statistical analysis.

8.3.4.1 Normality, collinearity and homoscedasticity

As part of the stepwise linear regression analysis the collected data was tested for robustness by examining the normality, collinearity and homoscedasticity of the data as explained in section 4.5.2. The normality of the data was tested using scatter plots that plotted obtained against predicted values. Data points greater than 3.3 or less than -3.3 were considered outliers. The scatter plots shown in Appendix 27 indicate that no outliers were found in Eccentric PF, concentric and eccentric DF and concentric inv. One outlier was found in concentric PF (participant number 154), one outlier was found in eccentric eve (participant number 80). Two outliers were found in concentric eve (participant numbers 113 and 154) and four outliers were found in eccentric eve (participant numbers 20, 80, 113 and 154). Where outliers were removed the analysis was repeated and further scatter plots were generated and if further outliers were detected these were removed and the analysis was repeated again. The results of the repeated analyses are shown in Appendix 27.

A collinearity test was performed on the collected data. Where outlying participants were removed it was necessary to perform separate collinearity tests. All of the relevant independent variables (gender, age, height, mass and shoe size) were within acceptable limits in terms of the Pearson's r value, tolerance value and VIF. Thus, it was accepted that each of the variables contributed to the variation in AMS independently. See Appendix 28 for a description of the actual values for each of the eight movements.

The homoscedasticity of the data was assessed by using a normal P-P probability plot of the regression standardised residual, the results of this are shown in Appendix 29. As all of the plots follow and approximate diagonal line through the centre of the graph homoscedasticity was accepted for all of the measures of AMS.

8.3.4.2 Linear regression analysis

A stepwise linear regression analysis, as described in Chapter 4, was performed on the reference data set (n=100) for each of the eight AMS measures: concentric and eccentric PF, DF, inv and eve. This analysis determined the level of influence of five independent variables (height, mass, age, gender and shoe size) on the dependent variable AMS. The significant predictors of AMS and their weighting, produced using the unstandardised co-efficients resulting from the stepwise linear regression analysis, are shown in Table 8-11 and Table 8-12. The R^2 change and fit statistics for alternate models and the excluded variables are described in Appendix 31.

Table 8-11

A summary of the un-standardised and standardised co-efficients used in the AMS reference equations

Model		Unstandardized Coefficients		95.0% Confidence Interval for B		Standardized Coefficients	95.0% Confidence Interval for Beta			
		B	Std. Error	Lower Bound	Upper Bound	Beta	Lower Bound	Upper Bound	t	Sig.
PFcon	(Constant)	-70.39	39.99	-149.77	8.98				-1.76	0.08
	Gender	14.12	3.74	6.70	21.53	0.39	0.21	0.59	3.78	0.00
	Height	0.68	0.24	0.20	1.16	0.29	0.06	0.46	2.82	0.01
DFcon	(Constant)	6.74	2.20	2.37	11.10				3.06	0.00
	Gender	6.06	0.88	4.30	7.81	0.50	0.35	0.64	6.85	0.00
	Mass	0.15	0.03	0.10	0.21	0.42	0.28	0.57	5.75	0.00
	Age	-0.08	0.03	-0.14	-0.01	-0.14	-0.26	-0.01	-2.26	0.03
PFecc	(Constant)	-153.21	88.44	-328.90	22.49				-1.73	0.09
	Height	1.35	0.53	0.29	2.41	0.30	0.07	0.56	2.53	0.01
	Gender	19.29	8.34	2.72	35.85	0.27	0.03	0.50	2.31	0.02
DFecc	(Constant)	-34.44	17.88	-69.94	1.06				-1.93	0.06
	Gender	9.42	1.68	6.09	12.75	0.40	0.24	0.52	5.61	0.00
	Mass	0.30	0.05	0.21	0.39	0.42	0.28	0.54	6.31	0.00
	Height	0.27	0.11	0.04	0.50	0.18	0.03	0.34	2.37	0.02

Note PF = plantar flexion; DF = dorsiflexion; inv = inversion; eve = eversion; con = concentric; ecc = eccentric

Table 8-12

A summary of the un-standardised and standardised co-efficients used in the AMS reference equations

Model		Unstandardized Coefficients		95.0% Confidence Interval for B		Standardized Coefficients	95.0% Confidence Interval for Beta		t	Sig.
		B	Std. Error	Lower Bound	Upper Bound	Beta	Lower Bound	Upper Bound		
Invcon	(Constant)	9.41	2.91	3.64	15.17				3.24	0.00
	Mass	0.11	0.04	0.03	0.19	0.27	0.07	0.49	2.61	0.01
	Gender	3.51	1.39	0.76	6.26	0.26	0.04	0.46	2.53	0.01
Evecon	(Constant)	18.33	1.45	15.45	21.21				12.65	0.00
	Gender	5.21	0.84	3.55	6.88	0.54	0.36	0.64	6.21	0.00
	Age	-0.07	0.04	-0.15	0.00	-0.17	-0.28	0.00	-2.01	0.05
Invecc	(Constant)	12.24	3.66	4.98	19.50				3.35	0.00
	Gender	5.34	1.75	1.86	8.82	0.31	0.11	0.49	3.05	0.00
	Mass	0.15	0.05	0.04	0.25	0.28	0.08	0.46	2.76	0.01
Eveecc	(Constant)	10.16	4.21	1.81	18.51				2.42	0.02
	Mass	0.24	0.06	0.13	0.35	0.40	0.16	0.43	4.26	0.00

Note PF = plantar flexion; DF = dorsiflexion; inv = inversion; eve = eversion; con = concentric; ecc = eccentric

Using concentric PF as an example only two of the independent variables were found to be significant: gender and height. Thus, the predictive equation for concentric PF is:

$$\text{Predicted concentric PF} = c + (B_1 \times \text{gender}) + (B_4 \times \text{height})$$
$$= -70.35 + (14.12 \times \text{gender}) + (0.68 \times \text{height})$$

Where gender male=1 and female=0 and height is in cm.

The following are predictive equations for each of the eight measures of AMS:
Concentric PF = -70.35 + (14.12 x gender) + (0.68 x height)
Eccentric PF = -153.21 + (19.29 x Gender) + (1.35 x Height)
Concentric DF = 6.74 + (6.06 x Gender) + (-0.08 x Age) + (0.15 x Mass)
Eccentric DF = -34.44 + (9.42 x Gender) + (0.30 x Mass) + (0.27 x Height)
Concentric inv = 9.41 + (3.51 x Gender) + (0.11 x Mass)
Eccentric inv = 12.24 + (5.34 x Gender) + (0.15 x Mass)
Concentric eve = 18.33 + (5.21 x Gender) + (-0.07 x Age)
Eccentric eve = 10.16 + (0.24 x Mass)

Gender: Male=1, female =0; Age is measured in years; Mass is measured in kilograms; Height is measured in centimetres; Shoe size is UK standard.

8.3.4.2 Strength of the models

Once the relevant independent variables had been identified and predictive model produced an ANOVA test was performed on each of the eight models to ascertain the model's strength. See Appendix 30 for the full ANOVA table for each of the measures. The significance of the models for predicting AMS was $P < 0.001$ for all eight models suggesting they are all strong models for predicting AMS.

8.3.4.3 Models predictive value

The R Square value produced by the linear regression analysis indicates the amount of variation in the dependent variable explained by the independent variables. The adjusted R Square value indicates the predictive value of the independent variables in the general population. These adjusted R squared values for each of the models are shown in Table 8-13.

Table 8-13

The adjusted R square values for each of the eight AMS prediction models.

		Adjusted R squared value
PF	Concentric	0.39
	Eccentric	0.27
DF	Concentric	0.63
	Eccentric	0.73
Inv	Concentric	0.22
	Eccentric	0.26
Eve	Concentric	0.30
	Eccentric	0.16

Note: PF = plantar flexion; DF = dorsiflexion; inv = inversion; eve = eversion

8.3.5 Testing the prediction equation.

The eight prediction equations detailed in section 8.3.4.2 were applied to the data from the reference group (n=100). The predicted range was calculated as ± RSD after Harbo et al. (2011). These ranges were compared to the average AMS values from the validation group (n=11). The results shown in
Table 8-14 indicates that all eight measured values were within the predicted range.

Table 8-14

The predicted values and predicted range for AMS, generated using the reference population compared to the actual AMS values generated from the validation population.

		Predicted	Predicted range minimum	Predicted range maximum	Actual
PF	Concentric	48.46	37.26	59.66	56.60
	Eccentric	79.86	61.46	98.26	94.13
DF	Concentric	16.87	12.07	21.67	15.63
	Eccentric	34.75	24.75	44.75	34.00
Inv	Concentric	18.30	15.20	21.40	19.18
	Eccentric	24.63	20.43	28.83	24.18
Eve	Concentric	17.51	14.81	20.21	17.27
	Eccentric	26.53	22.63	30.43	25.00

Note: PF = plantar flexion; DF = dorsiflexion; inv = inversion; eve = eversion
All torque measurements are in Nm

A paired samples t-test test was performed comparing the predicted and actual AMS values in the validation set population. The results of this are shown in Table 8-15.

Table 8-15

Results of a paired samples t-test comparing predicted and actual AMS values in the validation set population.

	PFcon	DFcon	PFecc	DFecc	Invcon	Evecon	Invecc	Eveecc
Mean difference	7.24	-1.25	11.61	-0.76	0.87	-0.25	-0.09	-1.53
Significance (2-tailed)	0.20	0.25	0.31	0.81	0.64	0.82	0.97	0.66

Note: PF = plantar flexion; DF = dorsiflexion; inv = inversion; eve = eversion; con = concentric; ecc = eccentric

The data shown in Table 8-15 indicates that there is no significant difference between the predicted and measured AMS values in concentric and eccentric PF, DF, inv and eve.

8.4 Discussion

8.4.1 AMS and population demographics

8.4.1.1 Gender

It has been established that average male AMS is greater than average female AMS in terms of concentric PF and DF (Danneskiold-Samsøe et al., 2009; Harbo et al., 2011) and concentric inv and eve (van Cingel et al., 2009). Analysis of the strength and gender data presented in the previous chapter supports this assertion and adds evidence indicating this is also true for eccentric PF and DF, and, inv and eve which, to the author's knowledge as of August 2015, is absent from current literature. However, it is not being male that makes an individual physically stronger but the attributes of a typical male. For example larger muscle mass or longer limbs associated with the average male may increase the amount of torque produced around the ankle. The effect of mass and height as well as age will be discussed further here.

8.4.1.2 Age

The Pearson's correlation test described in Appendix 12 indicates no correlation between age and strength in any of the eight AMS measures. As previous research analysed their data in single gender groups (Danneskiold-Samsøe et al., 2009; Harbo et al., 2011; Lategan, 2011) the data here was also split into single gender groups and analysed again. Table 8-7 indicates that there was no significant relationship between age and AMS in males but there was a weak correlation between age and concentric PF and DF and concentric eve in females. Comparison of this finding to the published literature is difficult. For example the ankle specific data presented by Harbo et al. (2011) is not clear in relation to age. Their results do seem to suggest that concentric PF and DF AMS in males and females are consistent up to the 50-59 year age group after which strength falls, however, it is not stated whether this decline is significant or not. Danneskiold-Samsøe et al. (2009) concluded that overall male strength declined from the age of 20 and female strength from the age of 40. However, if just the ankle is considered their data suggests that concentric PF declined from the age of 60-69 in both males and females and concentric DF declined from age 50-59 in males and 70-79 in females. This conclusion is derived from a multivariate regression model which differs from the between groups independent samples t-test performed here. Furthermore, these higher age ranges are beyond the scope of the research presented here; however, the age matched data presented by Danneskiold-Samsøe et al. (2009) is consistent with the data presented here. Danneskiold-Samsøe et al. (2009) and Harbo et al. (2011) present age related AMS data, however, they did not perform the statistical analysis to indicate whether or not the fall in AMS with age is significant.

To the author's knowledge, as of August 2015, the relationship between age and eccentric PF, DF, and concentric and eccentric inv and eve had not been published previously. This information could allow clinicians to tailor training and rehabilitation programmes; however, it should be considered alongside other factors such as mass, height and shoe size.

8.4.1.3 Mass

The results of a Pearson's correlation indicated a significant correlation between concentric and eccentric DF in both males and females and an increase in mass. Ass mass increased, so did concentric and eccentric DF strength. This demonstrates that the interaction of the anthropometric measures and AMS varies between movements as well as with mass.

The relationship between AMS and mass may also linked to age. In the data presented by Danneskiold-Samsøe et al. (2009) the average mass of the female participants increased from 62.8kg (20-29 years) to 69.6kg (50-59years). There was no decrease in AMS between these two groups despite the increase in age. It could be argued that any decline in strength with age is offset by the need for extra strength to support extra mass. Thus, if mass reduces with increasing age, strength is reduced but if mass does not decrease with age then strength will not decrease. This theory is supported by research from Janssen et al. (2000) and Newman et al. (2003). Janssen et al. (2000) found a significant correlation between age and muscle mass in males and females. They demonstrated that skeletal muscle mass was not related to age in either males or females below the age of 44yrs, however, in the 45+yrs group skeletal muscle mass significantly declined with age in both males and females. In both males and females the greater decline with age was in the lower body. In an examination of data from 2623 males and females Newman et al. (2003) concluded lower strength in older age was a result of loss of muscle mass. Thus, if mass loss is related to loss of muscle mass which in turn is related to age, then strength will decline with age as long as muscle mass, and so mass, also declines.

Evidence highlighted here suggests changes in mass can be a contributing factor to changes in some measures of AMS peak torque. However, as this is not demonstrated in all eight measures of ankle peak torque it can be concluded that factors other than mass also contribute to the difference between genders in some of the ankle movements. This was highlighted when comparing peak torque between genders in the same mass category. AMS of males and females in the 60-79.9kg were compared and the results showed a significant difference between genders in seven of the eight measures (all apart from eccentric eve). In the 80-99.9kg range there was a significant difference between genders in four of the eight AMS measures (concentric and eccentric DF and eccentric inv and eve). One explanation for the discrepancy in differences between genders between mass categories may be the differences in muscle to fat ratio. In the 60-79.9kg mass range it is logical to assume a larger proportion of the males' bodies are made up of muscle compared to the 80-99.9kg mass category whereas in the 60-79.9kg mass range females naturally have increased fat compared to males. As previously discussed larger muscle mass correlates with greater peak torque, thus, in the 60-79.9kg mass range males are stronger than females.

In the 80-99.9kg mass category the extra mass in the males may be due to fat, thus, the fat to muscle ratio would be closer to that of the females. The difference in AMS between genders due to mass varies from movement to movement. Where there was a smaller difference in AMS in the lighter mass category, for example in con PF, increasing the body mass reduces the difference to non-significant levels. Where there is a greater difference in AMS the effect size of a mass increase is not sufficient to make the differences between genders non-significant. This conclusion is supported by the results of the regression analysis described later in the chapter. These results indicate that mass is only a significant predictor of concentric and eccentric DF and eccentric inv and eve, the same measurements which were significantly different between genders in both mass categories.

Based on the results here and evidence from the literature it can be concluded that mass does contribute to some aspects of AMS. Determining the muscle to fat ratio of the participants would give insight into the cause of this relationship.

8.4.1.4 Height

Height may affect generated peak torque as longer limb length means there is a greater amount of muscle and a longer lever arm. If limb length were to affect AMS due to changes in the lever arm at the ankle then this would be demonstrated in concentric and eccentric PF and DF. Due to the axis of motion when inverting and everting, the lever arm would be increased by making the foot significantly wider which is not necessarily related to height. The data presented here indicates that there is a significant relationship between concentric and eccentric DF and height in males and concentric and eccentric PF and DF in females.

When differences in AMS between genders were analysed controlling for height the results were varied. Gender differences in AMS were compared in the 165.0-169.9cm, 170.0-174.9cm and 175.0-179.9cm groups. Differences between genders were demonstrated in eccentric DF and concentric eve (165.0-169.9cm group), concentric PF and DF, eccentric DF and inv, and concentric eve (170.0-179.9 cm group) and concentric and eccentric DF and concentric inv and eve (175.0-179.9cm group). This suggests that height contributes to the differences in AMS between genders in certain movements but not in others.

The data presented here suggests there is some relationship between height and AMS, however, research in the literature is not conclusive. Both Danneskiold-Samsøe et al. (2009) and Harbo et al. (2011) measured ankle strength and height, however, neither performed a direct analysis to determine if there was a significant relationship between the two and Danneskiold-Samsøe et al. (2009) concluded that there was no relationship between height and strength whereas Harbo et al. (2011) concluded that there was. Harbo et al. (2011)

measured eighteen different muscle actions in a group of males and a group of females generating thirty-six models of muscle strength. They found that in thirteen of these thirty-six models there was a significant relationship between height and strength with strength increasing with increased height in each model. They did not, however, state which thirteen models had a significant relationship so it was not possible to determine if they found a relationship between ankle strength and height. Similarly, Danneskiold-Samsøe et al. (2009) did not state their findings regarding the relationship between AMS and height, however, they did state that there was no correlation between 'lower limb strength' and height. This measure of strength was a composite of hip, knee and ankle strength so it is not possible to determine the specific relationship between AMS and height based on the data they published.

Biomechanically greater height will give a longer lever arm and larger muscles and so in theory greater PF and DF strength. This is, to a certain extent, supported by the findings presented here, however, other factors that also influence AMS may mask the lever arm effect.

8.4.1.5 Shoe size

Shoe size was measured to determine if the changes in AMS related to height were because of foot size alone or if other factors were involved. The Pearson's correlation results indicate that in the male group there is no significant correlation between any of the measures of AMS and shoe size. However, there was a tendency towards a significant correlation in concentric PF (P = 0.07) and DF (P = 0.09) as well as eccentric DF (P = 0.09). The female data showed a significant correlation between concentric and eccentric DF and shoe size, there was also a tendency towards a significant correlation between concentric PF (P = 0.06) and eccentric (P = 0.06) PF and shoe size. The range of values for the measures of AMS is large, particularly in terms of eccentric PF, suggesting other factors may have a greater influence on the amount of torque produced.

As with the height data, no correlation was indicated between any of the inv or eve measurements and shoe size in either the male or female groups. This is consistent with the argument put forward previously that biomechanically there is no reason that increasing the length of the foot would alter the amount of torque produced about the axis of motion of an inv and eve movement.

These results give some support to the theory that increasing foot size would increase the amount of torque that can be produced as the lever arm around the PF/DF axis of movement ankle is being increased. The results of the analysis of the relationship between height and AMS showed several statistically significant correlations in terms of certain measures of AMS. The results of the analysis of the shoe size AMS relationship produced fewer statistically significant results suggesting that there is a different relationship between height and AMS compared to shoe size and AMS. Therefore, it must be concluded that while the size of foot contributes to the relationship between height and concentric and eccentric PF and DF AMS there must be another factor involved as well.

8.5.1 Mean average reference value

Comparison of the results presented here to those published in the literature support the assertion that variation in both equipment and population demographics affect peak torque outcome measures.

Table 8-16

A comparison of the mean average peak torque scores for AMS.

		Data from this thesis	Lategan (2011)	Harbo et al. (2011)	van Cingel et al. (2009)
PF	Con	52.3Nm	130.0Nm	94.1Nm	-
	Ecc	85.5Nm	-	-	-
DF	Con	18.1Nm	36.2Nm	27.2Nm	-
	Ecc	37.8Nm	-	-	-
Inv	Con	19.1Nm	-	-	24.2Nm
	Ecc	25.8Nm	-	-	-
Eve	Con	18.4Nm	-	-	20.8Nm
	Ecc	29.5Nm	-	-	-

Table 8-16 demonstrates the differences between published figures for AMS peak torque and the figures described in this thesis. It is likely that the difference in these results is due to the different protocols used in the experiments. For example Lategan (2011) found PF and DF peak torque to be considerable higher, however, they used a speed of 30°/s compared to 60°/s used here. Isokinetic movement at slower speeds will produce greater maximal peak torque as previously discussed. Harbo et al. (2011) also tested concentric PF and DF at 60°/s, however, they were testing on a Biodex System 3 PRO rather than a Cybex Norm isokinetic dynamometer. It has been established that peat torque results produced vary between dynamometers as discussed in Chapter 1. This conclusion supports the notion that reference values should be machine specific. There was greater comparability between the data produced by van Cingel et al. (2009) and the data produced here, possibly due to both experiments use of the Cybex Norm dynamometer and testing at 120°/s. The slightly higher results produced by van Cingel et al. (2009) may be due to variations between the populations being tested. For example the population used by van Cingel et al. (2009) had fewer females, a lower average age and a greater average height. All of these variables may affect AMS and will be discussed in detail later in this chapter. From the results presented here it is clear that the previous research is supported in concluding that variations in the protocol for measuring AMS will alter the outcome measures.

Table 8-16 also demonstrates the current lack of reference values for AMS as Lategan (2011), Harbo et al. (2011) and Danneskiold-Samsøe et al. (2009) each only measured two of the eight measures of AMS. Furthermore, the reference values produced by Lategan (2011) were produced by measuring concentric PF and DF in males aged 19±1.86 years, as such they are only relevant to those two movements in similar populations and can make no comment on eccentric, inv or eve or any movement in older people or females. A search of the literature suggested that nine papers have cited Lategan (2011), however, none have used the reference values. The reference values presented by Danneskiold-Samsøe et al. (2009) are also limited to concentric PF and DF, however, the data presented in their paper did account for age and gender. The paper also included a link to a website (www.parkerinst.dk), where text files pertaining to reference data for muscle strength that also accounted for height and mass could be downloaded, unfortunately these data sets are no longer available.

8.5.2 Validating reference values

The data presented here supports the conclusion that mean average reference values may not be appropriate. Comparison of Table 8-4 and Table 8-6 indicated that five of the eight AMS reference values, each produced by a mean average of 100 individuals in the reference group, could not be validated by comparing to average AMS values from a further eleven individuals in the validation group. One reason for the inability to validate these reference values could be the difference in anthropometric demographics between the population the reference values were derived from, and the population used to validate the reference values. 45% of the reference group were males compared to 36% of the validation group; if males are stronger than females then it would be expected that a population with a larger proportion of males in would be stronger. This imbalance is reflected in the other anthropometric measures in the height, mass and shoe size were also greater in the reference set. The test-retest reliability experiment described in Chapter 4 indicated that the protocol used here was reliable for all eight measures of AMS, this suggests that problem with validating the reference values lies with the differences in the population rather than a problem with the measurement.

Table 8-4 and Table 8-6 indicate that the validation group AMS in concentric and eccentric DF as well as eccentric eve was indeed lower than the reference value. It could be concluded that this was due to the discrepancy in numbers of males and females between the two groups. However, both concentric and eccentric PF were greater in the validation group suggesting gender is not the only determinant of AMS. The following sections will discuss the results in terms of each of the measured anthropometric variables. Understanding the nature of the relationship between these variables and AMS will indicate their appropriateness for inclusion when producing reference values.

8.5.3 Predictive equations

To overcome the problems associated with the interactions of the anthropometric variables discussed in the previous sections and their effect on AMS, a linear regression analysis was performed using gender, age, mass, height, and shoe size as independent variables. By using this method of statistical analysis the individual effects of each of the independent variables on the dependent variable (i.e. AMS) can be assessed and those variables considered significant predictors can be identified.

8.5.3.1 Robustness of the data

Prior to the linear regression analysis the robustness of the data was assessed. As discussed in the previous sections, correlations were demonstrated between certain independent variables, for example between height and shoe size. In this example it is possible that the only reason shoe size apparently affects AMS is because shoe size is related to height which affects AMS. However, the collinearity analysis (Appendix 28) indicated that each of the independent variables contributed to the variability of AMS independently. Analysis of the normality plots (Appendix 27) ndicated that there were a number of outliers in some of the movements. Once these had been removed the obtained and predicted scores for AMS were normally distributed. The homoscedasticity analysis (Appendix 29) indicated that any variation in the relationships between the dependent and independent variables were the same across all measurements. It is not possible to compare the robustness of the data here to that of Harbo et al. (2011) who also performed a linear regression analysis, as they did not state the results of any collinearity, normality or homoscedasticity analysis. This is also the case with the data produced by Danneskiold-Samsøe et al. (2009). Whilst they did not perform a regression analysis, the reference values put forward would have greater credibility if the normality of their data set were discussed.

8.5.3.2 Linear regression analysis

The stepwise linear regression analysis produced eight equations with which it is possible to predict AMS based on the significant independent variables. Six of these eight models produced here are novel. Whilst Harbo et al. (2011) also produced gender specific predictive equations for concentric PF and DF based on age, height and body mass, without the collinearity, normality or homoscedasticity data it is not possible to comment on the robustness of the predictions made by their equations. Furthermore, their paper does not present any validation of the predictions so the validity is unknown. It is, however, possible to state that the predictions made by the equations described in the previous chapter are both valid and robust based on the evidence presented here. Harbo et al. (2011) did not use the stepwise linear regression analysis used here which identifies the best model for the equation based on the statistical analysis. They used a 'normal' linear regression analysis which uses all of the independent variables whether they are statistically significant or not. However, they did state that not all of the independent variables were statistically significant in the prediction of each muscle strength models (see Appendix 31 for the variables which were not relevant to each of the specific models produced here). They found that muscle strength was significantly related to age in twenty-four out of the thirty-six models; in the data presented here age was a significant predictor of concentric DF but not PF. It could be that this data agrees with Harbo et al. (2011), however, as they did not state which independent variables were significant predictors for which models it is not possible to tell.

Danneskiold-Samsøe et al. (2009) stated that they had produced a mathematical model based on the data they collected. They indicated the model that was used was found on a website (www.parkerinst.dk), however, the model is no longer available. Furthermore there was no discussion as to the robustness of their data used to generate the equation. Thus, it is not possible to comment on the relative robustness and validity of their models compared to the eight equations presented here.

8.5.3.3 Strength of the models

The strength of the models presented here were measured by an ANOVA test. Each one showed that the model as a whole was significant i.e. a good predictor of AMS (Appendix 30). It is not possible to compare this to the literature as the significance data for the models produced by Harbo et al. (2011) were not discussed.

8.5.3.4 Models predictive value

The predictive values of the models are shown by the r squared values produced in the statistical analysis (Table 8-13). This figure represents the amount of variation accounted for by the independent variables used in the model. The r squared values described by Harbo et al. (2011) were 0.25 and 0.29 for male and female PF respectively and 0.12 and 0.35 for male and female DF respectively. This compares to 0.39 (PF) and 0.63 (DF) presented here. This comparison suggests that the equations presented here for concentric PF and DF account for a larger proportion of the variation of AMS and as such any prediction using these equations would have greater accuracy than those presented by Harbo et al. (2011). Other papers that have produced ankle reference values (Danneskiold-Samsøe et al., 2009; Lategan, 2011) have done so by testing specific population groups and thus, the r squared value is not relevant to them. Because of this it is not possible to compare the remaining six r squared values as these relate to novel AMS predictive models which do not exist in the current literature.

8.5.3.5 Testing the prediction equations

The prediction equations were validated by using them to predict AMS in a small validation population based on their mean gender, age, height, mass and shoe size. All of the eight AMS peak torque measurements were within the predicted range and a paired samples t-test indicated that there was no significant differences between the mean predicted and measured values. This demonstrates that the eight AMS peak torque models developed in this thesis are valid tools for predicting normal AMS and as such can be used to produce reference values.

The discussed limitations regarding the r squared values indicate these equations are not yet suitable for predicting AMS for an individual or for detecting small changes in AMS peak torque. Increasing the number of significant predictive factors would enable this to be possible. However, as demonstrated, the prediction equation can be used to predict average AMS torque measurements in a group. These measurements can then be analysed using an independent samples t-test to compare actual and predicted AMS for the group.

8.5.3.6 Improving the models

Whilst all of the models presented here are based on robust data, are statistically strong and have been validated, the r squared values indicate that there is still some room to improve the accuracy. Higher r squared values indicate a larger proportion of the variance in AMS is accounted for. To improve these scores further relevant independent variables could be added. A major physiological determinant of muscle strength is muscle size as demonstrated by Edwards et al. (2013). They used peripheral quantitative computed tomography to calculate forearm muscular cross sectional area in 313 men and 318 women. They found that this had a positive correlation with grip strength. This position supports conclusions from a review by Jones, Bishop, Woods, and Green (2008), however, they also emphasized that the relationship between muscle size and torque production is complex. The discrepancies in the results of the papers that they reviewed suggest that while there is a relationship between cross sectional area muscle strength, other factors also play a role. They suggested age and gender, dealt with in this thesis, influence torque production as well as training status. The argument put forward is that untrained individuals are likely to see an initial increase in force production without an increase in muscle size due to neural adaptations. These adaptations increase the frequency of the action potentials created which will lead to a greater stimulus to the muscle and an increase in the number of motor units recruited. Whilst it is probable that the inclusion of muscle size would improve the accuracy of a predictive equation, the term muscle size needs to be qualified. Jones et al. (2008) examined muscle size in terms of cross sectional area, however, Fukunaga et al. (2001) argued that cross sectional area can be either anatomical or physiological. The anatomical measurement does not take into account the pennation of the muscle fibres which would alter the force to anatomical cross sectional area ratio. In a population of 259 college students they demonstrated a stronger correlation between muscle volume and elbow extension torque (r =0.935, $P < 0.001$) and anatomical cross sectional area ($r = 0.705$, $P < 0.05$).

Another factor which could influence AMS torque production is the type of shoe an individual wears. This was demonstrated by Ottaviani, Ashton-Miller, Kothari, and Wojtys (1995) who found that the height of basketball shoes affected the amount of resistance to inv movement in moderate PF. High top shoes effectively increased the resistive strength of the ankle, thus reducing the need for the muscles surrounding the ankle to stabilise the joints. It could be argued that reducing muscle usage would reduce muscle strength. Ramanathan, Wallace, et al. (2011) found the EMG amplitude of peroneus longus to be greater in response to unanticipated inv of the foot shod in standard sole, flared sole and boot style footwear than barefoot. This increase in EMG amplitude suggests the muscle is working harder when shod compared to barefoot, thus, in the long term would become stronger. Ramanathan, Parish, et al. (2011) found that thicker soles on shoes increased eversion response of the peroneus longus following sudden foot inv. They concluded that this increase was due to the thicker insoles effectively increasing the lever arm length of the subtalor joint. This would in turn increase the torque moment which would require greater muscle activity to stabilise the ankle and muscles which work harder will become stronger. This suggests thicker soles are likely to increase the risk of lateral ligament injury as well increasing AMS. However, there is no evidence to support or refute the suggestion that regularly wearing thick soled shoes would elicit a compensatory increase in inv muscle strength.

Munro et al (2009) concluded that closed back shoes with hard soles were safest for older people in terms of falls as the ankle had to work harder to keep open back shoes on. This could, however, mean open back shoes would increase the strength of the ankle due to increased use. They also concluded that research in this area was lacking. ‘Unstable’ shoes such as ‘MBT shoes’ or ‘Sketchers shape ups’ increase muscle activity intentionally to make the ankle muscles stronger and so increase joint stability (Landry, Nigg, & Tecante, 2010; Romkes, Rudmann, & Brunner, 2006). A review by Tortora and Derrickson (2008) concluded that wearing unstable shoes increased muscle activity, particularly of tibialis anterior and as a result increased strength. Y. Kim, Lim, and Yoon (2013) investigated the effect of high heels on ankle function and found that individuals that habitually wear high heels have significantly higher concentric eve AMS. Adding information on the length of time different types of shoe are worn and how much time the individual spends on their feet could increase the accuracy of the predictive equations.

It has also been suggested that the level of physical activity an individual undertakes would influence AMS. As with any muscle group, increased use results in greater strength, conversely muscle atrophy will occur in muscles that are not used. Harbo et al. (2011) found a relationship between physical activity level and muscle strength in four of the thirty-six models, however, these models all related to knee strength in females. No relationship was found between activity level and ankle strength. Harbo et al. (2011) used a 24 hour questionnaire to determine the activity level of the participants on an average week day. Not only did this questionnaire not take into account participants who were particularly active on the weekend, a validation study found the questionnaire to have poor correlation with accelerometer data (Aadahl & Jørgensen, 2003) which casts doubt on the conclusions of Harbo et al. (2011). Furthermore, any participants who demonstrate 'extensive physical activity' were excluded meaning any training effect of a large amount of physical activity may have on AMS may be missed. Danneskiold-Samsøe et al. (2009) included a physical activity scale in their participant questionnaire, however, this data was not compared to muscle strength. The lack of robust literature concerning the relationship between physical activity and AMS suggests further research is needed in this area.

Harbo et al. (2011) also suggested genetic factors as well as analysing muscle mass rather than mass would increase the accuracy of predictive equations. Although this may increase the accuracy it would make the resultant equation less accessible as accurate muscle mass analysis and gene analysis are not as readily available as gender, height, mass, age and shoe size.

8.6 Conclusion

The analysis presented here indicates that the data produced from testing was robust in terms of normality, collinearity and homoscedasticity. These data were used to construct eight predictive equations for different aspects of AMS which were shown to be statistically strong models. The eight equations were tested using a validation set and were shown to be a valid predictor of AMS. The eight predictive equations produced here represent a more comprehensive set of equations compared to those available in the wider literature, thus, the equations produced here have greater potential for application.

8.6.1 Significance of reference equations for AMS

The reference equations presented in this thesis could provide a valuable tool in research and rehabilitation. Whilst the decision was made to use the Cybex Norm isokinetic dynamometer, providing the same protocol is used for testing and particular attention is paid to the position of the participant on the machine, the reference equations produced here should be relevant to people using other dynamometers. The first chapter of this thesis articulated a number of arguments pertaining to the importance of ankle muscle strength and the usefulness of reference values. For example ankle strength measures have been used in predicting injury, sporting and elderly populations and rehabilitation. An equation which can be used to determine an ideal AMS range would be of great use in all of these areas. For example, reference value equations for AMS could be an alternative to the use of control groups in experiments where these are not practical. This was the case in the research of Alta et al. (2012) who was examining strength in older patients with a reverse shoulder prosthesis. It was not possible to test an age matched healthy control group as there is a large number of unrecognised rotator cuff tears in that population. Equally it was not possible to test the contralateral shoulder due to the prevalence of rotator cuff problems in both shoulders. Thus, the research used the reference values generated by Harbo et al. (2011) to assess the effectiveness of the operation. In terms of AMS this principle would apply when examining AMS and susceptibility to ankle injury. If both ankles are weak then it would not be valid to compare to the contralateral ankle. It may also be difficult to ascertain if a control group had weak ankles or not. It would be possible to screen for history of falls but it is perfectly possible that not everyone with reduced ankle strength has history of falls.

Eitzen et al. (2010) used the reference values produced by Danneskiold-Samsøe et al (2009) whilst demonstrating the efficacy of a five week post-surgery exercise programme on knee strength. They argued that the patients in their study had regained adequate muscle strength as their post-exercise programme torque measurements were similar to the reference values supplied by Danneskiold-Samsøe et al. (2009). They also compared their results to the reference values produced by Kannus (1994). These values were obtained using a different protocol on a different piece of equipment in a different age group. Based on the arguments put forward in this thesis it could be suggested that the results were equivalent by coincidence. The reference equations presented in this thesis acknowledge strength variations with height, mass, age, gender, and shoe size and so provide a valid comparison for a range of populations tested using the Cybex Norm.

Use of predictive equations for muscle strength have been demonstrated previously in the work of Severinsen et al. (2011) who used the equations generated by Harbo et al. (2011) to 'normalise' the strength data they measured in hemiparetic stroke patients. They found that the normalised data correlated with results from a 10m walk test, a 6m walk test and the Scandinavian Stoke Scale, whereas the absolute values only correlated with the 10m walk test. Severinsen et al. (2011) concluded that the critical amount of strength required to generate power during the gait cycle varied between subjects depending on gender, age, height and mass. Hence, the data normalised using reference values showed a stronger correlation with performance compared to the absolute strength data.

Chapter 9

A comparison of AMS between athletes and non-athletes

9. A comparison of AMS between athletes and non-athletes

This thesis describes the production and accuracy of reference equations for eight different measures of AMS. To improve on the accuracy of the predictive equations it was postulated that level of physical activity would increase ankle strength. To investigate this further active and inactive, age and gender matched populations were compared in terms of ankle strength. This chapter will discuss this experiment in detail.

9.1 Introduction

The information presented in Chapter 1 examined the importance of AMS in, amongst other areas, sport. The arguments put forward in Chapter 1, based on the analysis of papers discussed by Sekir et al. (2007), suggest that lack of muscle strength at the ankle predisposes an individual to injury. This information maybe of relevance to ankle injuries in sport and in particular football. Research by Woods et al (2003) found that 2033 matches were missed in the English FA over two seasons because of ankle injuries. Thus, any information on ankle strength related to football players would be of value in terms of injury prevention. The data considered by Sekir et al. (2007) was not collected from elite athletes. It is logical to assume that the high level of physical activity undertaken by elite athletes would affect muscle strength. To the author's knowledge, as of August 2015, no research has indicated whether ankle strength in an elite athlete population is greater than that of a 'normal' or inactive population. It is, therefore, not clear how published reference values would relate to elite athletes and as such how useful these reference values would be in predicting injury in this population. For example, Danneskiold-Samsøe et al. (2009) produced reference values based on a 'normal' population in which they also measured activity levels. However, in the analysis the activity level data and strength data were not compared, so, from their results it is not clear if the level of physical activity had an effect on strength generally and specifically on AMS. Because of this lack of clarity in the literature there are two clear aims of this experiment, firstly to determine if footballers are significantly stronger in terms of the eight measures of AMS compared to an inactive population, and secondly to determine if the reference equations generated in this thesis predict AMS accurately in these two groups.

9.2 Method

This procedure was approved by the ethics committee of the University of Huddersfield 11th November 2010. To ensure the safety of the participants a health screening questionnaire was completed (Appendix 7) and a risk assessment for the procedure was completed (Appendix 5). All participant data was anonymised and stored on a password protected PC.

9.2.1 Population

Forty-two males were tested; twenty-one elite athletes (professional footballers in full time training) and twenty-one age and gender matched inactive individuals recruited from the student population at the University of Huddersfield. Inactivity was defined as self-reported failure to meet the public health recommendations for weekly healthy lifestyle activity targets over the last two months (Bull, 2010).

9.2.2 Procedure

Participants attended a single session in the musculoskeletal laboratory at the University of Huddersfield where the experimental procedure was explained. Eight measures of AMS were taken concentrically and eccentrically in PF and DF, inv and eve using a Cybex Norm isokinetic dynamometer following the protocol set out in section 5.8.

9.2.3 Analysis

The collected data was analysed using SPSS version 22 (IBM statistics). An independent samples t-test was used to identify any differences in anthropometric variable between the active and inactive groups. A Shapiro-Wilk test was used to assess the normality of the distribution of the data a significance of < 0.05 indicates the data is not normally distributed.. Based on the results of this test, either an independent samples t-test or a Mann Whitney U test was used to identify any difference in peak torque measurements between groups. $P \leq 0.05$ was considered statistically significant. Cohen's d values were calculated using the mean and the SD (parametric data) or the z and n values (non-parametric data). The magnitude of the differences between the means was considered either insignificant (d =0 to 0.19), small (d = 0.2 to 0.49), intermediate (d = 0.5 to 0.79) or large (d = 0.8 to ≥ 1).

The predictive equations developed in this protocol were used to predict AMS of the two groups:

Concentric PF = -70.35 + (14.12 x gender) + (0.68 x height)

Eccentric PF = -153.21 + (19.29 x Gender) + (1.35 x Height)

Concentric DF = 6.74 + (6.06 x Gender) + (-0.08 x Age) + (0.15 x Mass)

Eccentric DF = -34.44 + (9.42 x Gender) + (0.30 x Mass) + (0.27 x Height)

Concentric inv = 9.41 + (3.51 x Gender) + (0.11 x Mass)

Eccentric inv = 12.24 + (5.34 x Gender) + (0.15 x Mass)

Concentric eve = 18.33 + (5.21 x Gender) + (-0.07 x Age)

Eccentric eve = 10.16 + (0.24 x Mass)

The predicted value ± RSD was calculated using these equations and this range was compared to the eight measured values of AMS.

9.3 Results

There were no significant differences in age and shoe size between the inactive and athlete populations. The athlete population was significantly taller than the inactive population ($t(40) = 2.64$, $P = 0.01$, $d = 0.81$) with a tendency towards significantly greater mass ($t(40) = 1.70$, $P = 0.09$, $d = 0.53$) Table 9-1 shows the anthropometric parameters of the test population.

Table 9-1

Anthropometric characteristics of the test population.

		Minimum	Maximum	Mean	Std. Deviation
inactive	Height	166.50	186.00	175.56	5.65
	Weight	59.00	107.00	73.07	11.89
	Age	19.00	31.00	22.24	2.64
	Footsize	6.00	11.00	8.48	1.17
active	Height	165.50	188.50	180.27*	5.89
	Weight	62.70	91.90	78.40	8.03
	Age	18.00	32.00	22.05	3.41
	Footsize	7.00	10.50	8.88	0.86

Note: Height is measured in cm, mass in kg, age in years and shoe size is UK standard.
*denotes significantly greater than the inactive population ($P < 0.05$)

9.3.1 Normality of the data

A Shapiro-Wilk test was performed to assess the normality of the distribution of the data (Table 9-2). The results indicated that not all of the data was normally distributed and therefore both parametric and non-parametric tests were used to analyse the data.

Table 9-2

Normality results for the active and inactive participant data.

	Active Shapiro-Wilk			Inactive Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
PFcon	0.89	21	0.02	0.99	20	1.00
DFcon	0.90	21	0.03	0.98	21	0.94
PFecc	0.93	21	0.14	0.96	17	0.59
DFecc	0.98	21	0.84	0.95	20	0.30
Invcon	0.90	21	0.04	0.96	18	0.66
Evecon	0.82	21	0.00	0.84	21	0.00
Invecc	0.98	21	0.90	0.95	19	0.42
Eveecc	0.93	21	0.11	0.90	21	0.04

Note PF = plantar flexion; DF = dorsiflexion; Inv = inversion; Eve = eversion; con = concentric; ecc = eccentric.
Normality of distribution assumed if $P > 0.05$

9.3.2 Athletic vs non athletic population

9.3.2.1 Non Parametric tests.

Table 9-2 indicated that concentric PF, DF, inv and eve as well as eccentric eve were not normally distributed. Therefore, the most appropriate test to assess differences between athletic and non-athletic populations was a Mann-Whitney U test.

Table 9-3

The descriptive statistics from the Mann-Whitney U test.

	N	Mean	SD	Min	Max	Percentiles 25th	50th (Median)	75th
PFcon IA	20	63.00	24.52	19.00	114.00	45.00	62.50	81.50
PFcon A	21	68.71	20.37	43.00	127.00	53.00	64.00	78.50
DFcon IA	21	22.95	7.01	11.00	37.00	18.00	22.00	27.50
DFcon A	21	23.62	5.31	16.00	34.00	19.50	22.00	28.00
Invcon IA	18	21.00	6.24	9.00	31.00	16.00	22.50	26.00
Invcon A	21	25.10	6.93	16.00	42.00	19.50	23.00	28.00
Evecon IA	21	20.62	6.66	11.00	43.00	16.00	20.00	23.00
Evecon A	21	26.90	8.50	19.00	52.00	20.00	24.00	32.00
Eveecc IA	21	28.67	14.57	9.00	64.00	18.00	27.00	33.00
Eveecc A	21	40.14	14.95	18.00	79.00	29.00	38.00	47.50

Note PF = plantar flexion; DF = dorsiflexion; Inv = inversion; Eve = eversion; con = concentric; ecc = eccentric. A = active; IA = inactive

Table 9-4

The results of a Mann-Whitney U test to assess the differences in AMS between an athletic and non-athletic population.

	PFcon	DFcon	Invcon	Evecon	Eveecc
Mann-Whitney U	189.00	204.00	139.00	104.50	115.50
Z	-0.55	-0.42	-1.41	-2.94	-2.65
Asymp. Sig. (2-tailed)	0.58	0.68	0.16	0.00	0.01
R	-0.09	-0.06	-0.23	-0.45	-0.41

Note PF = plantar flexion; DF = dorsiflexion; Inv = inversion; Eve = eversion; con = concentric; ecc = eccentric.

The results displayed in Table 9-3 and Table 9-4 indicate that there is a significant increase in concentric eve (median concentric athletic = 24Nm, median concentric non-athletic = 20Nm).

9.3.2.2 Parametric tests

The results described in Table 9-2 indicate that eccentric PF, DF and inv were normally distributed, therefore an independent samples t-test was the most appropriate statistical test. **Error! Reference source not found.** describes the mean and SD of the of the tested MS measures.

Table 9-5

The descriptive statistics from the independent samples t-test.

		N	Mean	minimum	maximum	Std. Deviation	Std. Error Mean
PFecc	Non - athletic	21	122.43	11.00	157.00	36.88	8.05
	athletic	17	84.41	18.00	190.00	43.53	10.56
DFecc	Non-athletic	21	49.29	12.00	80.00	11.02	2.40
	Athletic	20	44.75	24.00	72.00	15.26	3.41
Invecc	Non-athletic	21	31.14	11.00	45.00	8.98	1.96
	Athletic	19	24.89	11.00	50.00	9.95	2.28

Note PF = plantar flexion; DF = dorsiflexion; inv = inversion, ecc = eccentric.
All torque measurements are in Nm.

The athlete population was significantly stronger in eccentric inv (t(38) = 2.09, $P = 0.04$, $d = 0.66$). The athlete population were also significantly stronger in eccentric PF (t(36) = 2.95, $P < 0.01$, $d = 0.94$).Table 9-5, Table 9-6 and Figure 9-1 shows the comparison of AMS between athlete and inactive groups. These results are found in Table 9-6

Table 9-6

Results of a paired samples t-test comparing athletic and non-athletic populations.

		Levene's Test for Equality of Variances		t-test for Equality of Means							
									95% Confidence Interval of the Difference		Cohen's d
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper	
PFecc	Equal variances assumed	1.22	0.28	2.92	36.00	0.01	38.02	13.04	11.57	64.46	0.94
	Equal variances not assumed			2.86	31.49	0.01	38.02	13.27	10.96	65.07	-
DFecc	Equal variances assumed	0.95	0.34	1.10	39.00	0.28	4.54	4.14	-3.84	12.91	-
	Equal variances not assumed			1.09	34.48	0.29	4.54	4.17	-3.94	13.01	-
Invecc	Equal variances assumed	0.90	0.35	2.09	38.00	0.04	6.25	2.99	0.19	12.31	0.66
	Equal variances not assumed			2.08	36.47	0.05	6.25	3.01	0.15	12.35	-

Note PF = plantar flexion, DF = dorsiflexion, inv = inversion, ecc = eccentric

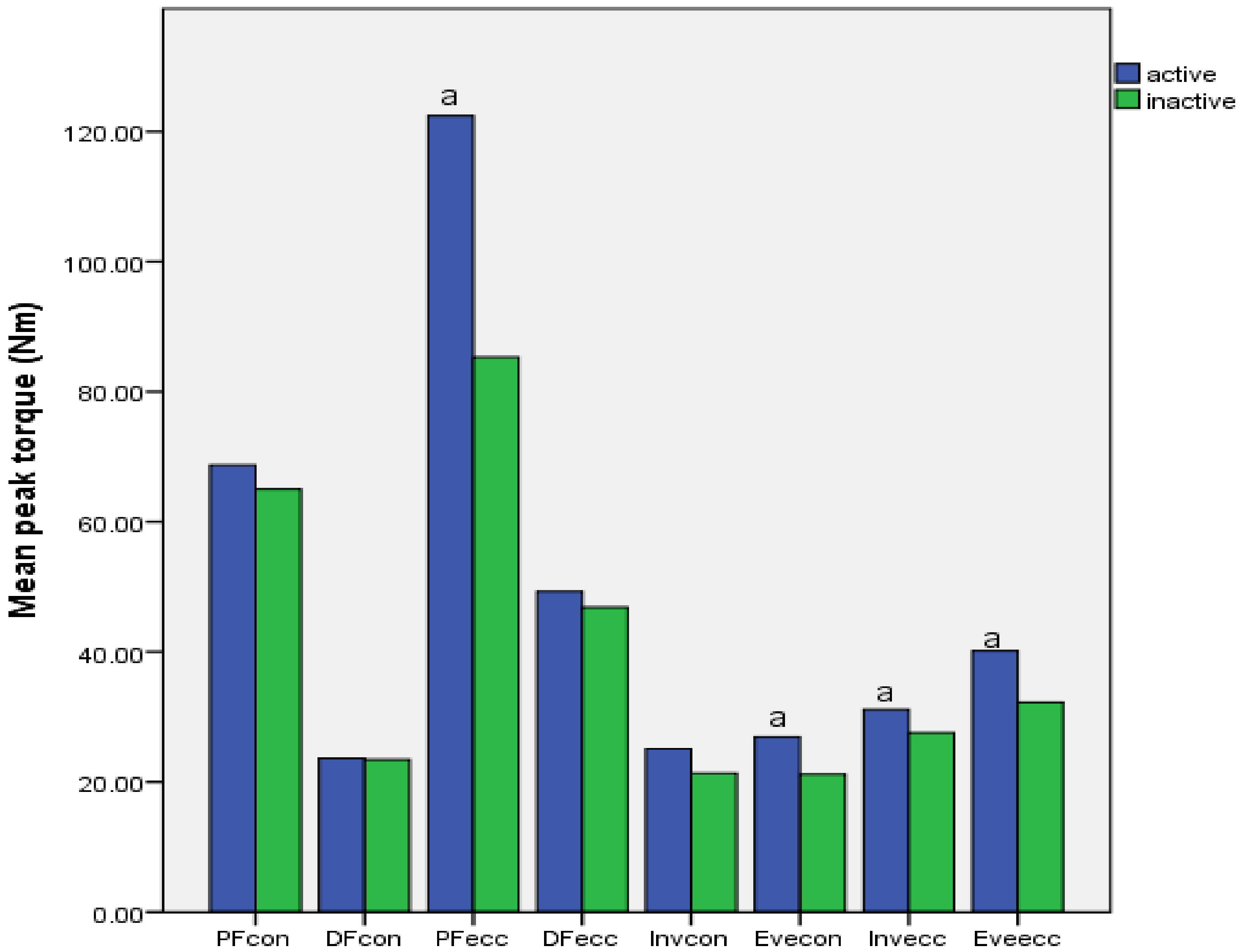


Figure 9-1. A graph comparing the AMS peak torque between athlete and inactive groups. a= significantly greater than inactive population. PF = plantar flexion; DF = dorsiflexion; inv = inversion; eve = eversion; con = concentric; ecc = eccentric

9.3.3 Predicted vs actual AMS

The equations generated in this thesis were used to predict the AMS range for both the inactive and athlete groups. Table 9-7 indicates that six of the eight measures of AMS taken from the athlete group were within the predicted range. Both concentric and eccentric eve were higher than the predicted range. Table 9-8 indicates that all eight of the AMS measures taken for the inactive group were within the predicted range.

Table 9-7

A comparison of predicted and actual AMS scores for the athlete groups.

		Predicted (Nm)	Predicted range minimum	Predicted range maximum	Actual (Nm)
PF	Concentric	66.17	50.95	81.38	68.71
	Eccentric	109.45	84.27	134.62	122.4
DF	Concentric	23.21	16.71	29.71	23.62
	Eccentric	46.91	33.31	60.51	49.28
Inv	Concentric	21.54	17.88	25.20	25.10
	Eccentric	28.99	23.77	34.21	31.14
Eve	Concentric	21.91	18.62	25.20	26.90*
	Eccentric	28.66	24.36	32.96	40.14*

Note PF = plantar flexion; DF = dorsiflexion; inv = inversion; eve = eversion;
*above the predicted range.

Table 9-8

A comparison of predicted and actual AMS peak torque values for the inactive group.

		Predicted	Predicted range minimum	Predicted range maximum	Actual
PF	Concentric	62.79	48.49	77.45	63.00
	Eccentric	103.09	79.38	126.80	84.41
DF	Concentric	22.38	16.11	28.64	22.95
	Eccentric	44.05	31.28	56.82	44.75
Inv	Concentric	20.95	17.39	24.51	21.00
	Eccentric	28.21	23.13	33.29	24.89
Eve	Concentric	21.90	18.61	25.18	20.62
	Eccentric	27.40	23.29	31.51	28.67

Note: PF = plantar flexion; DF = dorsiflexion; inv = inversion; eve = eversion; con = concentric; ecc = eccentric.
All torque measurements are in Nm

A Shapiro-Wilk test indicated that not all of the predicted data was normally distributed. (See Table 9-9).

Table 9-9

The results of a Shapiro-Wilk test examining the normality of the predicted data

		Shapiro-Wilk		
		Statistic	df	Sig.
inactive	predPFcon	0.95	21	0.30
	predDFcon	0.91	21	0.06
	predPFecc	0.95	21	0.30
	predDFecc	0.90	21	0.04
	predinvcon	0.90	21	0.04
	predevecon	0.77	21	0.00
	predinvecc	0.90	21	0.04
	predeveecc	0.90	21	0.04
active	predPFcon	0.95	21	0.40
	predDFcon	0.98	21	0.87
	predPFecc	0.95	21	0.41
	predDFecc	0.97	21	0.68
	predinvcon	0.97	21	0.65
	predevecon	0.89	21	0.03
	predinvecc	0.97	21	0.65
	predeveecc	0.97	21	0.66

Note PF = plantar flexion; DF = dorsiflexion; inv = inversion; eve = eversion; con = concentric; ecc = eccentric; pred = predicted.
Normality of distribution assumed if $P > 0.05$
All torque measurements are in Nm

To further analyse the predicted AMS values, based on the results of the Shapiro-Wilk normality test, either a paired samples t-test or Mann-Whitney U test was used to compare predicted values to measured values.

9.3.3.1 Parametric tests

Con ecc PF (inactive). ecc PFDF inv eve (active) Table 9-10 shows that there was no significant difference between any of the predicted values and measured values of AMS in the inactive group. There were, however, significant differences between predicted and measured AMS in eccentric eve ($t(20) = 3.68$, $P < 0.01$) in the athlete population.

Table 9-10

Data comparing predicted and measured mean AMS values in the active and inactive groups.

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
active	PFecc - predPFecc	12.99	39.04	8.52	-4.79	30.76	1.52	20	0.14
	DFecc - predDFecc	2.38	9.76	2.13	-2.06	6.82	1.12	20	0.28
	Invecc - predinvecc	2.15	8.61	1.88	-1.76	6.07	1.15	20	0.27
	Eveecc - predeveecc	11.48	14.29	3.12	4.98	17.99	3.68	20	0.00
inactive	PFcon - predPFcon	-0.28	23.70	5.30	-11.37	10.81	-0.05	19	0.96
	PFecc - predPFecc	-19.45	45.24	10.97	-42.71	3.81	-1.77	16	0.10

Note: PF = plantar flexion; DF = dorsiflexion; inv = inversion; eve = eversion; con = concentric; ecc = eccentric

9.3.3.2 Non-parametric tests

Analysis of Table 9-2 and Table 9-9 indicate that in the inactive population, concentric and eccentric DF, inv and eve are not normally distributed. This is also the case with concentric PF, DF, inv and eve in the active population. Therefore to compare predicted and actual measures a Mann-Whitney U test was used.

Table 9-11

Results of a Mann-Whitney test exploring the relationship between AMS measures in an Active population.

	PFcon	DFcon	invcon	evecon
Mann-Whitney U	210.00	178.00	145.00	168.00
Z	-0.26	-1.07	-1.90	-1.33
Asymp. Sig. (2-tailed)	0.79	0.29	0.06	0.19

Note PF = plantar flexion; DF = dorsiflexion; inv = inversion; eve = eversion; con = concentric;

Table 9-12

Results of a Mann-Whitney test exploring the relationship between AMS measures in an Inactive population.

	DFcon	DFecc	invcon	evecon	invecc	eveecc
Mann-Whitney U	215.00	169.00	178.00	162.00	148.00	216.00
Z	-0.14	-1.07	-0.31	-1.48	-1.40	-0.11
Asymp. Sig. (2-tailed)	0.89	0.29	0.76	0.14	0.16	0.91

Note PF = plantar flexion; DF = dorsiflexion; inv = inversion; eve = eversion; con = concentric;

9.4 Discussion

The aim of this experiment was to answer two questions. Firstly are elite athletes significantly stronger than an inactive population and secondly to determine if the reference equations generated in this thesis accurately predict AMS in elite athletes. The hypothesis that athletes have significantly greater ankle strength than inactive people is partially supported by the data presented in Figure 9-1. Four of the eight measures of AMS, concentric and eccentric eve, eccentric inv and eccentric PF, are significantly greater in the athlete population compared to the inactive population and there was a tendency towards significantly greater concentric inv in the athlete population. In answer to the second question, in the athlete group both concentric and eccentric eve were higher than the predicted range and the remaining six measures of AMS were within the predicted range.

Comparison of the predicted and measured concentric and eccentric eve AMS using a paired samples t-test found them to be significantly different to each other in the athlete group. It could be concluded that this indicates increased levels of physical activity cause an increase in eve AMS. However, the type of physical activity is an important factor in determining how AMS varies. The athletes in this study were professional footballers and as such will regularly perform cutting manoeuvres as they rapidly change direction. This would put added strain on the concentric and eccentric ankle evertors which would train them to be stronger hence the increased eve strength seen here. This may not, however, be the case for generally active people. Runners for example have a linear running style with fewer rapid changes of direction compared to a footballer. If long distance runners were compared to an inactive population it maybe that there would be no difference in eve strength as neither group regularly performs rapid changes in direction.

Figure 9-1 indicates a significant difference between the athlete and inactive groups in eccentric PF. However, the comparative anthropometric data presented in Table 9-1 indicates that there is also a significant difference in height between the athlete and inactive groups. The model which predicts eccentric PF uses gender and height as independent variables indicating height has an effect on eccentric PF. This difference in height may cause the difference in eccentric PF torque between groups, furthermore this difference is considered in the predictive equation and hence, there is no significant difference between predicted and actual eccentric PF values. Thus, from this data it is not possible to conclude that eccentric PF torque increases with increased level of physical activity.

In terms of concentric and eccentric inv the differences between athlete and inactive groups is not clear. In terms of concentric inv the measured value was within the predicted range. However, the paired samples t-test suggested there was a significant difference between the predicted and measured values in the active group. The statistics also indicated a tendency towards a significant difference in concentric inv (P = 0.06) between the athlete and inactive groups. In terms of eccentric inv the data showed a significant difference between the active and inactive groups, however, the measured value was within the predicted range and the paired samples t-test indicated that there was no significant difference between measured and predicted values. It could be argued that a footballer striking the ball would do so with the medial aspect of the foot and so utilise the invertor muscles to a greater extent than non-footballers in the inactive group. Therefore, a higher inversion strength in the athlete group may be expected. Furthermore, the predictive models for concentric and eccentric inv are based on gender and mass, and analysis of the anthropometric variables indicated a tendency towards a significant difference in mass between the athlete and inactive groups (P = 0.09). This this may also contribute to the ambiguity of the difference in peak torque between athlete and inactive groups and the accuracy of the predicted values for both groups. The athlete group are professional footballers. If they had a higher percentage muscle mass compared to the inactive group they would be able to achieve a higher torque per unit mass. Thus, from the data presented here, the relationship between concentric and eccentric inv, and physical activity level cannot be determined.

In the inactive group, each of the eight measurements of AMS were within the reference range and the paired samples t-test indicated that there was no significant difference between measured and predicted values. One reason for this lack of difference could be the definition of inactive used here. A self-reported level of activity below the levels recommended by the public health guidelines (Bull, 2010) was considered inactive. In the literature it had been demonstrated that a lack of physical activity decreases muscle strength. For example Valderrabano et al. (2006) examined PF and DF joint torque in osteoarthritis patients. They demonstrated not only a difference between the affected ankle and the control group but also between the non-affected ankle and the control group. It could be argued that this difference is due to the lower levels of activity seen in the patients. A theory supported by the reduced shank circumference they measured in both legs of the patients compared to the control group as muscles will reduce in size of not used. Furthermore, the equations used for the reference values developed in this thesis were based on a university population. Although the participants in the inactive population were different to those described in Chapter 5 who were tested to produce reference values, they were selected from the same university population. As such it is likely that a portion of the reference value population were inactive. Equally, it is unlikely that a significant number of elite athletes were in the reference value population. It is, therefore, further validation of the predictive equations that all of the measures of AMS peak torque in the inactive group were within the predicted range.

9.5 Conclusion

The data presented here indicates that the athlete group tested were significantly stronger in concentric and eccentric eve compared to an inactive population. The results comparing concentric and eccentric inv between athlete and inactive groups were inconclusive and there was no difference between the athlete and inactive groups in terms of PF and DF strength when predictive variables were controlled for. Therefore it can be concluded that the equations predicting concentric and eccentric PF and DF, developed in this thesis, are suitable for predicting AMS in elite football players. Furthermore it can be concluded that training (specific to football players) will influence the level of eversion strength and as such should be considered when predicting ankle strength.

10. General discussion and conclusions

10.1 Limitations of the study

Although the AMS reference range equations produced here are robust in terms of validity and reliability, there are limitations in terms of the protocol used. Due to the nature of isokinetic testing there are a number of variables (described in detail in Chapter 4) which need to be fixed when testing. Altering the variables would lead to changes in the outcome measures, thus the reference range equations are only relevant to experiments which have used the same protocol.

Active insufficiency, whereby contraction of the gastrocnemius muscle is inhibited when the knee is flexed, means that the PF reference ranges may not include maximal gastrocnemius contraction strength. This would be an issue if using the reference values to plot the recovery of a gastrocnemius specific injury for example.

The accuracy of the equations in terms of the r^2 values has scope for improvement. Because the reference range is relatively broad the equations could not validated for individuals. Further work is needed to reduce the predicted range, thus allowing the prediction of a reference range for an individual.

10.2 Strengths of the study

The systematic review provided a robust and repeatable search of the literature ensuring all of the papers that have used the Cybex Norm to measure AMS were identified and available for analysis.

The test – retest reliability study, detailed in Chapter 7, demonstrated that the fully justified protocol developed from the analysis of the sixty papers that have measured AMS using the Cybex Norm is a reliable protocol. Because the protocol gives detail regarding all of the key variables needed for isokinetic testing it is repeatable and can be used on any isokinetic dynamometer.

In producing the reference value equations 100 individuals were tested. As the equation from Tabachnick and Fidell (2007) recommends at least ninety participants for a linear regression analysis, using a reliable protocol to test 100 participants resulted in a robust set of predictive equations. Furthermore the equations were validated by using them to predict the mean AMS of a group of eleven participants.

Six of the eight AMS equations are not available in the literature and so are a novel contribution. The two similar equations which are available in the literature are not as robust as the equivalent equations produced here, as described in Chapter 8.

10.3 Summary and main findings

The main aims of this thesis were as follows:

a. As there are a number of variables which need to be defined when measuring AMS, once the systematic review was complete, the first aim of this thesis was to develop a protocol for measuring AMS with each variable justified (Chapter 4). This included determining the effect of altering the angle at which the knee is fixed on AMS (Chapter 6).

b. As this protocol was to be used to take measurements of AMS from which reference values would be generated, the second objective was to ensure the protocol and the Cybex Norm were robust using a test re-test experimental design. (Chapter 7).

c. Using the justified and reliable protocol, the main aim of this thesis was to determine reference ranges for AMS collecting data and using a linear regression analysis to produce reference range equations (Chapter 8).

d. Previous research has indicated that there is variation in strength with variation in different anthropometric measurements, for example height, weight, age and gender. In the production of reference values knowledge of the factors which affect AMS are crucial. Thus, the data collected was also used to explore a fourth aim, the effect of variations in anthropometric measurements on AMS (Chapter 8).

e. Validated reference equations for AMS could have a range of clinical, rehabilitation and sporting applications. The fifth aim of this thesis was to demonstrate an application of the validated reference equations. (Chapter 9).

The relevance of AMS and importance of reference values were investigated and the findings set out in Chapter 2. It was established that the measurement of AMS has an important role in predicting injury, assessing functional movement and plotting the progression of certain diseases as well as monitoring the efficacy of rehabilitation programmes. It was also established that the Cybex Norm was a popular and reliable piece of equipment with which to measure AMS.

Prior to the production of reference range equations it was necessary to perform a systematic review of the literature to identify all of the papers that have used the Cybex Norm dynamometer to measure AMS. The method and results of this review were presented in Chapter 3. The review identified sixty papers which used the Cybex Norm to measure AMS, however, analysis of these papers revealed none had set out to produce reference values. In theory it would be possible to combine the results of the individual papers in a meta-analysis to produce reference values. Analysis of the methods of data collection indicated varied methods which would alter the outcome measures of AMS and as such, a meta-analysis was not possible.

Analysis of the sixty papers identified in Chapter 3 identified eight variables common to the protocols of each of the papers. The effect of changing these variables on AMS measures were discussed and conclusions drawn which informed the production of a standardised protocol with which to measure AMS. A novel AMS testing protocol was described in Chapter 5 which partially answered the first aim of the thesis in suggesting a novel protocol for measuring AMS.

In order to ensure all of the key variables were understood an experiment was performed to understand the effect of altering the angle at which the knee is fixed on AMS production. This experiment was described in Chapter 6 and demonstrated that altering the knee angle from 10° to between 80° and 110° decreased the amount of torque that could be produced in concentric and eccentric PF, whereas concentric and eccentric eve and concentric inv reduced. This clearly indicated the need to define the angle at which the knee is flexed in any protocol and further answers the first aim of the thesis.

Chapter 7 describes test-retest experiment which was performed to investigate the reliability of the novel protocol in measuring eight AMS movements. The experiment concluded that the novel protocol was reliable when used to test all eight AMS measures, answering the second aim of the thesis.

The fourth research aim, addressed in Chapter 8, was to explore the relationship between the anthropometric measurements and AMS. The results presented suggested that the anthropometric measures taken affected the ability to produce torque at the ankle. It was clear that the effect of these variables was not the same for each of the eight measures of AMS and the effects varied between genders. It suggests that multiple factors in terms of changes in anthropometric measures will affect different measures of AMS in different ways. The results presented here and the limited results in the literature demonstrated the need to consider anthropometric variables when measuring AMS and address the fourth research aim.

The main aim of this thesis was to produce equations which can predict a reference range for AMS. Chapter 8 also described the data collection and subsequent statistical analysis which used a stepwise linear regression analysis on data from 100 participants. The interactions between the measures of AMS and gender, height, mass, age and shoe size were explored and these variables were used in the linear regression analysis to produce the novel equations. Each of the eight equations was validated by successfully predicting a mean AMS range for a further 11 individuals, thus, fulfilling the main research aim of this thesis. A review of the literature indicated that these equations do not exist and as such the eight validated equations presented here represent a novel contribution.

This thesis has demonstrated the importance of AMS and potential uses for reference values for AMS. It has also been demonstrated that no reference values for AMS, measured using the Cybex Norm, exist. This thesis has investigated and produced a reliable method for measuring AMS and statistical analysis of the collected data has produced eight equations which give reference values for AMS. These reference values have been validated and are recommended here for use in clinical, sporting and research environments.

10.4 Future Directions

Establishing reference equations which can predict AMS could facilitate research in a number of areas. The following are some research ideas which could extend the relevance of the reference values to a wider population and utilise the AMS reference equations.

- Once reference values have been established it would be clinically useful to investigate the production of a scale, based on AMS, to define the risk of injury, for example in patients with diabetic neuropathy. It would first be necessary to establish if a greater reduction in strength correlates with an increased risk of ankle injury. If this relationship does exist then it would be possible to determine a graded scale with which to assign an injury risk factor.

- Use of barefoot running techniques to reduce injury and improve performance have recently gained significant attention in scientific literature. A review by Tam, Wilson, Noakes, and Tucker (2014) suggested that the research surrounding barefoot running and the possible benefits is largely inconclusive. They further suggest that time consuming longitudinal studies are necessary to identify the long term effects of barefoot running. Longitudinal studies would not be necessary if the reference equations were used to identify differences in AMS between habitual barefoot runners and a normal population. The same principal could be applied to habitual wearers of other shoe types, for example football boots, high heels or army boots.

- The act of running up and down hills gives fell runners a unique AMS profile. The reference equations could be used to compare AMS in fell runners with reference values. It may also be possible to determine if there is a correlation between markers of running efficiency (oxygen consumption at specific speeds up hills, blood lactate levels, blood creatine kinase and interleukin-6 levels) and above normal AMS.

- Engsberg et al. (2006) found that an increase in ankle strength improved function and gait speed in children with Cerebral Palsy. Use of reference equations could assess the effect of exercise interventions on patients with cerebral palsy. While absolute improvements could be measured, improvements relative to a reference value may be more relevant.

- Expanding the reference range age group would allow ankle strength deficits in an older population to be explored. It has been demonstrated that AMS deficits can contribute to falls in older populations (Rubenstein & Josephson, 2006) and is an important factor in stair ascent (Reeves et al., 2009) and descent (Reeves et al., 2008). Thus, knowledge of normal ankle strength may help prevent falls and maintain quality of life in this population.

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12. Appendices

Appendix 1

Inversion and eversion papers based on Sekir et al (2007)

Authors	Test Speed	Subject Group	Results	Strength values
Lentell et al.(1990)	0°/s and 30°/s Cybex II+	Unilateral CAI and uninjured opposite ankles	No difference in concentric evertor strength between ankles	Isometric involved 16.9(4.8) uninvolved 16.4(4.9)
Lentell et al.(1995)	30°/s, 90°/s ,150°/s and 210°/s Cybex II+	Unilateral FAI and uninjured opposite ankles	No difference in eversion strength between ankles	
Kaminski et al. (1999)	30°/s, 60°/s, 90°/s, 120°/s, 150°/s and 180°/s Kin Com 125AP	Subjects with CAI and healthy control group	No difference in concentric and eccentric evertor strength between groups	
Bernier et al. (1997)	90°/s Kin Com II	Unilateral FAI and healthy control group and contralateral limb	No difference in eccentric invertor and evertor strength between groups or limbs	

Authors	Test Speed	Subject Group	Results	Strength values
(Heitman et al., 1997)	30°/s and 60°/s Equipment not stated	Unilateral FAI and uninjured opposite ankles	No difference in eccentric evertor strength between ankles	
(Munn et al., 2003)	60°/s and 90°/s Biodex	Unilateral FAI and uninjured opposite ankles	No difference in eccentric or concentric evertor strength between ankles	
(Hartsell & Spaulding, 1999)	60°, 120°, 180° and 240° per second Cybex (model not stated)	Subjects with FAI and a healthy control group	Significant difference in eccentric and concentric evertor and invertor strength between groups	
(Willems et al., 2002)	30° and 120° per second Biodex 2	Subjects with CAI and a healthy control group	Significant difference between groups in concentric and eccentric evertor strength at 30° sec	
(Y. Yildiz et al., 2003)	120° per second Cybex Norm	Subjects with CAI and a healthy control group	Significant difference in eccentric evertor strength between groups	

Authors	Test Speed	Subject Group	Results	Strength values
(Ryan, 1994)	30° per second Cybex II	Unilateral CAI and Uninjured opposite ankles	No difference in concentric evertor strength, significant difference in concentric invertor strength between ankles	
(Wilkerson et al., 1997)	30° and 120° per second Biodex 2	Unilateral CAI and uninjured opposite ankles	No difference in evertor strength, significant difference in invertor strength between ankles	

Appendix 2

Comparison of experimental and control populations in papers which used the Cybex Norm to measure isokinetic AMS. Based on Fish et al. (2014)

Reference	Experimental population	Control Population
Oliveira, Oliveira, Jones, and Natour (2015)	2 male 28 female Rheumatoid arthritis patients aged 50±1.8 years	2 male and 28 female healthy participants aged 51±2.1 years
Rosso et al. (2015)	52 patients with unilateral Achilles tendon rupture aged 48.6 (SD 8.7)	Uninjured contra lateral limb
Brown et al. (2014)	20 diabetic patients with peripheral neuropathy, 33 diabetic patients without peripheral neuropathy. Gender not stated	27 healthy participants aged 51 (SD 19) Gender not stated
Keles et al. (2014)	Training group – 12 males aged 21.9±3.1 years	12 males aged 24.3±3.1 years
Buckley et al. (2013)	10 males 5 females aged 75±3 years 10 males 7 females aged 25±4years	N/A – older vs younger population
David, Halimi, Mora, Doutrellot, and Petitjean (2013)	12 CAI patients: 8 male aged 21.3±18 years, 4 female aged 23.5±4.4 years	12 health participants: 6 males aged 22.5±2.4 years, 6 females aged 24.0±3.0
Tallent, Goodall, Hortobágyi, St Clair Gibson, and Howatson (2013)	10 resistance trained males aged 22±2 years	9 untrained males aged 26±3 years
Taskiran et al. (2013)	2 males, 11 females aged 34.3±9.2 years	N/A test – retest reliability study

Reference	Experimental population	Control Population
Alfieri et al. (2012)	1 male, 22 females aged 70.18±4.8 years	N/A – strength training vs multisensory training experiment.
S. S. M. Fong and Tsang (2012)	13 males, 7 females aged 15±1.2 years	N/A – correlation study between hours of taekwondo training and muscle strength
Noguchi, Demura, and Nagasawa (2012)	10 males football players aged 20±0.8 years	10 males athletes aged 21.1±0.57 years
Strejcová, Šimková, and Baláš (2012)	8 males 1 female aged 25.0±0.9 years (slackline walkers)	8 males 1 female aged 22.9±0.8 years (non-slackline walkers)
Tan, Li, and Wang (2012)	13 male and 12 female Diabetes patients aged 65.9±4.2 years	No healthy control
X. Wang (2012)	"elite skaters" no other detail given	N/A
Zhang and Xia (2012)	6 males aged 25.8±3.87 years 12 males aged 22.3±2.56 years	N/A – comparison of national and international skaters
Behrens et al (2010)	7 short track speed skaters aged 17.1±1.3 years (gender not stated)	N/A – test-retest design
Collado et al (2010)	6 males, 3 females aged 25.1±2.57 (eccentric training); 4 males, 5 females aged 23.3±2.8 (concentric training)	2 males, 8 females aged 24.4±3.06
Gopalakrishnan et al (2010)	4 males aged 49.5±4.7 years	N/A – strength measured pre and post space flight
Latour et al (2010)	10 males, age not stated (training on sand)	10 males, aged not stated

Reference	Experimental population	Control Population
Patterson & Ferguson (2010)	8 females aged 23±3 years 8 females aged 22±3 years	N/A – training method comparison between blood restriction and no restriction and 25%1RM and 50%1RM reps
Urguden et al (2010)	15 males, 5 females aged 20.6 years (range 16 – 32 years) with chronic ankle instability	'20 patients with same demographic characteristics'
Vismara et al. (2010)	11 adults aged 33±4.3 years with Prader-Willi Syndrome	20 healthy adults aged 28±7.8 years
van Cingel et al (2009)	15 males aged 34.2±9.32 years; 15 females aged 28.6±8.64 years	N/A – reproducibility study
Giagazoglou et al. (2009)	10 blind females aged 33.5±7.9 years	10 healthy females aged 33.5±8.3 years
Guo and Song (2009)	10 males aged 22.4±2.6 years (elite speed skaters)	14 males aged 19.4±0.8 years
Koutsioras et al (2009)	7 males aged 16.3±1.2 years 7 females aged 16.1±1.2	N/A – examination of muscle strength and long jump performance
Li, Xu, & Hong (2009)	13 males 12 females 64.9±3.2 years (healthy performed Tai Chi)	12 males 13 females 65.6±3.5 years (healthy did not perform Tai Chi)
Reeves, et al (2009)	5 males 10 females aged 74.8±2.8 years 10 males 7 females aged 24.6±4.1 years	N/A Comparison of older vs younger stair ascent
Sanioglu et al. (2009)	9 males, 7 females aged 24.3 ±4.12 years	Strength with ankle taped vs not taped

Reference	Experimental population	Control Population
Eyigor et al. (2008)	8 males 25 females aged 55.79±12.4 years with Rheumatoid arthritis	7 males 26 females aged 60.27±10.7
Özçaldiran & Durmaz (2008)	14 males median age 18(6) (elite swimmers) 8 males median age 20(5) (elite runners)	N/A comparison between swimmers and runners.
Reeves et al (2008)	15 "older adults" aged 74±2.8 years 17 "young adults" aged 24.6±4.1 years gender not stated	N/A – comparison of older and younger biomechanics of stair descent
Sekir et al. (2008)	24 males aged 21.1±1.8 with functional ankle instability	N/A – reliability study
Dehail et al. (2007)	6 males aged 75.6±5.4 years, 18 females aged 73.2±6.7 years	N/A analysis of strength and sit to walk movement
Eyigor et al. (2007)	20 participants aged 70.3±6.5 years gender not stated	N/A – test-retest design
Frasson et al. (2007)	36 females, age not stated	Ballet dancers versus volleyball players
Geremia, Galvão, and Diefenthaeler (2007)	5 individuals (no population data given)	Contra lateral ankle
Muller et al (2007)	10 males, 33 females aged 86.0±5 years. Hospitalised patients	6 males, 22 females aged 75.4±6.2 years
Sekir et al. (2007)	24 males aged 21±2 years with unilateral functional ankle instability	Contra lateral ankle
Thom et al (2007)	9 males aged 74.7±4.0 years 15 males aged 25.3±4.5 years	N/A – comparison between older and younger males
Ferri, et al (2006)	9 males aged 71.8±4.3 years	N/A – test-retest design

Reference	Experimental population	Control Population
Gerodimos et al (2006)	30 males in each group: aged 12.3±0.1 years Aged 13.4±0.2 years Aged 14.5±0.3 years Aged 15.2±0.1 years Aged 16.5±0.3 years Aged 17.4±0.2 years	N/A – analysis of strength in basketball players
Greene et al (2006)	20 females aged 15.9±1.6 years (middle distance runners) 20 males aged 16.8±00.6 years (middle distance runners	20 females aged 16±1.8 years, 20 males aged 16.4±0.7 years
Mahieu et al (2006)	69 males aged 18.41±1.29 years	N/A – cohort study examining risk factors for Achilles over use injury
Neto et al (2006)	8 males between 20 and 23 years	N/A – test-retest design
Sammarco, Bagwe, Sammarco, and Magur (2006)	16 males mean age 53.4 range 18-74 and 24 female mean age 55 range 15-74	Contra lateral ankle control
Xu et al (2006)	13 males, 8 females aged 66.2±5.1 years (Tai Chi practitioners) 11 males, 7 females aged 65.2±3.0 years (joggers)	12 males, 10 females aged 64.9±3.2 years
Greene et al.(2005)	20 females aged 16±1.7 years (middle distance runners)	20 females aged 16±1.8 years
Demonty et al (2004)	10 males mean age 52.8 with occlusive arterial disease	10 males mean age 53.9 years
McCarthy, et al (2004)	47 females aged 64.51±3.08 years	N/A – comparison of sit to stand movement and hip, knee and ankle strength
Ferri et al (2003)	16 males aged 67.9±0.9 years	N/A – test-retest protocol

Reference	Experimental population	Control Population
Høiness et al (2003)	9 males aged 26.2±4.4 years (using normal bike pedal); 10 males aged 24.5±3.9 years (using bi-directional bike pedal)	Contra lateral ankle
Reeves and Narici (2003)	4 males, 4 females aged 25.1±2.6 years	N/A – examination of muscle fascicles during dynamic movement
Yildiz et al (2003)	8 males aged 26.2±2 years with chronic ankle instability	9 males aged 25±2 years
Schulze et al (2002)	8 males 27.1±3.0, 8 males 29.5±2.9 years (underwent unilateral lower limb suspension for 21 days)	8 males 31.4±2.9 years, 8 males 32.5±3.9 years
Tsiokanos, et al (2002)	29 males aged 22.1±2.2 years	N/A – comparison of leg strength and jumping performance
Ademoglu et al. (2001)	3 males, 1 female between 24 and 47 years (average 35) (wound complications after Achilles tendon rupture)	Contra lateral ankle
Bourdel-Marchasson et al (2001)	4 males, 7 females aged 87.1±5.7 years (malnourished)	4 males, 9 females aged 83.4±6.1 years
Mouraux et al (2000)	4 males, 6 females aged 24.7±3.2 years	N/A – test-retest design
Wilcox, Bohay, and Anderson (2000)	8 males, 12 females mean age 61 range 28 – 80	Contra lateral ankle control

Appendix 3

A description of the protocols used by the sixty papers that have used the Cybex Norm to measure AMS. Based on Fish et al. (2014).

Reference	Prone/Supine/ weight bearing	Degree of Knee Flexion	Warm up	Speed / contraction type, in °/s	Sets and Repetitions	Dominant or non-dominant foot	Encouragement given
Oliveira et al. (2015)	Supine	30°	5 min cycling at 60rpm	30, 60 concentric PF, DF, inv, eve	5 reps at each speed, 30seconds between speeds	Both	Not stated
Rosso et al. (2015)	Seated	'full extension'	10mins cycling, 3 reps familiarisation	30, Concentric PF,	3 reciprocal reps	Injured limb – dominance not stated	Not stated
Brown et al. (2014)	Prone	180°	Not stated	60, 120, 180, 240 concentric, eccentric PF	Not stated	Not stated	Not stated
Keles et al. (2014)	Supine	80°-110° eve 30°-40° DF	10 min warm up 'general ROM', 2 sets of stretching exercises.	Concentric eccentric DF, eve	5 reps of each movement	dominant	Verbal
Buckley et al. (2013)	Not stated	Not stated	Not stated	60, 120, 180, 240 eccentric PF	3reps at each speed	Not stated	Not stated

Reference	Prone/Supine/ weight bearing	Degree of Knee Flexion	Warm up	Speed / contraction type, in °/s	Sets and Repetitions	Dominant or non-dominant foot	Encouragement given
David et al. (2013)	Supine	90°	Familiarisation, 5mins cycling, ‘several’ reps at 50% max	60,120 Concentric Inv, eve. 30, 60, 90 ccentric inv, eve	8 reps at each speed, 1 min rest between concentric and eccentric	Non-dominant	Verbal and visual feedback given
Taskiran et al. (2013)	Prone	‘full extension’	4 submax reps	30, 120 PF DF concentric	5 reps at 30° per sec 10mins rest 20 reps at 120°per sec	dominant	Not stated
Tallent et al. (2013)	Supine	120°	Not stated	15 DF concentric and eccentric	3 reps	dominant	Not stated
Alfieri et al (2012)	Supine	80°	3 reps at free angular speed	30 PF, DF, inv, eve	5 reps	Not stated	Verbal encouragement given
S. S. M. Fong and Tsang (2012)	Prone	0°	3 trials	60, 240 PF DF concentric	3 trials, 10 seconds between trials (reps per trial not stated)	Dominant (self reported)	Not stated

Reference	Prone/Supine/ weight bearing	Degree of Knee Flexion	Warm up	Speed / contraction type, in °/s	Sets and Repetitions	Dominant or non-dominant foot	Encouragement given
Noguchi et al. (2012)	Not stated	Not stated	1 'practice run'	30 PF DF	'2 tests in between I minute intervals'	Not stated	Not stated
Strejcová et al. (2012)	Supine	90°	Not stated	30, 120 PF DF	5 reps 30°,15 reps 120°	dominant	Not stated
Tan et al. (2012)	Supine	Not stated	'familiarisation and a warm up' no detail given	30, 60 PF DF	2sets of 3 reps 1 minute rest between	dominant	Not stated
Wang (2012)	Not stated	Not stated	Not stated	60, 120, 180, 240, 300, 360, 420, 480 concentric; 60,120, 180, 240, 300 eccentric DF	8 reps at each concentric speed and 5 reps at each eccentric speed	both	Not stated
Zhang and Xia (2012)	Not stated	Not stated	10 mins 'warm up' and 3 reps at 60° per sec	60, 120, 180, 240, 300, 360, 420, 480 concentric PF DF	3 reps at each speed, 20secs between reps	both	Not stated

Reference	Prone/Supine/ weight bearing	Degree of Knee Flexion	Warm up	Speed / contraction type, in °/s	Sets and Repetitions	Dominant or non-dominant foot	Encouragement given
Behrens et al (2010)	Supine	Between 100° - 110°	10 mins bike at 100W 5 submax concentric reps at 240° per sec	240 inv eve Concentric	3 max reps	right	No visual feedback, verbal encouragement was given
Collado et al (2010)	Supine	90°	3 practice trials	30 inv eve concentric eccentric	3 reps	Both (one had suffered lateral ankle sprain)	Not stated
Gopalakrishnan et al (2010)	Prone	0°	5mins bike 25-50W 60-80rpm. 5 sub max reps, 2-3 max reps 2mins rest	30 PF DF concentric eccentric	5 reps ecc 5 reps con	right	Not stated
Latour et al (2010)	Supine (based on photo, not stated in text)	Flexed (based on photo, not stated in text)	Not stated	30, 120, inv eve concentric eccentric	Not stated	Not stated	Not stated
Patterson & Ferguson (2010)	Prone	0°	5 contractions at each speed	30, 60, 120 PF concentric	3 reps at each speed. 1 minute between reps	both	Verbal encouragement given

Reference	Prone/Supine/ weight bearing	Degree of Knee Flexion	Warm up	Speed / contraction type, in °/s	Sets and Repetitions	Dominant or non-dominant foot	Encouragement given
Urguden et al (2010)	Supine	80 – 110°	Not stated although proprioception test performed on the Cybex prior to isokinetic tests	60, 150 inv eve	5 reps 60° sec. 10 reps 150° sec	Both (1 injured 1 uninjured)	Not stated
Vismara et al. (2010)	Prone	180°	Not stated	60, 120 PF DF	5 reps at each speed, 1min rest between reps	both	Not stated
van Cingel et al (2009)	Supine	10°	5min bike 75w 70 – 80rpm, 3 submax inv eve 2 max inv eve	30, 120 inv eve	3 sets of 3 reps at each speed	both	No visual feedback or verbal encouragement given
Giagazoglou et al. (2009)	Supine	'fully extended'	3 submax contractions	30, 60, 120 PF DF concentric eccentric	3 reps of each movement at each speed with 2mins between each rep	Dominant	Consistent, identical verbal encouragement provided, no visual feedback given

Reference	Prone/Supine/ weight bearing	Degree of Knee Flexion	Warm up	Speed / contraction type, in °/s	Sets and Repetitions	Dominant or non-dominant foot	Encouragement given
Guo and Song (2009)	Not stated	Not stated	10 mins preparatory activities and 2 sets 3 reps at 60° per sec	60, 120, 180, 240, 300 PF concentric	3 reps at each speed 20 seconds between each rep	right	Not stated
Koutsioras et al (2009)	Prone	0°	3 sub max reps	60, 120 concentric and eccentric PF	3 max reps at each speed for each movement	right	Not stated
Li, Xu, & Hong (2009)	Not stated	Not stated	Not stated	30 PF DF concentric.	3 reps no info on rest	dominant	Not stated
Reeves, et al (2009)	Prone	0°	Not stated	60, 120, 180, 240 concentric PF	Not stated	left	Not stated
Sanioglu et al. (2009)	Supine	Not stated	5mins cycling, 6-10 submax PF DF contractions, 2-3 max PF DF contractions then 2mins rest	60, 180 PF DF Concentric	5reps at 60° per sec 15 reps at 180° per sec	both	Not stated

Reference	Prone/Supine/ weight bearing	Degree of Knee Flexion	Warm up	Speed / contraction type, in °/s	Sets and Repetitions	Dominant or non-dominant foot	Encouragement given
Eyigor et al. (2008)	Supine	90°	10 min walk 2 sub max reps 180° per sec	60, 120, 180 PF DF	6 reps at each speed 20s between speeds	Not stated	Verbal encouragement given
Özçaldiran & Durmaz (2008)	Supine	0°	5 min warm up plus 4 sub max reps	30, 120 PF DF	5 reps at 30° per sec 15 reps at 120° per sec with 30 sec rest between sets	Both	Verbal encouragement given
Reeves et al (2008)	Prone	0°	Not stated	60, 120, 180, 240 eccentric PF	3 reps at each speed 2-3 minute rest between	left	Not stated
Sekir et al. (2008)	Supine	80° - 110°	10minute 'general ROM and stretching' 3 submax contractions	120 inv eve concentric eccentric	5 maximal contractions 2mins between inv and eve tests	14 dominant 10 non dominant (only injured ankle tested)	Verbal encouragement given

Reference	Prone/Supine/ weight bearing	Degree of Knee Flexion	Warm up	Speed / contraction type, in °/s	Sets and Repetitions	Dominant or non-dominant foot	Encouragement given
Dehail et al. (2007)	Supine	0°	3 training reps before each set	30, 60 Concentric PF	2 x 5 reps at 30°per sec 1 x 5reps at 60°per sec 2mins between sets	dominant	Verbal encouragement given
Eyigor et al. (2007)	Supine	90°	10 min walk then 2 sub max PF/DF reps at 180° per sec	60, 120, 180 PF DF	6 reps at each speed. 20s between reps	both	Verbal encouragement given
Frasson et al. (2007)	prone	180°	A 'series' of submax contractions at different speeds	60, 120, 180, 240, 300, 360, 420 PF DF concentric	3 reps at each speed, 2mins rest between reps	right	Not stated
Geremia et al. (2007)	Not stated	Not stated	Not stated	60, 120, 180, 240, 300 PF DF concentric	3 reps per speed, 90sec rest between speeds	Both (non-dominant was sprained)	Not stated

Reference	Prone/Supine/ weight bearing	Degree of Knee Flexion	Warm up	Speed / contraction type, in °/s	Sets and Repetitions	Dominant or non-dominant foot	Encouragement given
Sekir et al. (2007)	Supine	80° - 110°	10minute 'general ROM and stretching' 3 submax contractions	120 inv eve Concentric eccentric	5 maximal contractions 2mins between inv and eve tests	14 dominant 10 non dominant injured both tested	Verbal encouragement given
Thom et al (2007)	Prone	0°	Familiarisation session and 5 isometric MVCs	50, 100, 150, 200, 250 Concentric PF	4 reps at each speed, 1 min between reps, 5mins between speeds.	left	Verbal encouragement given
Ferri, et al (2006)	Prone	0°	'several' warm up contractions	60, 120 concentric 60 eccentric PF DF	3 reps at each speed, 1 min between reps	Left (non dominant in all subjects)	Verbal encouragement given
Gerodimos et al (2006)	Supine	0°	15 minutes cycling and stretching 3 submax reps and 1 max rep at 30° and 90° per sec	30, 90 Concentric eccentric PF DF	5 reps of each movement at each speed. 5 min rest between speed	1 randomly determined leg	Visual feedback, no verbal feedback

Reference	Prone/Supine/ weight bearing	Degree of Knee Flexion	Warm up	Speed / contraction type, in °/s	Sets and Repetitions	Dominant or non-dominant foot	Encouragement given
Greene et al (2006)	'Standard positioning used'	Not stated	Not stated	60 PF DF	5 reps	dominant	Not stated
Mahieu et al (2006)	Supine	0°	10 sub-max reps at 90° per sec	30, 120 Concentric PF DF	3 reps at 30° per sec and 5 reps at 120° per sec. 1 minute rest between tests	both	Verbal encouragement given
Neto et al (2006)	Not stated	Not stated	Not stated	30, 60, 120, Concentric 60, eccentric PF	3 reps of each apart from 5 reps of 120°	All subjects were right leg dominant, not clear which leg was tested.	Not stated
Sammarco et al. (2006)	Supine	Knee 'flexed'	Not stated	'standardised protocol' PF	5 reps	Both	Not stated
Xu et al (2006)	Supine	Not stated	5mins bike 50-60w 3 submax reps	30 concentric PF DF	3 reps	dominant	Not stated

Reference	Prone/Supine/ weight bearing	Degree of Knee Flexion	Warm up	Speed / contraction type, in °/s	Sets and Repetitions	Dominant or non-dominant foot	Encouragement given
Greene et al (2005)	'Standard positioning used'	'Standard positioning'	Not stated	60 PF DF	5 reps	dominant	Not stated
Demonty et al (2004)	Supine	'straight'	10 mins bike 40w 60rpm 3 submax reps	120, 30 concentric PF DF	5 reps 120° 3 reps 30° 30s rest between sets	both	Not stated
McCarthy et al (2004)	Not stated	Not stated	3 submax reps at 60° per sec	60 PF DF	5 reps right PF DF, 5mins rest, 5 reps left PF DF	both	Not stated
Ferri et al (2003)	Prone	180°	Several sub max reps	30, 60, 90, 120, PF	3 reps at each speed	dominant	Verbal encouragement given
Høiness et al (2003)	Supine	80° - 110°	No warm up	60, 180 eve	5 reps 15min rest 5 reps (to ensure reliability)	Both (1 injured 1 uninjured)	Verbal encouragement given

Reference	Prone/Supine/ weight bearing	Degree of Knee Flexion	Warm up	Speed / contraction type, in °/s	Sets and Repetitions	Dominant or non-dominant foot	Encouragement given
Reeves and Narici (2003)	Supine	90°	Warm up not stated	50, 100, 150, 200, 250, concentric eccentric DF	5 reps each movement each speed 180s rest between contraction sets	right	Not stated
Yildiz et al (2003)	Supine	80° - 110°	10 minute warm up – general rom and stretching. 3 submax trials	120 concentric inv, eccentric eve	5 reps inv, 2mins rest, 5 reps eve	Not stated	Verbal encouragement given
Schulze et al (2002)	Supine	160°	4 sub max contractions at 50% peak torque at each speed	30, 60, 120, 180, 240, 300 concentric eccentric PF	4 maximal contractions at each speed 90s rest between speeds.	left	Not stated
Tsiokanos, et al (2002)	Prone	0°	3 submax reps at each speed	60, 120, 180 Concentric PF	3 reps at each speed, 30s between reps, 5 mins between speeds	Not stated	Not stated

Reference	Prone/Supine/ weight bearing	Degree of Knee Flexion	Warm up	Speed / contraction type, in °/s	Sets and Repetitions	Dominant or non-dominant foot	Encouragement given
Ademoglu et al. (2001)	Supine	10°	2 submax and 1 max rep	30, 120 PF DF	3 reps, 30 seconds between speeds	Both	Not stated
Bourdel-Marchasson et al (2001)	Supine	0°	3 training exercises (reps) for each set	30, 60 PF	2 sets 5 reps at 30° per sec, 1 set of 5 reps at 60° per sec	Right (or the healthy side)	Not stated
Mouraux et al (2000)	Supine	90°	10 minutes bike and familiarisation with the equipment	30, 60, 90 PF Concentric eccentric	3 max reps at each speed. 90 seconds between speeds.	Both pre and post training	Not stated
Wilcox et al. (2000)	Prone	Knee fully extended	3 trial reps at each speed	30, 120 PF DF concentric inferred but not stated	5 reps at 30° per sec, 10 reps at 120° per sec	Both	Not stated

Appendix 4

Calculation of significance based on inv and eve data from van Cingel et al (2009)

		Speed (°/sec)		Mean peak torque	SD	SE	CI
men	inv	30	d	36.73	11.68	3.02	5.91
			nd	33.80	7.66	1.98	3.88
		120	d	27.26	9.61	2.48	4.86
			nd	26.53	9.80	2.53	4.96
	eve	30	d	30.00	8.40	2.17	4.25
			nd	27.86	7.84	2.02	3.97
		120	d	22.40	8.36	2.16	4.23
			nd	21.33	8.30	2.14	4.20
women	inv	30	d	29.93	11.20	2.89	5.67
			nd	31.00	11.30	2.92	5.72
		120	d	21.20	9.17	2.37	4.64
			nd	20.20	7.36	1.90	3.72
	eve	30	d	27.13	13.58	3.51	6.87
			nd	26.13	13.05	3.37	6.60
		120	d	19.20	10.49	2.71	5.31
			nd	18.46	10.41	2.69	5.27

Note:=dominant, nd=non-dominant, SD=standard deviation, SE=standard error calculated as SD/root n, CI = confidence interval calculated as 1.96 x SD.

If the mean peak torque ± the CI of the dominant ankle overlaps the mean of the non-dominant ankle then it can be inferred that there is no significant difference between them.

Appendix 5

Risk assessment for lab work

UNIVERSITY OF HUDDERSFIELD

HEALTH & SAFETY RISK ANALYSIS & MANAGEMENT (RISK ASSESSMENT)

ACTIVITY: USING THE Cybex Isokinetic Dynamometer	**ASSESSMENT BY: Michael Fish**
LOCATION: RG/03	**ASSESSMENT DATE: 19 Oct 2010**

<table>
<tr><th colspan="5">HAZARD IDENTIFIED: Risk of injury whilst using the Cybex Isokinetic Dynamometer</th></tr>
<tr><th rowspan="2">RISKS TO HEALTH AND SAFETY</th><th rowspan="2">PEOPLE AT RISK</th><th rowspan="2">EXISTING RISK MANAGEMENT MEASURES</th><th colspan="2">ADEQUATE?</th></tr>
<tr><th>YES</th><th>NO</th></tr>
<tr><td>musculoskeletal injury due to misuse of the Cybex Isokinetic machine</td><td>Students, staff and external visitors</td><td>Full training given to staff and students on all aspects of using the equipment.
An emergency cut off switch for the user for all tests.
1. Students who are carrying out studies on the machine and are using the machine should always be supervised and the machine should be checked for correct operation.
2. When the machine is in use with a patient or user the patient should not under any circumstances be left alone in the room.
3. The patient should hold the emergency cut out button whilst carrying out exercises and testing on the cybex.
4. Senior staff who supervise students in their studies should attend clinical days at regular intervals for training.</td><td>x</td><td></td></tr>
</table>

<table>
<tr><th colspan="4">ACTIONS REQUIRED:</th></tr>
<tr><th>ADDITIONAL RISK MANAGEMENT MEASURES</th><th>BY WHO?</th><th>BY WHEN?</th><th>COMPLETED</th></tr>
</table>

HAZARD IDENTIFIED: Storage of personal belongings				
RISKS TO HEALTH AND SAFETY	PEOPLE AT RISK	EXISTING RISK MANAGEMENT MEASURES	ADEQUATE?	
			YES	NO
Trips, slips and falls due to personal belongings in the lab. Blocking access and egress in case of emergency	Students, staff and external visitors	All students have access to a locker in the changing rooms in which to store personal clothing and belongings. Smaller valuable items may be brought into the lab and placed on the desks or in a safe corner of the room.		
ACTIONS REQUIRED:				
ADDITIONAL RISK MANAGEMENT MEASURES	BY WHO?	BY WHEN?	COMPLETED	

HAZARD IDENTIFIED: Equipment Cables				
RISKS TO HEALTH AND SAFETY	PEOPLE AT RISK	EXISTING RISK MANAGEMENT MEASURES	ADEQUATE?	
			YES	NO
Trips, slips and falls due to trailing cables	Students, staff and external visitors	Where available all cables are safely housed in appropriate cable bindings. Where this is not possible, all cables are situated as close to the wall as possible and all participants are made aware of the trailing cables to ensure that access and egress in the lab is still available.		
ACTIONS REQUIRED:				
ADDITIONAL RISK MANAGEMENT MEASURES	BY WHO?	BY WHEN?	COMPLETED	

HAZARD IDENTIFIED: Water Spillage				
RISKS TO HEALTH AND SAFETY	PEOPLE AT RISK	EXISTING RISK MANAGEMENT MEASURES	ADEQUATE?	
			YES	NO
Slips, trips or falls due to water spillage around the sinks	Staff, students and visitors	Any water spillages must be wiped up immediately and there are rolls of paper towels above both basins that are checked regularly and stocked up.		
ACTIONS REQUIRED:				
ADDITIONAL RISK MANAGEMENT MEASURES	BY WHO?	BY WHEN?	COMPLETED	

RISK ASSESSMENT REVIEW
TO BE CARRIED OUT ON: Annually
TO BE CARRIED OUT BY:

K:\PhD\The Real Thing2\Post viva\28-07-16 The real thing2 post viva.docx

Appendix 6

E-mail and poster requesting participants

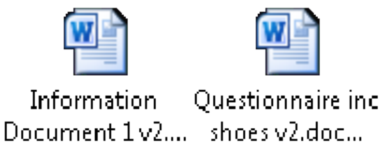
Thank you to those of you who have already taken part in this research!

I am now in a position to carry on testing so if anyone is in the Huddersfield area and can spare 30mins to have their ankle strength tested I would very much appreciate it.

I have attached further details and a questionnaire, if you are interested get in touch via e-mail or phone.

Thank you very much

Michael



From: Michael Fish

Sent: 23 May 2012 16:04

To: HP1003 - BSc Podiatry; HP1203 - BSc Physiotherapy; H403 - BSc(Hons) Exercise, Physical Activity & Health FT

Subject: Isokinetics research

Hello,

As part of my PhD I am investigating muscle strength at the ankle using the Cybex Norm and I need volunteers to have their ankle strength tested. The test will take approximately 30 minutes. I appreciate it is a busy time with exams but if anyone is available between now and the 1st of June I would really appreciate your help.

If you are available please get back to me in RG18 or by e-mail and I will send you further details.

Thanks

Michael

Michael Fish B.Sc M.Sc FHEA

Chief Clinical Technician
Human and Health Sciences
RG18 Ramsden Building
University of Huddersfield

m.fish@hud.ac.uk

Appendix 7

Participant Questionnaire

Questionnaire

Participant number:

Gender: Height: Dominant side: L / R

Weight: Age: Shoe Size:

Section 1 Personal History

1. Do you currently have any ankle pain or an ankle injury? Yes / No
2. Have you ever consulted a healthcare professional regarding an ankle injury? Yes / No
3. Do you have any ankle pain, injury or other impairment that affects everyday function eg walking up or down stairs or crouching down? Yes/No
4. Do you or have you ever been diagnosed with diabetes? Yes / No
5. Do you or have you ever been diagnosed with a disease that affects the muscles eg Guillain-Barré syndrome? Yes / No
6. Do you or have you ever been diagnosed with a disease of the nervous system eg Parkinsons disease, Multiple Sclerosis, chronic fatigue syndrome? Yes / No
7. Do you have or have you ever been diagnosed with conditions of the bone or joint eg shin splints, osteoarthritis, Still's disease, rheumatoid arthritis, osteoporosis, Perthes disease? Yes/No
8. Do you suffer or have you suffered from low-back pain and/or sciatica? Yes/No
9. Do you know of any other reason why you cannot take part in this experiment?

"I have read, completed and understood this section of the questionnaire. Any questions that I had were answered to my full satisfaction"

Signed (participant) ……………………………………………… Date…………………..

Print ………………………………………………..

Signed (principal researcher)…………………………………… Date……………………

Appendix 8

Informed Consent Form

UNIVERSITY OF HUDDERSFIELD

Testing Ankle Strength

Michael Fish

Consent form

I have been fully informed of the nature and aims of this research and consent to taking part in it.	☐
I understand that I have the right to withdraw from the experiment at any time without giving any reason, and a right to withdraw my data if I wish.	☐
I understand that the data will be kept in secure conditions at the University of Huddersfield.	☐
I understand that no person other than the principal researcher will have access to the data.	☐
I understand that my identity will be protected by the use of participant number in the research report and that no information that could lead to my being identified will be included in any report or publication resulting from this research.	☐

Name of participant

Signature

Date

Name of researcher

Signature

Date

Two copies of this consent from should be completed: One copy to be retained by the participant and one copy to be retained by the researcher

Appendix 9

Randomisation table to determine the testing order.

PFDF ecc	PFDF con	inv eve ecc	inv eve con	1	9	17	25	33	41	49	57	65	73	81	89	97
inv eve ecc	inv eve con	PFDF ecc	PFDF con	2	10	18	26	34	42	50	58	66	74	82	90	98
PFDF ecc	PFDF con	inv eve con	inv eve ecc	3	11	19	27	35	43	51	59	67	75	83	91	99
inv eve con	inv eve ecc	PFDF ecc	PFDF con	4	12	20	28	36	44	52	60	68	76	84	92	100
PFDF con	PFDF ecc	inv eve ecc	inv eve con	5	13	21	29	37	45	53	61	69	77	85	93	101
inv eve ecc	inv eve con	PFDF con	PFDF ecc	6	14	22	30	38	46	54	62	70	78	86	94	102
PFDF con	PFDF ecc	inv eve con	inv eve ecc	7	15	23	31	39	47	55	63	71	79	87	95	103
inv eve con	inv eve ecc	PFDF con	PFDF ecc	8	16	24	32	40	48	56	64	72	80	88	96	104

PFDF ecc	PFDF con	inv eve ecc	inv eve con	105	113	121	129	137	145	153	161	169	177	185	193	201
inv eve ecc	inv eve con	PFDF ecc	PFDF con	106	114	122	130	138	146	154	162	170	178	186	194	202
PFDF ecc	PFDF con	inv eve con	inv eve ecc	107	115	123	131	139	147	155	163	171	179	187	195	203
inv eve con	inv eve ecc	PFDF ecc	PFDF con	108	116	124	132	140	148	156	164	172	180	188	196	204
PFDF con	PFDF ecc	inv eve ecc	inv eve con	109	117	125	133	141	149	157	165	173	181	189	197	205
inv eve ecc	inv eve con	PFDF con	PFDF ecc	110	118	126	134	142	150	158	166	174	182	190	198	206
PFDF con	PFDF ecc	inv eve con	inv eve ecc	111	119	127	135	143	151	159	167	175	183	191	199	207
inv eve con	inv eve ecc	PFDF con	PFDF ecc	112	120	128	136	144	152	160	168	176	184	192	200	208

Note PF = plantar flexion; DF = dorsiflexion; inv = inversion; eve = eversion; con = concentric; ecc = eccentric

Appendix 10

A comparison of the test-retest reliability data of studies which used the Cybex Norm to measure AMS.

Study	Variables				*P* value	SEM%	SEM (Nm)	ICC
	Position	Contraction type	Speed	Gender				
van Cingel et al. (2009)	Supine, seated, knee at 10° flexion	Concentric inv	30°/s	M	-	15.63	5.69	0.74
				F	-	11.00	3.20	0.93
			120°/s	M	-	17.04	4.52	0.78
				F	-	19.22	4.05	0.80
		Concentric eve	30°/s	M	-	12.99	3.89	0.77
				F	-	10.05	2.67	0.96
			120°/s	M	-	13.21	2.94	0.82
				F	-	14.48	2.99	0.91
Laughlin et al. (2009)	Prone, knee at full extension	Concentric PF	30°/s	M	0.124	4.3	5.2	0.93
		Concentric DF			0.429	9.2	2.8	0.67
		Eccentric PF			0.079	4.7	7.1	0.93
		Eccentric DF			0.083	2.6	1.2	0.96
(Taskiran et al. (2013))	Prone, knee at full extension	Concentric PF	30°/s	11F / 2M mixed group	-	-	-	0.92
			120°/s		-	-	-	0.86
		Concentric DF	30°/s		-	-	-	0.91
			120°/s		-	-	-	0.85

Note SEM = standard error of the mean; ICC = intraclass correlation coefficient. PF = plantar flexion; DF = dorsiflexion; inv = inversion; eve = eversion. *P* value refers to the significance of a paired samples t-test result.

Appendix 11

The results of an independent samples t-test to determine the difference in AMS between males and females.

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% CI of the Difference	
									Lower	Upper
PFcon	Equal variances assumed	3.62	0.06	7.67	108.00	0.00	23.23	3.03	17.22	29.24
	Equal variances not assumed			7.38	82.64	0.00	23.23	3.15	16.97	29.49
DFcon	Equal variances assumed	12.55	0.00	9.96	109.00	0.00	8.41	0.84	6.74	10.09
	Equal variances not assumed			9.38	72.33	0.00	8.41	0.90	6.63	10.20
PFecc	Equal variances assumed	6.45	0.01	5.57	99.00	0.00	34.59	6.21	22.26	46.92
	Equal variances not assumed			5.44	81.35	0.00	34.59	6.36	21.94	47.24
DFecc	Equal variances assumed	10.71	0.00	10.86	109.00	0.00	17.41	1.60	14.23	20.58
	Equal variances not assumed			10.33	77.40	0.00	17.41	1.69	14.05	20.76

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% CI of the Difference	
									Lower	upper
Invcon	Equal variances assumed	0.04	0.84	4.98	109.00	0.00	5.74	1.15	3.46	8.03
	Equal variances not assumed			4.96	101.52	0.00	5.74	1.16	3.44	8.04
Evecon	Equal variances assumed	0.04	0.84	5.98	109.00	0.00	5.72	0.96	3.83	7.62
	Equal variances not assumed			5.92	98.57	0.00	5.72	0.97	3.80	7.64
Invecc	Equal variances assumed	2.87	0.09	5.20	109.00	0.00	8.11	1.56	5.01	11.20
	Equal variances not assumed			5.09	93.84	0.00	8.11	1.59	4.95	11.27
Eveecc	Equal variances assumed	0.56	0.46	2.22	108.00	0.03	5.48	2.47	0.58	10.37
	Equal variances not assumed			2.29	107.50	0.02	5.48	2.40	0.73	10.22

Note PF = plantar flexion; DF = dorsiflexion; inv = inversion; eve = eversion; con = concentric; ecc = eccentric; df = degrees of freedom

Appendix 12

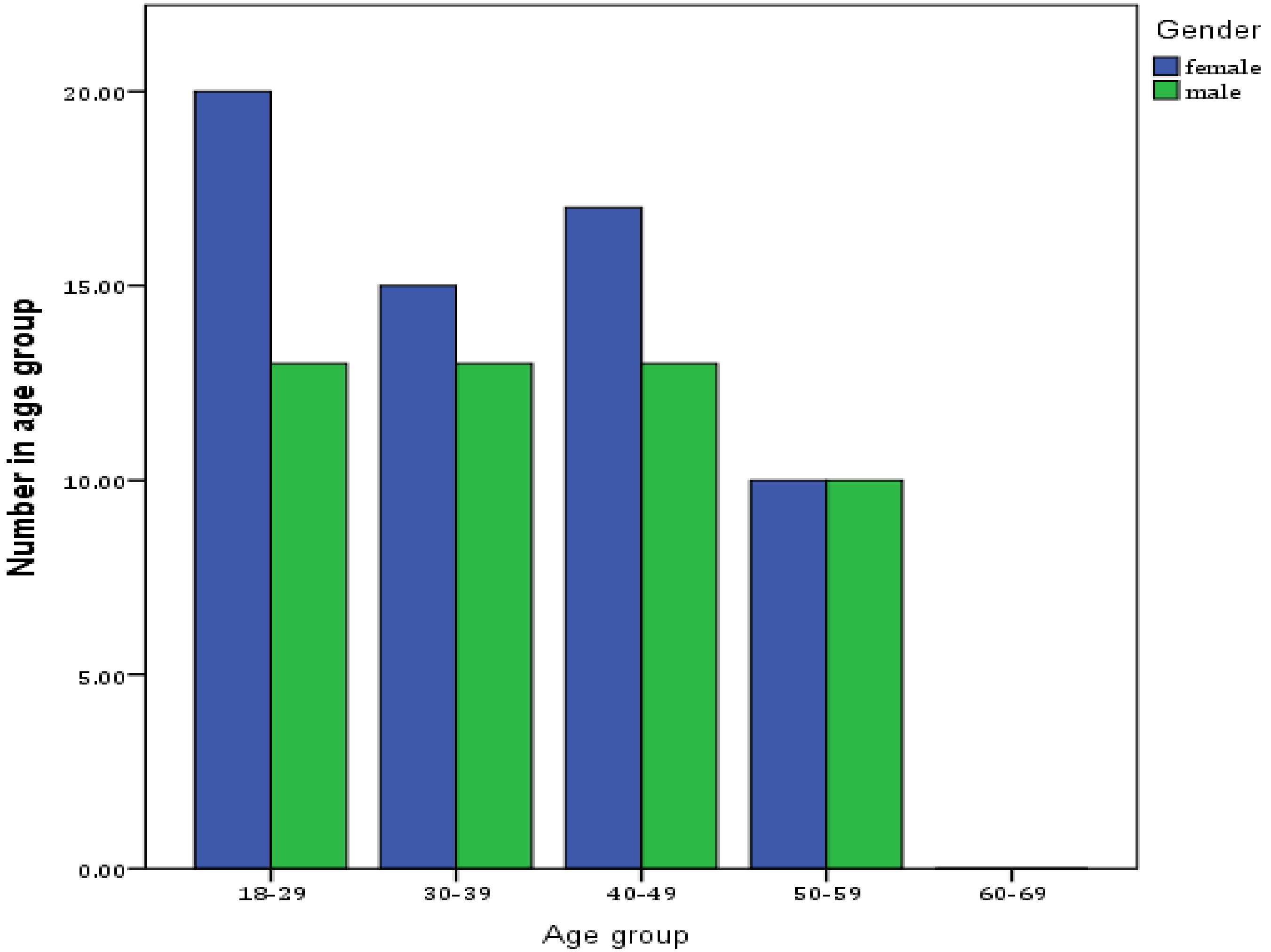
The results of a Pearsons correlation test to determine a possible relationship between age and AMS.

	PFcon	DFcon	PFecc	DFecc	Invcon	Evecon	Invecc	Eveecc
Pearson Correlation	-0.10	-0.06	0.05	0.06	-0.08	-0.17	0.02	-0.02
Sig. (2-tailed)	0.32	0.56	0.64	0.53	0.41	0.08	0.88	0.88
N	110	111	101	111	111	111	111	110

Note PF = plantar flexion; DF = dorsiflexion; inv = inversion; eve = eversion; con = concentric; ecc = eccentric

Appendix 13

A graph comparing the number of each gender per age group



Appendix 14

The results of a Pearsons correlation test to determine the relationship between mass and AMS.

	PFcon	DFcon	PFecc	DFecc	Invcon	Evecon	Invecc	Eveecc
Pearson Correlation	0.46	0.67	0.36	0.69	0.38	0.32	0.38	0.23
Sig. (2-tailed)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
N	110	111	101	111	111	111	111	110

Note PF = plantar flexion; DF = dorsiflexion; inv = inversion; eve = eversion; con = concentric; ecc = eccentric

Appendix 15

An independent samples t-test comparing mass between genders

	Levene's Test for Equality of Variances		t-test for Equality of Means						
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% CI of the Difference	
								Lower	Upper
Equal variances assumed	3.73	0.06	-5.99	109.0	0.00	-16.30	2.72	-21.69	-10.91
Equal variances not assumed			-5.82	89.31	0.00	-16.30	2.80	-21.86	-10.74

Appendix 16

An independent samples t-test comparing AMS between genders in a 60-79.9kg body mass group.

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% CI of the Difference	
									Lower	Upper
PFcon	Equal variances assumed	0.47	0.50	-5.56	56.00	0.00	-20.52	3.69	-27.91	-13.13
	Equal variances not assumed			-5.41	44.45	0.00	-20.52	3.79	-28.16	-12.87
DFcon	Equal variances assumed	0.38	0.54	-5.52	56.00	0.00	-5.16	0.94	-7.04	-3.29
	Equal variances not assumed			-5.52	49.55	0.00	-5.16	0.94	-7.04	-3.28
PFecc	Equal variances assumed	7.35	0.01	-3.56	52.00	0.00	-32.03	9.01	-50.11	-13.95
	Equal variances not assumed			-3.28	32.62	0.00	-32.03	9.76	-51.90	-12.16
DFecc	Equal variances assumed	4.35	0.04	-5.79	56.00	0.00	-10.29	1.78	-13.85	-6.73
	Equal variances not assumed			-5.44	38.11	0.00	-10.29	1.89	-14.12	-6.46

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% CI of the Difference	
									Lower	Upper
Invcon	Equal variances assumed	1.19	0.28	-2.61	56.00	0.01	-4.38	1.68	-7.75	-1.02
	Equal variances not assumed			-2.72	55.05	0.01	-4.38	1.61	-7.62	-1.15
Evecon	Equal variances assumed	0.07	0.80	-5.48	56.00	0.00	-5.41	0.99	-7.39	-3.43
	Equal variances not assumed			-5.55	52.01	0.00	-5.41	0.97	-7.37	-3.46
Invecc	Equal variances assumed	1.87	0.18	-2.39	56.00	0.02	-5.32	2.23	-9.79	-0.85
	Equal variances not assumed			-2.32	44.70	0.03	-5.32	2.29	-9.94	-0.71
Eveecc	Equal variances assumed	0.13	0.72	-0.22	55.00	0.83	-0.70	3.16	-7.04	5.64
	Equal variances not assumed			-0.24	54.32	0.81	-0.70	2.96	-6.64	5.23

Note PF = plantar flexion; DF = dorsiflexion; inv = inversion; eve = eversion; con = concentric; ecc = eccentric

Appendix 17

An independent samples t-test comparing AMS between genders in a 80-99.9kg body mass group.

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% CI of the Difference	
									Lower	Upper
PFcon	Equal variances assumed	0.00	0.99	-1.84	21.00	0.08	-18.31	9.95	-39.01	2.38
	Equal variances not assumed			-2.01	10.51	0.07	-18.31	9.10	-38.45	1.82
DFcon	Equal variances assumed	3.31	0.08	-4.56	22.00	0.00	-8.45	1.85	-12.29	-4.60
	Equal variances not assumed			-6.10	21.60	0.00	-8.45	1.39	-11.32	-5.57
PFecc	Equal variances assumed	0.26	0.62	-1.03	20.00	0.32	-19.28	18.73	-58.36	19.79
	Equal variances not assumed			-1.14	7.77	0.29	-19.28	16.88	-58.42	19.85
DFecc	Equal variances assumed	0.67	0.42	-4.44	22.00	0.00	-16.66	3.75	-24.43	-8.88
	Equal variances not assumed			-3.81	8.49	0.01	-16.66	4.38	-26.65	-6.66

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% CI of the Difference	
									Lower	Upper
Invcon	Equal variances assumed	0.02	0.90	-1.43	22.00	0.17	-4.56	3.19	-11.17	2.05
	Equal variances not assumed			-1.43	11.28	0.18	-4.56	3.18	-11.55	2.42
Evecon	Equal variances assumed	0.58	0.46	-1.92	22.00	0.07	-5.55	2.89	-11.53	0.44
	Equal variances not assumed			-2.35	18.38	0.03	-5.55	2.36	-10.49	-0.60
Invecc	Equal variances assumed	0.01	0.95	-2.08	22.00	0.05	-8.04	3.87	-16.06	-0.03
	Equal variances not assumed			-2.03	10.72	0.07	-8.04	3.96	-16.78	0.69
Eveecc	Equal variances assumed	0.00	0.97	-2.62	22.00	0.02	-14.08	5.38	-25.24	-2.93
	Equal variances not assumed			-2.74	12.44	0.02	-14.08	5.14	-25.23	-2.94

Note PF = plantar flexion; DF = dorsiflexion; inv = inversion; eve = eversion; con = concentric; ecc = eccentric

Appendix 18

A Pearsons correlation test examining the relationship between height and AMS

	PFcon	DFcon	PFecc	DFecc	Invcon	Evecon	Invecc	Eveecc
Pearson Correlation	0.55	0.67	0.48	0.71	0.31	0.32	0.35	0.25
Sig. (2-tailed)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
N	110	111	101	111	111	111	111	110

Appendix 19

An independent samples t-test showing the relationship in height between genders

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% CI of the Difference	
									Lower	Upper
Height	Equal variances assumed	0.47	0.50	-8.73	109.00	0.00	-10.42	1.19	-12.78	-8.05
	Equal variances not assumed			-8.76	104.61	0.00	-10.42	1.19	-12.77	-8.06

Appendix 20

An independent samples t-test examining the relationship in height between genders in the 165-169.9 height group.

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% CI of the Difference	
									Lower	Upper
Height	Equal variances assumed	0.10	0.76	-1.74	17.00	0.10	-1.32	0.76	-2.92	0.28
	Equal variances not assumed			-1.68	9.03	0.13	-1.32	0.78	-3.09	0.45

Appendix 21

An independent samples t-test examining the relationship in AMS between genders in the 165-169.9 height group.

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% CI of the Difference	
									Lower	Upper
PFcon	Equal variances assumed	1.58	0.23	-1.51	17.00	0.15	-10.55	7.01	-25.33	4.23
	Equal variances not assumed			-1.28	6.99	0.24	-10.55	8.26	-30.08	8.98
DFcon	Equal variances assumed	0.00	0.96	-1.28	17.00	0.22	-2.46	1.92	-6.51	1.59
	Equal variances not assumed			-1.36	11.42	0.20	-2.46	1.81	-6.42	1.50
PFecc	Equal variances assumed	4.62	0.05	-1.25	14.00	0.23	-19.33	15.45	-52.46	13.80
	Equal variances not assumed			-1.03	5.32	0.35	-19.33	18.85	-66.94	28.28
DFecc	Equal variances assumed	1.13	0.30	-3.51	17.00	0.00	-10.77	3.07	-17.25	-4.29
	Equal variances not assumed			-3.01	7.12	0.02	-10.77	3.58	-19.21	-2.33

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% CI of the Difference	
									Lower	Upper
Invcon	Equal variances assumed	0.08	0.78	-1.33	17.00	0.20	-4.55	3.42	-11.77	2.67
	Equal variances not assumed			-1.30	9.25	0.23	-4.55	3.51	-12.46	3.36
Evecon	Equal variances assumed	0.27	0.61	-2.84	17.00	0.01	-6.42	2.26	-11.19	-1.66
	Equal variances not assumed			-2.69	8.62	0.03	-6.42	2.39	-11.87	-0.98
Invecc	Equal variances assumed	0.04	0.85	-1.18	17.00	0.25	-5.44	4.60	-15.14	4.27
	Equal variances not assumed			-1.35	13.73	0.20	-5.44	4.03	-14.09	3.22
Eveecc	Equal variances assumed	0.32	0.58	-0.14	17.00	0.89	-1.22	8.82	-19.82	17.39
	Equal variances not assumed			-0.18	16.88	0.86	-1.22	6.90	-15.78	13.34

Note PF = plantar flexion; DF = dorsiflexion; inv = inversion; eve = eversion; con = concentric; ecc = eccentric

Appendix 22

An independent samples t-test exploring the height relationship between genders in the 170-174.9cm group.

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% CI of the Difference	
									Lower	Upper
Height	Equal variances assumed	0.53	0.48	-1.90	21.00	0.07	-0.98	0.51	-2.05	0.09
	Equal variances not assumed			-1.88	19.53	0.08	-0.98	0.52	-2.06	0.11

Appendix 23

An independent t-test exploring the AMS relationship between genders in the 170-174.9cm group.

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% CI of the Difference	
									Lower	Upper
PFcon	Equal variances assumed	0.27	0.61	-3.49	21.00	0.00	-22.00	6.30	-35.11	-8.89
	Equal variances not assumed			-3.45	18.95	0.00	-22.00	6.37	-35.34	-8.66
DFcon	Equal variances assumed	5.78	0.03	-4.12	21.00	0.00	-6.61	1.61	-9.95	-3.27
	Equal variances not assumed			-3.98	12.88	0.00	-6.61	1.66	-10.20	-3.02
PFecc	Equal variances assumed	1.03	0.32	-1.14	19.00	0.27	-18.08	15.92	-51.39	15.23
	Equal variances not assumed			-1.12	16.89	0.28	-18.08	16.12	-52.11	15.95
DFecc	Equal variances assumed	12.30	0.00	-2.74	21.00	0.01	-9.32	3.40	-16.38	-2.25
	Equal variances not assumed			-2.64	11.19	0.02	-9.32	3.54	-17.08	-1.55

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% CI of the Difference	
									Lower	Upper
Invcon	Equal variances assumed	0.37	0.55	-1.42	21.00	0.17	-3.55	2.50	-8.74	1.64
	Equal variances not assumed			-1.43	20.69	0.17	-3.55	2.47	-8.69	1.60
Evecon	Equal variances assumed	0.14	0.72	-2.41	21.00	0.03	-3.04	1.26	-5.66	-0.42
	Equal variances not assumed			-2.42	20.99	0.03	-3.04	1.26	-5.65	-0.42
Invecc	Equal variances assumed	4.26	0.05	-2.40	21.00	0.03	-8.90	3.72	-16.63	-1.17
	Equal variances not assumed			-2.36	17.45	0.03	-8.90	3.78	-16.86	-0.94
Eveecc	Equal variances assumed	0.67	0.42	-0.84	20.00	0.41	-3.18	3.79	-11.10	4.73
	Equal variances not assumed			-0.84	18.49	0.41	-3.18	3.79	-11.14	4.77

Note PF = plantar flexion; DF = dorsiflexion; inv = inversion; eve = eversion; con = concentric; ecc = eccentric

Appendix 24

An independent samples t-test examining the relationship in height between genders in the 175-179.9cm height group.

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% CI of the Difference	
									Lower	Upper
Height	Equal variances assumed	0.50	0.49	-1.62	21.00	0.12	-1.14	0.70	-2.61	0.32
	Equal variances not assumed			-1.78	10.54	0.10	-1.14	0.64	-2.56	0.28

Appendix 25

An independent samples t-test examining the relationship in AMS between genders in the 175-179.9cm height group.

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% CI of the Difference Lower	Upper
PFcon	Equal variances assumed	0.12	0.74	-1.70	21.00	0.11	-14.96	8.82	-33.31	3.38
	Equal variances not assumed			-1.63	8.22	0.14	-14.96	9.19	-36.06	6.13
DFcon	Equal variances assumed	2.00	0.17	-3.23	21.00	0.00	-7.98	2.47	-13.12	-2.84
	Equal variances not assumed			-4.42	18.28	0.00	-7.98	1.81	-11.77	-4.19
PFecc	Equal variances assumed	0.07	0.79	-1.11	21.00	0.28	-18.28	16.45	-52.49	15.92
	Equal variances not assumed			-1.14	9.21	0.28	-18.28	16.06	-54.49	17.92
DFecc	Equal variances assumed	1.54	0.23	-3.43	21.00	0.00	-14.65	4.27	-23.54	-5.76
	Equal variances not assumed			-4.19	13.68	0.00	-14.65	3.50	-22.17	-7.12

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% CI of the Difference	
									Lower	Upper
Invcon	Equal variances assumed	5.53	0.03	-3.06	21.00	0.01	-7.89	2.58	-13.25	-2.54
	Equal variances not assumed			-4.46	20.46	0.00	-7.89	1.77	-11.58	-4.21
Evecon	Equal variances assumed	1.32	0.26	-4.21	21.00	0.00	-7.56	1.80	-11.29	-3.82
	Equal variances not assumed			-5.46	15.96	0.00	-7.56	1.39	-10.50	-4.62
Invecc	Equal variances assumed	1.49	0.24	-1.42	21.00	0.17	-5.59	3.94	-13.78	2.60
	Equal variances not assumed			-1.84	15.97	0.08	-5.59	3.04	-12.03	0.85
Eveecc	Equal variances assumed	3.27	0.09	-0.66	21.00	0.52	-3.14	4.76	-13.03	6.76
	Equal variances not assumed			-0.85	15.76	0.41	-3.14	3.69	-10.96	4.69

Note PF = plantar flexion; DF = dorsiflexion; inv = inversion; eve = eversion; con = concentric; ecc = eccentric

Appendix 26

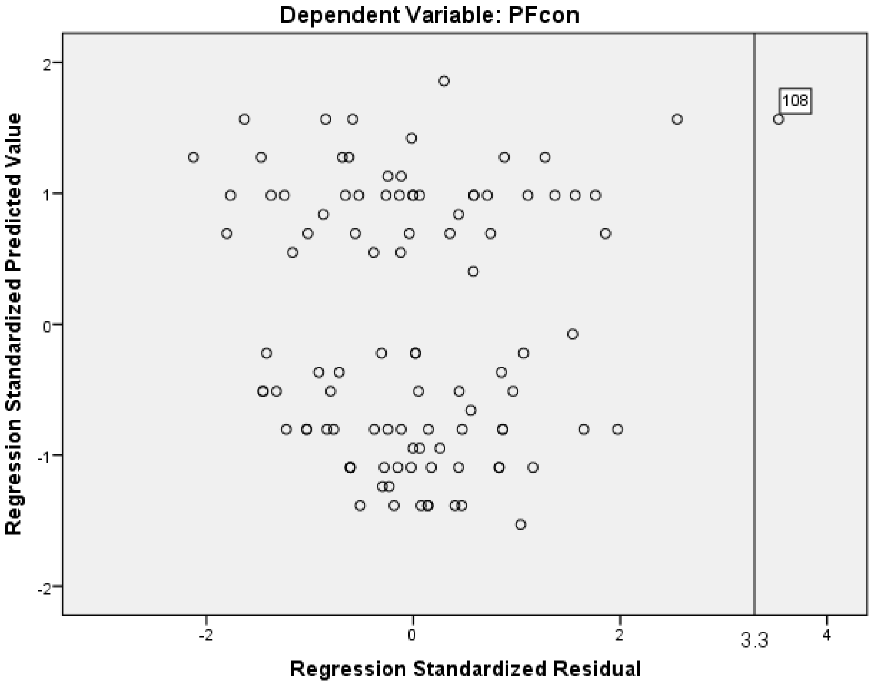
A Pearson's correlation test showing the relationship between shoe size and AMS

		PFcon	DFcon	PFecc	DFecc	Invcon	Evecon	Invecc	Eveecc
Footsize	Pearson Correlation	0.60	0.66	0.50	0.71	0.38	0.43	0.41	0.23
	Sig. (2-tailed)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
	N	110	111	101	111	111	111	111	110

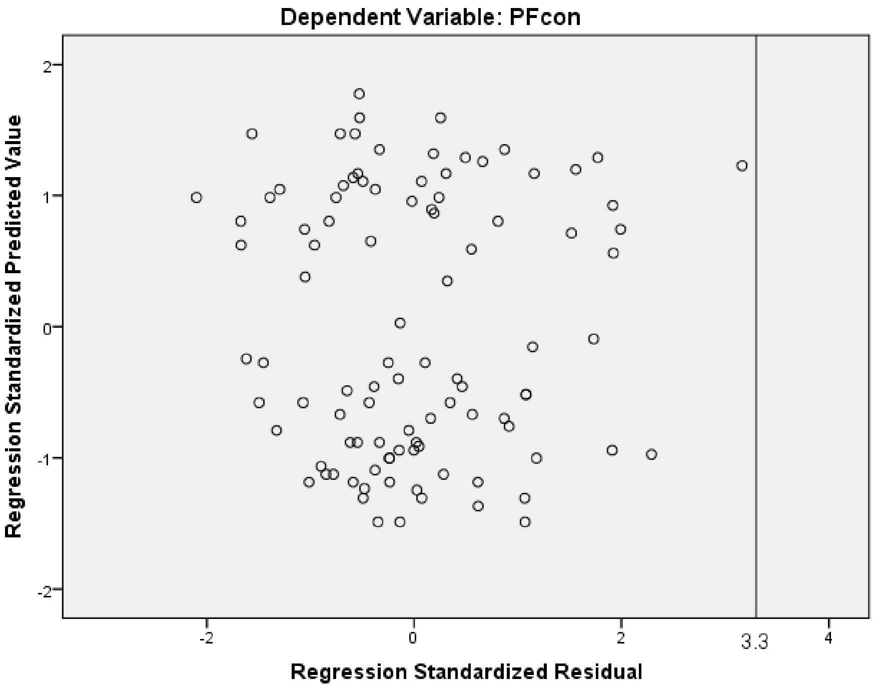
Note PF = plantar flexion; DF = dorsiflexion; inv = inversion; eve = eversion; con = concentric; ecc = eccentric

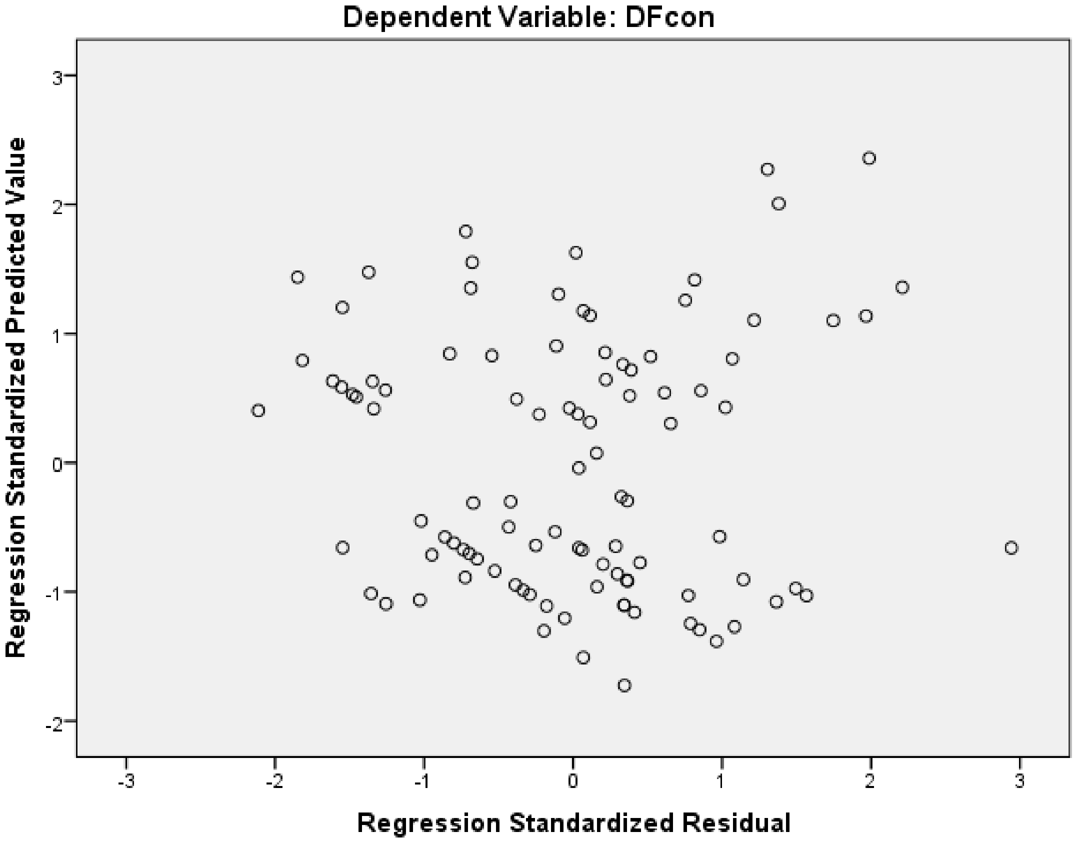
Appendix 27

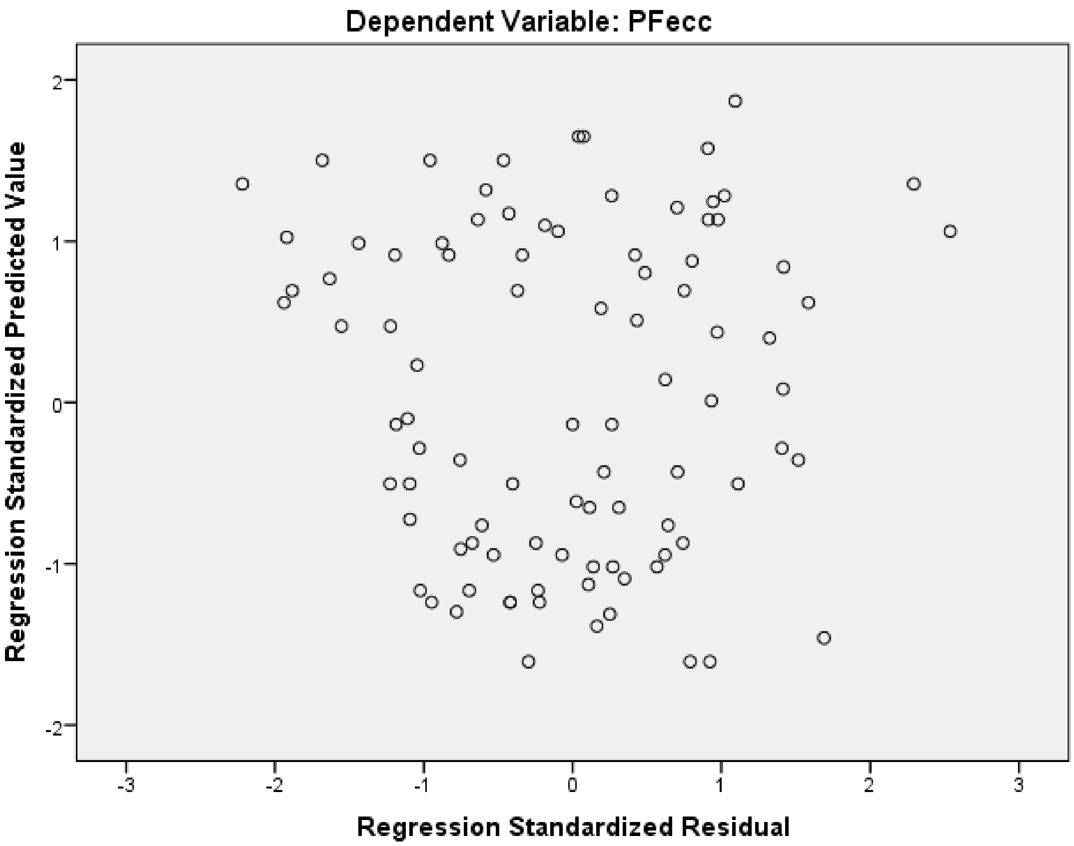
Scatter plots indicating the distribution of the residual variation in predictions of AMS

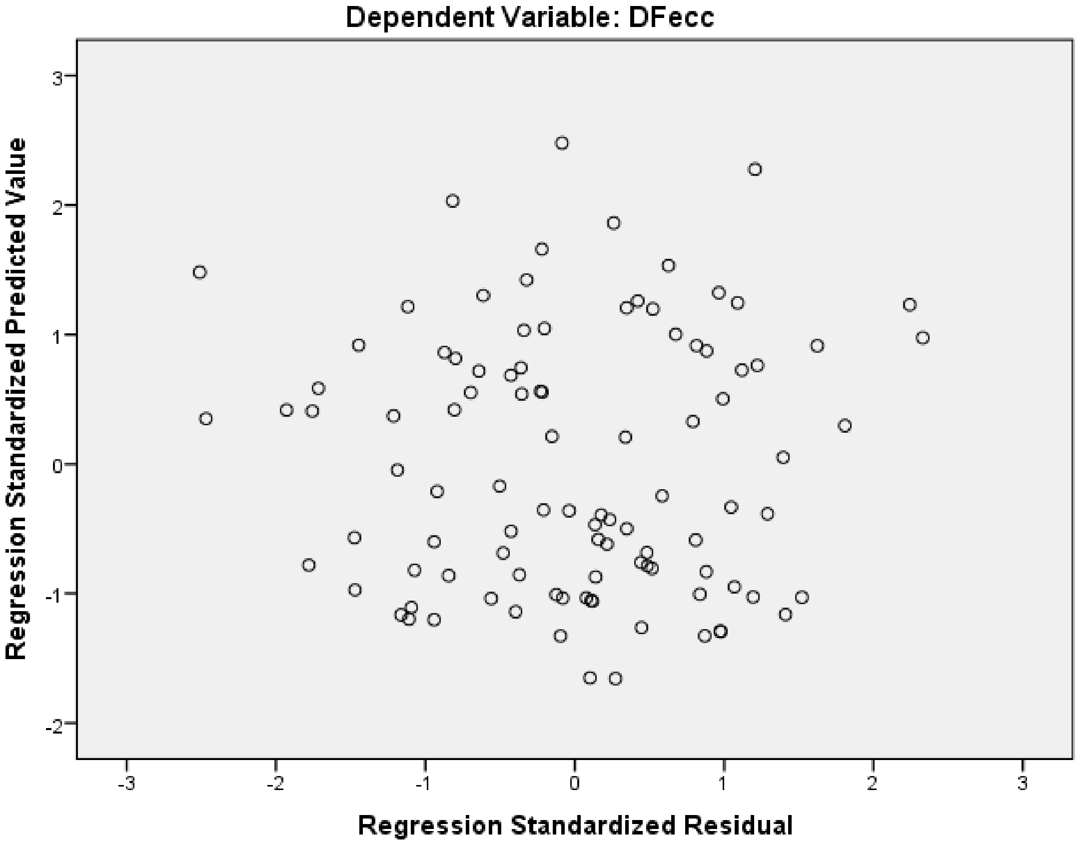


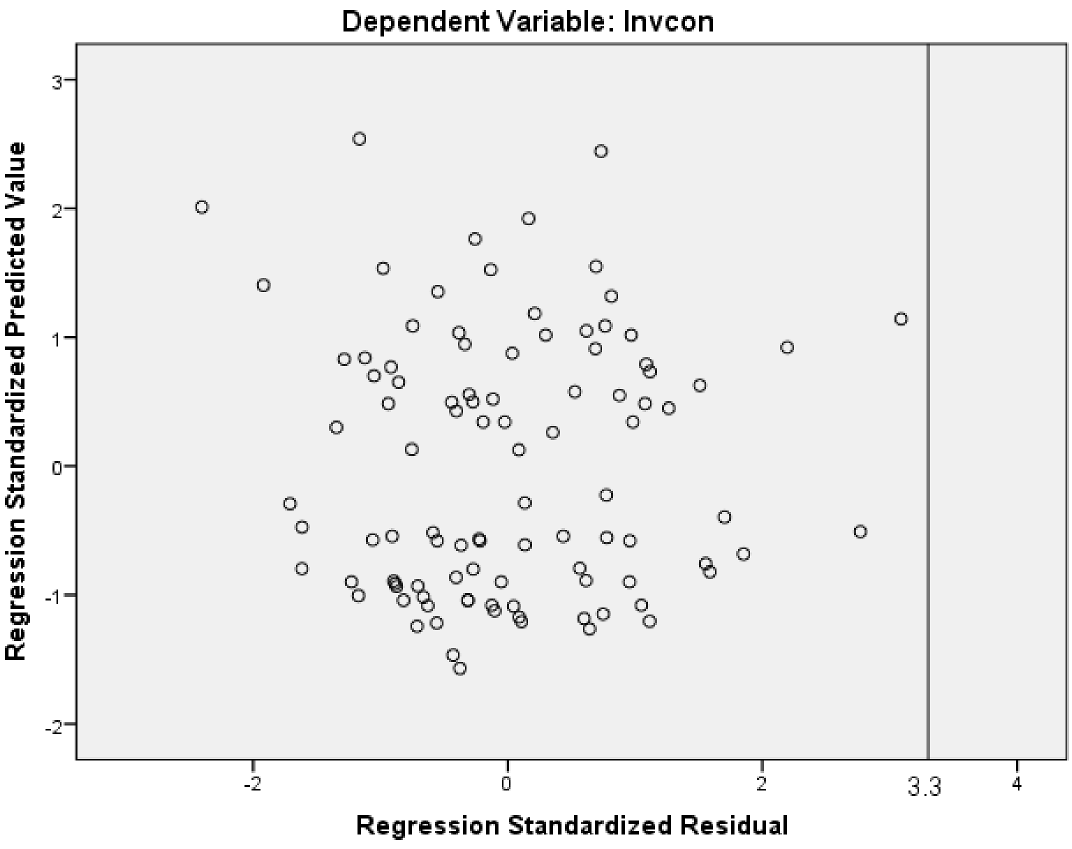
After outlier removed:

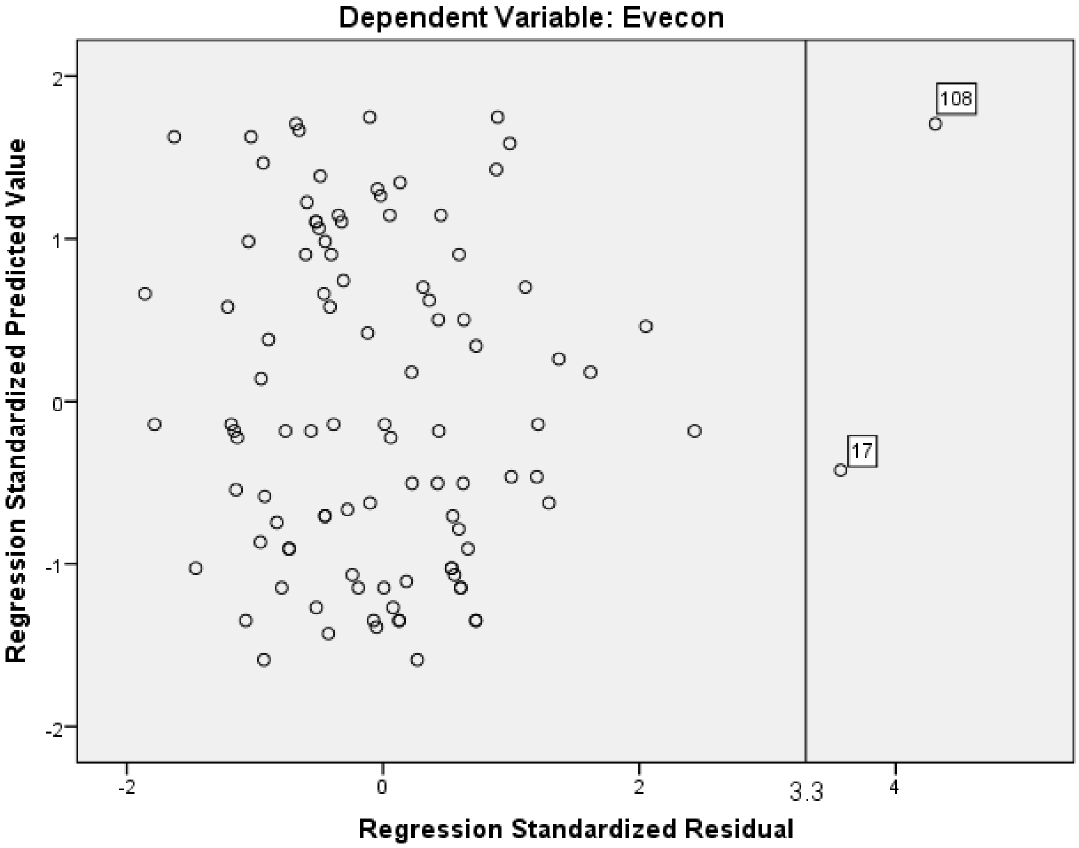



Dependent Variable: DFcon
Regression Standardized Predicted Value
Regression Standardized Residual
3
2
1
0
-1
-2
-3
-2
-1
0
1
2
3

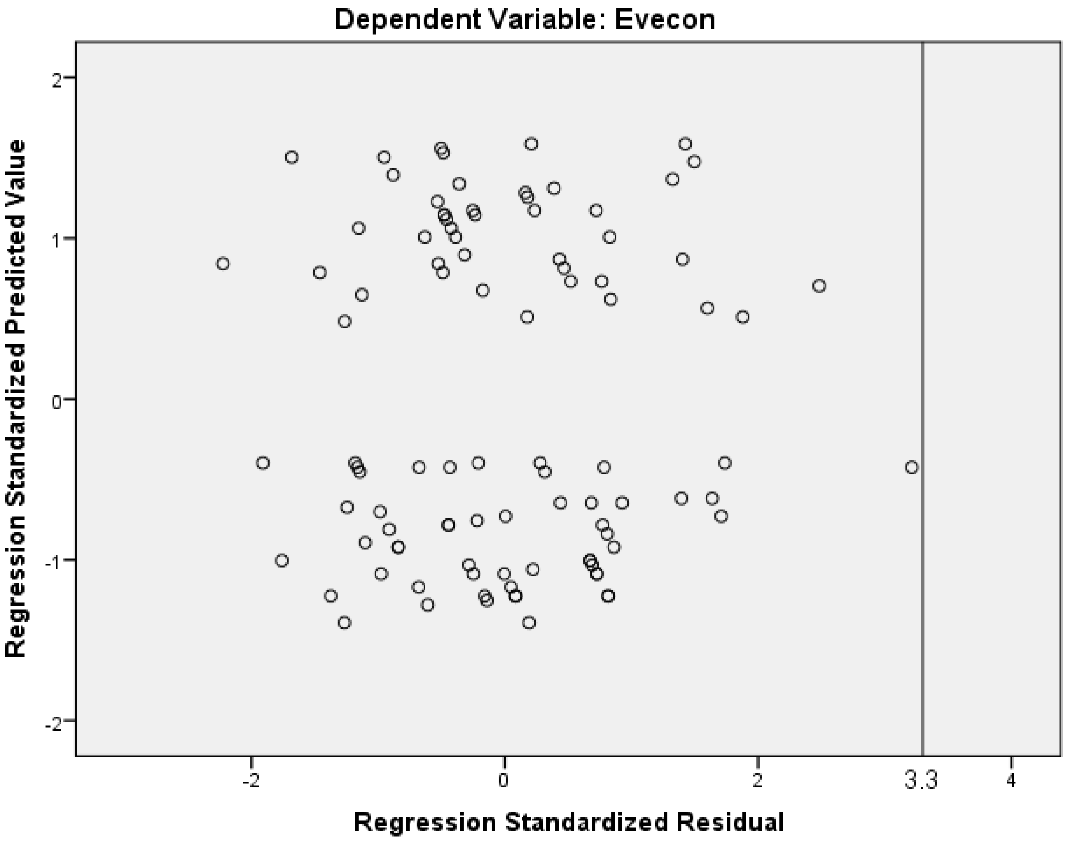

Dependent Variable: PFecc
Regression Standardized Predicted Value
Regression Standardized Residual
2
1
0
-1
-2
-3
-2
-1
0
1
2
3

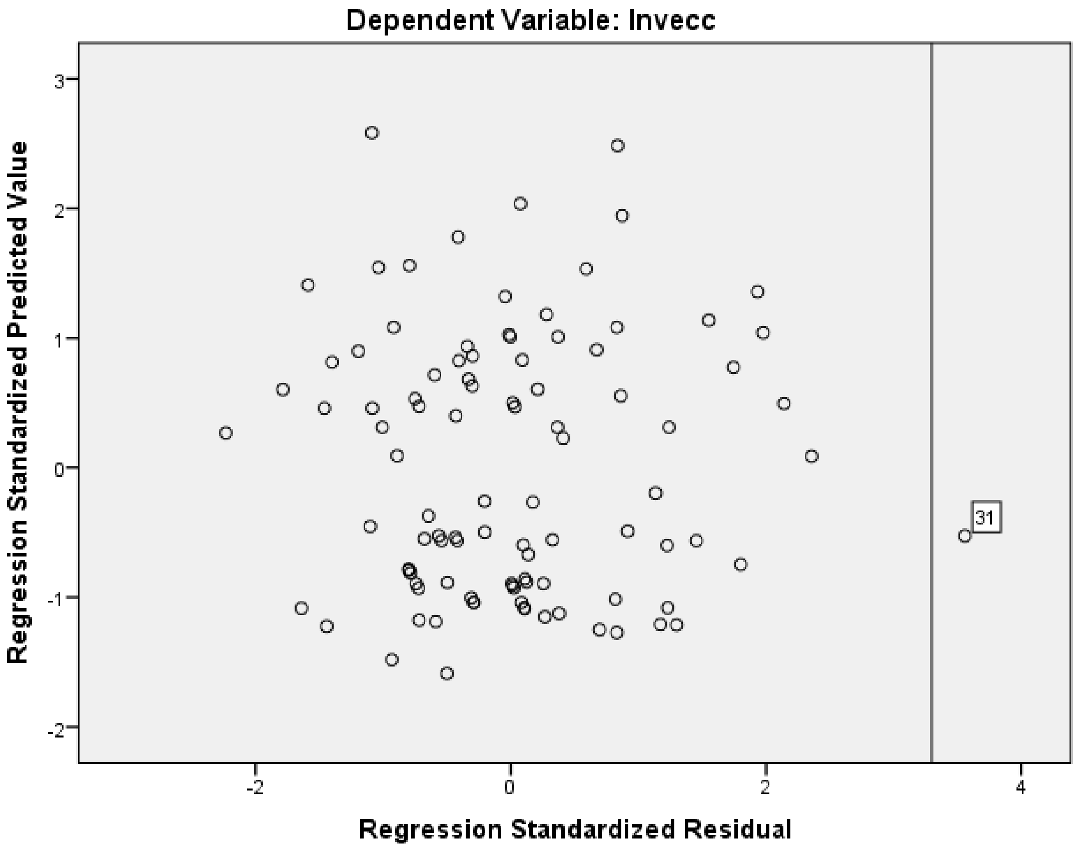

Dependent Variable: DFecc
Regression Standardized Predicted Value
3
2
1
0
-1
-2
-3
-2
-1
0
1
2
3
Regression Standardized Residual


Dependent Variable: Invcon
Regression Standardized Predicted Value
3
2
1
0
-1
-2
-2
0
2
3.3
4
Regression Standardized Residual

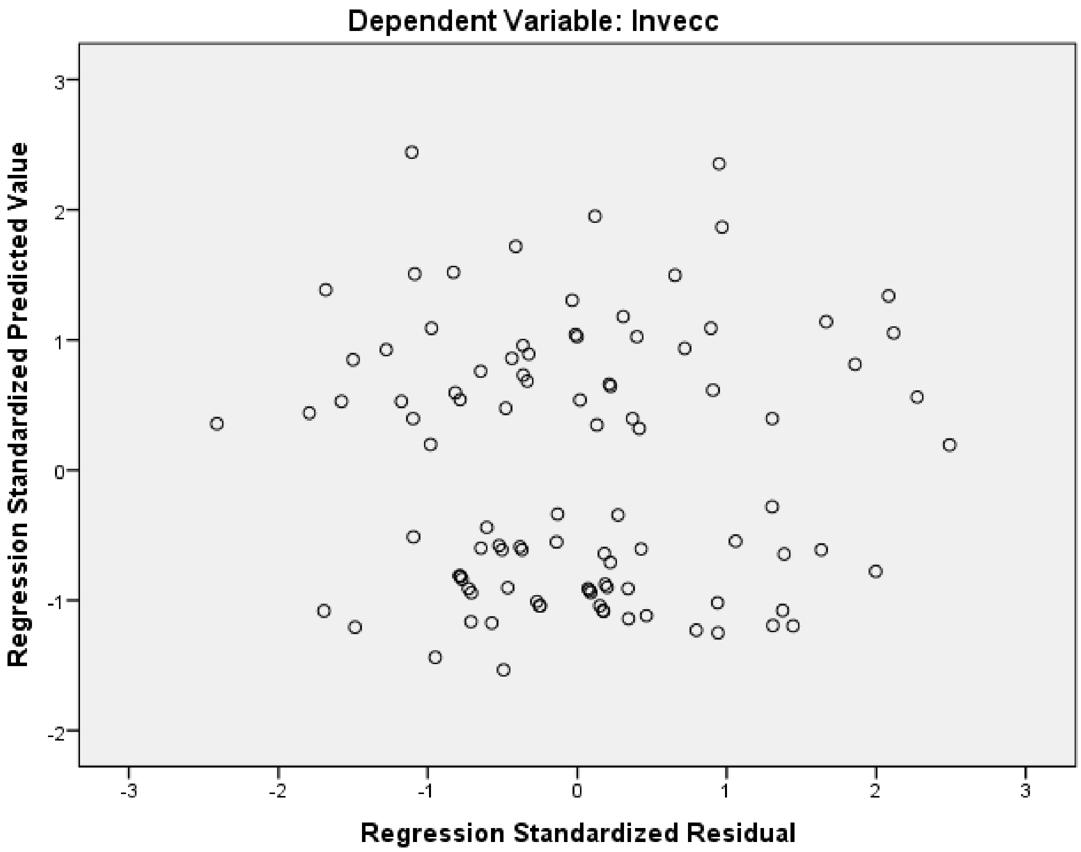


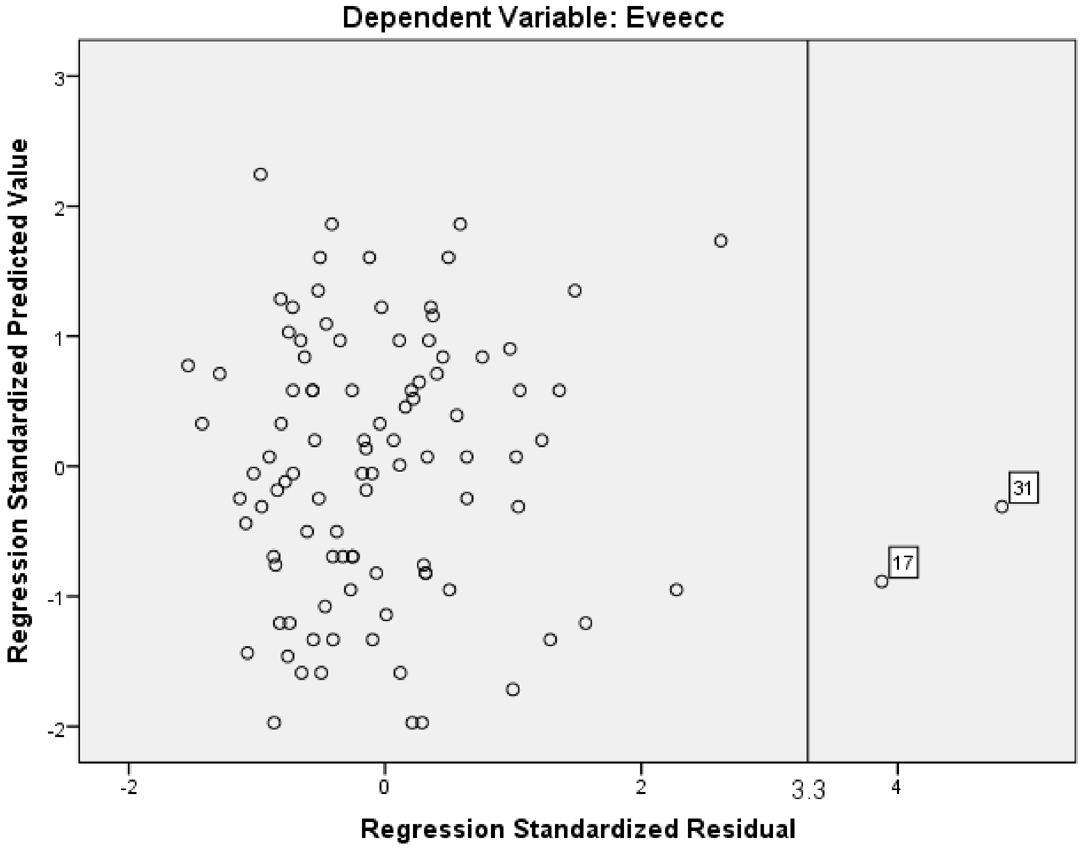
After outliers were removed:



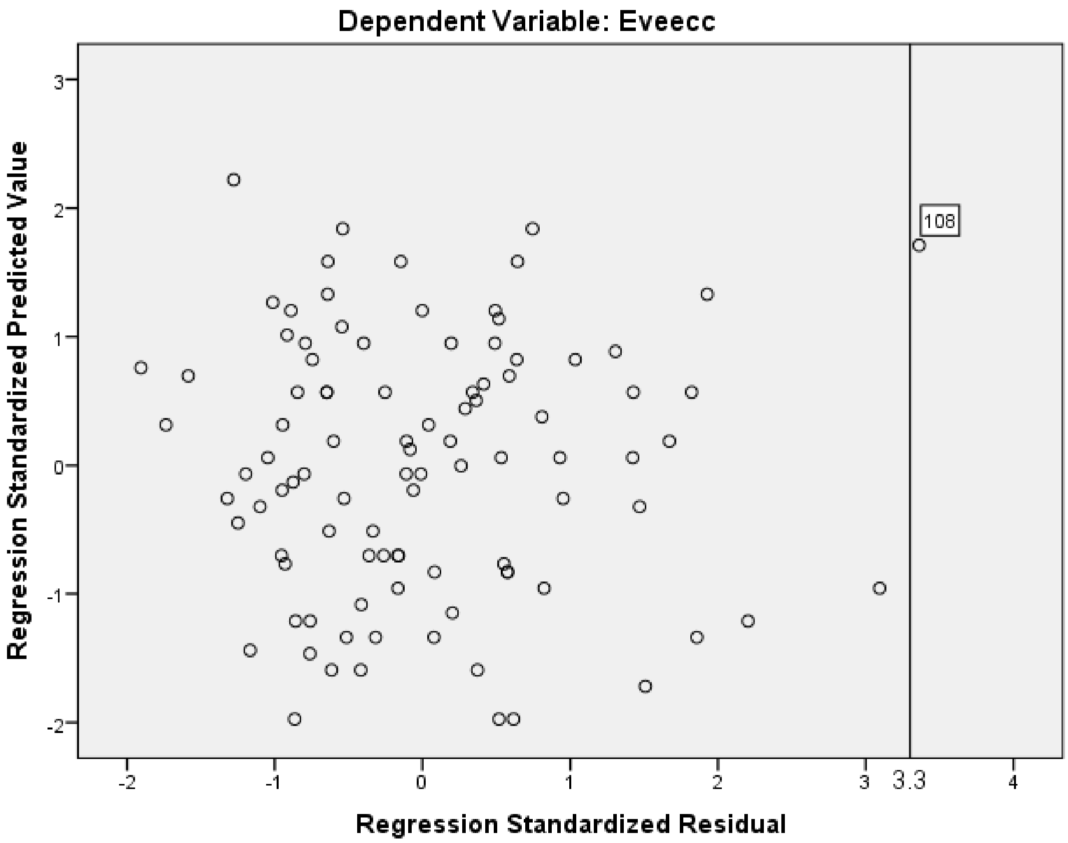


After outliers were removed:

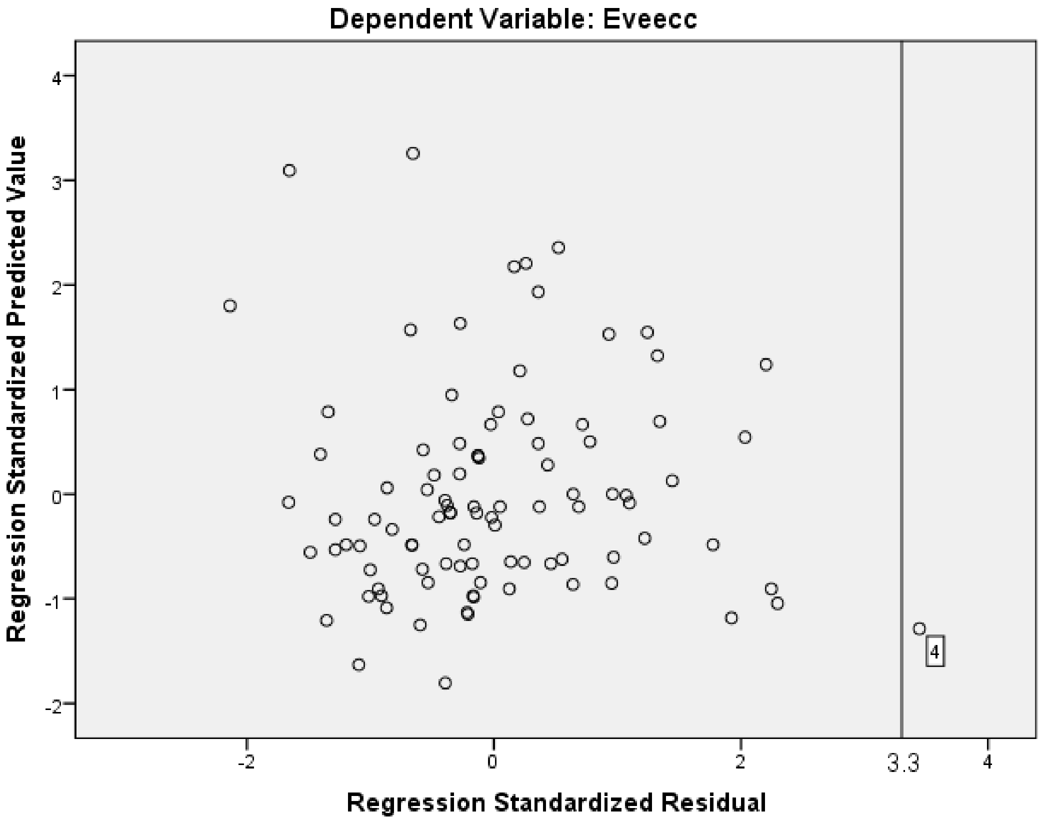




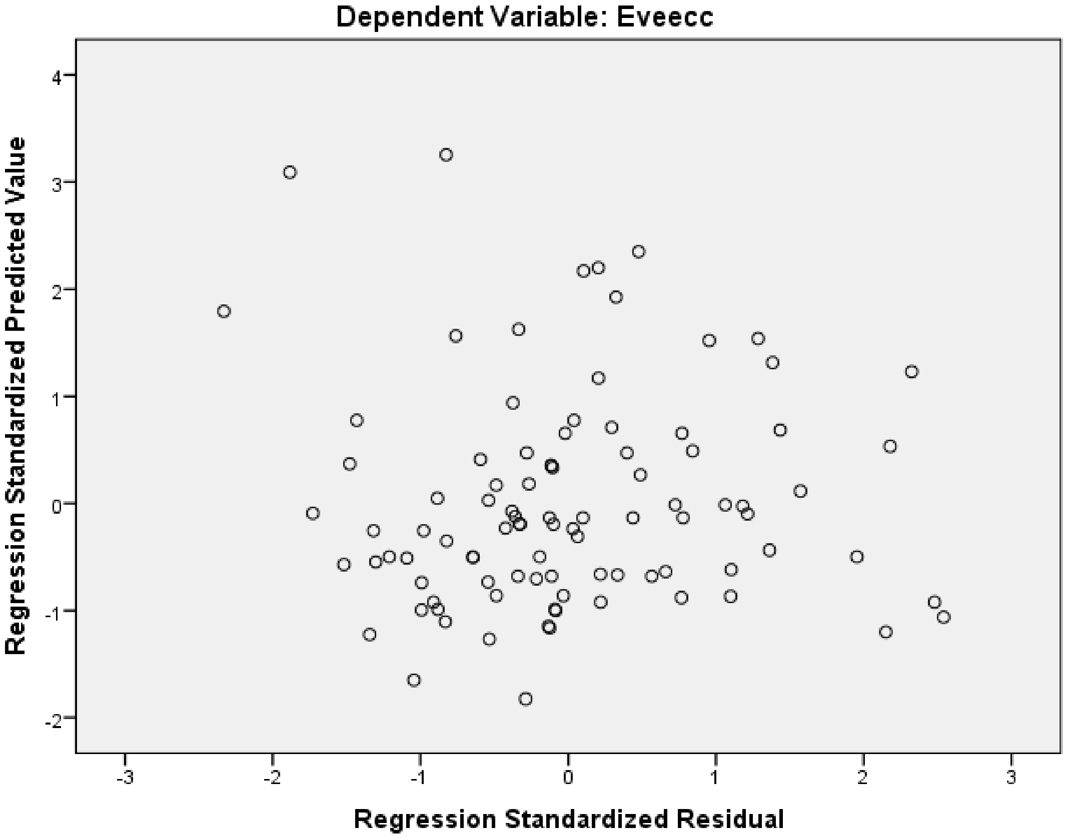
After outliers were removed:



After further outliers were removed:



After further outliers were removed:


Dependent Variable: Eveecc
Regression Standardized Predicted Value
4
3
2
1
0
-1
-2
-3
-2
-1
0
1
2
3
Regression Standardized Residual

Appendix 28

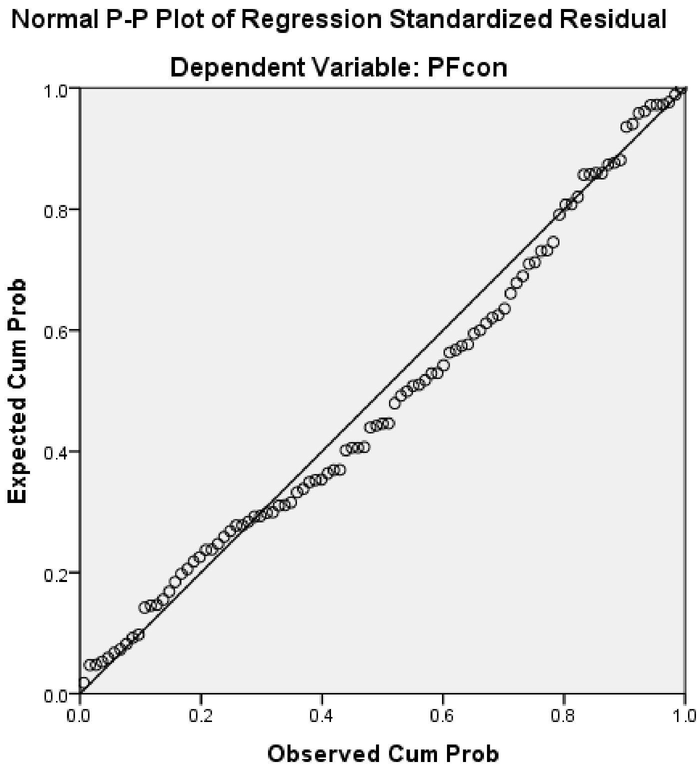
Collinearity analysis results

Movement	Variable	Pearson's r value.	Collinearity Statistics	
			Tolerance	VIF
Concentric PF	Gender	0.58	0.58	1.71
	Height	0.57	0.58	1.71
Concentric DF	Gender	0.58	0.74	1.35
	Mass	0.46	0.75	1.34
	Age	-0.12	0.99	1.01
Eccentric PF	Gender	0.58	0.58	1.73
	Height	0.57	0.58	1.73
Eccentric DF	Gender	0.58	0.55	1.81
	Height	0.57	0.64	1.57
	Mass	0.46	0.49	2.03
Concentric inv	Gender	0.58	0.75	1.34
	Mass	0.46	0.75	1.34
Concentric eve	Gender	0.58	0.99	1.01
	Age	-0.12	0.99	1.01
Eccentric inv	Gender	0.58	0.74	1.34
	Mass	0.46	0.74	1.34
Eccentric eve	Mass	0.46	1.00	1.00

Note PF = plantar flexion; DF = dorsiflexion; inv = inversion; eve = eversion; con = concentric; ecc = eccentric

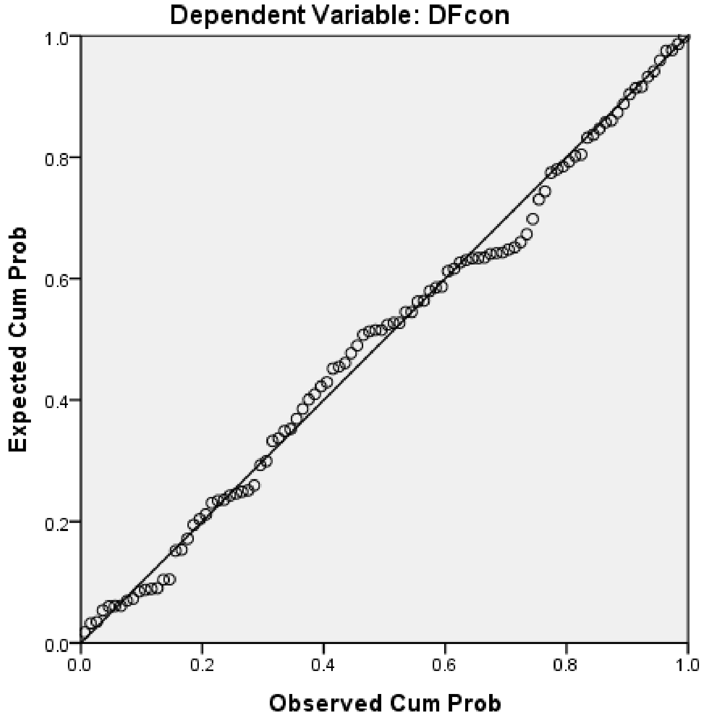
Appendix 29

Normal P-P plots of the regression standardised residual



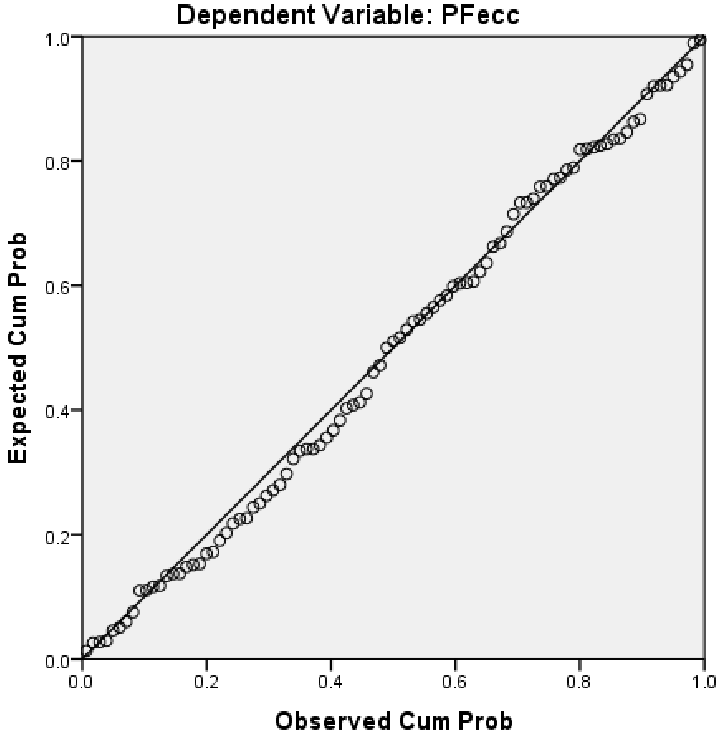
Normal P-P Plot of Regression Standardized Residual

Dependent Variable: DFcon



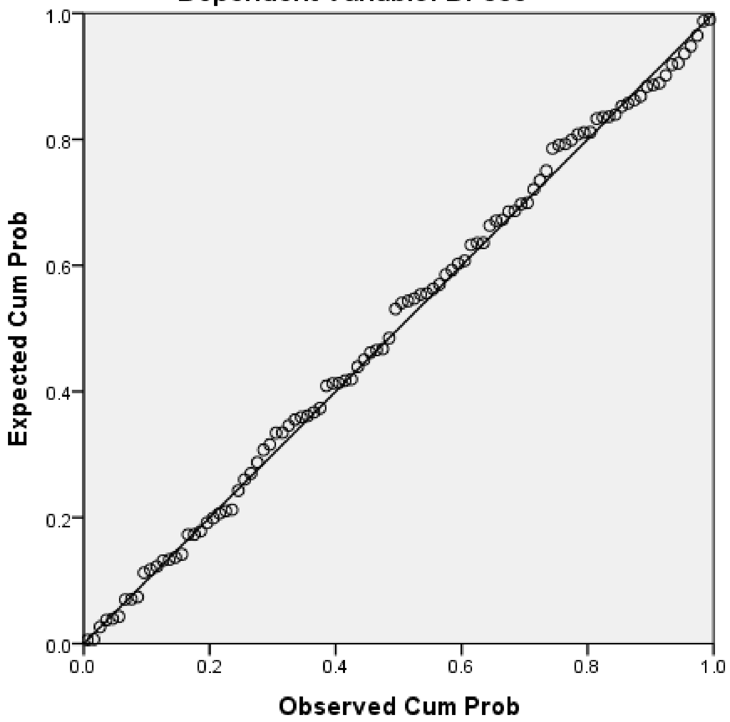
Normal P-P Plot of Regression Standardized Residual

Dependent Variable: PFecc



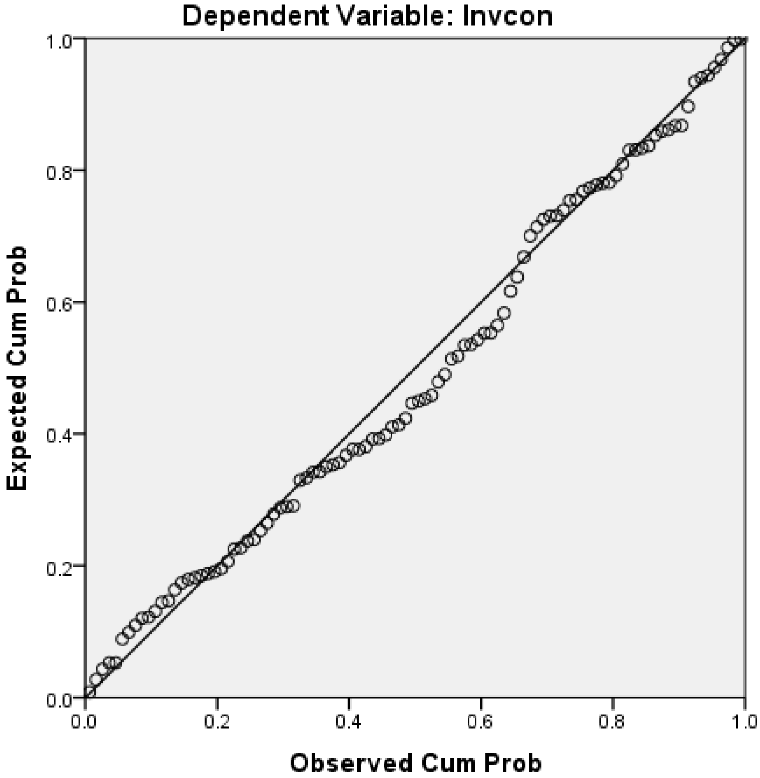
Normal P-P Plot of Regression Standardized Residual

Dependent Variable: DFecc



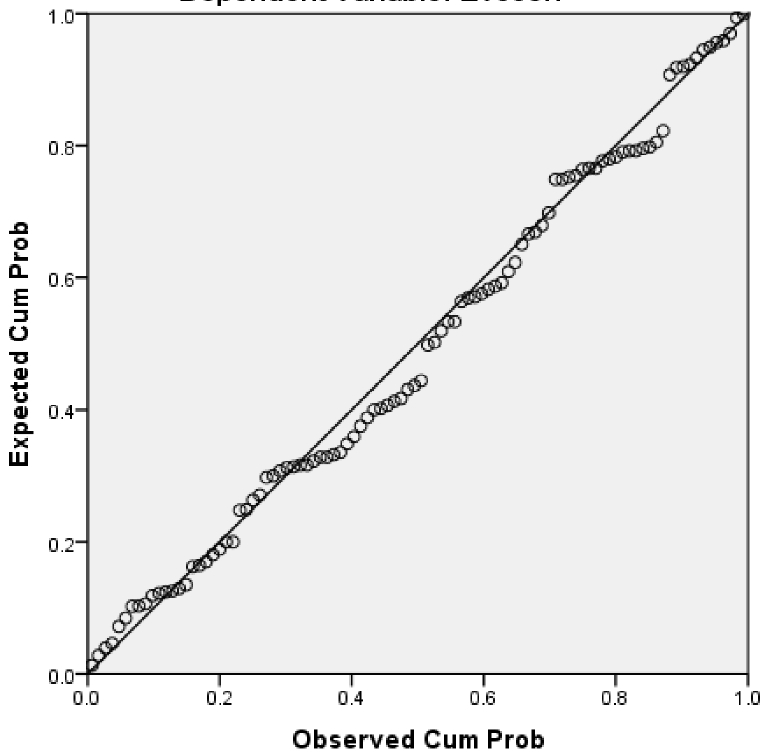
Normal P-P Plot of Regression Standardized Residual

Dependent Variable: Invcon



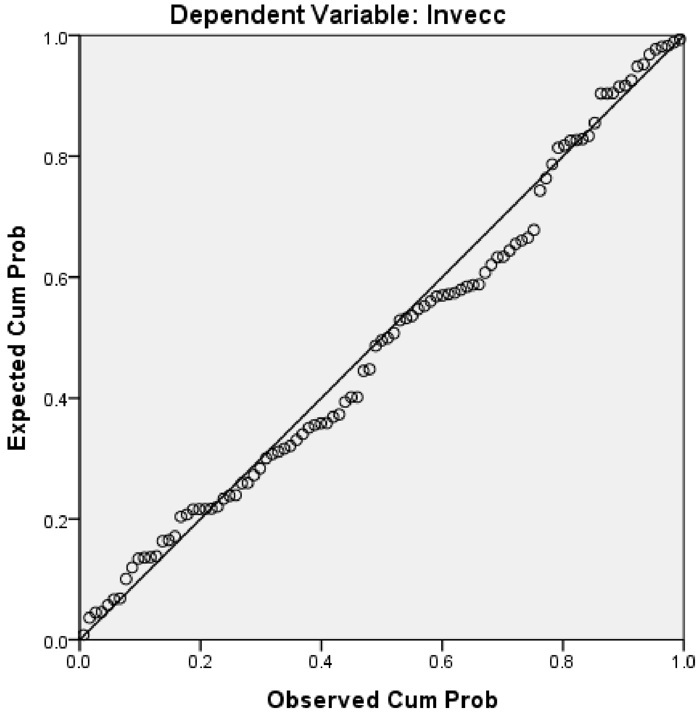
Normal P-P Plot of Regression Standardized Residual

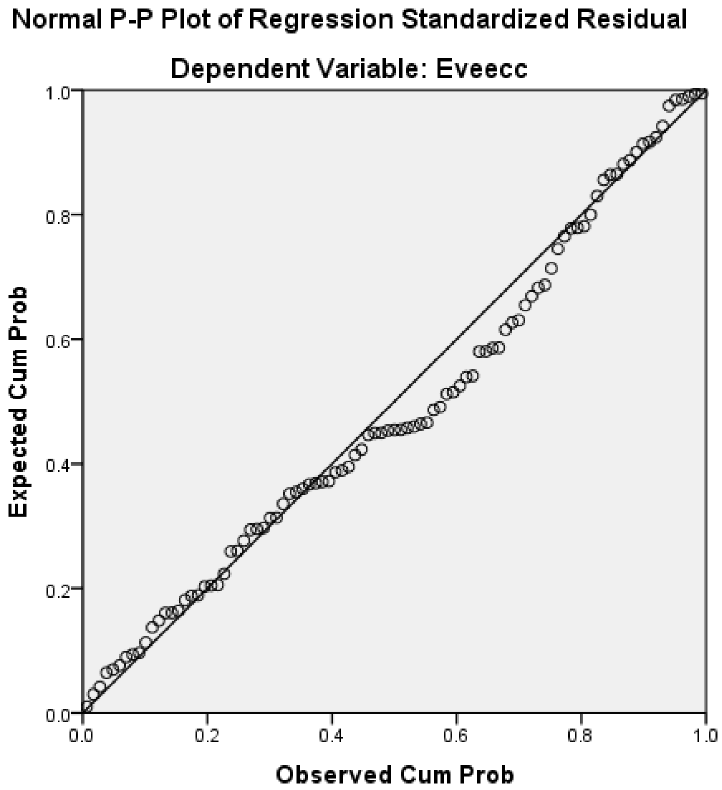
Dependent Variable: Evecon



Normal P-P Plot of Regression Standardized Residual

Dependent Variable: Invecc




Normal P-P Plot of Regression Standardized Residual
Dependent Variable: Eveecc
Expected Cum Prob
Observed Cum Prob
0.0
0.2
0.4
0.6
0.8
1.0

Appendix 30

ANOVA tables describing the strength of the AMS prediction models

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	12276.35	2	6138.17	30.83	0.00[b]
Residual	19113.68	96	199.10		
Total	31390.02	98			

Note a. Dependent Variable: PFcon
b. Predictors: (Constant), Gender, Height

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	2322.74	3	774.25	53.94	0.00[b]
Residual	1378.01	96	14.35		
Total	3700.75	99			

Note a. Dependent Variable: DFcon
b. Predictors: (Constant), Gender, Mass, Age

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	31018.18	2	15509.09	16.82	0.00[b]
Residual	82993.07	90	922.15		
Total	114011.25	92			

Note a. Dependent Variable: PFecc
b. Predictors: (Constant), Height, Gender

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	9832.76	3	3277.59	85.13	0.00[b]
Residual	3696.00	96	38.50		
Total	13528.76	99			

Note a. Dependent Variable: DFecc
b. Predictors: (Constant), Gender, Mass, Height

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	944.59	2	472.30	13.33	0.00[b]
Residual	3437.60	97	35.44		
Total	4382.19	99			

Note a. Dependent Variable: Invcon
b. Predictors: (Constant), Mass, Gender

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	688.04	2	344.02	20.33	0.00[b]
Residual	1607.30	95	16.92		
Total	2295.35	97			

Note a. Dependent Variable: Evecon
b. Predictors: (Constant), Gender, Age

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	1917.71	2	958.85	17.08	0.00[b]
Residual	5389.02	96	56.14		
Total	7306.73	98			

Note a. Dependent Variable: Invecc
b. Predictors: (Constant), Gender, Mass

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	1421.51	1	1421.51	18.16	0.00[b]
Residual	7280.03	93	78.28		
Total	8701.54	94			

Note a. Dependent Variable: Eveecc
b. Predictors: (Constant), Mass

Appendix 31

R^2 change and fit statistics for alternate prediction models and excluded variables.

PFcon Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.60	0.35	0.35	15.56
2	0.62	0.38	0.37	15.30

1. Predictors: (Constant), Footsize
2. Predictors: (Constant), Footsize, Gender

PFcon Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics Tolerance
Predictors in the Model: (Constant), Footsize	Gender	0.28	2.10	0.04	0.21	0.35
	Height	0.23	1.56	0.12	0.16	0.30
	Weight	0.17	1.74	0.09	0.17	0.66
	Age	-0.13	-1.55	0.12	-0.16	1.00
Predictors in the Model: (Constant), Footsize, Gender	Height	0.25	1.74	0.09	0.17	0.30
	Weight	0.16	1.63	0.11	0.16	0.65
	Age	-0.15	-1.85	0.07	-0.19	0.99

Appendix 32 cont.

R^2 change and fit statistics for alternate prediction models and excluded variables.

Model PFecc	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.48	0.23	0.22	31.08
2	0.52	0.27	0.26	30.39

1. Predictors: (Constant), Height
2. Predictors: (Constant), Height, Gender

Model PFecc		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics Tolerance
1 Predictors in the Model: (Constant), Height	Gender	0.27	2.29	0.03	0.23	0.57
	Weight	0.15	1.37	0.17	0.14	0.69
	Age	0.04	0.48	0.63	0.05	1.00
	Footsize	0.24	1.43	0.16	0.15	0.31
2 Predictors in the Model: (Constant), Height, Gender	Weight	0.10	0.91	0.37	0.10	0.66
	Age	0.02	0.17	0.87	0.02	0.98
	Footsize	0.01	0.03	0.97	0.00	0.19

Appendix 32 cont.

R^2 change and fit statistics for alternate prediction models and excluded variables.

Model DFcon	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.69	0.48	0.48	4.43
2	0.78	0.61	0.60	3.87
3	0.79	0.63	0.62	3.79

1. Predictors: (Constant), Gender
2. Predictors: (Constant), Gender, Weight
3. Predictors: (Constant), Gender, Weight, Age

Model DFcon		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics Tolerance
1 Predictors in the Model: (Constant), Gender	Height	0.33	3.60	0.00	0.34	0.58
	Weight	0.41	5.62	0.00	0.50	0.75
	Age	-0.14	-1.92	0.06	-0.19	0.99
	Footsize	0.25	2.09	0.04	0.21	0.35
2 Predictors in the Model: (Constant), Gender, Weight	Height	0.17	1.92	0.06	0.19	0.49
	Age	-0.14	-2.26	0.03	-0.23	0.99
	Footsize	0.05	0.40	0.69	0.04	0.31
3 Predictors in the Model: (Constant), Gender, Weight, Age	Height	0.15	1.75	0.08	0.18	0.49
	Footsize	0.02	0.20	0.85	0.02	0.30

Appendix 32 cont.

R^2 change and fit statistics for alternate prediction models and excluded variables.

Model DFecc	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.73	0.54	0.53	7.99
2	0.84	0.71	0.71	6.35
3	0.85	0.73	0.72	6.20

1. Predictors: (Constant), Gender
2. Predictors: (Constant), Gender, Weight
3. Predictors: (Constant), Gender, Weight, Height

Model DFecc		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics Tolerance
Predictors in the Model: (Constant), Gender	Height	0.36	4.38	0.00	0.41	0.58
	Weight	0.48	7.63	0.00	0.61	0.75
	Age	-0.05	-0.65	0.52	-0.07	0.99
	Footsize	0.30	2.63	0.01	0.26	0.35
Predictors in the Model: (Constant), Gender, Weight	Height	0.18	2.37	0.02	0.24	0.49
	Age	-0.05	-0.90	0.37	-0.09	0.99
	Footsize	0.06	0.56	0.58	0.06	0.31
Predictors in the Model: (Constant), Gender, Weight, Height	Age	-0.04	-0.70	0.49	-0.07	0.99
	Footsize	-0.16	-1.24	0.22	-0.13	0.18

Appendix 32 cont.

R^2 change and fit statistics for alternate prediction models and excluded variables.

Model Inv con	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.41	0.16	0.16	6.12
2	0.46	0.22	0.20	5.95

1. Predictors: (Constant), Weight
2. Predictors: (Constant), Weight, Gender

Model Invcon		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics Tolerance
Predictors in the Model: (Constant), Weight	Gender	0.26	2.53	0.01	0.25	0.75
	Height	0.11	0.96	0.34	0.10	0.67
	Age	-0.12	-1.35	0.18	-0.14	1.00
	Footsize	0.17	1.51	0.13	0.15	0.66
Predictors in the Model: (Constant), Weight, Gender	Height	-0.05	-0.35	0.73	-0.04	0.49
	Age	-0.14	-1.56	0.12	-0.16	0.99
	Footsize	-0.07	-0.44	0.66	-0.05	0.31

Appendix 32 cont.

R^2 change and fit statistics for alternate prediction models and excluded variables.

Model Invecc	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.42	0.17	0.17	8.22
2	0.47	0.22	0.21	8.01

1. Predictors: (Constant), Weight
2. Predictors: (Constant), Weight, Gender

Model Invecc		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics Tolerance
Predictors in the Model: (Constant), Weight	Gender	0.26	2.50	0.01	0.25	0.75
	Height	0.18	1.59	0.12	0.16	0.67
	Age	-0.06	-0.60	0.55	-0.06	1.00
	Footsize	0.22	1.92	0.06	0.19	0.66
Predictors in the Model: (Constant), Weight, Gender	Height	0.05	0.41	0.69	0.04	0.49
	Age	-0.07	-0.78	0.44	-0.08	0.99
	Footsize	0.03	0.18	0.86	0.02	0.31

Appendix 32 cont.

R^2 change and fit statistics for alternate prediction models and excluded variables.

Model Evecon	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.45	0.21	0.20	5.17
2	0.51	0.26	0.25	5.01

1. Predictors: (Constant), Gender
2. Predictors: (Constant), Gender, Age

Model Evecon		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics Tolerance
Predictors in the Model: (Constant), Gender	Height	0.01	0.11	0.92	0.01	0.58
	Weight	0.13	1.23	0.22	0.12	0.75
	Age	-0.24	-2.71	0.01	-0.27	0.99
	Footsize	0.07	0.48	0.63	0.05	0.35
Predictors in the Model: (Constant), Gender, Age	Height	-0.01	-0.11	0.91	-0.01	0.57
	Weight	0.13	1.29	0.20	0.13	0.75
	Footsize	0.04	0.26	0.80	0.03	0.35

Appendix 32 cont.

R^2 change and fit statistics for alternate prediction models and excluded variables.

Model Eveecc	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.24	0.06	0.05	12.98

1. Predictors: (Constant), Height

Model Eveecc		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics Tolerance
Predictors in the Model: (Constant), Height	Gender	0.03	0.22	0.82	0.02	0.57
	Weight	0.14	1.18	0.24	0.12	0.67
	Age	-0.05	-0.46	0.65	-0.05	1.00
	Footsize	0.01	0.07	0.95	0.01	0.30

Publications from this thesis

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Is it possible to establish reference values for ankle muscle isokinetic strength? A meta-analytical study.

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Abstract

BACKGROUND: The importance of measuring ankle muscle strength (AMS) has been demonstrated in a variety of clinical areas. Much data has been accumulated using the Cybex Norm isokinetic dynamometer but a uniform framework does not exist.

OBJECTIVE: To identify pertinent studies which have used the Cybex Norm to measure AMS in order to establish reference values.

METHODS: A narrative review of the literature was used to identify papers that have used the Cybex Norm to measure isokinetic concentric and eccentric AMS.

RESULTS: Fifty five research papers were identified but each study used a different isokinetic protocol.

CONCLUSIONS: It is not possible to produce AMS reference values due to the wide variation in data collection methods. This is therefore an area of research that needs further exploration.

1. Introduction

The importance of measuring muscle strength across the ankle has been demonstrated in a variety of research and clinical areas. These include investigations indicating relationships between AMS and both ankle stability (Fox et al., 2008) and with falling episodes and functional movement in the elderly (Dehail et al., 2007; Rubenstein & Josephson, 2006). Measurement of AMS has been established as a performance indicator and a predictor of injury in athletic populations (Tsiokanos et al., 2002; Witchalls et al., 2011) as well as an indicator of the effectiveness of rehabilitation (Sekir et al., 2007) and intervention strategies (Li et al., 2009). Reference values for AMS (sometimes also referred to as normal or normative values) represent a normal range of strength and are commonly used as a frame of reference in scientific literature. Reference values have been produced using various isokinetic dynamometers (Danneskiold-Samsøe et al., 2009; Harbo et al., 2011; Lategan, 2011). Harbo et al., (2011) used the Biodex System 3 to produce reference values for the shoulder, elbow, wrist, hip, knee and ankle. These values have subsequently been used in several studies. Examples are a baseline for assessing the severity of muscle function impairment in chronic hemiparetic stroke patients (Severinsen et al., 2011) and a comparison to joint torque in patients with a reverse shoulder prosthesis (Alta et al., 2012). However, the reference values produced by Harbo et al., (2011) are only relevant to studies which have used the Biodex System 3 to measure muscle torque.

They cannot be applied to studies using other dynamometers such as the Cybex Norm as the reference values produced are largely considered machine specific (Bardis et al., 2004; English et al., 2011).

Isokinetic dynamometry using the Cybex Norm is a safe, reliable and popular way to AMS (Laughlin et al., 2009; van Cingel et al., 2009; Whimpenny, 2011). It has been used in a variety of studies for example as an indicator of the effectiveness of rehabilitation (Sekir et al., 2007) and intervention strategies (Li et al., 2009). Sekir et al (2007) used the Cybex Norm in an experimental test re-test design study to examine the effect of a six week exercise intervention programme in twenty four recreational athletes using the contralateral ankle as a control measure. They found that the intervention did improve strength but also stated that there was no significant difference in strength between injured and uninjured ankles in three of the four ankle strength tests performed. It could be argued that there was no difference in the three strength measurements as both ankles were weaker than average thus susceptible to ankle injury. It may be equally likely that the uninvolved ankle could be injured in the future, however, the availability of reference values could to a certain extent highlight muscle weakness and as such become a factor in predicting injury. In the absence of reference values for AMS using the Cybex Norm Li et al (2009) used a controlled test re-test experimental design for the measurement of AMS in forty individuals. They found a sixteen week Tai Chi intervention programme did not significantly improve plantar flexion or dorsiflexion strength as measured using the this system. Li et al (2009) observed that the participants could not effectively manage ankle joint movement throughout the study and suggested this was a reason for the lack of improvement in ankle strength. Without relevant reference values it is not clear if the participants had an ankle strength deficiency to start with leading to this inability to manage the movement.

However, in spite of the relatively large number of studies making use of the Cybex Norm for assessing AMS, a brief review of the literature has revealed that no such reference values existed. Thus an in depth narrative review was necessary to determine this more definitely.

2. Method

2.1 Eligibility criteria

The objective of the narrative review was to identify those studies which have measured AMS in terms of peak torque (PT) using the Cybex Norm. Paper inclusion criteria consisted of a defined dynamometer (Cybex Norm) for the assessment of strength using concentric or eccentric active isokinetic plantar flexion, dorsiflexion, inversion or eversion. The search was not restricted to one experimental type as the outcome measures listed above could come from multiple experimental designs.

2.2 Scope of the search

In order to access the maximum number of papers six electronic databases were searched and three academic search engines used. Four of these six databases could be searched through the National Library for Health website (NICE, 2011) thus allowing the automatic elimination of duplicate results from these databases. These were MEDLINE, EMBASE (Excerpta Medical Database), CINAHL (Cumulative Index of National Allied Health Literature) and AMED (Allied and Complimentary Medicine). The span of the search was January 1995 (when the Cybex Norm Isokinetic Dynamometer was first introduced) to March 2013. The remaining two of the six databases, namely the Science Direct database (ScienceDirect, 2011) and Pubmed (PubMed, 2011) were searched outside of the National Library for Health website. Three academic search engines were also used; Summon (Summon, 2011), a search engine used in some higher education institutions which provides access to scholarly material; The Web of Science

(WebofScience, 2011) and Google Scholar. Manual removal of duplicate results was necessary from these five resources.

2.3 Search Terms

To identify studies likely to meet the eligibility criteria the terms ‘Cybex’, ‘norm’, ‘isokinetic’ and ‘ankle’ were used to search the databases and in the search engines. There are a number of different isokinetic dynamometers such as Kin-Com, Biodex and Lido so the term ‘Cybex’ was used to limit the search to the relevant machine. There is a large amount of physiological testing equipment under the Cybex brand and a number of older versions of the isokinetic dynamometer (CSMi, 2005c). To isolate the specific piece of equipment the term ‘norm’ was also used. The National Library for Health website (NICE, 2011) and Google Scholar allows quotation marks to enable searching for exact phrases. “Cybex Norm” was used to determine only papers which contain this phrase. As well, to discount unrelated research concerning the shoulder, elbow, wrist, hip and knee as well as isometric and isotonic tests the Boolean phrase AND was used to include the search terms ‘ankle’ and ‘isokinetic’.

3. Analysis

Figure 1 shows the number of papers identified at each stage of the search process. The initial search produced 613 papers which matched the search terms. The title and abstract of each of these papers was analysed and if eligibility could not be determined the whole paper was read. 542 papers were rejected as the eligibility criteria were not met. Any duplicate papers were removed which left 55 papers that met the eligibility criteria.

Of the 55 papers found in this search there was no single paper which set out to produce reference values for AMS using this dynamometer. However, many of the papers have compared their findings to measurements derived from a control group. A control group may provide a basis for comparison but the collected data cannot be considered reference due to low external validity resulting from the small numbers used and the specific sample demographics. On the other hand, however, it may be theoretically possible to combine the results of control groups from separate studies in a meta-analysis to produce valid reference values which could be used in a general clinical setting (Deeks et al., 2011), subject to very strict factors including gender, age, activity level and test protocol . Table 1 lists the papers in terms of the experimental and control groups that have been used. Reference values for a healthy population by their definition should be produced by a healthy population, however, analysis of the data presented in table 1 shows two of the papers have not tested a healthy population or used one as a control meaning only 53 of the papers are potentially eligible to contribute to a meta-analysis. Additionally, it has been demonstrated that age and gender affect the amount of torque produced (Danneskiold-Samsøe et al., 2009; Harbo et al., 2011) and as such any reference value produced would have to be specific to age and gender. This means that the populations described in table 1 would have to be matched for age and gender before a meta-analysis can be performed.

The graph in figure 2 shows the breakdown of populations described in table 1 in terms of age and gender. For reference values to have sufficient external validity a large amount of data should be considered. Significant numbers were only tested in the 18 – 29 years and 60 – 69 years age ranges and as such reference values could only potentially be produced for these groups.

The papers within these age and gender specific groups were analysed and differences in the data collection methods were found. Examination of all 55 papers produced 7 common methodological variables, these are: the position of the body on the Cybex Norm; degree of knee flexion; use of a warm up; speed of contraction and contraction type; the number of sets and reps used; whether the dominant or non-dominant foot was used; use of verbal or visual encouragement. Details of these variables are given in table 2. If altering these variables affects the outcome measures then it is not possible to combine the data in a meta-analysis. The effects of altering these seven variables are discussed here.

3.1 Position

Seymour and Bacharach (1990) showed that when using a Cybex II+ to measure ankle plantar flexion, altering from a supine to a prone position significantly reduced the amount of torque produced at 0° per second and 30° per second. As they used the Cybex II+ and not the Cybex Norm it is difficult to draw an exact comparison. However due to the lack of empirical evidence using the latter, it is necessary to infer the effect of an alteration in body position from a closely related protocol.

3.2 The degree of knee flexion.

Extension of the knee stretches the plantar flexors thus reducing range of movement as the dorsiflexion displacement angle is reduced (Souza et al., 2009). Plantar flexion PT occurs at near full dorsiflexion (Billot et al., 2011) so fully extending the knee may prevent development of PT during a concentric contraction. However, during an eccentric contraction the increased tension in the plantar flexors as a result of extending the knee produces higher PT compared to a flexed knee (Wakahara et al., 2009). As such angle of knee extension should be considered when producing a reference value.

3.3 Warm up.

One or combinations of three types of warm up were used in the papers described in table 2; these were cardiovascular, stretching and familiarisation. The rationale for a cardiovascular warm up is exercise would increase the muscle temperature and so improve the neuromuscular function (McArdle et al., 2007). However, in an experiment to determine the effect of warming up and stretching on Achilles tendon reflex activity

Rosenbaum and Hennig (1995) demonstrated that a 10 minute warm up on a treadmill did not affect torque production of the plantar flexors in fifty healthy males. A review on stretching and its effect on performance by McHugh and Cosgrave (2010) stated there is an acute loss of strength after relaxed muscle has been stretched. This conclusion supports the ankle specific research by Rosenbaum and Hennig (1995) and Fowles and Sale (1997) both of whom demonstrated that static stretching prior to testing significantly reduced plantar flexion PT production. From this it can be concluded that any papers to be included in a meta-analysis should have a standardised warm-up and familiarisation procedure.

3.4 The speed and type of contraction.

Decreases in PT associated with increased angular velocity are well established (2002). Equally, an eccentric contraction produces greater torque than a concentric contraction (2007; Sekir et al., 2008). Hence, if results are to be combined in a meta-analysis, both the speed any type of contraction should be constant.

3.5 The number of sets and repetitions used.

If participants were given just one attempt at achieving PT it is unlikely the results would be reliable as without practice the movement can be unfamiliar. Equally fatigue has been shown to alter muscle strength (Forestier et al., 2002) so multiple attempts at achieving PT at one speed or movement type could reduce the accuracy of subsequent tests. van Cingel et al. (2009) compared reproducibility of inversion eversion strength between one set of three reps and three sets of three reps and found that the standard error of measurement and intraclass correlation coefficient between the two was noticeably different. As such, papers included in a meta-analysis should use the same number of sets and reps, and that protocol should be reproducible.

3.6 Effect of foot dominance.

There is conflicting evidence regarding the effect of limb dominance on the level of plantar-dorsiflexion PT produced at the ankle. Some evidence suggests that there is no difference due to dominance in terms of the above (Ersoz et al., 2009; Konradsen et al., 1998; Leslie et al., 1990 ; So et al., 1994). Özçaldiran and Durmaz (2008) did show a significant difference between left and right dorsiflexion at 30°/s in runners. However, no such difference was found in plantar flexion at 30°/s or in plantar flexion or dorsiflexion at 120°/s in runners, or in any ankle movement or speed in swimmers. Theoharopoulos and Tsitskaris (2000) found a significant difference between dominant and non-dominant plantar flexion PT at 60°/s in basketball players. Both Özçaldiran and Durmaz (2008) and Theoharopoulos and Tsitskaris (2000) found, in instances where there was significant difference between left and right, that the non-dominant side was significantly stronger. Lin et al (2009) concluded there were no differences in inversion / eversion PT between dominant and non-dominant ankles when testing concentric strength at 30° and 120°/s using a Biodex 3 dynamometer. Konradsen et al. (1998) demonstrated no difference in isometric eversion strength between left and right ankles six weeks post unilateral ankle injury. They assumed that the PT in the contralateral ankle was the same as the involved ankle pre injury based on unpublished data cited in the paper.

3.7 Encouragement or feedback

Campenella, Mattacola, and Kimura (2000) showed that visual feedback or a combination of visual and verbal feedback increased the amount of PT produced in the hamstrings, however verbal feedback alone did not. Jung and Hallbeck (2004) found similar results in terms of visual feedback when investigating handgrip strength but found that verbal encouragement did increase torque production. Although the specific relationship between encouragement and AMS has not been studied, these conclusions suggest that standardising verbal feedback could be problematic as participants may respond differently verbal encouragement.

Thus alteration of any of the variables describes above would alter the PT produced. As such the lack of standardisation in the papers which have used the Cybex Norm to measure ankle muscle strength means it is not possible to combine the results and produce reference values by meta-analysis.

4. Conclusion

To date no paper has published reference values for AMS using the Cybex Norm. The differences in the variables presented in the references rendered a unified picture not possible. As such reference values for AMS using this dynamometer cannot be determined from the current literature. The apparent non-standardisation of data collection methods for AMS seen across these papers suggests the need for a consensus method. Once a consensus method is produced reference values can be determined for future use both in clinical rehabilitation and research.

Reference	Experimental population	Control Population
Buckley et al. (2013)	10 males 5 females aged 75±3 years 10 males 7 females aged 25±4years	N/A – older vs younger population
Alfieri et al. (2012)	1 male, 22 females aged 70.18±4.8 years	N/A – strength training vs multisensory training experiment.
(S. S. M. Fong & Tsang, 2012)	13 males, 7 females aged 15±1.2 years	N/A – correlation study between hours of taekwondo training and muscle strength
Noguchi et al. (2012)	10 males football players aged 20±0.8 years	10 males athletes aged 21.1±0.57 years
Strejcová et al. (2012)	8 males 1 female aged 25.0±0.9 years (slackline walkers)	8 males 1 female aged 22.9±0.8 years (non-slackline walkers)
(Tan et al., 2012)	13 male and 12 female Diabetes patients aged 65.9±4.2 years	No healthy control
X. Wang (2012)	“elite skaters” no other detail given	
Zhang and Xia (2012)	6 males aged 25.8±3.87 years 12 males aged 22.3±2.56 years	N/A – comparison of national and international skaters
Patterson & Ferguson (2010)	8 females aged 23±3 years 8 females aged 22±3 years	N/A – training method comparison between blood restriction and no restriction and 25%1RM and 50%1RM reps

Gopalakrishnan et al (2010)	4 males aged 49.5±4.7 years	N/A – strength measured pre and post space flight
Reeves, et al (2009)	5 males 10 females aged 74.8±2.8 years	10 males 7 females aged 24.6±4.1 years
Li, Xu, & Hong (2009)	13 males 12 females 64.9±3.2 years (healthy performed Tai Chi)	12 males 13 females 65.6±3.5 years (healthy did not perform Tai Chi)
Koutsioras et al (2009)	7 males aged 16.3±1.2 years 7 females aged 16.1±1.2	N/A – examination of muscle strength and long jump performance
Eyigor et al. (2008)	8 males 25 females aged 55.79±12.4 years with Rheumatoid arthritis	7 males 26 females aged 60.27±10.7
Reeves et al (2008)	15 “older adults” aged 74±2.8 years 17 “young adults” aged 24.6±4.1 years gender not stated	N/A – comparison of older and younger biomechanics of stair descent
Özçaldiran & Durmaz (2008)	14 males median age 18(6) (elite swimmers) 8 males median age 20(5) (elite runners)	N/A comparison between swimmers and runners.
Thom et al (2007)	9 males aged 74.7±4.0 years 15 males aged 25.3±4.5 years	N/A – comparison between older and younger males
Muller et al (2007)	10 males, 33 females aged 86.0±5 years. Hospitalised patients	6 males, 22 females aged 75.4±6.2 years
Eyigor et al. (2007)	20 participants aged 70.3±6.5 years gender not stated	N/A - test retest design

Dehail et al. (2007)	6 males aged 75.6±5.4 years, 18 females aged 73.2±6.7 years	N/A analysis of strength and sit to walk movement
Xu et al (2006)	13 males, 8 females aged 66.2±5.1 years (Tai Chi practitioners) 11 males, 7 females aged 65.2±3.0 years (joggers)	12 males, 10 females aged 64.9±3.2 years
Neto et al (2006)	8 males between 20 and 23 years	N/A – test retest design
Mahieu et al (2006)	69 males aged 18.41±1.29 years	N/A – cohort study examining risk factors for Achilles over use injury
Greene et al (2006)	20 females aged 15.9±1.6 years (middle distance runners) 20 males aged 16.8±00.6 years (middle distance runners	20 females aged 16±1.8 years, 20 males aged 16.4±0.7 years
Gerodimos et al (2006)	30 males in each group: aged 12.3±0.1 years Aged 13.4±0.2 years Aged 14.5±0.3 years Aged 15.2±0.1 years Aged 16.5±0.3 years Aged 17.4±0.2 years	N/A – analysis of strength in basketball players
Ferri, et al (2006)	9 males aged 71.8±4.3 years	N/A – test retest design
Greene et al.(2005)	20 females aged 16±1.7 years (middle distance runners)	20 females aged 16±1.8 years
McCarthy, et al (2004)	47 females aged 64.51±3.08 years	N/A – comparison of sit to stand movement and hip, knee and ankle strength

Demonty et al (2004)	10 males mean age 52.8 with occlusive arterial disease	10 males mean age 53.9 years
Reeves and Narici (2003)	4 males, 4 females aged 25.1±2.6 years	N/A – examination of muscle fascicles during dynamic movement
Ferri et al (2003)	16 males aged 67.9±0.9 years	N/A – test retest protocol
Tsiokanos, et al (2002)	29 males aged 22.1±2.2 years	N/A – comparison of leg strength and jumping performance
Schulze et al (2002)	8 males 27.1±3.0, 8 males 29.5±2.9 years (underwent unilateral lower limb suspension for 21 days)	8 males 31.4±2.9 years, 8 males 32.5±3.9 years
Bourdel-Marchasson et al (2001)	4 males, 7 females aged 87.1±5.7 years (malnourished)	4 males, 9 females aged 83.4±6.1 years
Ademoglu et al. (2001)	3 males, 1 female between 24 and 47 years (average 35) (wound complications after Achilles tendon rupture)	Contralateral ankle
Mouraux et al (2000)	4 males, 6 females aged 24.7±3.2 years	N/A – test retest design
Guo and Song (Guo & Song, 2009)	10 males aged 22.4±2.6 years (elite speed skaters)	14 males aged 19.4±0.8 years
Behrens et al (2010)	7 short track speed skaters aged 17.1±1.3 years (gender not stated)	N/A – test retest design
Collado et al (2010)	6 males, 3 females aged 25.1±2.57 (eccentric	2 males, 8 females aged 24.4±3.06

	training); 4 males, 5 females aged 23.3±2.8 (concentric training)	
Latour et al (2010)	10 males, age not stated (training on sand)	10 males, aged not stated
Urguden et al (2010)	15 males, 5 females aged 20.6 years (range 16 – 32 years) with chronic ankle instability	'20 patients with same demographic characteristics'
van Cingel et al (2009)	15 males aged 34.2±9.32 years; 15 females aged 28.6±8.64 years	N/A – reproducibility study
Sekir et al. (2008)	24 males aged 21.1±1.8 with functional ankle instability	N/A – reliability study
Sekir et al. (2007)	24 males aged 21±2 years with unilateral functional ankle instability	Contralateral ankle
Høiness et al (2003)	9 males aged 26.2±4.4 years (using normal bike pedal); 10 males aged 24.5±3.9 years (using bi-directional bike pedal)	Contralateral ankle
Yildiz et al (2003)	8 males aged 26.2±2 years with chronic ankle instability	9 males aged 25±2 years
Sanioglu et al. (2009)	9 males, 7 females aged 24.3 ±4.12 years	Strength with ankle taped vs not taped
Vismara et al. (2010)	11 adults aged 33±4.3 years with Prader-Willi Syndrome	20 healthy adults aged 28±7.8 years
Giagazoglou et al. (2009)	10 blind females aged 33.5±7.9 years	10 healthy females aged 33.5±8.3 years

Taskiran et al. (2013)	2 males, 11 females aged 34.3±9.2 years	N/A test – retest reliability study
Geremia et al. (2007)	5 individuals (no population data given)	Contralateral ankle
Tallent et al. (2013)	10 resistance trained males aged 22±2 years	9 untrained males aged 26±3 years
Frasson et al. (2007)	36 females, age not stated	Ballet dancers versus volleyball players
Wilcox et al. (2000)	8 males, 12 females mean age 61 range 28 - 80	Contralateral ankle control
Sammarco et al. (2006)	16 males mean age 53.4 range 18-74 and 24 female mean age 55 range 15-74	Contralateral ankle control

Table 1. Papers which used the Cybex Norm to measure isokinetic AMS displayed in terms of age and gender of participants

Reference	Prone/Supine/ weight bearing	Degree of Knee Flexion	Warm up	Speed / contraction type, in °/s	Sets and Repetitions	Dominant or non-dominant foot	Encouragement given
Buckley et al. (2013)	Not stated	Not stated	Not stated	60, 120, 180, 240 eccentric PF	3reps at each speed	Not stated	Not stated
Alfieri et al. (2012)	Supine	80°	3 reps at free angular speed	30 PF DF INV EVE	5 reps	Not stated	Verbal encouragement given
S. S. M. Fong and Tsang (2012)	Prone	0°	3 trials	60, 240 PF DF concentric	3 trials, 10 seconds between trials (reps per trial not stated)	Dominant (self reported)	Not stated
Noguchi et al. (2012)	Not stated	Not stated	1 'practice run'	30	'2 tests in between I minute intervals'	Not stated	Not stated

Strejcová et al. (2012)	Supine	90°	Not stated	30, 120 PF DF	5 reps 30°,15 reps 120°	dominant	Not stated
Tan et al. (2012)	Supine	Not stated	'familiarisation and a warm up' no detail given	30, 60 PF DF	2sets of 3 reps 1 minute rest between	dominant	Not stated
X. Wang (2012)	Not stated	Not stated	Not stated	60, 120, 180, 240, 300, 360, 420, 480 concentric; 60, 120, 180, 240, 300 eccentric	8 reps at each concentric speed and 5 reps at each eccentric speed	both	Not stated
Janssen et al. (2000)	Not stated	Not stated	10 mins 'warm up' and 3 reps at 60° per sec	60, 120, 180, 240, 300, 360, 420, 480 concentric	3 reps at each speed, 20secs between reps	both	Not stated
Patterson & Ferguson (2010)	Prone	0°	5 contractions at each speed	30, 60, 120 PF concentric	3 reps at each speed. 1 minute between reps	both	Verbal encouragement given

Gopalakrishnan et al (2010)	Prone	0°	5mins bike 25-50W 60-80rpm. 5 sub max reps, 2-3 max reps 2mins rest	30 PF DF concentric eccentric	5 reps ecc 5 reps con	right	Not stated
Reeves, et al (2009)	Prone	0°	Not stated	60, 120, 180, 240 concentric PF	Not stated	left	Not stated
Li, Xu, & Hong (2009)	Not stated	Not stated	Not stated	30 PF DF concentric.	3 reps no info on rest	dominant	Not stated
Koutsioras et al (2009)	Prone	0°	3 sub max reps	60, 120 concentric and eccentric PF	3 max reps at each speed for each movement	right	Not stated
Eyigor et al. (2008)	Supine	90°	10 min walk 2 sub max reps 180° per sec	60, 120, 180 PF DF	6 reps at each speed 20s between speeds	Not stated	Verbal encouragement given
Reeves et al (2008)	Prone	0°	Not stated	60, 120, 180, 240 eccentric PF	3 reps at each speed 2-3	left	Not stated

					minute rest between		
Özçaldiran & Durmaz (2008)	Supine	0°	5 min warm up plus 4 sub max reps	30, 120 PF DF	5 reps at 30° per sec 15 reps at 120° per sec with 30 sec rest between sets	Both	Verbal encouragement given
Thom et al (2007)	Prone	0°	Familiarisation session and 5 isometric MVCs	50, 100, 150, 200, 250 Concentric PF	4 reps at each speed, 1 min between reps, 5mins between speeds.	left	Verbal encouragement given
Muller et al (2007)	Supine	30°	5 sub max reps	30, 60 PF concentric	2 sets 5 reps 30°sec 1 set 5 reps 60° per sec	right	Not stated
Eyigor et al. (2007)	Supine	90°	10 min walk then 2 sub max PF/DF reps at 180° per sec	60, 120, 180 PF DF	6 reps at each speed. 20s between reps	both	Verbal encouragement given

Dehail et al. (2007)	Supine	0°	3 training reps before each set	30, 60 Concentric PF	2 x 5 reps at 30°per sec 1 x 5reps at 60°per sec 2mins between sets	dominant	Verbal encouragement given
Xu et al (2006)	Supine	Not stated	5mins bike 50-60w 3 submax reps	30 concentric PF DF	3 reps	dominant	Not stated
Neto et al (2006)	Not stated	Not stated	Not stated	30, 60, 120, Concentric 60, eccentric PF	3 reps of each apart from 5 reps of 120°	All subjects were right leg dominant, not clear which leg was tested.	Not stated
Mahieu et al (2006)	Supine	0°	10 sub-max reps at 90° per sec	30, 120 Concentric PF DF	3 reps at 30° per sec and 5 reps at 120° per sec. 1 minute rest between tests	both	Verbal encouragement given

Greene et al (2006)	'Standard positioning used'	Not stated	Not stated	60 PF DF	5 reps	dominant	Not stated
Gerodimos et al (2006)	Supine	0°	15 minutes cycling and stretching 3 submax reps and 1 max rep at 30° and 90° per sec	30, 90 Concentric eccentric PF DF	5 reps of each movement at each speed. 5 min rest between speed	1 randomly determined leg	Visual feedback, no verbal feedback
Ferri, et al (2006)	Prone	0°	'several' warm up contractions	60, 120 concentric 60 eccentric PF DF	3 reps at each speed, 1 min between reps	Left (non dominant in all subjects)	Verbal encouragement given
Greene et al (2005)	'Standard positioning used'		Not stated	60 PF DF	5 reps	dominant	Not stated
McCarthy et al (2004)	Not stated	Not stated	3 submax reps at 60° per sec	60 PF DF	5 reps right PF DF, 5mins rest,	both	Not stated

					5 reps left PF DF		
Demonty et al (2004)	Supine	'straight'	10 mins bike 40w 60rpm 3 submax reps	120, 30 concentric PF DF	5 reps 120° 3 reps 30° 30s rest between sets	both	Not stated
Reeves and Narici (2003)	Supine	90°	Warm up not stated	50, 100, 150, 200, 250, concentric eccentric DF	5 reps each movement each speed 180s rest between contraction sets	right	Not stated
Ferri et al (2003)	Prone	180°	Several sub max reps	30, 60, 90, 120, PF	3 reps at each speed	dominant	Verbal encouragement given
Tsiokanos, et al (2002)	Prone	0°	3 submax reps at each speed	60, 120, 180 Concentric PF	3 reps at each speed, 30s between reps, 5 mins between speeds	Not stated	Not stated

Schulze et al (2002)	Supine	160°	4 sub max contractions at 50% peak torque at each speed	30, 60, 120, 180, 240, 300 concentric eccentric PF	4 maximal contractions at each speed 90s rest between speeds.	left	Not stated
Bourdel-Marchasson et al (2001)	Supine	0°	3 training exercises (reps) for each set	30, 60 PF	2 sets 5 reps at 30° per sec, 1 set of 5 reps at 60° per sec	Right (or the healthy side)	Not stated
Ademoglu et al. (2001)	Supine	10°	2 submax and 1 max rep	30, 120 PF DF	3 reps, 30 seconds between speeds	Both	Not stated
Mouraux et al (2000)	Supine	90°	10 minutes bike and familiarisation with the equipment	30, 60, 90 PF Concentric eccentric	3 max reps at each speed. 90 seconds between speeds.	Both pre and post training	Not stated
Guo and Song (2009)	Not stated	Not stated	10 mins preparatory activities and 2	60, 120, 180, 240, 300 PF concentric	3 reps at each speed 20 seconds	right	Not stated

			sets 3 reps at 60° per sec		between each rep		
Behrens et al (2010)	Supine	Between 100° - 110°	10 mins bike at 100W 5 submax concentric reps at 240° per sec	240 inv eve Concentric	3 max reps	right	No visual feedback, verbal encouragement was given
Collado et al (2010)	Supine	90°	3 practice trials	30 concentric eccentric	3 reps	Both (one had suffered lateral ankle sprain)	Not stated
Latour et al (2010)	Supine (based on photo, not stated in text)	Bent (based on photo, not stated in text)	Not stated	30, 120, inv eve concentric eccentric	Not stated	Not stated	Not stated
Urguden et al (2010)	Supine	80 – 110°	Not stated although proprioception test performed on the Cybex prior to isokinetic tests	60, 150 inv eve	5 reps 60° sec. 10 reps 150° sec	Both (1 injured 1 uninjured)	Not stated

van Cingel et al (2009)	Supine	10°	5min bike 75w 70 – 80rpm, 3 submax inv eve 2 max inv eve	30, 120 inv eve	3 sets of 3 reps at each speed	both	No visual feedback or verbal encouragement given
Sekir et al. (2008)	Supine	80° - 110°	10minute 'general ROM and stretching' 3 submax contractions	120 inv eve concentric eccentric	5 maximal contractions 2mins between inv and eve tests	14 dominant 10 non dominant (only injured ankle tested)	Verbal encouragement given
Sekir et al. (2007)	Supine	80° - 110°	10minute 'general ROM and stretching' 3 submax contractions	120 inv eve Concentric eccentric	5 maximal contractions 2mins between inv and eve tests	14 dominant 10 non dominant injured both tested	Verbal encouragement given
Høiness et al (2003)	Supine	80° - 110°	No warm up	60, 180 eve	5 reps 15min rest 5 reps (to ensure reliability)	Both (1 injured 1 uninjured)	Verbal encouragement given

Sanioglu et al. (2009)	Supine	Not stated	5mins cycling, 6-10 submax PF DF contractions, 2-3 max PF DF contractions then 2mins rest	60, 180 PF DF Concentric	5reps at 60° per sec 15 reps at 180° per sec	both	Not stated
Vismara et al. (2010)	Prone	180°	Not stated	60, 120 PF DF	5 reps at each speed, 1min rest between reps	both	Not stated
Giagazoglou et al. (2009)	Supine	'fully extended'	3 submax contractions	30, 60, 120 PF DF concentric eccentric	3 reps of each movement at each speed with 2mins between each rep	Dominant	Consistent, identical verbal encouragement provided, no visual feedback given
Taskiran et al. (2013)	Prone	'full extension'	4 submax reps	30, 120 PF DF concentric	5 reps at 30° per sec 10mins rest	dominant	Not stated

					20 reps at 120°per sec		
Geremia et al. (2007)	Not stated	Not stated	Not stated	60, 120, 180, 240, 300 PF DF concentric	3 reps per speed, 90sec rest between speeds	Both (non-dominant was sprained)	Not stated
Tallent et al. (2013)	Supine	120°	Not stated	15 DF concentric and eccentric	3 reps	dominant	Not stated
Frasson et al. (2007)	prone	180°	A 'series' of submax contractions at different speeds	60, 120, 180, 240, 300, 360, 420 PF DF concentric	3 reps at each speed, 2mins rest between reps	right	Not stated
Wilcox et al. (2000)	Prone	Knee fully extended	3 trial reps at each speed	30, 120 PF DF concentric inferred but not stated	5 reps at 30° per sec, 10 reps at 120° per sec	Both	Not stated
Sammarco et al. (2006)	Supine	Knee 'flexed'	Not stated	'standardised protocol'	5 reps	Both	Not stated

Yildiz et al (2003)	Supine	80° - 110°	10 minute warm up – general rom and stretching. 3 submax trials	120 concentric inv, eccentric eve	5 reps inv, 2mins rest, 5 reps eve	Not stated	Verbal encouragement given

Table 2 Details of the methodological variables found in papers using the Cybex Norm to measure isokinetic AMS. PF = plantar flexion; DF = dorsiflexion; Inv = inversion; Eve = eversion

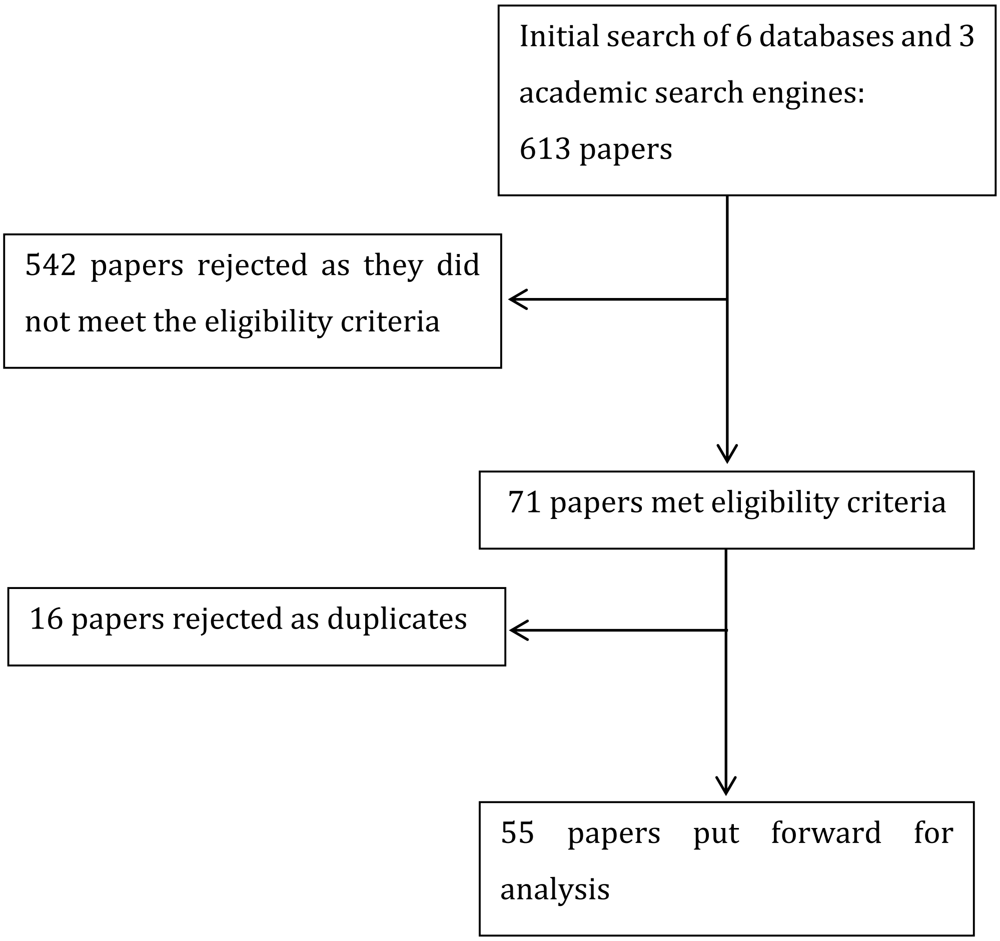

Figure 1. A chart showing the results at each stage of the search process.

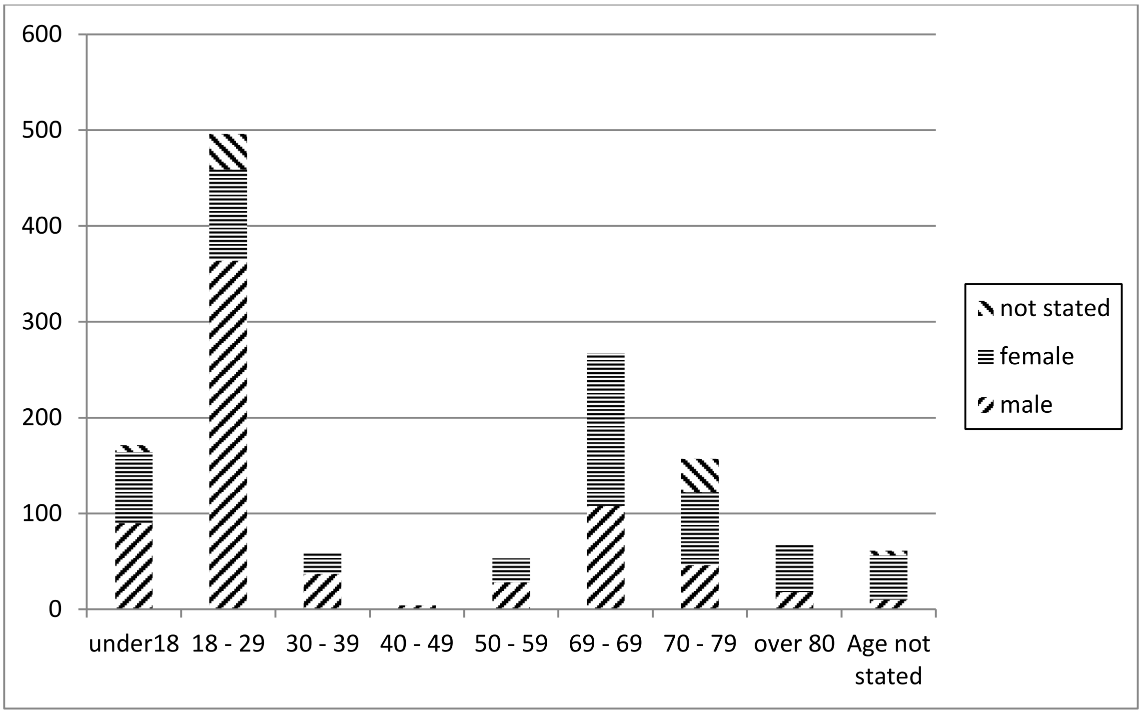

Figure 2. A graph showing the breakdown of the numbers of males and females tested in different age groups

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