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Studies of lower limb isokinetic strength and proprioception in young football players

Saeed Fayaz

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In the name of the most gracious and the most merciful;

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List of Abbreviations

ACL: Anterior Cruciate Ligament

AFL: Australian Football League

AP: Antero-Posterior

APSI: Anterior/posterior Stability Index

BBS: Biodex Balance System

BOS: Base of Support

CI: Confidence Intervals

CNS: Central Nervous System

COG: Centre of Gravity

EccH/ConQ ratio: Eccentric hamstring peak torque: Concentric quadriceps peak torque ratio

EFP: Elite Football Players

H/Q ratio: Hamstring maximum contraction/ Hamstring maximum contraction ratio

ICC: Intra Class Correlation

ICHRPT30: Isokinetic concentric right hamstring peak torque at the speed of 30º/s

ICLQPT30: Isokinetic concentric left quadriceps peak torque at the speed of 30º/s

ICLQPT180: Isokinetic concentric left quadriceps peak torque at the speed of 180º/s

ICRHPT180: Isokinetic concentric hamstring peak torque of the right knee at the speed of 180º/s

ICRQPT180: Isokinetic concentric right quadriceps peak torque at the speed of 180º/s

IELQPT30: Isokinetic eccentric left quadriceps peak torque at 30º/s

KG: Kilogram

LOG: Line of Gravity

LOS: Limits of Stability

M: Mean

MD: Mean Difference

MIRHT25: Maximum isometric right hamstring torque at 25° of knee flexion

MILHT25: Maximum isometric left hamstring torque at 25° of knee flexion

MLSI: Medial/lateral Stability Index

NFP: Non Football Players

NM: Nanometre

OSI: Overall Stability Index

PCL: Posterior Cruciate Ligaments

Q-Q plot: Quantile Plot

RFP: Recreational Football Players

SPSS: Statistical Package for Social Sciences

SFIQ: Scottish Football Injury Questionnaire

(95%) CI: 95% Confident Intervals

(95%) CID: 5 % Confident Intervals of Difference

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Preface

This thesis is the report of four studies on sports injuries and their relationship with postural and neuromuscular control. The target group of the research was young football players in set age groups. This age group was selected, due to the importance of youth football programmes in any long term planning to enhance performance in this popular sport, as well as recognising the high prevalence of sports injury in adolescents during growth. The four studies are related starting with a retrospective study to determine the epidemiology of injuries in young Scottish football players over the season 2002-2003 and to identify common football injuries in this population. It provided a broad knowledge about the sports injuries in youth football. It was a good foundation for the familiarisation of the author as an international PhD student with Scottish youth teams. It also provided a good link for communication and recruitment of subjects for the other studies.

The second study aimed to determine the reproducibility of the unipedal and the bi-pedal stability of standing balance on the Biodex Stability System. This study complemented a similar study which was performed in 2001-2002 by the author to investigate the reproducibility of the Isokinetic Dynamometer REV 9000. These instruments provided the endpoint data for the subsequent studies. The results of both instruments had good to excellent test re-test reproducibility for all obtained variables.

The second study was extended and used a comparative cross sectional method, in which the isokinetic strength, bipedal and unipedal standing balance; and limits of stability were measured in professional, non-professional and non-football players. This study was designed to find out potential differences in the strength and balance characteristics of professional, non-professional and non-football players.

The final study was designed to find whether there was any difference in postural control in unilateral standing balance and isokinetic performance of the knee muscles in subjects with ACL reconstructed knees compared to the uninjured extremities. This study was conducted to find which methods of assessment could differentiate neuromuscular impairment after ACL reconstruction.

A considerable number of subjects were recruited for this research. In the first study the rate of sports injuries in 221 young football players from clubs and high schools teams was investigated retrospectively, to obtain information on the common anatomical sites, nature, aetiology and severity of common football injuries. In the reproducibility study 35 subjects took part in two age groups. They attended three times each for the familiarisation and two main testing sessions. In the extension to study two 54 participants were recruited from two levels of young football teams and a control non-football player group. Their neuromuscular performance was analysed, using the Biodex Balance System and the REV-9000 dynamometer. Finally 52 ACL-injured patients were assessed by the balance system and the isokinetic dynamometer to evaluate their neuromuscular impairment after ACL reconstruction compared to the intact non-injured knee. The data collection of all subjects was devised and carried out by the author between 2003 and 2005.

The thesis was designed in a way that four main areas of theoretical background would be covered. These four pillars are the necessary aspects of any investigation regarding neuromuscular performance or impairment in sport and sports injury.

Although the strengths of these studies are presented there were limitations similar to that occurring in many research projects. The plan of the research was modified as it developed due to available facilities, and time constraints

Further studies have been identified from the results of this thesis involving a prospective longitudinal study to investigate the role of proprioception and its modification on the prevention of ACL injury.

Abstract

More young people are participating in organised sport, due to growing physical activity promotion programmes. This may increase the risk of injury in adolescents. The rate of injury in football, in particular at a professional level has increased. There is a lack of literature in Scottish youth football in different aspects of sports injuries. There is a need in sports medicine for a static and dynamic standing balance and proprioception tests to quantify balance ability in adolescents. Although there are many studies focussing on the risk of falls in the elderly there are few studies of balance and measures of proprioception and muscle strength in young and adolescent sports participants.

Young football players were selected as the target population of these studies, because of the growing number of young participants in this popular sport, as well as the vulnerability of this group to sports injury during their growth.

Knee injuries commonly occur during sports activity. The consequences of ACL injury, in particular, are more serious and costly compared to the injuries of other joints. Football players suffer from an increased of knee injuries. In various stages of rehabilitation of the injured athlete after ACL injury a sensitive method of evaluation is required to identify neuromuscular impairment.

This thesis reflects the results of four studies on different aspects of sports injury. The first study, the retrospective epidemiology section, looked at the prevalence of sports injury in youth football players, using a self administered questionnaire as the data collection instrument. The focus of the research was football related injuries, which happened during the season 2002-2003. The subjects of this study were 221 young Scottish football players aged between 12 and 19 years old.

The second or reproducibility study was designed to examine whether the results from one of the main equipment tools utilised in this study were reproducible and consistent. This part of the study aimed to determine the test-retest reliability of one

tester dynamic unipedal and bipedal balance in two groups of youth football players and young active adults. A group of healthy active adults (over 19 years old) participated in the first part and a group of younger adults (under 19 years old) participated in the second part of the reproducibility study.

The extension to the second study was designed to compare balance and strength in professional and non-professional players and non-football players.

The final study aimed to find whether there was any differences in strength and postural control in unilateral standing balance and isokinetic performance of the knee muscles in subjects with ACL reconstruction and the uninjured extremities. There were two methods of assessment using the Biodex Stability System (BSS) and the REV dynamometer. Fifty-two patients, who were receiving physiotherapy treatment at the Sport, Health and Injury clinic of the Scottish National Stadium after ACL reconstruction, were examined.

In the retrospective study injury data were obtained from 221 respondents with a response rate of 55.25%. The prevalence of injury was 128 out of 221. 57.9% of players had at least one injury over the season 2002-2003. The rate of injury per 1000 hours of exposure time was 5.41 in training sessions and 6.56 in competitions. The incidence was 6.31 injuries per 1000 hours of total exposure.

Of the injured players 43.0% (55 players) were midfield players, 29.7% (38 players) were defenders, 17.2% (22 players) forwards and just 10.2% (13 players) were goal keepers. The most injured anatomical site was the knee (17.33%) with a similar number of ankle injuries (16.5%). In respect to the type of injury, muscle strain was the most common with 26.8% of all injuries. The second highest rate was that of fracture with 20.5%. The cause of 56.3% of all injuries was reported as having a contact mechanism, of which 52.8% were in club players and 47.2% were in high school teams.

The variables obtained in the reproducibility study were overall stability index (OSI) for bipedal standing, unipedal standing on the right leg, unipedal standing on the left leg and bipedal limits of stability. These variables were recorded in two groups of youth and adults with lower values indicating greater balance stability.

The intraclass correlation coefficient was calculated for all balance values obtained for test-retest comparisons. The results of the reproducibility study on two groups of subjects in two age ranges demonstrated good to excellent test re-test reliability for all four balance characteristics.

In the second study extension, data was obtained from isokinetic and balance assessments of fifty four young participants' age range 15 to 18 years. They were recruited in three groups. Twenty subjects from full-time Scottish Premier League Clubs, twenty one recreational youth football players, and thirteen non-football players within the same age range.

The professional group showed significantly higher values in several isokinetic tests assessing the quadriceps and hamstring muscles when compared to the non-football players group. Values that were related to the balance characteristics, however, were not significantly different when tested using one-way ANOVA post hoc procedure. The results of the balance tests that were performed using the Biodex Balance System did not show any differences among the three groups.

The final study confirmed that a number of tests regarding muscle imbalance including the hamstring quadriceps ratios obtained from eccentric and concentric isokinetic tests could show functional impairments in patients with reconstructed knees. There were no differences detected in the balance assessments using the BSS between the injured and intact knees. This may have reflected that the stability of the ACL-injured knees might have been very close to the normal condition after reconstruction and rehabilitation and/or the protocol of balance assessment using BSS was not sensitive enough to identify the potential impairments in balance.

1 Chapter One: Introduction

Regular physical activity reduces the risk of common diseases such as coronary heart disease, obesity, diabetes mellitus and hypertension [1] Recognising these health benefits exercise has been advocated for all either by lifestyle adjustment with a chance in physical activity or through sports participation. Sporting activity not only improves physical health but helps social inclusion and interaction.

Participation in physical activities and sport may lead to a risk of injury in recreational athletes as well as elite athletes. It has been estimated that each year 1-1.5 million people attend the accident and emergency departments in Britain[2] and about 2.7% of these attendances are due to sports injuries. In the US, around 7 million people each year receive medical attention to their sport injuries.

It is generally accepted that the occurrence of injuries is unavoidable and a price worth paying for the generalised health benefits.

Football is the most commonly played sport in the world and is a major vehicle for exercise activity for most ages and both sexes. Twenty millions sports injuries occur each year in Britain, half of which are in football.[3] Football is an intense, dynamic and intermittent contact sport [4] with demanding functional requirements. An intense sport, such as football, puts a significant level of stress on the individual player resulting in a high injury incidence compared to other contact team sports[5].

Success in competition is a main driver of attitudes and practice in sport. The achievement of systems of talent recognition and subsequent sporting success practiced in the previous Eastern European countries has stimulated interest in such activities in nations like Scotland where football is the predominant sport.
This has lead to the creation of academies of football where young talented footballers are identified and developed by professional coaches. This system has the advantage of exposure to scientific methods of nutrition and preparation by sports scientists and education regarding good habits of preparation and avoidance of sports injuries.

Although professional forms can only be signed at 16 years of age problems may arise from the amount of physical exposure which occurs in training programmes from a very young age with children's and youth teams affiliated to professional clubs under the age of 10 years.

Doubts have been expressed regarding the wisdom of taking fun and play out of children's and young people's activities particularly at a time of variable growth and maturation. Increasing amounts of cardiovascular training may lead to the risk of overuse injuries which may limit physical development at any stage and perhaps lead to problems in the future. This is particularly the case by increased exposure to organised competitive games with the physical challenge leading to traumatic injuries which may have long term consequences.

The increase in the number of children taking part in organised sport has lead to an increase of sports injuries in this group One of every 14 adolescents aged 13 to 19 years is hospitalised annually for a sport injury and football is the most hazardous sport with 28 injuries per 100 participants. The injury prevalence in football is calculated about a thousand times more than industrial injuries even in those occupations that are known as high risk.

Governing bodies of sport have the duty to organise and maintain standards but may be measured by the success and achievements on financial, political and nationalistic grounds. They also have responsibilities to monitor the facilities and care being provided for their member participants and clubs in team sports.

The approach to medical care and facilities within organised sport has usually been organised within the framework of the technical department and organisation. There is now increasing recognition that sports medicine is a new and developing specialty with an increasing professional role within sport. This has lead to new standards of care, better integration with the professions allied to medicine, and coaches with enhanced education and training for both medical and non medical staff.

There is a general lack of academic studies in sports medicine and particularly in the young. Three areas of interest were studied in this thesis. The results of each study allowed progression and development of the next investigation having identified new questions from the study results.

The aim of the first study was to determine the incidence and prevalence of sports injuries in young football players in Scotland and to identify the causes and aetiological factors, to examine the investigations and medical care given and to determine if methods of prevention might be applied. The results confirmed a very high prevalence of injuries, and although many were simple and self limiting, a major number of injuries were serious and associated with long periods of absence form training and competitive matches. The study results identified that early diagnosis; first aid treatment and initial management were often undertaken by non medical personnel suggesting that training for such individuals delivering care should be improved. The long periods of absence following injury identified a need for facilities to be made available for the young for rehabilitation which are not available within standard medical care systems. The need for serial assessments of young players during rehabilitation identified a requirement for methods to measure muscle strength and coordination including balance and joint proprioception. These tests would help to guide individual programmes of recovery targeting areas with particular loss of function.

The aim of the second study was to assess the reproducibility of tests of balance and proprioception in young trial subjects utilising the Biodex Stability System. Most previous studies had been conducted in older subjects with neurological pathology. This assessment studied its application in the young. This initial study was complementary to previous studies of muscle strength assessment performed by the author utilising the Rev 9000 isometric dynamometer. Having established the limits of reproducibility of the two methods of assessment these tests were applied to two groups of non injured football players of varying standard and training and to a control group. This gave further practical data these testing methods to give serial outcome measures in the assessment of sporting injuries with particular emphasis to the knee. In addition it explored the practical application of these tests in identification of differences in strength and proprioceptive function in elite and non elite players with a view to establish talent recognition and selection. The tests of muscle strength were different in the player and control groups suggesting further studies to help clarify if selective training methods might improve the function of the elite and the performance of non elite players.

The results of the second paired studies confirmed the utilisation of the tests in a specific young healthy group. It also identified that these tests were most applicable to the assessment of the knee and its associated muscle groups.

These tests of muscle strength, balance and proprioception were then applied to a specific group of subjects with ACL injuries of the knee at variable times during rehabilitation after ACL reconstruction. This injury is relatively rare in the young and a group of patients with a wider age range were studied using two protocols selected clinically according to their functional status. Some tests of muscle strength were reduced in the affected knee compared to the uninjured side although tests of balance and stability showed no difference. These observations suggest that rehabilitation to regain muscle strength may be guided after ACL reconstruction; however the tests of balance and stability may only be helpful in conditions with more effects on the proprioceptive function than that seen in these sporting injuries of the knee.

Further studies are indicated in each of the areas under study in this thesis.

2.1 introduction: the epidemiology study

The first chapter of this thesis explores the broad area of sports injury. Common injuries in sports include sprain, strain and fracture these constitute a large fraction of all sports injuries. Sports injuries commonly occur due to accidents; however the professional or competitive athlete may also suffer from overuse injuries.

The general incidence of injury in football, in particular at a professional level has dramatically increased. The development of youth football is a core part of the mission for success in top-level football all over the world. It appears that injuries are common during adolescence. Although studies in this field are numerous in other countries, there is a lack of epidemiological literature regarding Scottish Youth Football. In order to develop training programmes and injury prevention schemes in this age group, epidemiological studies are essential to delineate the size of the problem.

Prevention of injury is one of the main aims in sports medicine. There are several types of sports injuries, which are not avoidable on the other hand many of these accidents could be prevented. Prevention strategies cannot be formulated without investigating the prevalence, incidence and risk factors causing sports injuries in specific populations. There must also be a clear understanding of the aetiology . This aetiological aspect of sports injury concerns why and how injuries happen, including the underlying risk and mechanisms, reasons and factors which cause an injured athlete to be at particular risk. The method of data collection should also be standardised, in order to gather valid and reliable information. The obtained results should be used to adopt acceptable strategies of prevention.

2.2 The aim of the epidemiology study

The aim of the first section of this study was to describe the epidemiology of injuries in young Scottish football players over the season 2002-2003 and identify common football injuries among them. These studies are in relation to identification and description of the extent of the problem and the recognition of the factors and mechanisms that contribute to the incidence of injuries. Additional objectives were to identify the anatomic sites and nature of common football injuries in young professional football players and also to measure the incidence, rate and severity of athletic injuries among students in Scottish High School Teams.

2:3 Epidemiology study: Injury Prevalence

This section describes the background to the study by giving the general aspects of football injury studies. The definition of football, its characteristics and popularity and incidence of injury are overviewed.

There is naturally contact and collision in football as it is a physical sport[6]. However, in a number of epidemiological studies it was found that many injuries in football are not caused by direct contact, but they are due to other mechanisms, such as overuse, micro trauma or overstrain[7]. These facts, in addition to the clinical findings in regards to football injury emphasise the necessity for etiological studies, which can only be performed following epidemiological studies.

Cambridge 1996 defined Football or soccer as a game in which two teams of 11 players aim to score by kicking or using their heads to send a round ball into the goal of the opposing side. In this study the words football and soccer are used interchangeably.

Definition of injury

To conduct a study investigating the incidence of injuries in football it is very important to define an injury in the first place within the context of this sport. An injury has been defined as an incident, which takes place in a competition or a training session and which causes a football player to miss the following session(s)[8 9].

The definition which was used in the present study was similar "any injury that caused a player to be unavailable for selection for a match or participation in a training session". This definition is simple and practical and does not have many conditions and allows the results of this study to be compared to other studies with similar definitions.

The definition of aetiology or cause of an injury is an event, a person, action, thing or state, which produces an injury as an effect[10].

The incidence is defined as the number of injuries per player per tournament or season. In epidemiological studies the distribution, rate and determinants of injuries, disease, or other health problems occurring in general populations are investigated. This is ultimately to establish and implement strategies for prevention of those events in humans.[140]. The study of the distribution of varying rates of injuries (i.e., who, where, when, what) is identified as descriptive epidemiology, and the study of the determinants of a presented distribution of varying rates of injuries (i.e., why and how) is identified as analytical epidemiology[140].

Other definitions of injury have been used. An investigation performed in Australia on injury prevalence in Australian Football League[11] added a condition to the baseline definition. Only those injuries that required specific medical treatment other than conservative measures were recorded.

Mechanism of injury

The mechanisms of sport injury can be a macro trauma, which is an acute trauma caused by major force such as tackle, fall or collision and it usually occurs in musculoskeletal system, such as bone fractures, ligament sprains and strains in tendons and muscles [12 13]. The other mechanism is a micro trauma, which is the result of repetitive chronic injury such as overuse injuries, stress fractures, bursitis and tendonitis. Macro-traumatic injuries occur in contact sport and sports that involve running, jumping, fast direct changes, twists such as football, rugby, ice hockey and American football. Micro- traumatic injuries occur in sports that have the repetition of the same movement, such as tennis, golf, baseball and long distance running.

A sprain refers to the overstretching of one or more ligaments through twisting or pulling, which could be a torn ligament in advanced cases. A strain occurs when a tendon or muscle is overstretched.

2.4 Epidemiological Study Literature Review

The main aims of this literature review is to examine the methods and definitions used in previous studies and to review previous studies recording the prevalence and incidence, the mechanism and risk factors, the common types and anatomical sites of injury and the development of strategies to prevent injury. The incidence of injuries is high in children and adolescents, with an estimate of 4,379,000 injuries occurring annually in children and adolescents during sports and recreation in the USA[14].

Smithers and Myers 1980, recorded 1652 injuries in a period of a 12 month survey in 3 casualty departments in Brisbane. They recorded injuries in 35 different sports. 60% of injuries occurred during competition, 11% during training and the remaining 20% happened during recreational activities. About 7% of the injuries in contact sports were due to foul play. 55% of the injuries were soft-tissue, of which just 8% were referred to physiotherapy. This hospital based study would tend to record relatively serious injuries with minor injuries requiring only first aid being omitted.

It was thought that the rate of sports injuries may be lower in some rural areas because there are more agricultural than sports activities. This was disproved however as rural people were found to suffer from sports injuries as frequently as from agricultural injuries. About half of 2586 recorded injuries (1301) were not related to agricultural activity and sports and recreational activities accounted for 733 (28%) of them. Males were injured more often than females[15].

In a study of 588 players Dvorak studied and reviewed players on a weekly basis during the one year season[16]. This study showed an incidence of 4.3 injuries per 1000 training hours, 20.3 injuries per 1000 competitive match hours, and 7.3 injuries per 1000 hours of total exposure. This identified a very high rate of injury during competitive games.

Hawkins et al examined the frequency, intensity and incidence of injuries at three levels of professional football in 808 players per season from around 2600 players in the four English professional football leagues[17]. They considered an injury when it occurred at a match and caused the player to miss at least one competitive match. The study was performed using videotaped recordings of 171 matches during three years. The permanent nature of the videotaped games allows the mechanism of injury and other factors to be verified.

Le Gall et al studied the incidence of injuries in elite French youth football players. This was conducted over a 10-season period from August 1993 to June 2003. The study group included under 14's (U14), 15's (U15) and 16's (U16)[18]. During the 10-season period, players were subjected to 205,920 hours of training and 31,680 hours of match time (total time – 237,600). The total number of injuries was 1152 across all three age groups, with a higher match time incidence compared with training 11.2/1000 hours and 3.9/1000hours, respectively *(P*=0.02). The overall injury rate was 4.8 injuries per 1000 hours of activities across the three age groups. This study confirmed an activity ratio between training and playing of almost 7 to 1.

Ekstrand et al reported a prospective questionnaire based football survey. Injuries were recorded if they occurred during training or competition and if the injured player was not able to attend routine training or competition for more than 48 hours apart from the day of injury. A total of 6030 injuries were reported with an average of 1.3 injuries per player per season in English professional football over two competitive seasons[19]. This confirmed that football players are prone to a high risk of injury. They recommended changes in the training programmes applied by clubs, and identified the causes and patterns of injuries during matches relating to the time of injury, and the subsequent rehabilitation programme.

A further survey was performed to investigate the exposure of players to injury risk during English Premier League football matches with respect to certain criteria such the site of injury with regard to the zone of the pitch, the duration of the match, and whether the match was played home or away. The matches were recorded allowing the location and the time of any events, to be noted. The incidence of injury was 53 per 1000 playing hours[20].

The data from 237 players from 10 different teams in California was collected in an analytic epidemiologic study. The athletic trainer or doctor of the team considered each injury prior to entry to the study. Factors influencing injury were noted including the date, diagnosis, duration and mechanisms of the injury, age and position of the player and whether the injury happened in a game or a training session.[21]. The reported rate was 6.2 injuries per 1000 hours of participation. (2.9 per 1000 hours in training and 35.3 per 1000 hours in competitive matches). This study suggests that if coaches are used to record injuries then an appropriate level of education must be confirmed.

A study of the rate of injuries in Australian football in 1997-2000, showed a very high incidence with 39 new injuries per club (of 40 players) per season playing 22 games. The incidence of injury in competitions was 25.7 injuries per 1000 player hours. The injury prevalence was 16%, 17% of the injuries were recurrent. The features of this sport incorporate tackling the upper body as well as the activities of football.

A study was conducted in young football players during an under-20 football tournament in a total number of 405 players aged between 17 and 19 years. The definition of injury was based on whether the injured player received medical treatment. 19% of the players were injured.

These studies emphasis the variability in the reported incidence of injuries using variable definitions and durations of observations. Other studies have provided information regarding other factors associated with football injuries.

Site of injury

Lower extremity injuries represent 60-87% of the total injuries incurred by football players of both sexes[2223] . Most studies support that the knee is the most affected joint.

Types of Injuries

Soft tissue injuries classified as strains, sprains, or contusions represent 69-81% of all football injuries. Other uncommon injuries include fractures and other injuries, which are not unique to football such as, dislocations, tendonitis, overuse injuries, and heat-related injuries. In football 39% of knee injuries and 67% of the ankle injuries were ligament sprains. The medial collateral ligament was the most commonly injured ligament of the knee (75% of all ligament injuries) and the lateral ligament of the ankle was the most injured ligament of the ankle (80%). Muscular strains also were found to be the main injury of the upper leg (81%).

Risk factors

Age was recognised as a risk factor for strains of the calf and hamstring muscles in younger adults, but not for the quadriceps muscles in a cohort study in the AFL between 1992 and 1999. In this study, age was considered independently of past history. It was also found that such muscle strains may be associated with lumbar spine abnormalities. The L5 and S1 nerve roots, which innervate the hamstring and calf muscles, are more involved in aging degeneration rather than the upper lumbar nerve roots of the lumbar spine, which innervate the quadriceps muscles. In a study in Australian Rules football however no relationship was found between age and the rate or severity of injury.

Lack of flexibility and in particular muscular tightness appears to be an intrinsic risk factor to predispose to muscle strain. In a cohort study, in professional football players in Belgium, 146 male players were tested during pre-season screening. The rate of hamstring and quadriceps muscle injury was higher in those players with lower flexibility in those muscle compared to the control group[24]. A similar comparison did not show any significant differences for adductor or calf muscle injury. As a result of these findings a pre-seasonal examination of hamstring muscles was recommended to prevent muscle strain in high risk players.

In a prospective cohort study, a significant association was found between the structure of the foot and the development of an overuse injury[25]. The rate of stress fracture was nearly twice in those with either pes planus or pes cavus compared to subjects with a normal foot arch. Technical errors in training exercises were also found to be a risk factor for sports injury. [26]

Effect of the playing Surface

A football player moves about 10 km distance per game, in a 105 m to 68 m field of which 8-18% of the activity involves sprinting.[27] This is usually played on a grass surface or infrequently on a surface of sand, gravel or artificial turf. Initial studies suggested that there were more injuries occurring on artificial turf than on grass or gravel.

It has been proposed that the type of playing surface may influence the rate of injury in female football players[28]. There was a statistically significant difference between Astroturf injury rates for knee injuries in comparison to natural grass[29]. Research on the different playing surfaces indicated a higher incidence of injuries on the early forms of artificial turf, in particular knee and ankle injuries compared to grass or gravel. It is believed it might be due to the stiffness of the artificial surface, which increases the impact forces and consequently develops more load on the joints. There is also more friction between the footwear and the playing surface. Although the friction force is essential for stopping, cutting, pivoting and even a quick start, it is associated with higher rate of injury in football. Ekstrand et al did not find any difference in the rate of injury when[30] football was played on natural grass compared with newer forms of artificial turf. Other studies have not found the same relationship between extrinsic factors such as weather, playing surface, temperature, or the position of the player within the team and the rate of injuries[31].

Use of protective equipment

It has been shown that shin pads are effective in terms of protection against tibial fractures in football players[32]. The shin guard can reduce the force by 11-17% and strain by 45-51% compared to an unguarded leg. FIFA regulated the application of appropriate footwear, and shin guards as an obligation in matches and even in training sessions in 1990.

Influence of warm up

There is evidence that a balanced warm up programme of about 15-20 minutes, including endurance, strengthening and power activities could be beneficial for football players in terms of improving performance[33].

Classification of the severity of injuries

The National Injury Registration System suggested [196] that injuries could be classified into three groups:

- Minor – up to 7 days
- Moderate – 1 to 3 weeks
- Severe – more than 3 weeks

This method was adopted by other research groups. It was found that minor injuries accounted for 54%, moderate 26% and severe 20% of injuries.

A similar classification categorised minor as absence for less than one week (0-6 days), moderate as absence between one week and one month (less than 30 days) and major being over a month.

Other research groups have applied different methods of measuring the severity, based on the level of treatment received to recover to full match fitness. In case of the application of minor first aid, such as plasters or the application of ice then the injury was classed as 'minor'. Medical care with a trip to hospital, but no further action more than first aid was classed as 'moderate'. 'Major' injury was determined if any further treatment was required at hospital other than operation. If the subject required a hospital operation or similar procedure, it was classified as 'Extreme'[34].

2.5 Epidemiology Study: methods

The current study was carried out to find the commonly sustained injuries in young football players and to measure both the prevalence and the severity of injuries. It also aimed to determine how and when these injuries occurred. As an important criterion of severity this study looked at the time out of training and competition following an injury.

This study looked at injury in youth football players retrospectively, using a self administered questionnaire as the data collection instrument. The focus of the research was football related injuries, which happened during the season 2002-2003.

Primarily the Scottish Schools' Football Association was approached and requested to supply a list of high schools and contact persons in early 2003. A list of 38 high schools across various places in Scotland with contact names was provided in February 2003 (appendix 1), of which 28 high schools were chosen. Subsequently a letter of invitation was sent to the athletic director of schools, along with an introductory letter providing a brief description and rationale of the study. There was a separate page with questions with yes/no answers. They were requested to respond whether they wished to participate in the research. Stamped addressed envelopes were provided for all correspondence. Six of them refused to take part in the study and 4 did not reply. After further correspondence 18 schools agreed to take part in the research. Following these responses, 400 questionnaires were posted to the schools in June 2003, along with stamped address envelopes. The response rate in the first attempt was very low, though all schools were contacted, as a following up reminder, via fax or phone. Only 51 questionnaires were completed and returned. Due to the approaching school holiday the second attempt was postponed to late August 2003. The non-respondent schools were sent a second group of questionnaires. In the second attempt another 48 questionnaires were returned.

A further group of schools were approached directly by the author. Appointments were made to meet the players at their football training sessions. Personal attendance at schools was effective and 73 questionnaires were completed and collected. 172

questionnaires were collected at that stage. Three further groups of professional football players, recreational football players and non-football players were invited to take part in the study. The first and second cohorts were asked to complete the injury questionnaire, when they attended the Sports, Health and Injury Clinic of the Scottish National Stadium in late 2003 and early 2004. Another 49 questionnaires were added and at the end, the study concluded with 221 completed questionnaires.

Figure 1-1 Scottish National Stadium Hampden Park

The participants were from two distinguishable groups. The first group played high school football as a recreational activity and the second group played at a professional level at clubs.

The questionnaire had been designed, trialled and used within the Division of Cardiovascular & Medical Sciences of the University of Glasgow for an injury prevalence study of track and field sports. It was adopted and modified by the author for football injuries and named the Scottish Football Injury Questionnaire (SFIQ). To minimise the administration and completion time and make the questions easier to answer, open ended questions were avoided and most of questions simplified to a multiple choice format. There was the opportunity to extend on areas at the end of some questions, if it was required. This format was also rather less complicated for statistical analysis.

The questionnaire was first trialled in a focus group prior to the main study, to ensure the clarity and specificity of the questions. A group of 15 high school players completed the questionnaires. This was carried out to ensure if questions were clear enough and also how specific they were. It was identified that the questions were appropriate and straight forward to complete. A few words were changed, based on the feedback of the focus group, for instance words with more than three syllabuses, such as investigation and participation were replaced with 'test' and 'take part' respectively.

The developed questionnaire, SFIQ (appendix 2) contained 34 questions. The questions determined various aspects of the injuries sustained and were analysed using SPSS to identify frequencies and also comparison between variables such as the level of players, activity in training sessions and competition, warm up, cool down activities, the playing position and injury type and also the length of absence due to the injury.

Questions 1 to 4 obtained demographic information regarding the age, height, weight and the name of club or school. The respondents were asked about the duration of their experience in football in question five and their dominant foot in question six.

Questions 7 to 9 detailed the number of training sessions and their duration and the number of games per week. The players were asked if they had performed any other sport activities and if so how often and the duration of each session.

Questions 11 to 13 detailed the training surface, such as grass, artificial surfaces etc and also the use of protective equipments, such as shin guards and shoes.

Questions 14 to 17 indicated whether the players performed a warm up and cool down before and after training sessions and competitions, and if so they specified the duration of running, stretching and ball work in each session.

Questions 18 to 21 were regarding injuries. Those players who did not sustain any injury during season 2002-2003 completed the first part of the questionnaire (questions 1-17). The injured players were asked if the injury happened in training, first or second half of a game, and when it occurred during the season and in which month, as well as the playing position at the time of injury in questions 18 to 21.

Questions 22 to 27 were related to the medical or other staff who made the diagnosis, initiated the treatment and rehabilitation, as well as the types of diagnostic investigations and the site of treatment.

Questions 28 and 29 concerned the duration of absence after the injury was sustained. This was the main criterion to indicate the severity of an injury.

Questions 30-32 were related to the completion of the rehabilitation course and also any previous history of the same injury. The respondents were asked if they had finished the treatment course, if they had any previous injury and if the sustained injury during the season 2002-2003 was a recurrence of the same injury.

Question 33-34 were about the cause and the type of injury respectively. There were two answers in response to the cause; a. contact e.g. tackling/ getting tackled, blocking/ being blocked, contact with opponent, contact with goal post etc.; and b. non-contact, e.g. cutting, pivoting, twisting, jumping, injury during running etc. The last question included a table, in which the injured player specified the kind of injury, such as fracture, dislocation, sprain or strain and the region of the injury.

The data were coded and entered onto a database. The data were analysed using the Statistical Package for Social Sciences (SPSS version 11.0); $P < 0.05$ was considered significant.

2.6 Results of the Epidemiology Study

The data collected from the injury questionnaires were analysed using descriptive and comparative statistics, using frequency, cross tabulation, Chi Square, T test and other comparative tests. The subjects of this study were 221 young Scottish football players aged between 12 and 19 years (Mean 15.14 years S.D. 1.46 years). Their height ranged between 135.0 and 188.0 centimetres (Mean= 170.8, S.D= 9.25) and their weight ranged between 30.0 and 85.0 kilograms (M=60.74, S.D. 11.30). Table1. The mean values of age, height and weight do not greatly differ from the median value G Skewness and kurtosis measures for all of these variables were less than one. This also indicates that the distributions of age, height and weight of the subjects of this study do not differ significantly from a normal, symmetric distribution (table 2-1)

		Age	Height (cm)	Weight (kg)
N	Valid	221	221	221
	Missing	0	0	0
Mean		15.14	170.82	60.74
Std. Error of Mean		.11	.62	.76
Median		15.00	173.0	63.50
Std. Deviation		1.46	9.25	11.36
Variance		2.12	85.53	128.96
Skewness		-.30	-.86	-.83
Std. Error of Skewness		.16	.16	.16
Kurtosis		-.18	.93	.19
Std. Error of Kurtosis		.33	.33	.33
Minimum		12	135	30.0
Maximum		19	188	85.0

Table 2-1 Descriptive statistics of age, height and weight of the subjects

2.6.1 Response rate

From 400 questionnaires provided, 221 questionnaires were completed and returned. This gives an overall response rate of 55.25%. From the 221 respondents in this study, 125 (56.56%) were players in clubs and 96 (43.44%) were players in high schools.
The respondents were aged between 12 and 19 years old (mean = 15.14 years; standard deviation = 1.46 years). In the club players the age varied between 12 and 19 years (mean = 15.51 years; SD = 1.24 years) and in the high school players the age varied between 12 and 17 years (mean = 14.65 years; SD = 1.56 years).

2.6.2 Injury Prevalence

The prevalence of injury was 128 out of 221. It means 57.9% of players had at least one injury over the season 2002-2003. The rate of injury per 1000 hours of exposure time was 5.41 in training sessions and 6.56 in competitions. The incidence was 6.31 injuries per 1000 hours of total exposure. The rate of injury during training was 25.0% of injured players (32 players) and 15.4% of all respondents. The injury rate during competition was 75.0% of injured players (96 players), which was 24.2% of all respondents. The percentage of injuries, which occurred in games (75%) and training (25%) seemed different. The result was not significant once the incidence per 1000 hours of exposure was calculated. There were 5.41 injuries in 1000 hours of training sessions and 6.56 injuries in 1000 hours of competition. Comparing them using Chi Square test showed no significant difference ($\chi^2 = 0.057$, $P = 0.81$)..

2.6.3 Experience of Players

The experience of the football players ranged from 1 to 14 years (Mean = 7.82 years; S.D. = 8.00 years). The experience of the club players also ranged from 1 to 14 years (M = 8.38; S.D. = 2.25) and that of the high school players was between 2 and 13 years (M = 7.10; S.D. = 2.40). This confirmed that club players had on average 1.28 years more experience than high school players (P< 0.02 and 95% CI: 0.66 to 1.9).

The difference of the means between the experience of injured (M=7.66; S.D.=2.30) and non-injured (M =8.03; S.D.=2.53) players although showing a trend was not significant (P =0.36, C.I.: -0.28 to 1.01).

The clubs and high schools showed an injury prevalence of 57.6% (72 players) and 58.3% (56 players) respectively, which are similar. (Figure 2-1) From injuries that occurred during competition 43.6% (41 players) were in the first half and 56.4% were in the second half.

		Health		Total
		non-injured	injured	
Professional	Professional club	53	72	125
	High school team	40	56	96
Total		93	128	221

Table 2-2 Cross tabulation table of injured and non-injured football players in the two groups

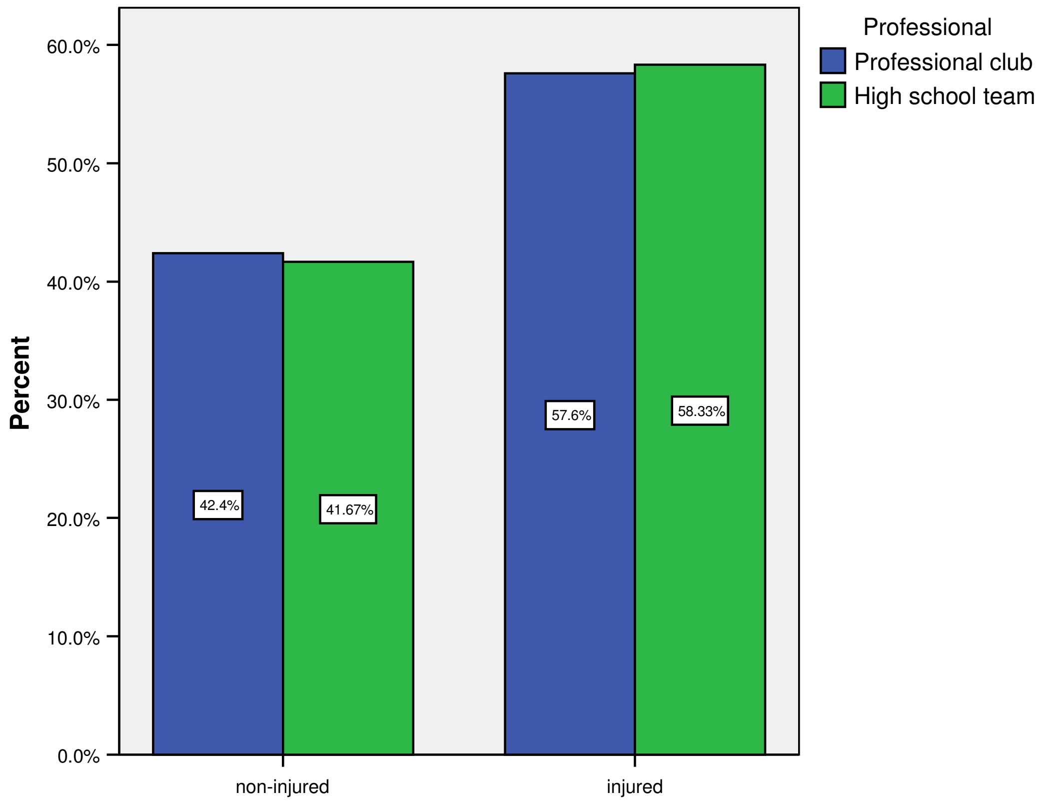

Figure 2-1 Graph of Cross tabulation table of injured and non-injured football players in the two groups

2.6.4 Playing Position

The positions of the injured players at the time of injury were recorded as 43.0% (55 players) midfield players, 29.7% (38 players) defence players, and 17.2 (22 players) forward players were just 10.2% (13 players) goal keepers. This descending order was the same when injured players are calculated in both club and high school groups (Tables 2-3 and 2-4). Chi Square test showed that the positions of injured players were significantly different (Chi Square 69.8, P= 0.000). However, because there was no question in the questionnaire to identify which position the players most often played there is no information about the positions of the non-injured players for comparison.

Position of the player		Frequency	Percent	Valid Percent	Cumulative Percent
1	Goal Keeper	13	10.2	10.2	10.2
2	Defence	38	29.7	29.7	39.9
3	Midfield	55	43.0	43.0	82.9
4	Forwards	22	17.2	17.2	100.0
	Total	128	100.0	100.0	

Table 2-3 Position of the injured players at the Time of Injury

			Total
Position at the Time of Injury	Professional club	High school team	
Goal Keeper	7	6	13
Defence	23	15	38
Midfield	30	25	55
Forwards	12	10	22
Total	72	56	128

Table 2-4 Cross tabulation of the position of the injured players at the Time of Injury

2.6.5 Anatomical site and type of injury

Figure 2-2 below summaries the anatomical sites of injuries in the 128 players. This is extended in table 2-5 to detail the type of injury sustained. The lower extremities were most commonly affected (78.1%). The most affected part in the lower extremities and in general was the knee (17.33%) followed by the ankle (16.5%). Other parts of the lower limb were also affected, such as food (10.2%), hamstring (9.5%) and hip (8.7%). The upper limb injuries occurred largely in elbow, forearm and hand (123.5%). Trunk injuries (7.1%) included the chest, abdomen and back. Head and neck injuries included the face (2.3%). The rest of the body parts such as the trunk, head and neck, shoulder, arm, foot, and toe were less affected. The knee and ankle were the most affected body parts.

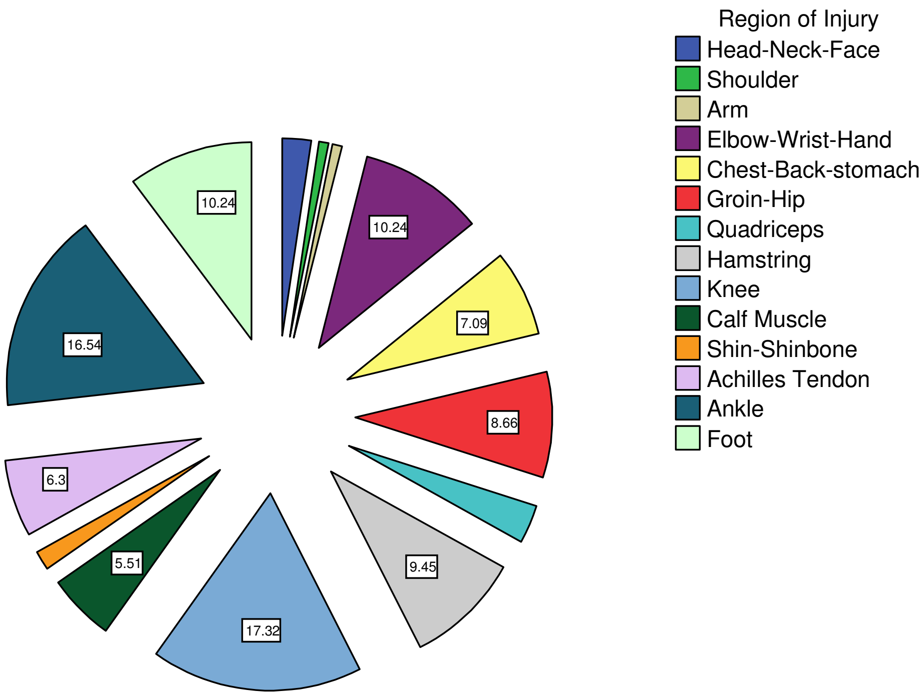

Figure 2-2 Graph of region of injuries in players

	Region of Injury	Fracture	Dislocation	Bruising	Strain	Sprain	Muscle Tear	Total
1	Head-Neck-Face	0	0	2	1	0	0	3
2	Shoulder	0	0	0	1	0	0	1
3	Arm	1	0	0	0	0	0	1
4	Elbow-Wrist-Hand	9	0	1	2	1	0	13
5	Chest-Back-stomach	2	0	1	3	2	1	9
6	Groin-Hip	1	0	0	6	1	3	11
7	Quadriceps	0	0	1	3	0	0	4
8	Hamstring	0	0	2	6	0	4	12
9	Knee	5	2	5	4	5	1	22
10	Calf Muscle	0	0	1	3	0	3	7
11	Shin-Shinbone	0	0	2	0	0	0	2
12	Achilles Tendon	0	0	2	3	0	3	8
13	Ankle	3	0	3	1	7	7	21
14	Foot	5	0	2	1	5	0	13
15	Non-injured	0	0	0	0	0	0	94
	Total	26	2	22	34	21	22	221

Table 2-5 Region and kind of Injuries in players

The knee and ankle were the anatomical sites of most injuries and the specific injuries and duration of absence from these injuries are detailed in figs 2-3 and 2-4.

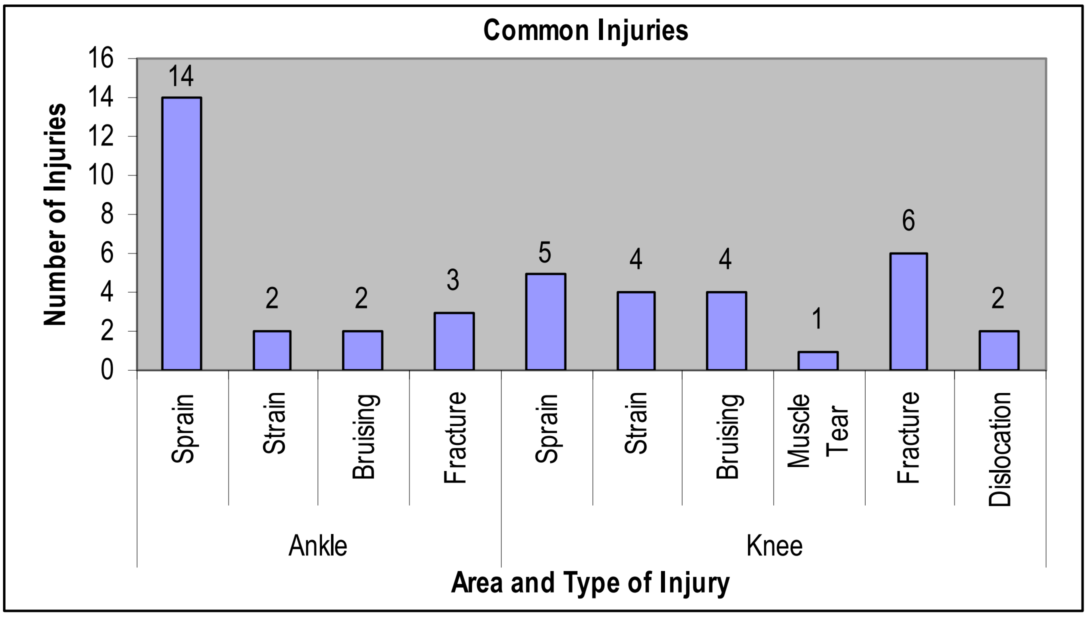

Fig 2-3 Graph of the Site and Type of Injury for the ankle and knee

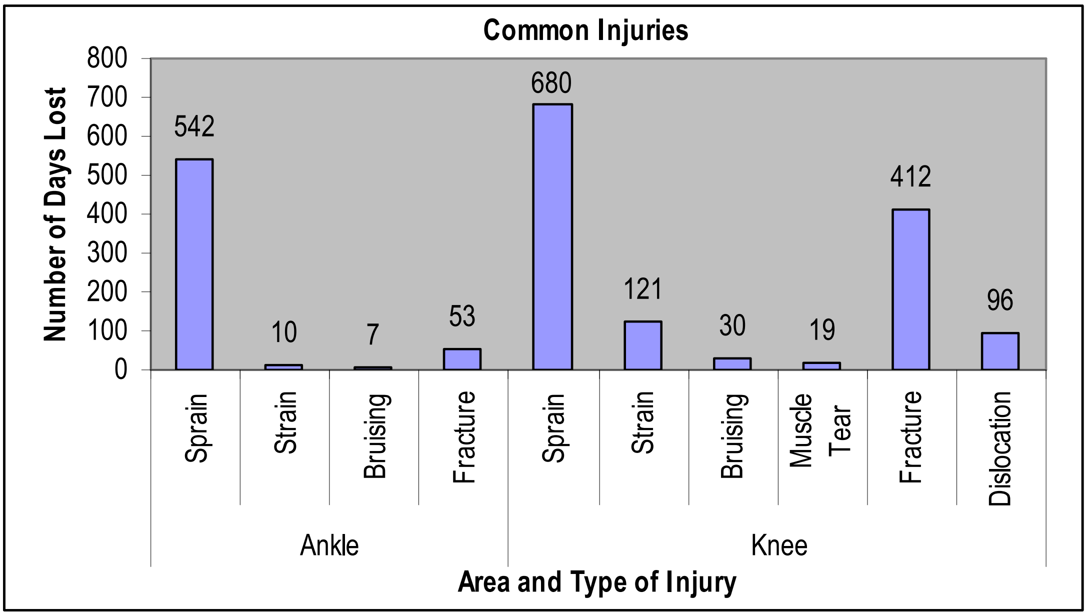

Fig 2-4 Graph of number of days lost from ankle and knee injuries.

In respect to the type of injury, muscle strain was the most common kind of injury with 26.8% of all injuries. The second highest rate was that of fracture with 20.5%. What came at the third place was again another type of muscle injury, which was muscle tear with 17.3%. The distribution of injuries are shown in fig 2-5 and table 2-6

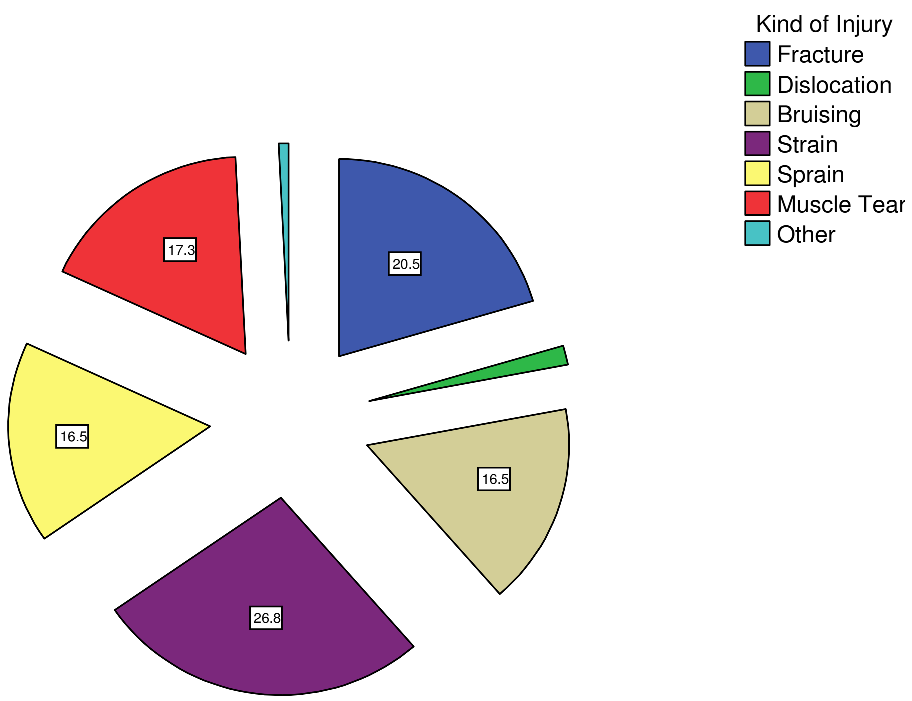

Figure 2-5 the graph of kind of injuries in players

		Frequency	Percent
1	Fracture	26	20.5
2	Dislocation	2	1.6
3	Bruising	22	16.5
4	Strain	34	26.8
5	Sprain	21	16.5
6	Muscle Tear	22	17.3
7	Other	1	0.8
	Total	128	100.0

Table 2-6 Frequency table of various kinds of sports injuries in players

Muscle and tendon injuries were common and lead to an average loss of activity of 34.7 days (Figs 2-6 and 2-7).

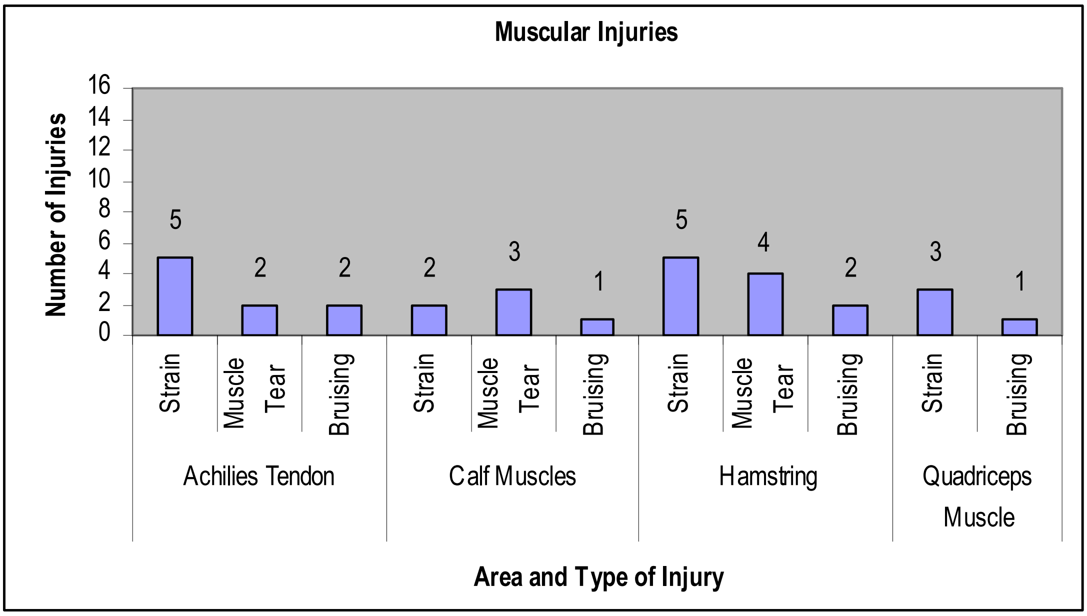

Figure 2-6 Graph of Site and Type for the common muscle injuries

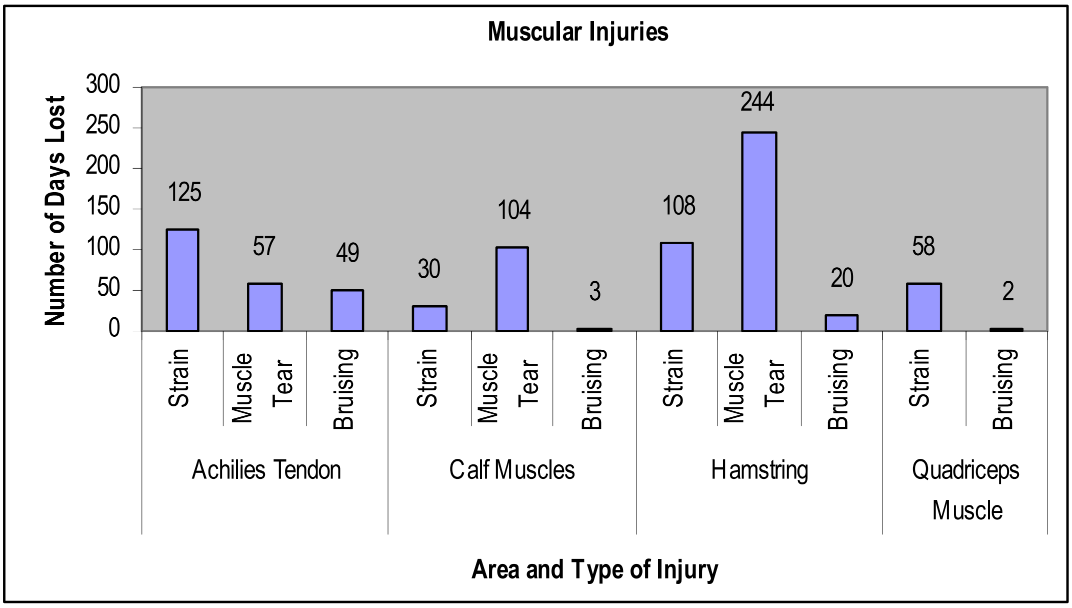

Figure 2-7 Graph of number of days lost in various site and types of common muscular injuries

2.6.6 Cause of injuries

The mechanisms of injuries, by which players are commonly injured during football training and match competitions, can be divided into contact and non-contact causes. Examples of contact mechanisms are tackling or being tackled and collision with another player and examples of non-contact mechanisms are landing, shooting, running and also other over use injuries. 56.3% of all injuries in this study had a contact mechanism of which 52.8% were in club players and 47.2% were in high school teams. Non-contact mechanisms were recorded as the cause of 43.7% of total injuries, of which 60% were in club players and 40% were in high schools teams (see Figure 2-7).

		Professional		Total
		Professional club	High school team	
Cause of the Injury	Contact	38	34	72
	Non-contact	34	22	56
Total		72	56	128

Table 2-7 Cause of the injury in football players in the two groups

2.6.7 Playing Equipment

The application of shin guards in competitions was almost universal. 96.8% used this protective equipment, however only 24.9% used them in training sessions. Table 2-9 Of 31 players who were injured in training sessions 23 of them did not use shin guards, however of the 90 players who did not report any injury only 22 of them used shin guards. Statistical analysis using chi square showed no relationship between using shin guards and sustaining injury in our study. There was no significant difference in the occurrence of injury between shin guard users and nonusers.

Count		Shin guard In Training		Total
		Yes	No	
Health	non-injured	23	70	93
	Injured	32	96	128
Total		55	166	221

Table 2-8 Cross tabulation table of shin guard users in training for injured and non-injured players

Studded boots were used in 43% of players and rubber soled shoes were used in 19% of players. About 27% reported that they used different types of shoes. No relationship was found between the type of shoes and sustaining injury. Table 2-10.

		Frequency	Percent	Valid Percent	Cumulative Percent
1	Studded boats	95	43.0	43.0	43.0
2	Training shoes	14	6.3	6.3	49.3
3	Rubbers	42	19.0	19.0	68.3
4	Other	10	4.5	4.5	72.9
5	Multiple	60	27.1	27.1	100.0
	Total	221	100.0	100.0	

Table 2-9 Frequency table of types of footwear in players

2.6.8 Duration of activities

Table 2-10 shows the duration of activities for the injured and non injured players.

The comparison of means of the “total training duration per week” of the two groups of injured (241.8 minutes) and non-injured players (289.61 minutes), using independent-Samples T Test procedure, showed that the mean values are significantly different. (*P*=0.047). The total duration of training was less in the injured players than in the non-injured players. There was no significant difference for the two other variables, ‘the total duration of games per week’ and ‘the total duration of other sporting activities per week.’

	Health	N	Mean	Std. Deviation	Std. Error Mean
Total training duration per week	non-injured	93	289.61	184.21	19.10
	injured	128	241.79	147.95	13.08
Total game duration per week	non-injured	93	198.39	63.03	6.54
	injured	128	220.43	63.85	5.64
Total duration of other activities	non-injured	93	43.71	64.90	6.73
	injured	128	38.30	59.87	5.29

Table 2-10 Duration of activities for injured and non-injured players

Table 2-11 shows the duration of activities for the club and high school players. The mean values of the “total training duration per week” of the club players (324.3 minutes) and high school players (193.7 minutes) were also shown to be significantly different (*P*=0.001). There was no significant difference in the “ total duration of games per week” between the two levels of club and high school players (P= 0.18 CI -19.6 -5.5) Similarly the mean values for the “total duration of other sporting activities” were not significantly different in the two groups of players. (*P*=0.89, CI: -17.7, 15.4).

	Professional	N	Mean	Std. Deviation	Std. Error Mean
Total training duration per week	Professional club	125	314.34	179.01	16.01
	High school team	96	193.66	115.20	11.76
Total game duration per week	Professional club	125	205.92	60.01	5.37
	High school team	96	217.97	69.20	7.06
Total duration of other activities	Professional club	125	40.07	62.79	5.61
	High school team	96	41.24	61.16	6.24

Table 2-11 Duration of players' activities for club and high school players.

2.6.9 Effect of Warm up

The duration and breakdown of activities performed during the warm up are shown in Tables 2-12 and 2-13 and expressed in figs 2-8 and 2-9.

Most of the respondents (96.8%) reported that they performed a period of warm up prior to training sessions and almost all of them (220 out of 221 players equal to 99.5%) did a warm up before a competitive match. About half of the respondents (50.7%) performed 10 minutes of running prior to a training session. More than one third of them (35.3%) did 5 minutes of running before training sessions (M= 8.51 and S.E= 3.81). The duration of stretching before training sessions was 5 minutes in 141 players (63.8%) or 10 minutes in 28.1% of players (M = 6.86 and S.E = 3.29). The median duration of ball work before training was 10 minutes in 58.8% of players (M = 10.54 and S.E = 4.31). The median of the total period of warming up before training session including running, stretching and ball work was 25 minutes. (M = 25.91 and S.E = 7.93).

The duration of warming up before competition was not significantly different from that of training. The median of running before competition was 10 minutes in 49.8% of respondents, followed by 5 minutes in 32.6%. (M = 9.21 and S.E = 3.92). The duration of stretching prior to competitions was reported with median of 5 minutes in 47.5% of players (M = 8.10 and S.E = 3.85)

	Health	N	Mean	Std. Deviation	Std. Error Mean
Running Before Training	non-injured	93	2.58	.80	.08
	injured	128	2.79	.73	.06
Stretching Before Training	non-injured	93	2.30	.62	.06
	injured	128	2.42	.68	.06
Ball Work Before Training	non-injured	93	3.24	.95	.10
	injured	128	3.02	.78	.07
Cool-down After Training	non-injured	93	1.29	.46	.05
	injured	128	1.27	.45	.04
Running After Training	non-injured	93	1.74	.59	.06
	injured	128	1.78	.55	.05
Stretching After Training	non-injured	93	1.74	.61	.06
	injured	128	1.77	.63	.06

Table 2-12 Type of warm up activities for injured and non-injured players

	N	Range	Minimum	Maximum	Mean	Std. Deviation
Warm-up Before Training	221	1	1	2	1.03	.18
Running Before Training	221	20	0	20	8.51	3.82
Stretching Before Training	221	20	0	20	6.86	3.30
Ball Work Before Training	221	20	0	20	10.54	4.31
Running Before Competition	221	20	0	20	9.21	3.92
Stretching Before Competition	221	20	0	20	8.10	3.85
Warm-up Before Competition	221	1	1	2	1.00	.07
Ball Work After Competition	221	20	0	20	9.82	3.23
Cool-down After Training	221	1	1	2	1.28	.45
Running After Training	221	10	0	10	3.87	2.71
Stretching After Training	221	15	0	15	3.80	3.06
Cool-down After Competition	221	1	1	2	1.21	.41
Running After Competition	221	20	0	20	4.52	3.07
Stretching After Competition	220	15	0	15	4.36	2.99
Valid N (list wise)	220					

Table 2-13 Descriptive Statistics of warm up characteristic before training and competition

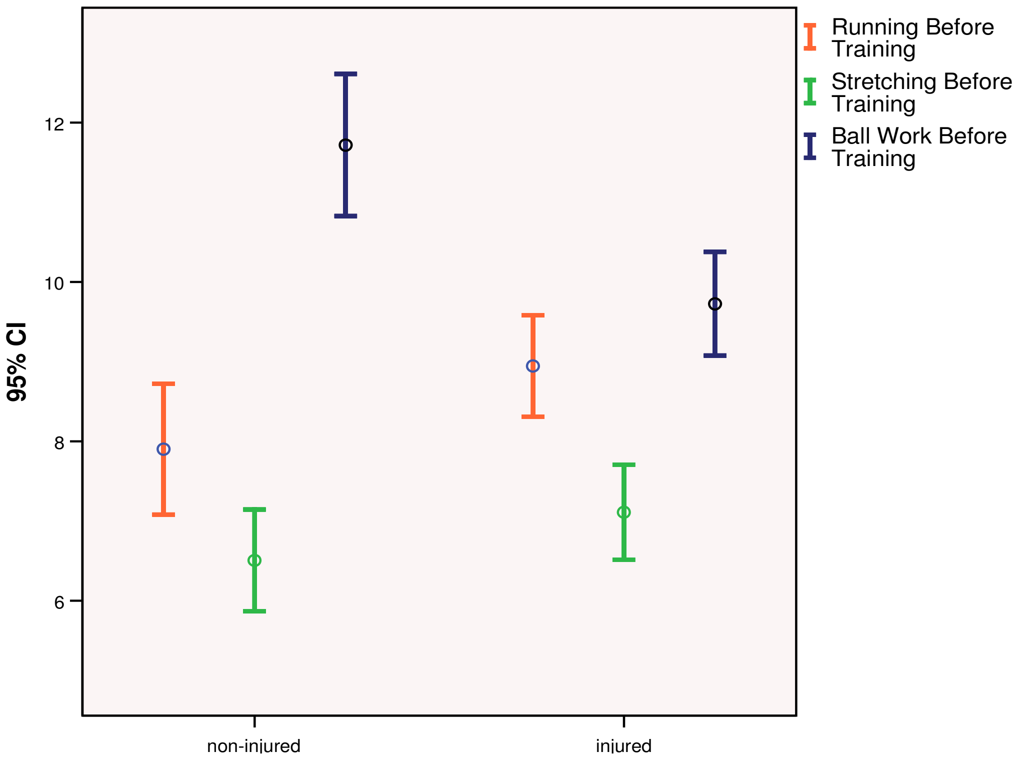

Figure 2-8 Graph of activities before training for injured and non-injured

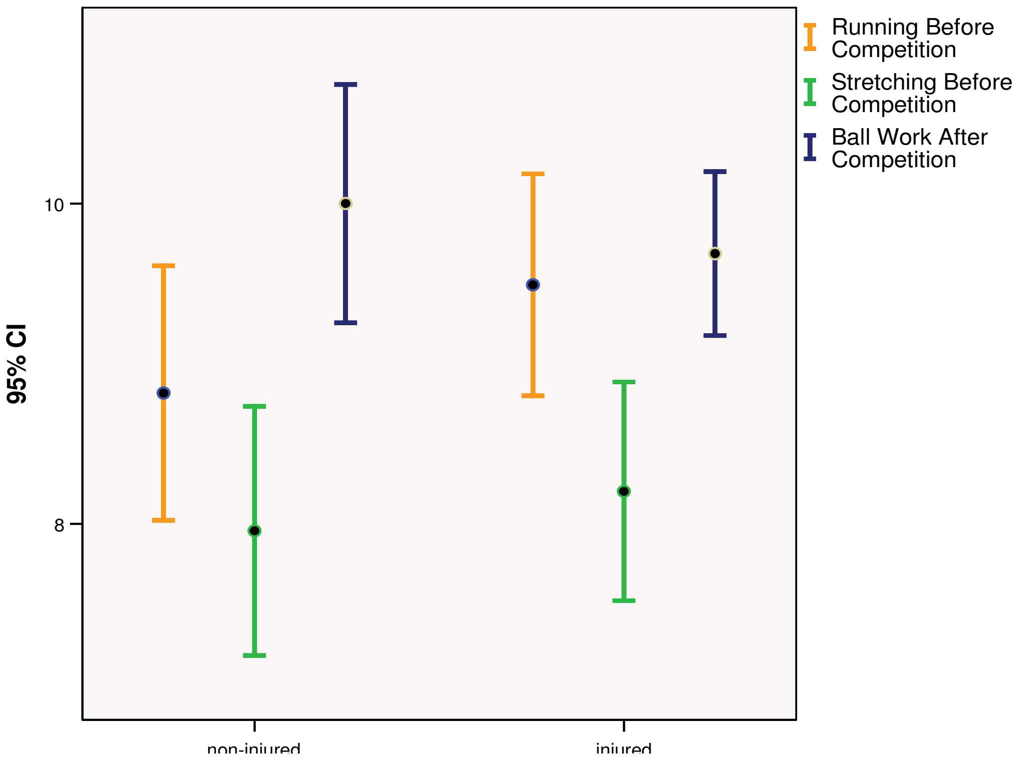

Figure 2-9 Graph of activities before competition for injured and non-injured

2.6.10 Severity of injuries

The severity of injuries was measured using the 3 categories suggested by the National Injury Registration System. Table 2-14 and 2-15 show the severity of the injuries, based on the total time missed. Minor injuries accounted for 9 injuries out of 128 (7.0%) in training and 19 injuries out of 128 (14.8%) in matches. Moderate injuries accounted for 7.8% in training sessions and 25.8% in matches. Severe injuries occurred more frequently in matches (34.4%) compared to training sessions (10.2%). In total, 21.9% of all injuries were categorised as minor injuries, 33.6% as moderate and 44.5% as severe injuries.

		Training		Competition		Total	
		Number	Percent	Number	Percent	Number	Percent
Severity Based on Total Time lost	Minor	9	7.0	19	14.8	28	21.9
	Moderate	10	7.8	33	25.8	43	33.6
	Severe	13	10.2	44	34.4	57	44.5
Total	Number	32		96		128	
	Percent		25.0		75.0		100.0

Table 2-14 Cross tabulation table of severity based on total time lost for training and competition

Severity of the injury		Frequency	Valid Percent	Cumulative Percent
1	Minor	28	21.9	21.9
2	Moderate	43	33.6	55.5
3	Severe	57	44.5	100.0
Total		128	100.0	

Table 2-15 Severity of the injury based on total time lost

2.6.11 Injury recurrence

In seventy injured players (53.4%) there was no previous history of injuries which caused them to be absent at a training session or a competition, however sixty one injured players (46.6%) had such a history before, either of a recurrence of the same or another injury. The reported injury was recurrent in thirty one players (24.2%), and new injuries were recorded in ninety seven players (75.8%).

2.6.12 Influence of treatment completion

Twenty two of the injured players did not complete the treatment course of which 4 had a recurrence (see Table 2-16). Of the 106 who did complete the treatment, 27 had a recurrence.

The risk estimate for the completion of the treatment course and recurrence rate of injuries was assessed. The risk estimate table shows that the confidence interval for the odd ratio contains 1, so completion of treatment did not affect injury reoccurrence.

		Recurrence		Total
		Yes	No	
treatment completed	Yes	27	79	106
	No	4	18	22
Total		31	97	128

Table 2-16 Cross tabulation table of the rate of treatment completion

2.6.13 Provision of Medical care

The first aid medical care for clubs was provided by the coach (40.6%), physiotherapist (47%), doctor (10%) or both physiotherapist and doctor (7%). Most of diagnoses were made by the physiotherapist (31.7%) or doctor (28.6%), however the coach made the diagnosis in a significant group (15.1%). Both doctor and physiotherapist made the diagnosis for 10.3% of the respondents. Rehabilitation of the injured players was guided in 37.5% of injuries by physiotherapist, but in 17.2% of them by coaches, and only 14.1% of them by doctors 6.3% of injuries had advice from both physiotherapist and doctor however 16.4% mentioned neither of these.

2.6.13 Investigations

Players had various types of clinical and paraclinical investigations, including clinical examination (23.6%), X-ray (26.8%), M.R.I scan (4.7%). A considerable number (29.9%) had no investigations.

2.6.14 Treatment methods

A large number (26.0%) of injured players were treated with I.C.E (ice, compression and elevation). Other types of treatment were ultrasound (15.4%), splint and plaster (9.8%), multiple procedures (10.6%), but a significant number (20.3%) did not have any formal treatment. The sites of treatment were variable and included hospitals (26.6%), sports clinics (18.8%), GP surgeries (5.8%) and other locations (17.2%).

The duration of time lost due to injury was examined based on the type of treatment that injured players received. Fig 2-10 Comparing the means of groups showed a significant difference, using one way ANOVA (P=0.000).

The post-hoc Bonferroni test was performed. Results showed that the mean of days lost due to injury in the group of players who were treated by ultrasound was not significantly different from any other groups' means ($P > 0.5$). The mean absence of the group treated with I.C.E (ice, compression and elevation) was significantly less than the “splint-plaster” group (*P*=0.001) and that of the multiple treatment group (P 0.004), but did not greatly differ from the duration of absence of the group with no treatment and the group who received ‘other treatments’. The mean absence of the “splint-plaster” group was not different from that of the multiple treatment group, but was significantly longer than the groups who received ‘other treatments’ (P=0.005) or no treatment (*P*=0.001). The means absence of the group who were treated with multiple treatments and the group with no treatment was also significantly different (*P*=0.013).

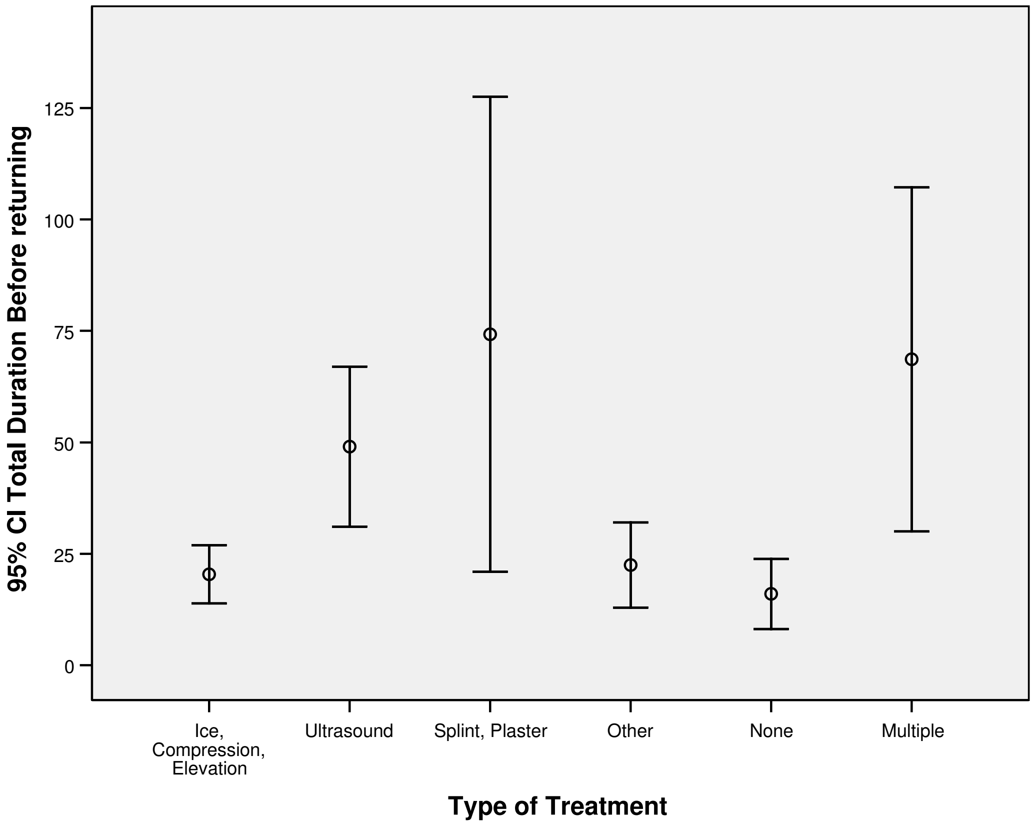

Figure 2-10 Graph of type of treatment based on total duration before returning

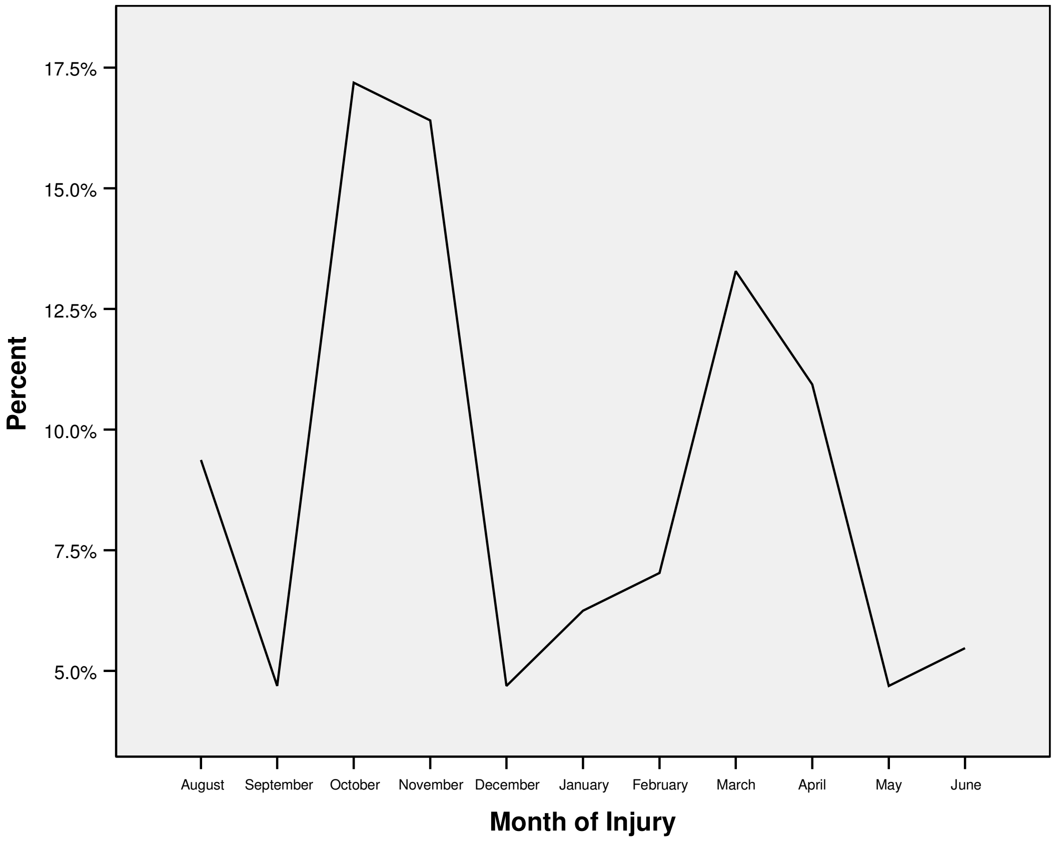

Figure 2-11 Time of the occurrence of injury during the season

2.6.15 Time of injury

The time of occurrence of injuries is shown in Fig 2-11

The rate of injury was higher in November (18.8%) and October (14.8 %), followed by March (13.3%) and April (10.9%). Injuries were infrequent in September (4.7%), and during the winter break in December (4.7%), and towards the end of season with fewer competitive matches in May (4.7%), and June (5.5%).

The injuries were however spread through the season. 50% of the injured players specified the middle of the season as their time of injury. This was followed by injuries which occurred at the end of season (22.7%) and in early season (20.3%). The frequency of injuries was surprisingly low in the preseason period (3.2%) Fig2-12.

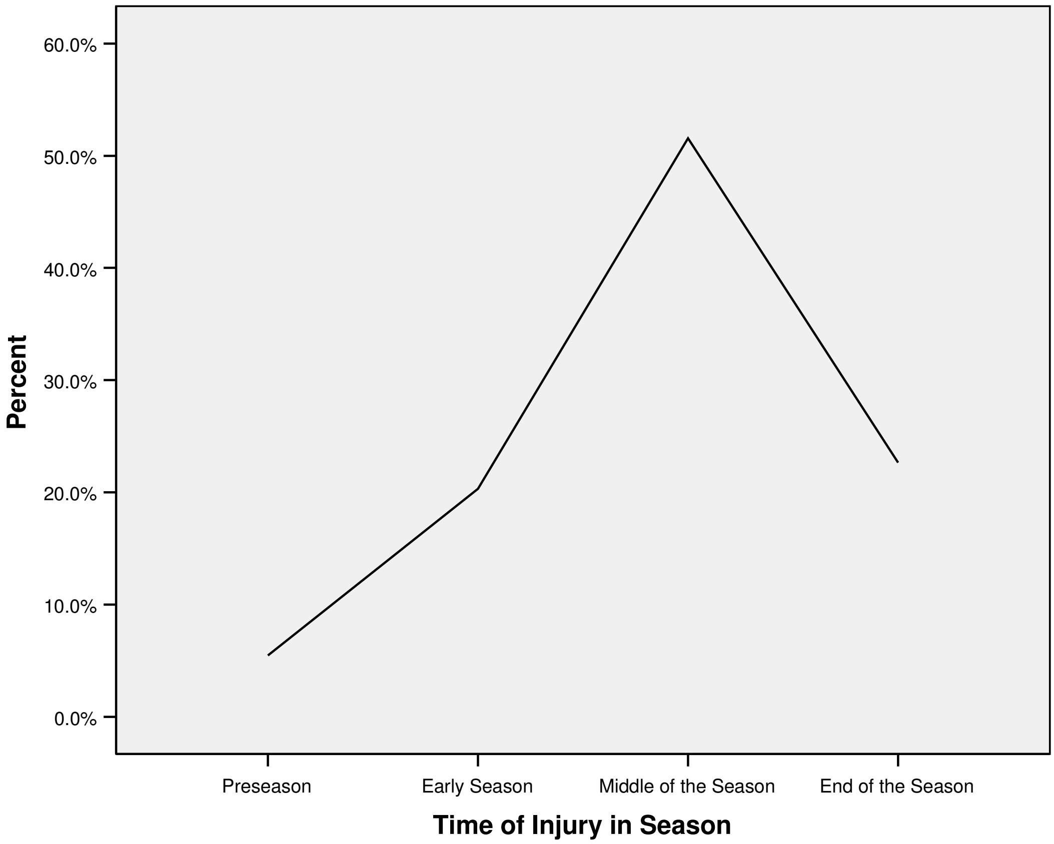

Figure 2-12 Graph of time of injury in various time in the season

2.7 Discussion: the Epidemiology Study

The cost of sports injury is an important dimension of the problem. In professional football the income is higher than £1 billion in recent years. Premiership football players are highly valuable, and their fitness worth millions to their clubs. Their injuries are the cause of major financial loss which was reported as £747 million in the 1999-2000 season. This covered expenses, such as medical care, treatment and insurance premiums. Due to these injuries, an average of 10% of football players were absent during the season. In addition to the immediate healthcare costs, sports injuries may have long-term effects on the musculoskeletal system, resulting in limb dysfunction and a subsequent reduction in levels of physical activity.

It is important that the cause and nature of injuries in football are understood, in order to reduce the risk to players during training and competition[35]. When financial aspects are concerned, the cost of buying professional players from young teams from all over the world, such as from Africa could be significantly reduced if the quality of Scottish Youth Football is improved and the rate of injury in this age group is diminished.

The results of this study focus on the first two phases in the process of football injury prevention, which are the identification and description of the incidence of injury and recognising the mechanisms and risk factors that cause common injuries in youth football [195,196]. The findings of the present study can fill the gaps in previous studies with new relevance for Scotland. The results emphasise the significance of injury in young football players, their severity and create awareness regarding possible methods of prevention [195, 196].

The topic of football injuries is a broadly studied area and has been investigated using a variety of methods, data collection and overall approaches by numerous researchers as outlined in the introduction section. Several authors have explored the frequency of football injuries in youth players. However, the results of these studies are inconsistent because of the different age groups investigated and the different methods applied.

The purpose of the first part of the present study was to quantify the prevalence, and severity of football-related injuries in Scottish young football players over the season 2002-2003. The objectives were to identify the anatomic sites and nature of common football injuries in young football players.

The outcome of interest in this study was injury and the method measured retrospective injury prevalence. As football injury is a general term the "injury" must firstly be defined. A review of the literature showed no overall consistent consensus about its definition. As far as the validity of data collection is concerned specific guidelines must be set to design a study with consistent findings across different football teams. There are many different opinions in respect to the definition of sports injury and it has been a controversial issue for many years.

A definition of injury in football was devised during the Football Association Research Programmes' Audit, which considered only injuries sustained during a training session or competition resulting in the player missing 48 hours or more of overall participation, excluding illnesses, i.e. the cold or flue etc[36]. Other researchers have also developed their own definitions of an injury and using only injuries, which were treated at a hospital by a medical professional.

Injury definition was devised in another study, which included all severities ranging from acute to chronic depending on the duration of time lost from training or matches.[37].

Based on this study the injuries also should have resulted in the player being unable to participate in a training session or a competition match. In a group of studies the injuries were collected through hospital casualty files or insurance claims. In these methods of data collection, a large percentage of serious and acute injuries might be recorded, but less serious or overuse injuries will not be recorded. So this kind of investigation may just reveal the top of the iceberg.

Definitions, which consider both a period of unavailability of the player and the need for medical care, seem to be very specific. Such definitions have some problems and complexity for research purposes. Alternatively very minor injuries might be recorded by players and coaches, which would not have influenced participation at all if only first aid treatment was needed.

In the present study, a simple definition was applied, as any injury that resulted in a football player missing one or more training session or competitive game. The simplicity of this definition allows comparison with a wide range of studies which used similar definitions.

Unlike the controversy around the definition of sports injury, the duration of time taken out of training and competition is a well accepted criterion to measure the severity of injuries. It was suggested that the severity of each injury should be defined as slight, minor, moderate or major depending on whether the player was absent from training or competition for two to three days (slight), four to seven days (minor), one to four weeks (moderate) or more than four weeks (major). In football over 65% were minor, 25% moderate and 10% major. Similar classifications have been used with differences in the duration of absence, a minor injury was considered as having a recovery time of less than one week; moderate injury one to four weeks and a severe injury having more than four weeks recovery time [38 39 40]. In another study, conducted in the AFL in seasons 1997-2000, the average number of games missed per injury was used to define the severity of an injury. The authors stated that the average injury severity assessment might have underestimated the average recovery time for serious injuries, because the season was only 22 weeks long. Severe injuries such as an anterior cruciate ligament (ACL) injury, which usually needs an operation, can prevent a player from playing for 6 - 10 months. If this occurred towards the end of a season the severity assessment would be an underestimation if based only on the number of games missed. Van Mechelen et al[195 196] described a system based on six criteria: including the sporting time lost, working time lost nature of injury, nature of the treatment, duration of the treatment, resultant permanent damage, and cost. The choice in the present study again was the use of a simple three category definition.

The aims of this study were to identify the common injuries that young football players experience. In addition to this, areas such as injury type, mechanism, injury location and player position was determined in order to identify possible correlations between variables such as whether the playing position affects the numbers and type of injury sustained.

Response rate of questionnaires

The overall questionnaire response rate of the study was 55.25%. This is comparable to that of the study of Maffulli et al which looked at the injury rate in elite young sports persons. The response rate in their study, which targeted four groups of swimmers, soccer players, gymnasts and tennis players, was 50.4% [41]. Another questionnaire based study looked at marathon race injuries and had a 48.3% response[42]. A similar injury study in skiers had a response rate of 50.4%[43].

The initial poor response reflected in part the unsolicited nature of the approach of the author to the schools rather than from an expression of interest by the schools to initiate the study. The improved response rate following personal, face to face contact provided a base for improved recruitment into the subsequent studies.

Football as a team-sport has many advantages for youngsters to increase their teamwork and communication skills. The communication and interaction, though sometimes causes contact with other players. The nature of a team-sport may necessitate sacrificing yourself for the greater good of your team. Young athletes require high physical skills to be in the right place at the right time as well as psychological skills to cope with unexpected physical challenges.

The risk of sustaining an injury per participation at each team event is highest in rugby, followed by football and field hockey[44]. This was supported in other studies where the incidence of injury per 1000 hours exposure for rugby players was 69[45] compared with 53 for ice hockey players and 28 for footballers and significantly less for cricket with only 2 injuries per 1000 hours exposure. Alternatively absolute numbers have been reported in other studies, in which 178 injuries occurred in football and just 18 occurred in rugby union during the same period. This might have been as a result of higher participation rate in football, as the national sport, in the UK. It could be inferred that this rate should be higher for rugby in countries such as New Zealand where rugby is the national sport. In other words it is related to the total hours of exposure in training and competition.

Prevalence of injuries

The prevalence of injury was 128 out of 221 subjects. This means that 57.9% of players had at least one injury over the season 2002-2003. The injury prevalence in a study by Woods et al in English Football League was only 40%, which was significantly lower than the injury prevalence in the present study. They looked at an audit of injuries in professional football across the time period of two seasons (July 1997 – May 1999), which included the participation of 92 teams from the English Football League. The definition of a football injury used in their study involved the recording of any injuries sustained during training or competition, which resulted in 48 hours or more of playing. The age of their target group was older than in the present study and secondly the definition had the condition that the injured player was not able to take part in at least 48 hours of activity. This added condition could reduce the rate of recorded injuries compared to the present study which included more minor injuries.

The rate of injury per 1000 hours of total exposure was 6.31. This incidence was not significantly different in training and competition. Since some teams participate in more games or train more times per week compared to others, the consistency and the reliability of data will be reduced, unless the method of measuring the injury rate per 1000 hours of exposure is operated. Arnason et al reported a higher injury rate for matches compared to the injury rate in training, with 4.4 versus 0.1 per 1000 hours of activity equating to 98% versus 2%. This inconsistency in results could be due to different programmes of training relative to competitive matches. In teams with a high demand in training the rate of injury does not differ greatly in matches and training.

According to Hawkins et al [46] the impact of an injury on a club can be considered in relation to its severity and the number of potential competitive matches and training sessions missed. When considering the time taken out of participation per injury, the average figure in this study was 34.7 days. The total time loss from knee ligament injuries was the highest with 680 days for 5 sprains, an average of 136 days for each. The average absence due to other severe injuries was 68.7 days for knee fracture, 61.0 days for hamstring muscle tear and 38.7 days for ankle injuries. The exact diagnosis may be in doubt in some cases of self reporting of players. It is felt that the site of injury and duration of absence should be simply recalled.

Previous studies have recorded a wide range of incidence, e.g. 0.518 [47] to 5.619 [48] injuries per 1000 hours of exposure during a season. In most of the studies, the time players spent in training and games was not reported separately. The circumstances of injury in youth players, such as overuse, trauma, and contact, have also rarely been reported. The incidence of soccer injury has been investigated in several studies, and varies for adult male outdoor players (>16 years) from 12–35 [49] injuries per 1000 match hours. For youth players, the reported incidences range from 0.5–13.7 [50] injuries per 1000 hours exposure. Specific analysis of youth soccer players has shown that the incidence of injury increases with age[51 52 53] . The present study confirms a high rate of injuries in an adolescent population.

Adolescents are more at risk during growth[54]. They are becoming more susceptible to injury in sport since the philosophy of 'catch them young' is becoming more popular. This is exposing children and adolescents to more overuse injuries[55]. The period of adolescence, at the age of peak height increase, is also unique in terms of vulnerability to fractures. This is when there may be an imbalance between muscle strength and relative bone strength[56].

Growing youngsters can also be considered as a vulnerable group in regard to sports injuries, due to their growth spurt and vulnerability to growth plate injuries. The growth plate is a weak point compared to the other anatomical structures around it, such as fibrous tissue and bone. These injuries occur before puberty and have no counterpart in adults. The growth plate cartilage has less resistance to shear and compression forces compared to articular cartilage. It has much less resistance against tension and shear forces compared to bone. Acute traumatic and over use injuries, due to intensive training may cause different types of injuries at the growth plate. It may vary from a type of Salter Harris fracture to a permanent injury to the growth cells and consequent growth disturbance. There is evidence that shows an association between peak height velocity (growth spurts) and the peak fracture rate above. The higher rate of injury during periods of rapid growth may also be due to enhanced bony growth relative to muscles and ligaments. It is possible that the muscles are not strong enough to support the developing skeleton. There might also be an increase in musculoskeletal tightness about the joints. Longitudinal growth occurs initially in the long bones of the upper and lower limbs and in the spinal column. The musculotendinous structures elongate later in response to bone growth. Thus, during the period of time until full adaptation of the soft tissues occur there might be a loss of flexibility[57]. However, other studies that failed to find a lack of flexibility in this growth period[58].

The incidence of injury per 1000 hours of exposure has been suggested to be higher in low-skill rather than in high-skill groups in previous studies[59]. In this study which looked at two levels of players. The high school level players would be expected to be of a lower skill level than the professional. The rate of injury was not significantly different, however, in these two groups. Both groups had high training and playing loads.

The recorded incidence in the current study (6.31 injuries per 1000 hours of exposure) is in the mid range of the findings of other studies. This finding may be surprising as the speed and physical nature of the Scottish style of football might be expected to have a higher injury rate than seen in other styles of football.

Anatomical site of injuries

The results of the present study showed that the rate of the lower extremity (78.1%) injury was about 6 times more than that of the rest of the body including the upper extremities (12.5%), the trunk (7.1%) and the head and neck (2.3%). This percentage (78.1%) is similar to that of Ekstrand's study in adult players (78%)[60]. This is also similar to the results of other studies, which reported lower extremity injuries of 60-87% of the total injuries incurred by football players. The rate of lower limb injury has been reported to be even higher at 90%.

The most commonly injured part was the knee (17.33%) with a similar involvement of the ankle (16.5%). In similar studies the knee and the ankle were the most affected areas with 25-29% at the knee and 19-23% at the ankle. Although the ankle accounted for 36% of injuries in another study the most severe injuries occurred in the knee. The present study was similar to previous studies in adolescent players. Injuries to the lower limbs accounted for 71.0% of the total injuries in elite French youth soccer players and similar values were also reported by Inklaar[61].

Injury severity

In relation to injury severity, it was found that 21.9% of the injuries prevented subjects from playing for less than one week (minor), 33.6% of injuries caused an absence from playing between one and three weeks (moderate) and 44.5% of injuries caused more than 3 weeks (major) absence from playing for more than one week. The rate of minor injuries (<7 days out of participation) was higher in other studies, being reported as being as much as 60.3% of all injuries. In the same study 26% were classed as moderate injuries and 14% categorised as major injuries. The rate of major injuries of the present study (44.5%) was much higher than other studies (14%). The reason of these differences might be the recall bias in retrospective studies, which could cause minor injuries to be forgotten and reported less than the real rate of occurrence compared to major injuries. The number of serious injuries in these Scottish players may reflect the physical nature of the style of football.

Time of injuries

From injuries that occurred during competition 43.6% occurred in the first half and 56.4% were in the second half. This was supported by Woods et al, who reported about half of ankle sprains which were sustained during games occurred during the last one third of each half. Similar finding were observed by Hawkins et al. Gleeson et al [62] suggested that this increase was associated with an electromechanical delay associated with tiredness. Fatigue has been suggested to be the reason for this increased rate of injury in the second half and also during the last one third of each half. This emphasises the importance of cardiovascular endurance training as well as sport specific activities, in injury rehabilitation to avoid fatigue at the end of each half and in injury prevention training programmes

Influence of Warm up

Most of the respondents reported that they performed a period of warm up prior to training sessions (96.8%) and competition (99.5%). The median of these periods were 10 minutes of running prior to a training session, 5 minutes of stretching and 10 minutes of ball work. The median of the total period of warming up before training session including running, stretching and ball work was 25 minutes, which was very close to the mean (M = 25.91). The duration and activities of warming up before competition was not significantly different from that of training. This suggests that the present perceived benefit of warm up activities has been endorsed by these players and their clubs.

Position of players

Of the injured players 43.0% were midfield players, 29.7% were defenders, 17.2% forwards and 10.2% were goalkeepers. This descending order was the same in both club players and high school players. The same order was found by Morgan et al. Midfielders sustained 37.6% injury occurrences, defenders sustained 29.6% and forwards and goalkeepers accounted for 20.5% of injuries in their studies. The exact influence of the players' position cannot be determined in the present study due to the lack of information about the position of the non-injured players. The rate of injuries related to the duration of activity in each position cannot be calculated. This was a limitation in the present study. This would be addressed by specific questions in future studies

Mechanism of injury

The cause of 56.3% of all injuries was reported as having a contact mechanism, of which 52.8% were in club players and 47.2% were in high school teams. Non-contact mechanisms were reported as the cause of 43.7% of total injuries, of which 60% were in club players and 40% were in high schools teams. This was similar to the rate of injury reported by Chomaic et al with 54% non-contact injuries and 46% contact injuries. The findings of Nelson et al were also close to those of the present study. They identified 45% of injuries to be contact and 55% of injuries to be non-contact. Identifying that such a high proportion of injuries are potentially due to overuse mechanisms it would seem likely that this incidence could be impacted upon by preventive methods.

Type of injury

In respect to the type of injury, muscle injuries, including strain and tears were a significant component of reported injuries with 44.1%, followed by fracture (20.5%), bruising (16.5%) and joint sprains (14.1%).

The rate of fractures is a worrying observation which may have major implications for long term sporting activity and degenerative joint changes such as osteoarthritis in later-life. Fractures could be due to the adolescent growth spurt and the susceptibility to growth plate injury[63] as noted above Although it has been shown that lower limb injuries are predominant in youth football, fractures occur more often in the upper limb. Court-Brown et al showed similar results. Many of these fractures occur in the hand. Football accounts for about one third (35.9%) of all hand fractures that occur in sport. One fifth (19.1%) of all football related fractures occur at the distal end of the radius and are caused by the protective mechanism of the outstretched hand in falls. This mechanism sacrifices the upper limb to protect the head and face. The treatment of fractures, in particular in a younger population is generally not complicated. There may be some complications, such as stiffness, mal-union with deformities or non-union.

A recent (2008) Scottish epidemiological study of sports-related hand fractures showed most of fractures result from a fall (32%), collision with objects (27%), collision with persons (26%), and twists (9%). Other authors have also shown similar findings. They suggested the risk of fractures in young soccer players is higher compared with older college players or professionals[64].

Woods et al. found a similar distribution of other injuries with muscle strains (42%) and tears (19%) the most common injuries followed by sprains (25%) but noted a lower incidence of fractures with 15%. Other studies have reported different rates of individual injuries with 30% of the injuries joint sprains, 16% fractures, 15% muscle strains, 12% ligament rupture and 8% meniscal injuries. There were no meniscal injuries reported in the present study. Ekstrand et al concluded that sprains to the lower extremities were the most common of all injuries in his adult series similar to the present study's findings. The different rates of injuries reported in different countries and in varying age groups emphasises the importance of the development of local injury banks such as the data base provided by the present study.

The epidemiology of sports injuries in children and youth players remains an important area of research that has been largely overlooked in the sports medicine literature. It deserves serious study, particularly with regards to further identification and analysis of risk factors and preventive measures.

The definition of a football injury used in their study involved the recording of any injuries sustained during training or competition, which resulted in 48 hours or more of playing. The age of their target group was older than in the present study and secondly the definition had the condition that the injured player was not able to take part in at least 48 hours of activity. This added condition could reduce the rate of recorded injuries compared to the present study which included more minor injuries.

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The incidence was recorded in a wide range, e.g. 0.518 [66] to 5.619 [67] injuries per 1000 hours of exposure during a season. In most of the studies, the time players spent in training and games was not reported separately. The circumstances of injury in youth players, such as overuse, trauma, and contact, have also rarely been reported. The incidence of soccer injury has been investigated in several studies, and varies for male outdoor players (>16 years) from 12–35 [68] injuries per 1000 match hours. For youth players, the reported incidences range from 0.5–13.7 [69] injuries per 1000 hours exposure. Specific analysis of youth soccer players has shown that the incidence of injury increases with age[70 71 72] .

The incidence of injury per 1000 hours of exposure was suggested to be higher in low-skill rather than in high-skill groups in previous[73]. In this study which looked at two levels of players at high school (96 players) level who would be expected to be of a lower skill level than the professional level (125 players), the rate of injury was not significantly different in these two groups. Both groups however had high training and playing loads.

The recorded incidence in the current study (6.31 injuries per 1000 hours of exposure) is in the mid range of the findings of other studies. This finding may be surprising as the speed and physical nature of the Scottish style of football might be expected to have a higher injury rate than seen in other styles of football.

Anatomical site of injuries: results of the present study showed that the rate of the lower extremity (78.1%) injury was about 6 times more than that of the rest of the body including upper extremities (12.5%), trunk (7.1%) and head and neck (2.3%). This percentage (78.1%) is similar to that of Ekstrand's study (78%)[74]. This is also similar to the results of other studies, which reported lower extremity injuries of 60-87% of the total injuries incurred by football players.

The most commonly injured part was the knee (17.33%) with a similar involvement of the ankle (16.5%). In similar studies the knee and the ankle were the most affected areas with 25-29% at the knee and 19-23% at the ankle. The ankle accounted for36% of injuries in another study but the most severe injuries occurred in the knee.

The rate of lower limb injury has been reported to be even higher at 90%. Injuries to the lower limbs accounted for 71.0% of the total injuries in elite French youth soccer players. Similar values were also reported by Inklaar [75].

Injury severity

In relation to injury severity, it was found that 21.9% of the injuries prevented subjects from playing for less than one week (minor), 33.6% of injuries caused the absence from playing between one and three weeks (moderate) and 44.5% of injuries caused more than 3 weeks (major) time taken out from playing for more than one week. The rate of minor injuries (<7 days out of participation) was higher in other studies, it was even reported as being up to 60.3% of all injuries. In the same study 26% were classed as moderate injuries and 14% categorised as major injuries. The rate of major injuries of the present study (44.5%) was much higher than other studies (14%). The reason of these differences might be the recall bias in retrospective studies, which could cause minor injuries to be forgotten and reported less than the real rate of occurrence compare to major injuries. There are recommendations in other epidemiological studies, which imply that slight injuries, which could be treated by ice and bandaging should be excluded from epidemiological studies

Time of injuries

From injuries that occurred during competition 43.6% were in the first half and 56.4% were in the second half. This was supported by Woods et al, who also reported about half of ankle sprains sustained during games occurred during the last one third of each half. Similar finding were observed by Hawkins et al. Gleeson et al [76] suggested that this increase was associated with in electromechanical delay associated with tiredness. Fatigue has been suggested to be the reason for this increased rate of injury in the second half and also during the last one third of each half. This emphasises the importance of endurance training in injury rehabilitation to avoid fatigue at the end of each half. For the same reason endurance exercise can play an important role in preventive training programmes

Influence of Warm up

Most of the respondents reported that they performed a period of warm up prior to training sessions (96.8%) and competition (99.5%). The median of these periods were 10 minutes of running prior to a training session, 5 minutes of stretching and 10 minutes of ball work. The median of the total period of warming up before training session including running, stretching and ball work was 25 minutes, which was very close to the mean (M = 25.91). The figure of warming up before competition was not significantly different from that of training. This suggests that the present perceived benefits of warm up activities has been endorsed by these players and their clubs.

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Mechanism of injury

The cause of 56.3% of all injuries was reported as having a contact mechanism, of which 52.8% were in club players and 47.2% were in high school teams. Non-contact mechanisms were reported as the cause of 43.7% of total injuries, of which 60% were in club players and 40% were in high schools teams. This was similar to the rate of injury reported by Chomaic et al with 54% non-contact injuries and 46% contact injuries. Findings of Nelson et al were also close to those of this study. They identified 45% of injuries to be contact and 55% of injuries to be non-contact. Identifying that such a high proportion of injuries are potentially overuse injuries, it would be likely that this incidence could be impacted upon by preventive methods.

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In respect to the type of injury, muscle injuries, including strain and tears were a significant component of reported injuries with 44.1%, followed by fracture (20.5%), bruising (16.5%) and joint sprains (14.1%). The rate of fractures is a worrying observation which may have major implications for long term sporting activity and degenerative joint changes such as osteoarthritis in later life. Fractures could be due to the adolescent growth spurt and the susceptibility to growth plate injury[77]. Woods et al. found a similar distribution of injuries with muscle strains (42%) and tears (19%) were the most common injuries followed by sprains with 25% and a lower incidence of fractures with 15%. Other studies are not similar to those of the present study. It was found that 30% of the injuries were joint sprains, 16% fractures, 15% muscle strains, 12% ligament rupture and 8% meniscal injuries. Ekstrand et al concluded that sprains to the lower extremities were the most common of all injuries similar to this study's findings.

The epidemiology of sports injuries in children and youth is an important area of research that has been largely overlooked in the sports medicine literature. It deserves serious study, particularly with regards to the identification and analysis of risk factors and preventive measures.

3.1 Strength and balance studies in young sports participants

Studies of strength and other physical modalities in young sports participants are of interest to help to identify talent and also to provide baseline values for comparison between individuals. In addition serial comparisons can be made to assess the effects of training programmes or to measure the return to fitness after rehabilitation for injury. Balance and proprioception are factors which may be determinants of skilful activities and also be major factors in the prevention of injuries. The second study in this thesis examined strength and proprioceptive function in young. The first part of this study determined the reproducibility of balance studies which would be applied as outcome measures in further studies in patient groups as well as football players. These studies utilising the Biodex Balance System complemented previous studies performed by the author in establishing the reproducibility of isokinetic tests using the Rev900 isokinetic dynamometer.

3.2 Introduction to balance studies

The upwards stance of the human is in a permanent fight against gravity to avoid falling, because this posture is unstable in most situations. “This situation of constant instability fosters a greater dynamism”[78]. There is a need in sports medicine for static and dynamic standing balance tests to quantify balance ability in adolescents. This study was firstly designed to determine the reproducibility of balance tests as assessed by the Biodex stability System in adults and adolescents. A further group of subjects were recruited for the second part of the study, to compare balance and strength measurements in non-professional and professional players and a control group of non football players. Many investigations regarding balance and strength have focused on studying the fall risk in elderly subjects. Data reporting reproducibility values for unilateral and bilateral stance tests in adolescents is scanty

3.3 Background: Balance

There is not a unique definition for human balance[79]. Postural control refers to the function of maintaining, restoring or achieving equilibrium (state of balance) during any posture or activity. Predictive or reactive strategies are employed to control posture. This neuromuscular control may be disturbed in some orthopaedic and neurological patient as well as vestibular disorders[80].

According to mechanical laws (Newton's first law) balance or equilibrium is the state of an object when the result of total forces applying on it is zero[81]. Examples of external forces are gravity, air resistance, friction or forces applied by another person, such as opponents in sports. The human body is constantly counteracting these forces and readjusting. The resultant of various counteracting forces causes the subject to be in different states of balance, including stable, unstable, and neutral. When an object or body remains in a still position or returns to its original rest position in spite of the application of a force, it is in stable equilibrium. If it is displaced due to the application of a force it will be in unstable equilibrium. If the position of the body or the object is changed with no change in the level of the centre of gravity the equilibrium is neutral. Stability may also refer to the amount of an athlete's resistance against a change of equilibrium[86].

The line of gravity (LOG) is an imaginary line running from the centre of gravity (COG) towards the centre of the earth. The object is more stable if the line of gravity is closer to the centre of the base of support (BOS). If it is near to the edge of the BOS stability is poorer. The BOS is a primary factor in the stability of an object. The BOS includes part(s) of the body which are in contact with the supporting surface and the area in between[82]. The more level the stability of the body is, the better its balance will be. This improvement of balance may be gained by lowering the COG over the base, increasing the weight of the body, centring the LOG over the base of support, enlarging the area of the base, or by broadening the shape of the base in the direction of the force being applied to the body. Maintaining a set position for a period of time refers to static balance. Reacting quickly to a changing environment is dynamic balance. Balance control can be described as the ability to regulate the relationship between the LOG and BOS during functional activities[84]. In the standing position COG is relatively high and the BOS is rather small. So maintaining the stability is a challenging function[83 84]. Where the LOG falls out of BOS the person should fall, but the body has an ability to feel it and to use muscular activity to resist against the force of gravity to prevent falling[85]. These mechanisms in the human body are in respect to the postural control. So various aspects of postural control maintain a posture, change a posture by an active motion and react to an external force, such as a push. Stability relates to the ability of remaining or returning to a state of equilibrium[86].

Motor control is a complex process, which is dependent on the information from certain receptors and the interpretation of their inputs. The structures that provide this input regarding balance are the eyes as visual receptors receiving input on relative spatial locations in the field of view; the semicircular canal structures located in the inner ear; the vestibular system that provides information on movement of the head and kinaesthetic receptors' whose function is the perception of the relative location of one part of the body in comparison to another part. These are various aspects of the mechanisms of body balance.

Normal neuromuscular control, the somatosensory system, visual and vestibular inputs are all necessary to maintain dynamic balance. These inputs combined with coordinated righting reflexes provide normal dynamic balance. Neural disturbances in vision may alter postural sway. Proprioception is feedback and neural awareness of the position and kinaesthesia of joints. The vestibular system in the inner ear in connection with the cerebellum monitors the balance[87]. In children prior to the age of 4-6 years vision is used dominantly to maintain balance. Although the somatosensory system is more dominant afterwards, many people rely on both the somatosensory and visual systems. The input of the vestibular system is effective in the case of contrasting inputs of the somatosensory and visual systems. Children before the age of 7 cannot deal with inaccurate visual input. Horak[88] found that this can influence their balance when they are on an unstable surface.

Postural sway is set by the neuromuscular control mechanisms, which are employed to keep the balance. The body sways backwards/forwards and pivoting about the ankle joint at the still standing position. This anteroposterior (AP) sway is about 5-7 mm in a young adult. The lateral sway was reported to be less than the AP sway (3-4 mm) during quiet stance in young adults[89].

There are various methods of evaluation of balance in neurological patients. These tests are very easy to perform for healthy or athletes. For instance the River Mead Stroke Assessment was employed by Kreighbaum[86] which examines the ability of a patient to do an activity when sitting with no support. There are other tests to assess the ability of a patient to do an activity while maintaining a position (Motor Assessment Scale) or changing positions e.g. sitting to standing. These tests are straightforward clinical methods for postural assessment.

There are few studies that have looked at the stability levels in sports persons and the reliability of the measuring equipments. The aim of this study was to determine the reproducibility of unipedal and bi-pedal stability on the Biodex Stability System. So a test-retest protocol was designed to measure the reproducibility of the BSS.

Dynamic balance is an active adjustment of moving the COG by motor control, so a subject can maintain balance due to a dynamic muscular activity. The measurement of static balance is usually performed when a subject stands still on a stable surface, but in measuring the dynamic balance, movement is involved. In dynamic balance there are many changing elements, such as the force of gravity and ground-reaction forces on an unstable, imbalanced, or irregular surface, as well as momentum and muscle forces.

Balance is the ability to maintain equilibrium. In unstable positions, such as unipedal standing the body demonstrates the ability to exhibit great balance. Although increasing stability reinforces the balance, maintaining balance does not necessarily generate stability. Stability is resistance against movements[90 91]. Different balance tests measure different mechanisms of postural performance. Many authors have used unipedal balance tests to evaluate postural control[92 112] as the major area of imbalance is in the mid-swing or mid-stance of a walking cycle [93 94 95].

3.4 Balance and neuromuscular control

Neuromuscular coordination is defined as the ability to move different parts of the body smoothly and at the same time involves both the nervous and muscular systems. The ability to maintain the position of the centre of body mass within the stability limits is termed postural stability or balance[96] . Postural control is defined as the ability to maintain control over posture [97] and is a complex function involving the somatosensory, vestibular and visual systems as well as muscle activity[85 98]. From these systems the CNS receives information regarding body position and balance, which contributes to the maintenance of postural control. To assess postural control in stance, centre of pressure (COP) displacements can be registered by stabilometry with different kinds of force platforms. The evaluation of postural control has several implications in sports medicine and has been used to identify subjects with increased risk for sport injuries and to evaluate rehabilitation programs. However, it is still controversial if a larger displacement of the centre of pressure is related to an increased risk of sport injuries[99].

3.5 Background: Proprioception

The sensorimotor pathway includes the receptors, afferent neurons and related areas in the CNS, where the signals are integrated and processed. Controlling the motor system and generating the central commands are also operated in the CNS. The outputs of the sensorimotor system after processing the sensory inputs are postural control, as well as muscle activation during gait and performance. So this system comprises the central control of dynamic joint stability as well as the afferent and efferent neurons.

Proprioception is inferred from Sherington's 1906 description of the proprioceptive system as the afferent information from proprioceptive field that contributes to conscious sensations ("muscle sense"), total posture (postural equilibrium), and segmental posture (joint stability). 'Proprioceptors' were referred to those receptors located in joints, muscles, and tendons that were "adapted for excitation consonantly with changes going on the organism itself". From this interpretation of Sherington's work it is concluded that the process termed "proprioception" refers to all neural inputs originating from joints, muscles, tendon, and associated deep tissue "proprioceptor."

At the highest level of organisation, the somatosensory cortex processes proprioceptive information to provide conscious awareness of joint position (joint position sense) and joint motion (kinaesthesia). It is within the motor areas of the cortex that proprioceptive information is believed to be stored for use with future descending motor commands. Since voluntary movements initiated at the cerebral cortex may be too slow to prevent injury, it is speculated that short-loop or spinal reflexes may be capable of a more timely response. Triggering these protective spinal reflexes during an "at risk" manoeuvre may play an even greater role in joint stability than the voluntary response[100].

Proprioception originates from sensory receptors located in joint, muscle, and coetaneous tissue. The presence of neuroreceptors in the human knee joint was described by Rauber in 1874. The relative importance of each receptor to proprioception has long been debated. These mechanosensitive receptors all appear to contribute to the transmission of peripheral information related to joint position and motion as well as muscle tension, and therefore they ultimately regulate muscle activation. Researchers, however, do not universally agree upon the mode of sensory acquisition and relative autonomy of the different populations of mechanoreceptors[101]. Different types of joint and musculotendinous receptors are summarised in figure 2-1.

Articular	Location	Rate of Adapting	Threshold	Influence On muscle	Dynamic or Static
Type I	Superficial Capsule layers	Slow	Low	Continuous	Both
Type II	Deeper layers Of capsule	Fast	Low	Brief, reflex	Dynamic
Type III	Joint ligaments	Slow	High	Reflex	Dynamic
Type IV	Capsule, fat pads	Non-adapting	High		
Muscular mechanoreceptors					
Golgi Tendon Organs					
	Tendons/ligs	Slow	High	Reflex	
Muscle Spindles					
	Muscle	Slow	Low	Reflex	

Figure 3.1 Joint and musculotendinous receptors [97]

3.6 Literature Review of the B.S.S. balance reproducibility study

Assessment of the dynamic balance of the lower limbs can provide information about the afferent as well as efferent neuromuscular pathways. Joint-stabilising muscle activity is influenced by proprioceptive, kinaesthetic, visual, and vestibular-system information as well as by cortical and spinal-nerve motor commands. Measuring the overall dynamic limits of stability is a good way to assess athletic performance[109]. There are various testing methods to measure balance and postural control. Knowledge of timing and activation level of the muscles that generate motion and also the joint biomechanics, which provides the planed movements are also involved in the mechanisms governing human balance and postural control[102].

The Biodex Stability System tests the semi-dynamic and dynamic measurement of balance. This device measures the overall stability index, anterior-posterior stability index and medial-lateral stability index and provides scientific measurements of semi-dynamic balance[103 104] .

In the field of balance there are several workers who have made significant contributions to the study of static balance. These include Dayhoff, Suhreinrich, Wigglesworth, Topp, & Moore, 1998; Fitzpatrick, Burke, & Gandevia, 1996; Gatev, Thomas, Kepple, & Hallett, 1999; Winter, Patla, Prince, Ishac, & Gielo-Perczak, 1998; Winter, Prince, Frank, Powell, & Zabjek, 1996 . The results of static balance are obtained in a stable condition and there is no motion. So this kind of measurement cannot appropriately represent the dynamic activities of real life[105].

A reproducibility study of the BSS was carried out by Pincivero and Lephart[106], who showed that the result provided by the BSS was reliable. The normative values for the overall stability index of BSS for 200 non-athlete subjects aged 18 to 89 were also established[107]. This study was conducted on bilateral stance using grade 8, which is the most stable level of the BSS. The results of this study cannot be extended to athletes.

A descriptive study reviewed the reproducibility of the BSS in 2000. It was reported that there were 4 studies, each involved two 30-second tests under varying conditions. Intra class correlation (ICC) was measured in a test-retest design. The calculated coefficient was measured mainly for the overall stability index (OSI) and the limits of stability (LOS). Calculated ICC ranged from .44 to .89 for static balance tests and .64 to .89 for the LOS. It was concluded from these results that the BSS is reliable for clinical testing[104]. One year after this review article [104] another study reported the reproducibility of dynamic balance tests using the BSS in a group of active adults engaged in weight-bearing sports. The level of difficulty was 2, which is the level of the resistance of the spring in BSS. This study examined the unipedal balance in 20-sec trials. Intra class correlation was reported .93 for medial-lateral Stability Index, .94 for the Overall Stability Index and .95 for Anterior-posterior Stability Index. Repeating the same study on a group of college student resulted in reproducibility measurement of .92 for the Overall Stability Index (OSI), .89 for Anterior/posterior Stability Index (APSI) and .93 for Medial/lateral Stability Index (MLSI)[105].

In another study four different balance tests were compared. Subjects were selected from normal university students. They completed three trials of balance assessment on four different systems, the balance score on the Biodex, a Stability Index score on the Cybex Fastex, a Balance Index score on the Breg K.A.T. 2000, and a Target Sway score on the NeuroCom Smart Balance Master. The Biodex and K.A.T. data were found to be directly correlated and also the Biodex and Fastex data were positively correlated. It was concluded that the NeuroCom test assessed different functions, because it showed no significant correlation with the other three measuring systems[108]. Clinical experience suggested that the hardest level of difficulty (higher than 4) was required to test an injured ankle[109].

There are only a few reproducibility studies in which the reproducibility of both unipedal and bipedal standing was studied using various stability levels. The findings of these studies showed that a single leg stance test of stability appeared to be highly reliable when performed using the Biodex Stability System Test[103].

In a recent study, in which the balance components were compared between males and females the vertical ground reaction forces of females was significantly more than that of males. Females' dynamic postural stability in the vertical plane and the composite score of dynamic postural stability index were greater than that of males[110]. Many investigations regarding balance and muscle strength have focused on the elderly, many of which studied their fall risk. In one study, a 12 month exercise intervention programme was conducted in elderly females. The intervention included balance and strengthening exercises. The study aimed to find out if the rate of falls was different between the intervention and the control group. No significant difference was reported in the proportion of fallers between the exercise and control subjects although promising trends were found, between reduced falls frequency and the performance of the exercise program. It was concluded that exercise could produce long-term benefits with regard to improving sensorimotor function in older persons. The findings also suggested that high compliance to an exercise program was required to reduce the frequency of falls[111]. In another study, however, looking at the relationship of balance, gait performance and muscular strength in 230 randomly selected 75 year old women; no significant association was found among the parameters studied and falls frequency[112]. No significant correlation was evident between the balance performance of the dominant or non dominant leg using the stand and wobble board score in men or women. It was concluded however that the potential differences in static balance did not appear to be related to muscle strength[113].

Reproducibility studies for unilateral and bilateral stance tests in adolescents are limited. A reproducibility study on 9 to 10 years old schoolchildren was developed using the Biodex stability system. This study examined the reproducibility of a static standing balance in children, using a clinical test of sensory interaction on balance and also examined the dynamic balance by the limits of stability test. The study concluded that the BSS demonstrated fair to good score of reliability for most postural parameters in 9 to 10 year olds[114].

3.7 The aim of the B.S.S. reproducibility study

The purpose of this study was to determine the test-retest reproducibility of one tester dynamic unipedal and bipedal balance in two groups of youths and adults in a young Scottish population.

3.8 The BSS Instrument and the research protocol

Assessment of balance of an injured athlete is a main part of the rehabilitation process. Several methods of evaluation of balance have been employed, such as the force plate [168] and stabilometry [115] . The Biodex Stability System was used in the present studies.[116] The Biodex Stability System is a multiaxial device to assess neuromuscular control by measurement of body balance ability in a dynamic postural stability method on a wobbling platform[117]. This device can measure the ability of a subject to control the angle of tilt of the platform. The platform is free to move in the anterior-posterior and medial-lateral axes simultaneously up to 20° of tilt in a 360° range of motion. The values provided by this balance system are quantified by the computer interface and presented as an objective measurement of stability scores[103]. The BSS assessment consists of an overall stability index (OSI), an anterior/posterior stability index (APSI) and a medial/lateral stability index (MLSI) and the dynamic limits of stability (LOS). The score that the BSS calculates is the tilt around each axis in degrees during dynamic balance test. For example, an index of 10 degree represents an average displacement from the zero point equal to 10°. There are eight levels if difficulty ranging from level 8, which is the most stable grade of the platform and the easiest level, to level one, which is the least stable one and the hardest level[116]. In the mode of LOS the cursor on the screen monitors the backward and forward movement of the platform among nine boxes on the screen monitor. The moving cursor on the screen presents the direction and the amount of tilt of the platform. There is one central box and eight boxes around it. These peripheral boxes appear randomly on the screen and the subject should follow them by moving the unstable platform. In the dynamic LOS test the subject is asked to move the cursor toward the flashing box and to keep it in the target for at least 0.5 seconds. Then the box is removed and another box starts flashing on the screen. This is continued until all nine boxes are used.. This index shows the variance of the platform displacements in degrees from zero degree position. In dynamic LOS subjects try to maintain their dynamic equilibrium in the limits of their range of motion. The score of the overall dynamic LOS is recorded. The total distance covered between the central box and other boxes and also the total duration of the test are recorded [109]. All measurements were carried out using the same instrument by the same researcher under the same environmental conditions.

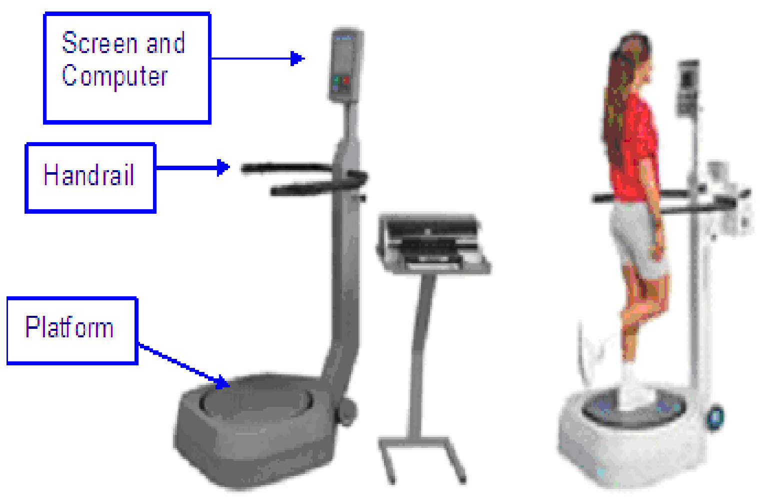

Figure 3-2 The Biodex Stability System

The protocol was developed, based on the aims of the study, which was measurement of the reproducibility of a consistent protocol that could be employed for normal subjects, athletic participants and injured subjects. Various protocols were collected from the methodology of literature, in which the dynamic balance was measured using BSS. In pilot trials potential protocols were tested in two normal subjects, two athletes and two injured athletes, one with a lateral ankle sprain and one with a reconstructed anterior cruciate ligament injury. After a few repetitions it was found that the level of difficulty with the spring resistance less than 4 was too hard for the injured and even for some of the normal subjects. In the injured group, in particular, the trial had to be stopped, because the subjects could not complete the tests of unipedal balance on the injured limb. On the other hand the easier levels (level 7 or 8) were not challenging enough for athletes and even for normal subjects. Finally with a few modifications a decreasing spring resistance level changing from 8 to 4 was found to be suitable and feasible for all participants. A similar changing level was also designed in previous reproducibility studies in active adults [103].

The procedure; Subjects were asked to keep the unstable platform in a level position for 30 second in each of four tests in one session. The stability index that the Biodex software presents is derived by the degree of tilting of the platform from the level position and also the period of time of the off level positions.

Subjects were allowed to move their arms in order to maintain the standing balance, as this is one of the dynamic mechanisms that the body employs in normal circumstances.

Subjects were instructed to hold the handrail and/or put their unsupported foot down on the stable corners of the BSS around the platform to prevent a fall in case of lost balance. The examiner also stood very close to the subjects to provide support. There were no falls in the subjects in the reproducibility study. In two subjects the trial had to be repeated, because they held the handrail in the middle of the test to avoid falling.

Subjects were tested in three occasions. The first session was for the familiarisation and two sessions of test and retest trials with one week between the two main sessions. Each session consisted of four tests; Overall Stability Index (OSI) for bipedal stability test and 2 unipedal stability tests for right and left legs and test of Limits of Stability (LOS). A one-minute rest was given between trials. In addition to the familiarisation session, a 20-second practice session was also allowed on the platform prior to the start of the tests so that subjects were confident to perform the tests. The subjects dress and shoes were comfortable with low-top flat-laced athletic shoes. They were tested with their eyes open at all times.

To assess the bipedal balance tests participants were instructed to adjust the position of their feet in a place that they could keep the unstable platform in a level position and for unipedal tests they were asked to stand on one leg at the centre of the platform. The position of the feet on the platform should have remained unchanged in the test and retest sessions. The Biodex platform has a permanent grid to record the position. So the platform was then locked and these coordinates were recorded and used for the retest session as well. The platform was released to begin the trial and participants were asked to maintain an upright standing position on both feet. The position of the feet was similar in all sessions. In unipedal tests, subjects hold their unsupported leg in a comfortable position with the hip joint in a neutral position and the knee bent to about 90 degrees. The platform was set at decreasing instability level of 8 to 4 indicating the degree of platform instability. Level 1 is the least stable and hardest to stand on and level 8 is the most stable.

3.9 The B.S.S. Reproducibility Study; General Methods

The methods of assessment of balance using the Biodex system were detailed above. The purpose of the current study was to measure the reproducibility of the results of dynamic balance acquired using the Biodex Stability System (BSS). The reproducibility study was carried out in two parts. The same protocol was employed for both parts.

A group of healthy adults (over 19 years old) participated in the first part and a group of younger adults (under 19 years old) participated in the second part of the reproducibility study. Subjects of the first group consisted of ten males and nine females with an age range between 19 and 53 years old with a mean of 36.24.years Sixteen male subjects ranging from 15 to 18 years of age took part in the second group of the reproducibility study. The second group were from youth football teams at elite and recreational levels and also non-football players in a similar age range being subjects recruited for the second part of this study.. The participants completed a health questionnaire regarding any history of injury and also a consent form. The location of the study was at the Performance Lab of the Sports, Health and Injury Clinics at the Scottish National Stadium at Glasgow Hampden Park.

3.10 Results of the B.S.S. balance reproducibility study

Statistical analysis was conducted using the Statistical Package for the Social Sciences for Windows version 14 (SPSS, Inc, Chicago, ILL). The values of obtained overall stability index (OSI) for bipedal standing, unipedal standing on the right leg, unipedal standing on the left leg and bipedal limits of stability (LOS) were recorded from two main sessions in two groups of youth and adults. Lower values were associated with greater balance ability. The intraclass correlation coefficient (ICC) was calculated for all balance values obtained for test-retest comparisons. The interpretation of the measured reproducibility values was based on the following ranges: less than 0.69 "poor", 0.70 to 0.79 ''fair'', 0.80 to 0.89 "good", and 0.90 to 1.00 "excellent"[118].

The age range of the subjects was 19 to 53 years old with a mean of 36.24 years (SD=3.1). Their body weight mean was 74.23 kg (SD=2.61) and their height mean was 174.84 cms (SD=5.28). In the second group of sixteen young male subjects the participants' age range was 15 to 18years with the mean age of 16.23 (SD= 0.6). Their weights ranged from 52 to 87 kg (Mean = 68.37, S.D. = 3.15) and their height ranged from 159 to 187 cms. (Mean=172.6, S.D. = 6.7).

3.10.1 Tests of normality

Statistical tests were applied to determine that the data were normally distributed. The Kolmogorov-Smirnov statistic test was not significant for the bipedal OSI for males and females (P>0.05) in both main sessions in the first group (over 19 years old).. In the present study p-values were more than 0.05, so the distribution of data was not significantly different from the normal distribution. As there were less than 50 cases, the Shapiro-Wilk test was also performed and was not significant in any of tests (P>0.05).

	Gender	Kolmogorov-Smirnov(a)			Shapiro-Wilk		
		Statistic	Df	Sig.	Statistic	df	Sig.
Bipedal Overall Stability Index (First Session)	Male	.187	9	.200(*)	.955	9	.743
	Female	.181	9	.200(*)	.895	9	.225
Bipedal Overall Stability Index (Second Session)	Male	.227	9	.199	.919	9	.383
	Female	.132	9	.200(*)	.964	9	.838

Table 3-1 Tests of Normality (Group one) * This is a lower bound of the true significance.

Figures 3-3 and 3-3 show the Q-Q (quartiles) plots of distribution of the bipedal OSI in the test and re-test sessions in the first group (over 19 years old) against the quartiles of normal distribution. These plots show all tested variables are samples from a normal distribution, because the points cluster around a straight line.

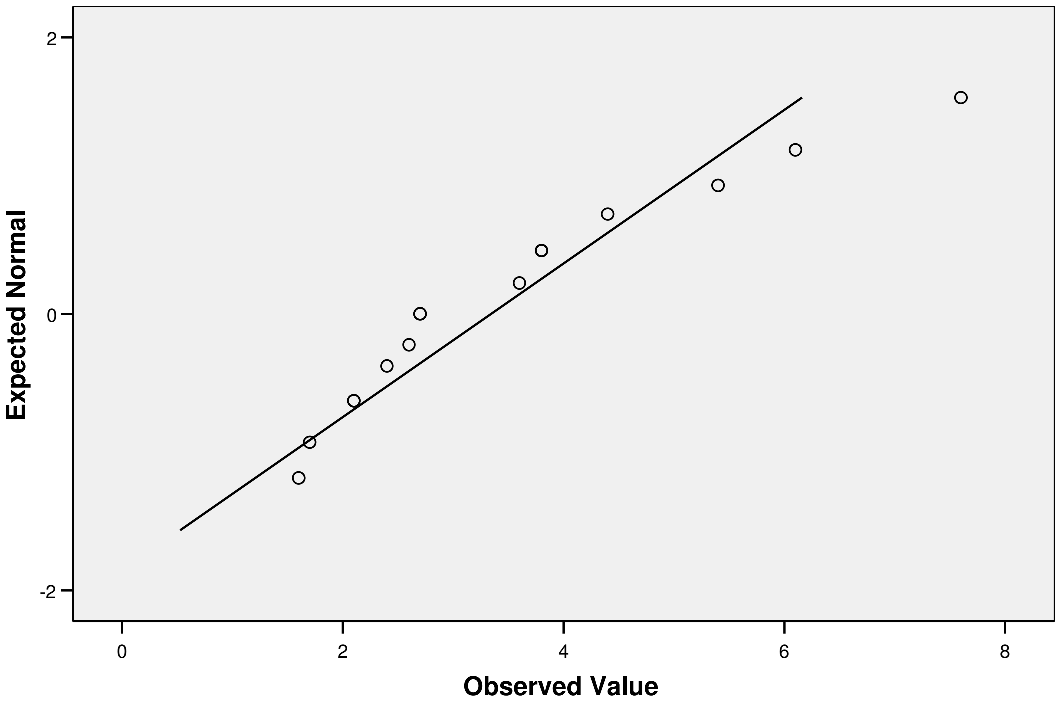

Figure 3-3 Normal Q-Q Plot of Bipedal Overall Stability Index (first Session)

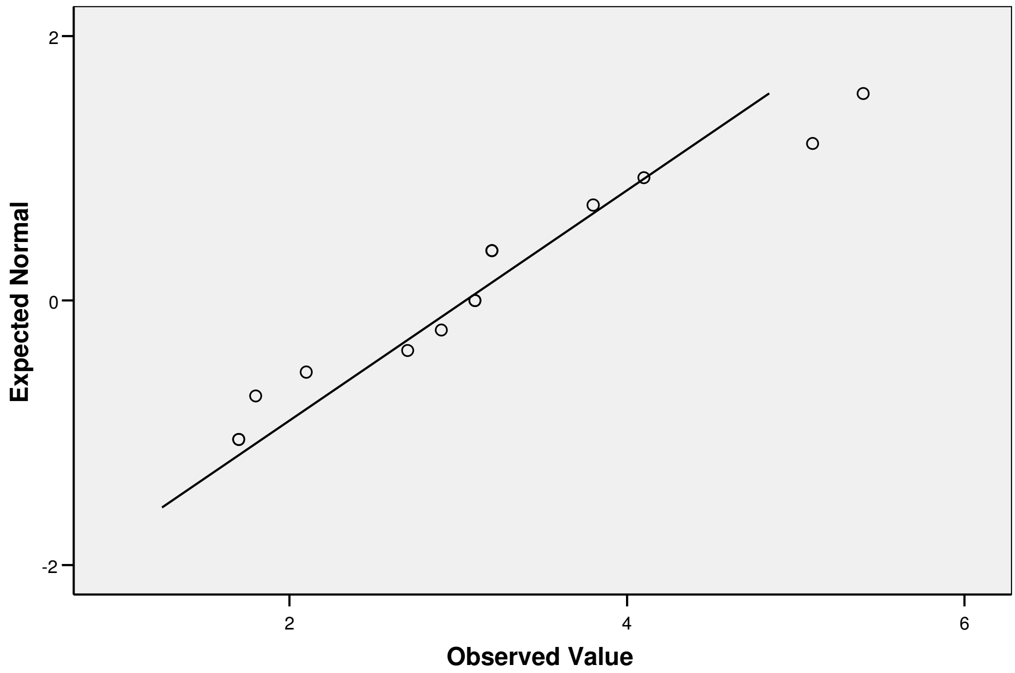

Figure 3-4 Normal Q-Q Plot of Bipedal Overall Stability Index (Second Session)

Normality tests (Kolmogorov-Smirnov and Shapiro-Wilk) for the bipedal OSI in both main sessions were not significant (*P*>0.05) in the second group (under 19 years old). So it showed that these variables are normally distributed.

	Kolmogorov-Smirnov(a)			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Bipedal Overall Stability Index (First Session)	.202	16	.080	.921	16	.177
Bipedal Overall Stability Index (Second Session)	.196	16	.102	.916	16	.144

Table 3-3 Tests of Normality (Group Two) for the bipedal OSI * This is a lower bound of the true significance

Figures 3-5 and 3-6 show plots of distribution of the bipedal OSI in the test and retest sessions in the second group (under 19 years old) against the quartiles of normal distribution. These plots also show all tested variables are samples from a normal distribution, because the points cluster around a straight line.

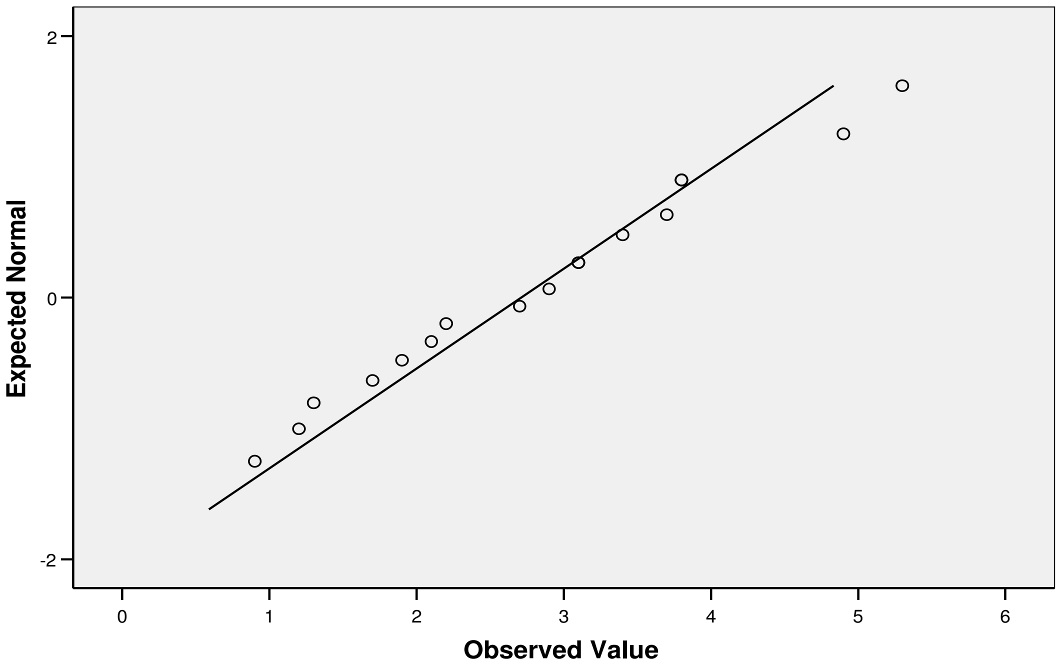

Figure 3-5 Normal Q-Q Plot of Bipedal Overall Stability Index (First Session) in the under 19 age group.

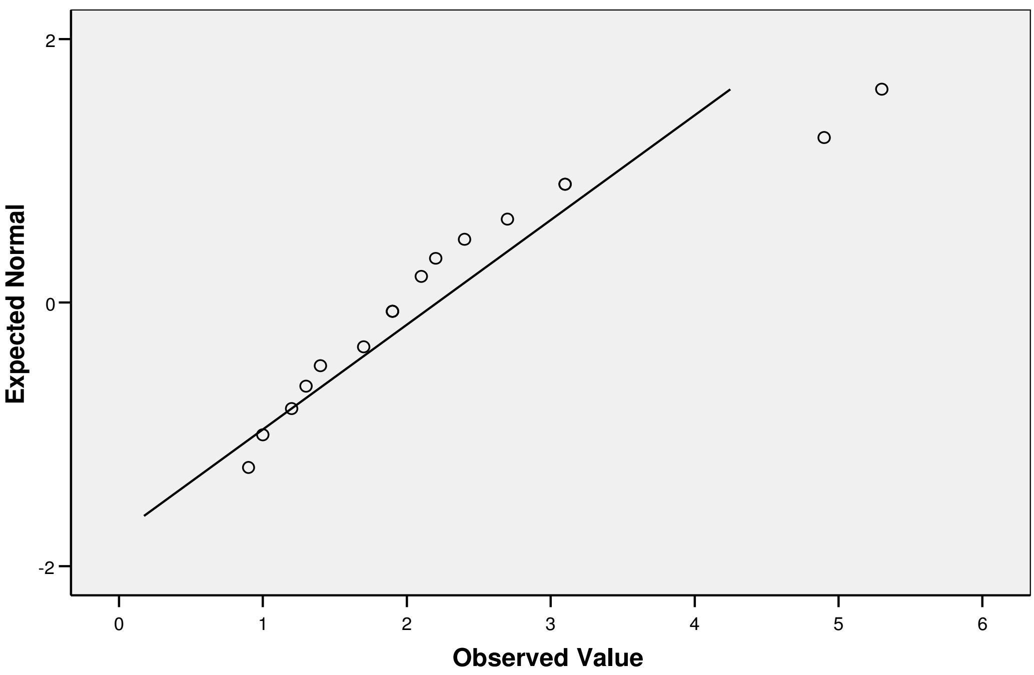

Figure 3-6 Normal Q-Q Plot of Bipedal Overall Stability Index (Second Session) in group 2

3.10.2 Results of the measured Intraclass Correlation Coefficient (ICC) in group one

ICCs of the collected data from the BSS were measured. The 95% confident intervals (CI) were obtained for all values. The average measure for bipedal OSI of the first group (over 19 years old) was graded as “good” reproducibility (0.80 to 0.89) with mean .83 (95% CI: .53-.94), however it was the lowest score obtained in this group. Statistical results regarding measuring the ICC for the bipedal OSI are presented in Table 3-4 The scatter plot of the correlation between bipedal OSI obtained in test and re-test sessions are also shown in Figure 3-5.

	Intraclass Correlation	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.70(b)	.37	.88	5.74	17.0	17	.000
Average Measures	.83(c)	.534	.96	5.74	17.0	17	.000

Table 3-3 Intraclass Correlation Coefficient of the Bipedal “Overall Stability Index"

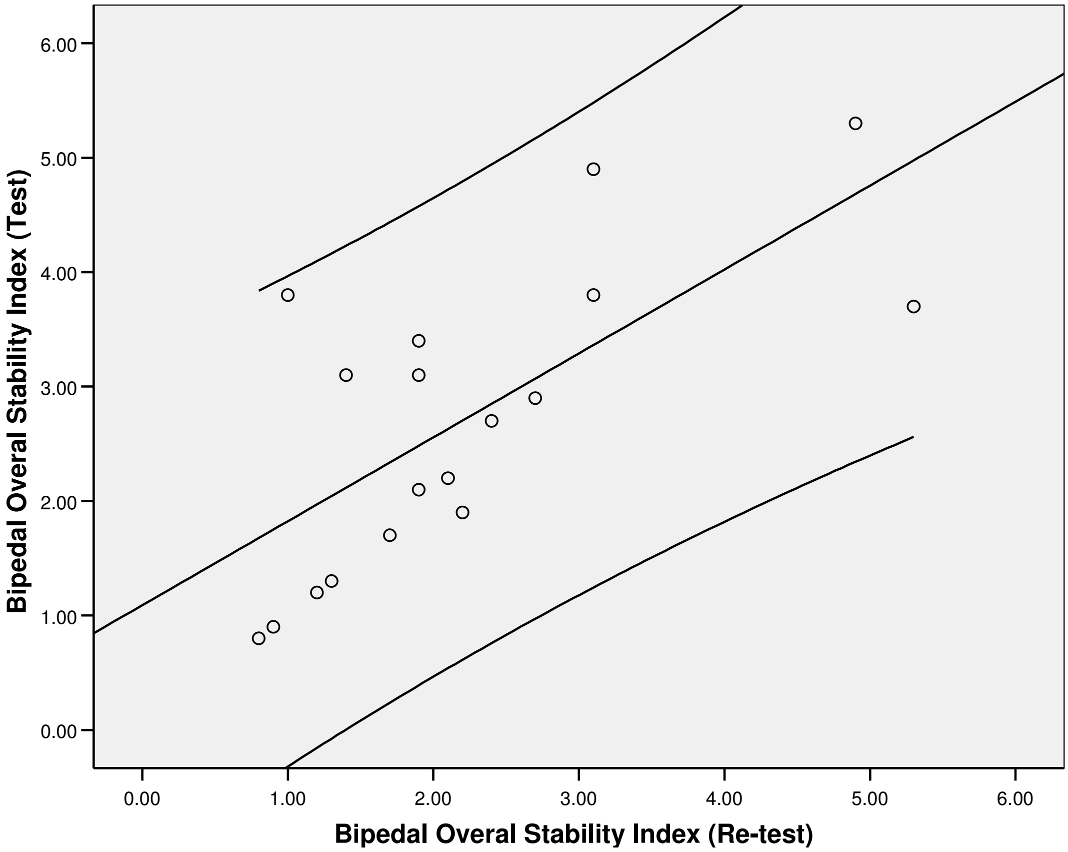

Figure 3-8 Test, Re-test Bipedal Overall Stability Index

As summarised in Table 3-5 the highest score of ICC was calculated for the LOS with .96, which can be interpreted as "excellent" reproducibility (0.90 to 1.00). Measured values in test and re-test sessions are strongly correlated as can be seen in Figure 3-9.

	Intraclass Correlation	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.92(b)	.77	.98	25.02	12.0	12	.000
Average Measures	.96(c)	.87	.99	25.02	12.0	12	.000

Table 3-4 Intraclass Correlation Coefficient of the "Limits of Stability" Completion Time

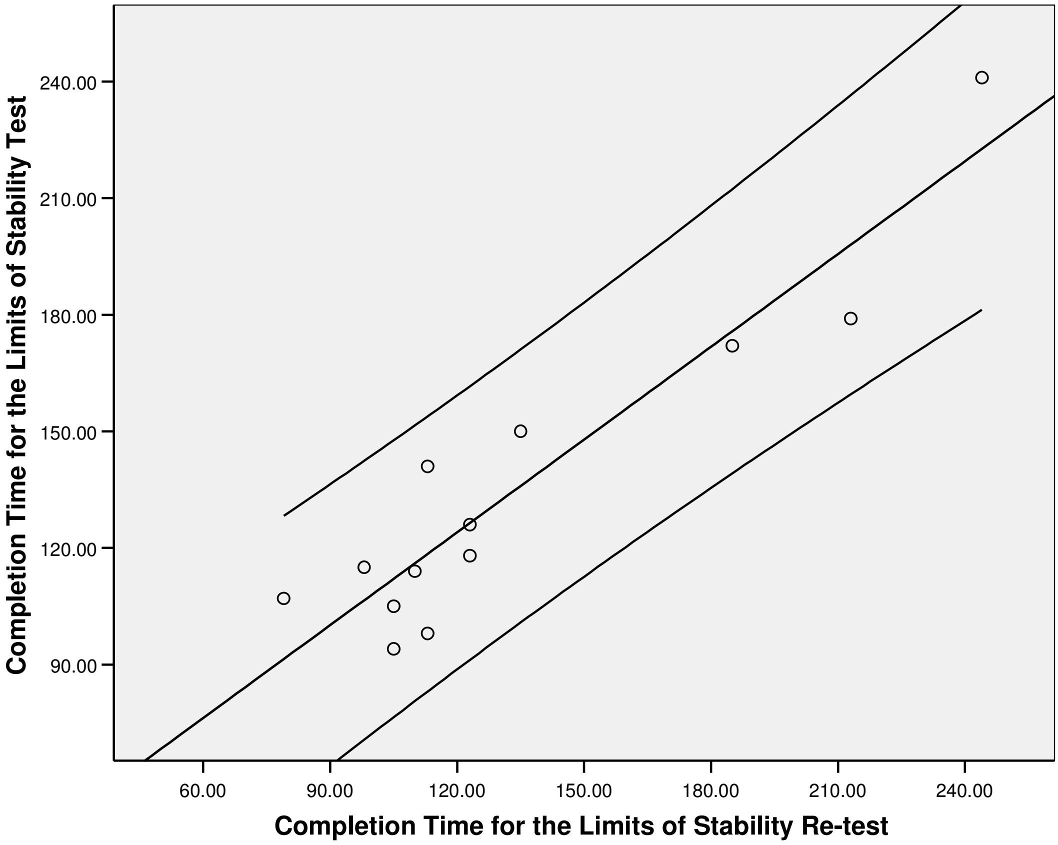

Figure 3-9 Test, Re-test Completion Time for the Limits of Stability

Reproducibility of measured values for unipedal OSI for both right leg (.94, CI: .83-.98) and left leg (.90, CI: .74-.96) were also in "excellent" range in the first group (tables 3-4 and 3-5). The scatter plots in figure 3-6 and 3-7 also indicate that the points cluster around straight lines, which are evidence of strong correlations between the obtained values in test and re-test sessions.

	Intraclass Correlation	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.88(b)	.72	.96	16.10	17.0	17	.000
Average Measures	.94(c)	.83	.98	16.10	17.0	17	.000

Table 3-5 Intraclass Correlation Coefficient of the Right Leg "Overall Stability Index"

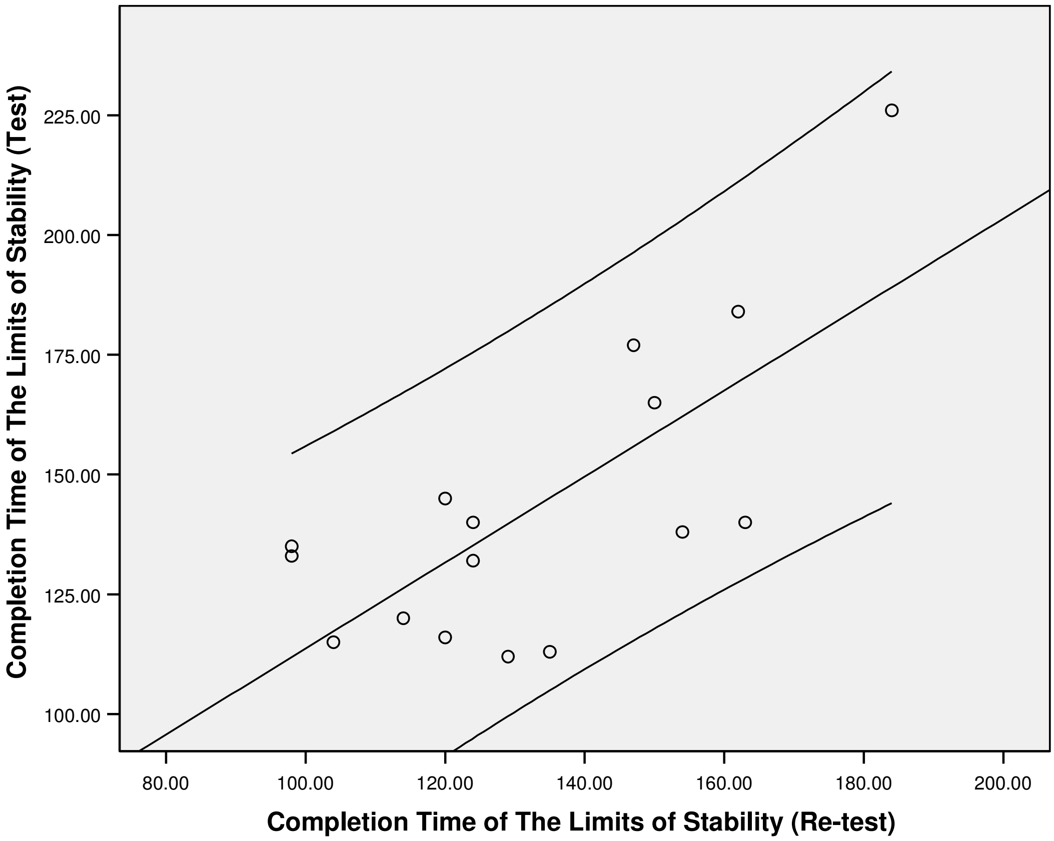

Figure 3-10 Test, Re-test Right Leg Overall Stability Balance

	Intraclass Correlation	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.82(b)	.59	.93	10.28	17.0	17	.000
Average Measures	.90(c)	.74	.96	10.28	17.0	17	.000

Table 3-6 Intraclass Correlation Coefficient of the Left Leg “Overall Stability Index”

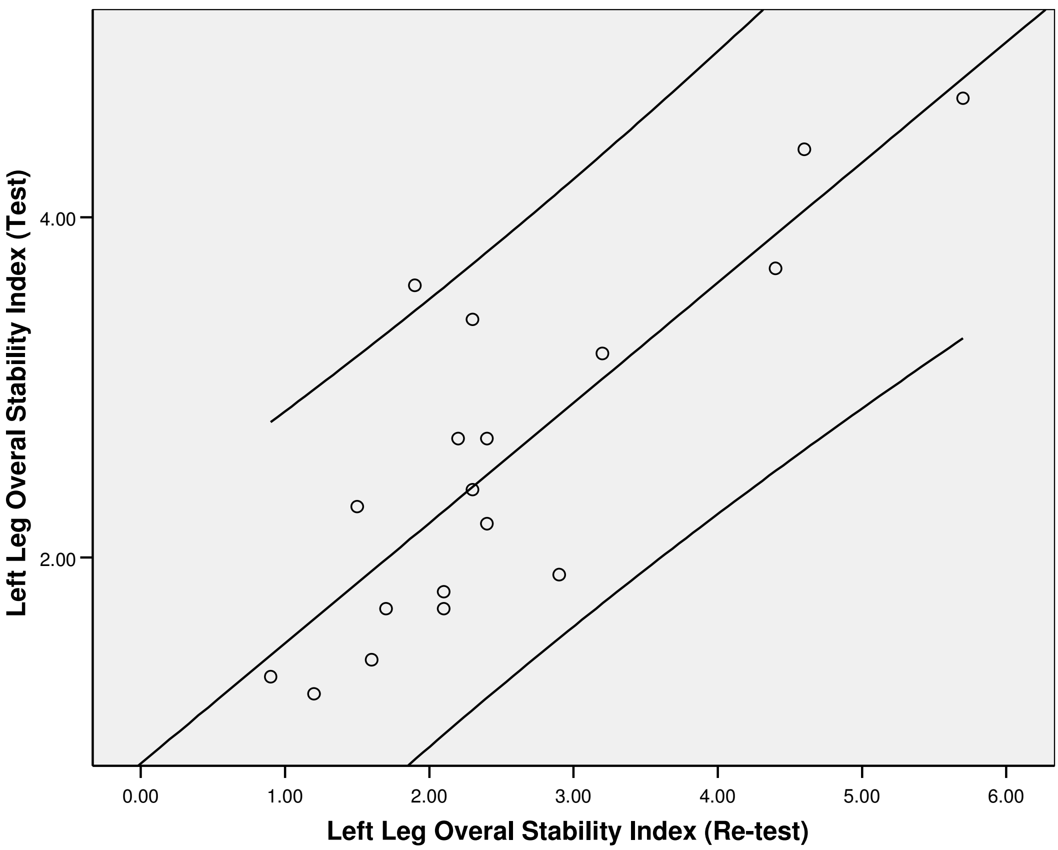

Figure 3-11 Test, Re-test Left Leg Overall Stability Index

3.10.3 Results of the measured ICCs in group two

In the second group (under 19 years old) the average measure of the ICC for bipedal and unipedal OSI, as well as bipedal LOS were measured. The lowest score for ICC in this group was measured for LOS with .83 with 95% CI of .51-.94 (table3-). This value can be categorised as "good" reproducibility (0.80 to 0.89). The graph in figure 3-9 shows the level of correlation between measured LOS in the test and re-tests sessions.

	Intraclass Correlation	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.71(b)	.35	.89	5.89	15.0	15	.001
Average Measures	.83(c)	.51	.94	5.89	15.0	15	.001

Table 3-7 Intraclass Correlation Coefficient of the "Limits of Stability" Completion Time

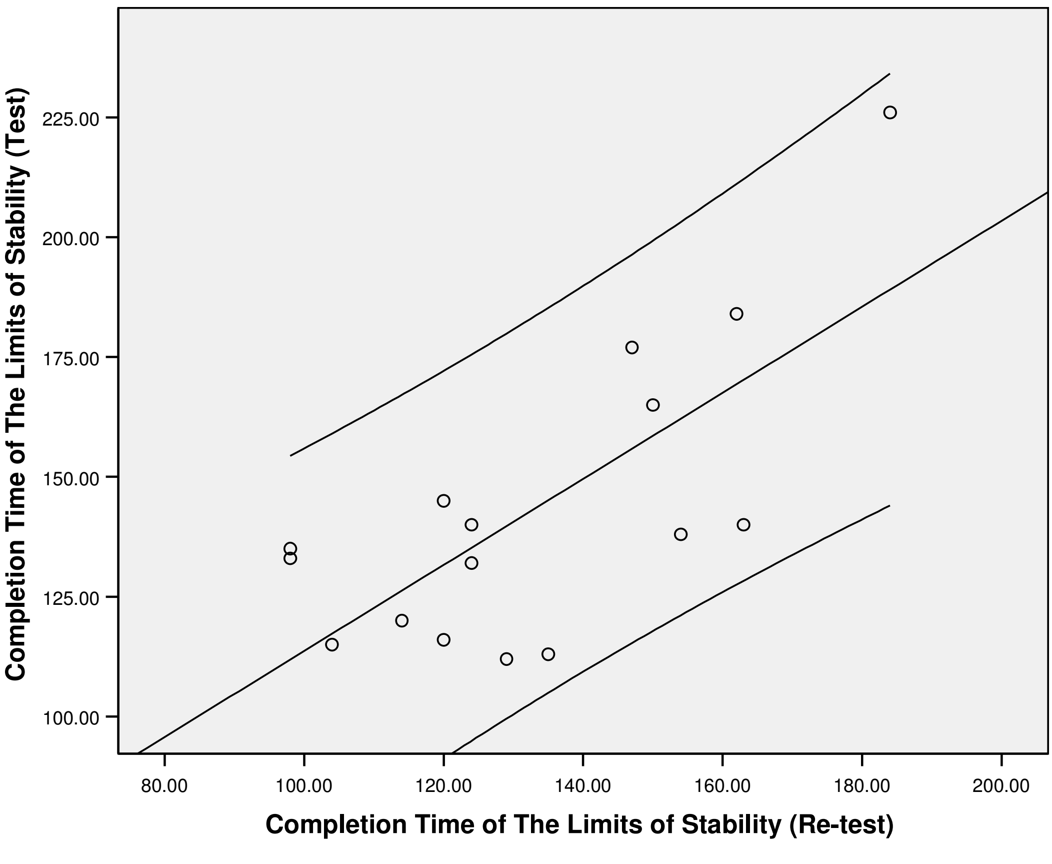

Figure 3-12 Test, Re-test Completion of the Limits of Stability

The highest score was calculated for the right leg OSI at .93 (95% CI: .51-.94), which can be interpreted as "excellent" (table 3-7). The scatter plot in figure 3-10 also indicates that the measured variables in two main sessions are strongly correlated.

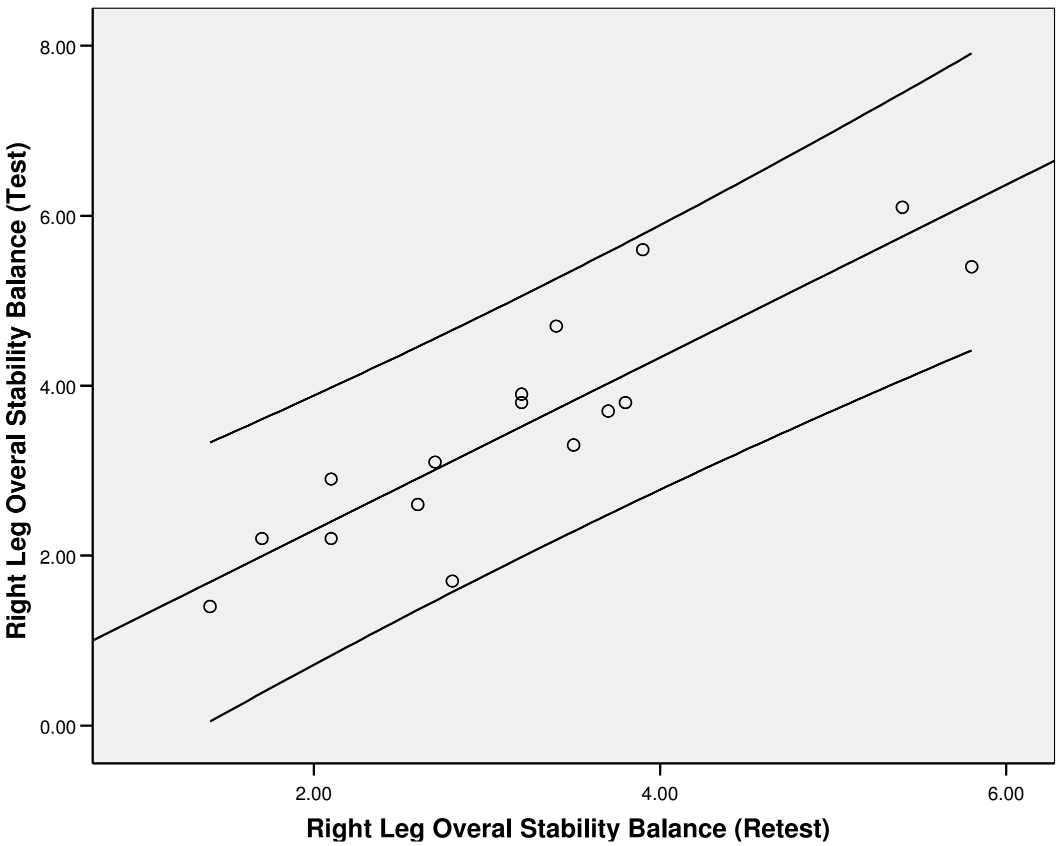

Figure 3-13 Test, Re-test Right Leg Overall Stability Balance

	Intraclass Correlation	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.87(b)	.66	.95	13.93	15.0	15	.000
Average Measures	.93(c)	.80	.98	13.93	15.0	15	.000

Table 3-8 Intraclass Correlation Coefficient of the Right Leg "Overall Stability Index"

The table 3-10 and 3-11 present the average measures of the ICC for the bipedal OSI (.87, CI:.62-.95) and left leg OSI (.87, CI: .64-.96). They were also in range of “good” reproducibility. The measured scores in the test and re-test sessions for these two variables are clustered close to straight lines in figure 5-33 and 5-34.

	Intraclass Correlation	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.768(b)	.454	.912	7.619	15.0	15	.000
Average Measures	.869(c)	.624	.954	7.619	15.0	15	.000

Table 3-9 Intraclass Correlation Coefficient of the Bipedal “Overall Stability Index"

	Intraclass Correlation	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.774(b)	.466	.915	7.848	15.0	15	.000
Average Measures	.873(c)	.635	.955	7.848	15.0	15	.000

Table 3-10 Intraclass Correlation Coefficient of the Left Leg “Overall Stability Index”

All values obtained for ICCs of the measured variables are summarised in table 3-11 and 3-12.

Variables	Test 1 Means (SD)	Test 2 Means (SD)	ICC (95% CI)
Bipedal Overall Stability Index	2.80 (1.33)	2.21 (1.28)	.83 (.53 -.94)
Right Leg Overall Stability Index	2.54 (1.17)	2.63 (1.05)	.94 (.83 -.98)
Left Leg Overall Stability Index	2.57 (1.06)	2.46 (1.24)	.90 (.74 -.96)
Limits of Stability	139.67 (40.44)	131.36 (48.22)	.96 (.87 -.99)

Table 3-11 Summary of the ICC values for Group one

Variables	Test 1 Means (SD)	Test 2 Means (SD)	ICC (95% CI)
Bipedal Overall Stability Index	3.34 (1.80)	3.04 (1.15)	.87 (.62 -.95)
Right Leg Overall Stability Index	3.52 (1.39)	3.21 (1.20)	.93 (.80 -.98)
Left Leg Overall Stability Index	2.96 (1.68)	2.91 (1.02)	.87 (.64 -.96)
Limits of Stability	143.19 (31.03)	132.88 (25.09)	.83 (.51 -.94)

Table 3-12 Summary of the ICC values for Group two

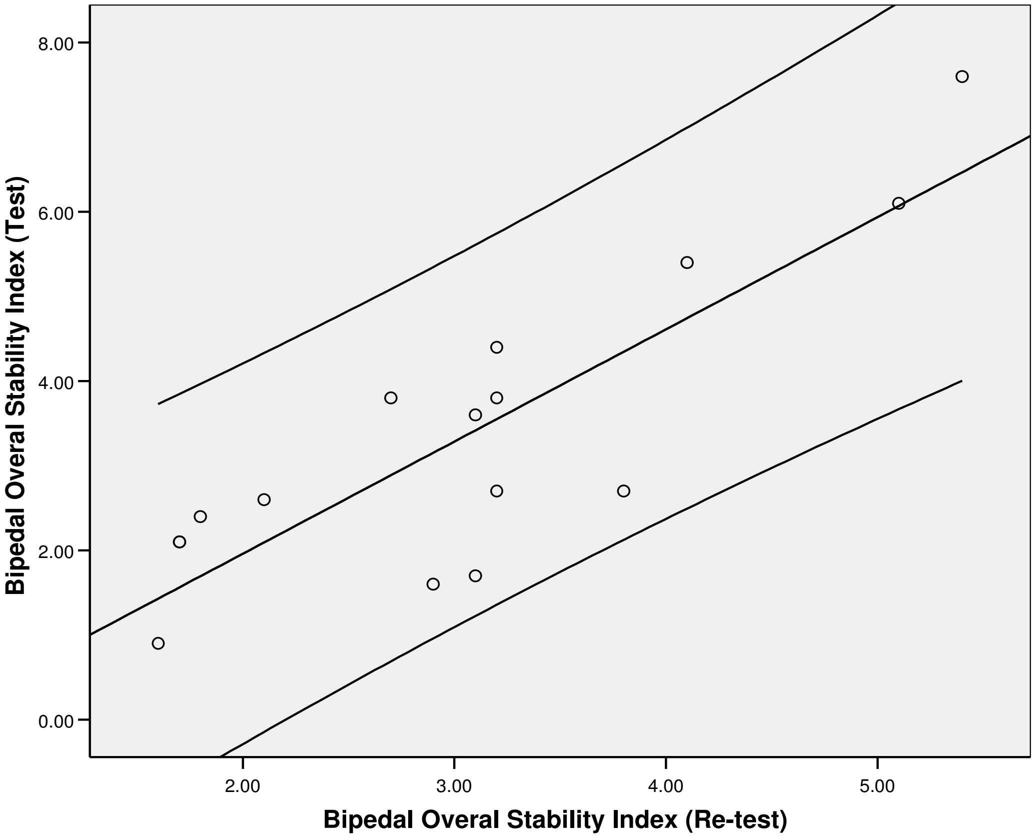

Figure 3-14 Test, Re-test Bipedal Overall Stability Index

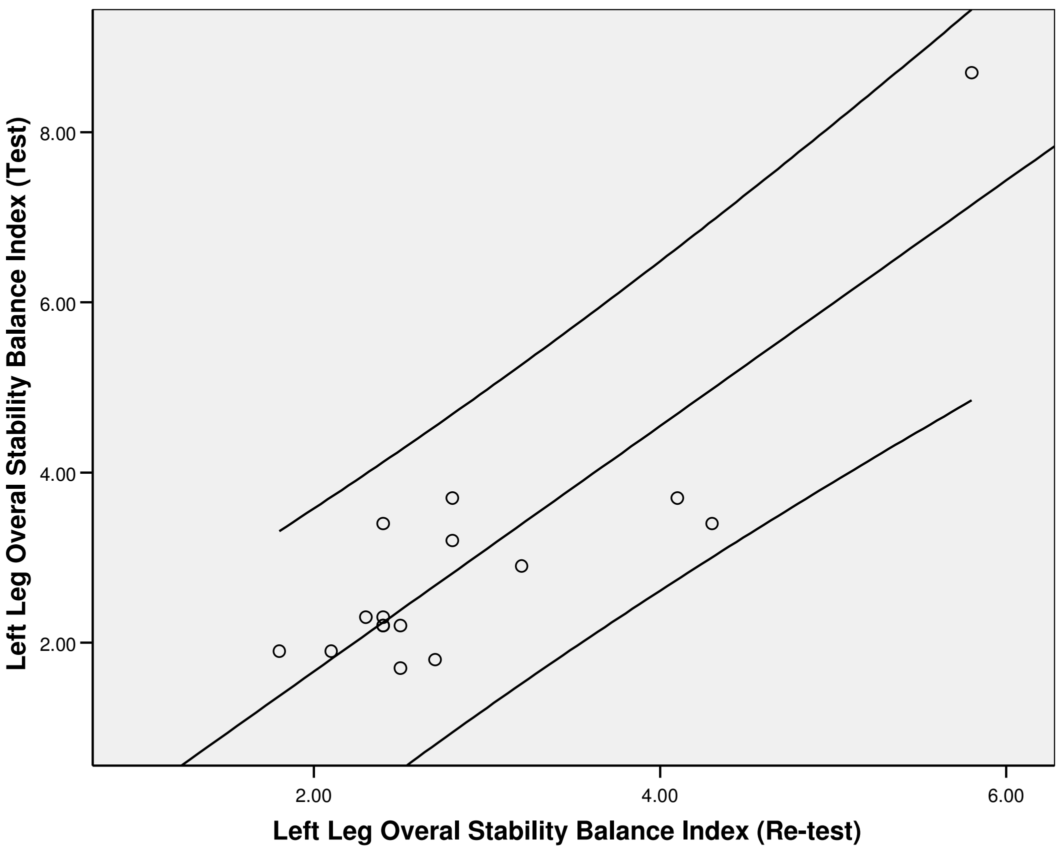

Figure 3-15 Test, Re-test Left Leg Overall Stability Balance Index

The table 3.14 and 3.15 present the average measures of the ICC for the bipedal OSI (.87,CI:.62-.95) and left leg OSI (.87, CI: .64-.96). They were also in range of "good" reproducibility. The measured scores in the test and re-test sessions for these two variables are clustered close to straight lines in figure 5-33 and 5-34.

	Intraclass Correlation	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.768(b)	.454	.912	7.619	15.0	15	.000
Average Measures	.869(c)	.624	.954	7.619	15.0	15	.000

Table 3-13 Intraclass Correlation Coefficient of the Bipedal "Overall Stability Index"

	Intraclass Correlation	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.774(b)	.466	.915	7.848	15.0	15	.000
Average Measures	.873(c)	.635	.955	7.848	15.0	15	.000

Table 3.14 Intraclass Correlation Coefficient of the Left Leg "Overall Stability Index"

All values obtained for ICCs of the measured variables were summarised in table 5-33 and 5-34.

Variables	Test 1 Means (SD)	Test 2 Means (SD)	ICC (95% CI)
Bipedal Overall Stability Index	2.80 (1.33)	2.21 (1.28)	.83 (.53 -.94)
Right Leg Overall Stability Index	2.54 (1.17)	2.63 (1.05)	.94 (.83 -.98)
Left Leg Overall Stability Index	2.57 (1.06)	2.46 (1.24)	.90 (.74 -.96)
Limits of Stability	139.67 (40.44)	131.36 (48.22)	.96 (.87 -.99)

Table 3.15 Summary of the ICC values for Group one

Variables	Test 1 Means (SD)	Test 2 Means (SD)	ICC (95% CI)
Bipedal Overall Stability Index	3.34 (1.80)	3.04 (1.15)	.87 (.62 -.95)
Right Leg Overall Stability Index	3.52 (1.39)	3.21 (1.20)	.93 (.80 -.98)
Left Leg Overall Stability Index	2.96 (1.68)	2.91 (1.02)	.87 (.64 -.96)
Limits of Stability	143.19 (31.03)	132.88 (25.09)	.83 (.51 -.94)

Table 3.16 Summary of the ICC values for Group two

3.11 Discussion: the Reproducibility Study of Biodex Stability System

In rehabilitation and sports medicine several tools are being used for assessment and management of patients or athletes. Evaluation of muscle strength, function, balance and gait are very popular, in particular. Reproducibility studies, as the foundation of clinical research, are crucial to determine if the results obtained using these tools are consistent. Assessment of balance may be performed by evaluation of maintenance of a still posture, such as standing or postural adjustment in voluntary movements. Postural stability is a complex process, which is controlled by the central nervous system (CNS). The CNS provides the complicated task of motor control by processing the visual, vestibular and proprioceptive inputs[119].

There are compensatory or reactive strategies in postural control, as well as anticipatory or predictive strategies. When a person performs a voluntary active motion, due to an anticipated disturbance of balance the anticipatory or predictive strategies are involved[86]. But in the case of controlling an unpredicted disturbance using muscular activity the strategy is a reactive one. If the LOG is moving but the BOS is fixed the responses maybe 'fixed-support' but if the BOS is also moving, such as the unstable platform of the Biodex Stability System the responses will be 'change-support'. The responses in controlling posture were considered as automatic reflex like responses by a sensory stimulus. So the central nervous system (CNS) controls these responses and balance evaluation.[120]. As postural strategies rely on motor skills integrated in the CNS, they can be more efficient by practice and training[85].

One important reason that the unipedal balance tests are commonly utilised is to evaluate postural control in major areas of imbalance in the mid-swing or mid-stance of walking, cycling and running. In the present study the BSS was utilised to obtain OSI for bipedal standing, unipedal standing on the right leg, unipedal standing on the left leg and bipedal LOS from two main sessions in two groups of youth and adults. Measured tests values in two main sessions were compared by calculation of ICC.

ICC values have been interpreted as poor if less than .69, fair if .70 to .79, good if .80 to .89 and excellent if .90 to 1.00[118]

Generally the ICCs for the measured values for test re-test reproducibility are similar to those from other studies[121 122 106 108]. These previous studies were conducted on different sample groups, such as those with stroke, head injury, spinal cord injury, the elderly and in orthopaedics patients using different methods of administration. For example in two studies the subjects were selected from elderly residents in a care-home and stroke patients[123 124]. Acceptable test re-test reproducibility of balance tests was also reported in another study in neurological patients[125]. These few studies are not comparable to the current one in terms of subjects and type of sampling; however they suggested that the BSS was a reliable device with consistent results in these populations.

In a descriptive study the results of four reproducibility studies before 2000, which utilised the BSS in a test re-test design were compared. In studies that measured the static balance the range of ICCs was from .44 to .89. It was also reported that ICCs were higher in tests performed in lower stability levels or with the eyes closed. The range of ICCs for LOS ranged between .64 and .89. The author of this study concluded that the results of BSS test were comparable to the tests using a force plate, and the test re-test reproducibility of the BSS were acceptable in further reviews[104].

According to the average measures of ICC values in the present study the reproducibility of the unipedal OSI for both right and left legs and also the LOS in the first group (over 19 years old) were excellent. The reproducibility of the bipedal OSI can be interpreted as good in this group.

The obtained reproducibility values, based on the average measure of calculated ICC scores in the second group (under 19 years old) was excellent for the right leg OSI and good for the LOS, the bipedal OSI and the left leg OSI. The calculated ICCs for the younger group ranged between .83 and .93.

Similar results were previously reported in a study in healthy college students[106]. The ICC was calculated .60 for the OSI measures of the unipedal stance at Level 2 resistance. The ICC was .95 for the dominant limb, and .78 for the non-dominant limb at level 8 resistance. It was concluded that the BSS to be a reliable assessment device across multiple 20-seconds tests. Findings are also consistent with reported ICC values, which ranged from .44 to .89 for OSI and .64 to 89 for the LOS [108].

In the protocol of this study, as explained in the method section, a decreasing stability level was used. Just in one study the protocol included a changing (decreasing) stability score (from Level 8 to Level 1 over 30 sec), in which the ICC of all three types of tests were calculated. Intertester and intratester values of the reproducibility were measured by Schmitz and Arnold using different stability levels for unipedal standing balance using the BSS. The intratester reliability measurements were .80 for the anterior/posterior stability index and .70 for the overall stability index.[103] . In their test re-test protocol ICCs ranged between .54 and .93 for intratester reliability. They concluded that a single leg stance test of decreasing stability seemed to be highly reliable when performed using the BSS. It can be concluded that the results of the current study are in line with those of the reported study in a relatively similar context.

3.12 Measurements of strength

The reproducibility of the isometric dynamometer REV 9000 was also reviewed an endpoint measure in the following studies. This dynamometer was used as one of the instruments of the current study at the Performance Lab located at Sports, Health and Injury Clinic at the Scottish National Stadium.

3.13 Background: Isokinetic Testing

Isokinetic assessments and exercises are commonly utilised in clinical settings for the evaluation and strengthening of muscle groups. This method of testing and practice is very safe to perform and is not too demanding, in terms of coordination. The information and definitions in this section are mainly from Sapega[126] The term "isokinetic" was introduced in 1966 after the "Cybex I" dynamometer was developed in the 1960s. The concept of isokinetic exercise is controlling the velocity of the movement during muscular performance by altering the resistance through a range of motion. To understand this concept, the main fundamental issues should be explained. The main related subjects are the maximal muscular strength, muscular endurance and types of muscle contraction. The maximal muscular strength is the maximal contractile power of muscles as a result of a single maximum effort. Muscular strength refers to the ability of muscles to produce force in contraction. The maximum muscle strength may be measured by performing one repetition with the maximum ability (RM). It is the maximal amount of resistance that can be overcome by a muscle group in one repetition. Muscular endurance refers to the ability to sustain the force generated by a muscle group. In endurance exercise muscles move sub-maximal loads to a certain tolerable level of fatigue or to perform work by holding a maximum contraction for a given length of time. Endurance exercises are also performed by repeated contractions against a load. In the isokinetic dynamometry endurance index can be measured by the magnitude that the peak torque is reduced over a period of time.

The contraction could be isometric, isotonic (concentric or eccentric), or isokinetic. The maximum isometric contraction, which occurs in static exercises, is a type of muscular contraction with the highest effort and with no visible movement of the joint or limb.

Isometric testing is reliable and valid. Performing this test does not need expensive equipments. Simple dynamometers in the forms of hand-grip and back-leg lift are available for static testing. It is also possible to perform isometric test using an isokinetic machine. Isotonic or dynamic exercise is moving a sub-maximal load or a weight a given number of times.

Concentric contraction refers to an isotonic muscle contraction in which the acting muscle becomes shorter. On the contrary, in eccentric contraction the length of the primary muscle increases. So in isotonic exercise if the muscle shortens while contracting, it contracts concentrically whereas in eccentric contraction the function is lowering a weight from a height and the muscle is lengthening while contracting.

Another related concept is muscle overload. It means that the workload of the muscle or the muscle group is more than the load that the muscle is accustomed to. Exercises may be divided into two groups, based on the factor that varies. An exercise can have variable resistance or variable velocity. In the first type the resistance changes as the muscle contracts, and in the second type the speed of movement changes, as the muscle contracts with maximal or sub-maximal tension. Isokinetic exercise is variable resistance, rather than variable velocity. So it can be defined as the muscular contraction at a constant velocity. The resistance changes with the changes of the muscle length. It is directly proportional to the force exerted by the muscle.

The external mean resistance holds the velocity of moving a segment of the body to a constant rate in order to achieve this kind of performance. The advantage of it compared to other methods of exercise is that the isokinetic dynamometer provides the resistance that matches the generated force of muscles throughout the range of motion. So it is possible for muscles to exert their maximal force, in theory, at every single degree of ROM. In isokinetic dynamometry the maximal contraction of a muscle group throughout a range of motion at a set velocity is measured.

The ability of a muscle to generate force quickly or work per unit of time refers to muscular power. So power can be defined as the amount of work performed by a muscle. The power is increased with higher angular velocity.

3.13.1 Peak torque

Peak torque (PT) is the main parameter that is measured in isokinetic dynamometry. It is the highest torque output reached by a muscle or a group of muscles and is measured in Newton-metres units (N.m). PT was shown to be a reproducible, reliable and valid measurement in a dissertation by the author submitted as a part of the requirements of the MSc in Sports Medicine at the University of Glasgow in 2002. The reproducibility of the isometric dynamometer REV 9000 was also identified. Intraclass correlations (ICC) were calculated following analysis of variance (ANOVA). ICC's was approximately 0.86. Results from the analysis demonstrated no main effect between test occasions for the test and retest assessments of peak torque (PT) of the flexors and extensors of the knee joint of the dominant leg. Since correlation values between two main visits ranged between $r = 0.74$ and $r = 0.97$ ($P < 0.01$) the methods used in this study to assess muscular strength have been shown to be reliable.

The magnitude of the PT that a muscle or a group of muscles generate is related to the velocity of the movement, which is called the torque-velocity relationship. It declines as the velocity increases and increases at the lower velocities.

3.13.2 Angle of peak torque

The angle of peak torque (PT) is an optimum part of the ROM where the muscle generates the maximum force. This point is often in the mid-range of the joint. It is suggested that the point of the PT in higher speed occurs later in the range. It seems that on the faster movements the muscle cannot recruit all possible fibres by midrange. So the angle of PT may alter [126].

3.13.3. Eccentric/Concentric ratio

One of the recent topics of research in sport medicine is eccentric/concentric muscle strength ratios (E/C ratio). More accurately this ratio is the maximal eccentric moment/maximal concentric moment, which can be calculated from the isokinetic dynamometry results. Very little has been published on this subject on normal or injured knees. The results of isokinetic strength tests for the quadriceps and hamstring muscles show that the eccentric values are significantly more than concentric values in both muscles[127]. So this ratio should be more than one.

Isokinetic dynamometry is often performed in open kinetic chain (OKC) positions. The OKC refers to the movement of the extremities when the distal part is moving freely in space. In closed kinetic chain (CKC) the distal end of the moving extremity, foot or hand, is fixed on the ground or stable platform. In CKC the element of weight bearing exists unlike in OKC. A non-weight bearing position cannot contribute to the stabilising function, which activates and synergistic muscles [128 129 130] .

Using CKC exercises after ACL injuries is suggested in many clinical studies, because they can increase the stability of the knee joint by recruiting both flexor and extensor muscles of the knee joint in co-contraction exercises. It is assumed that the stress on ACL is less in the CKC exercises compared to that of OKC exercises.

3.14 Literature review: isokinetic assessment

Only one decade after isokinetic equipment was introduced, in the 70's; it became a very popular method for the assessment of muscle performance, in the 80's. Over 30 publications per year have reported data from isokinetic dynamometers during last 20 years[131]. A range of dynamic isokinetic devices are available. Early dynamometers had a rotary lever with force-input, which controlled the velocity of the body's movement during maximum concentric contraction. Recent models are equipped with servo-controlled input levers that are programmed to move at a constant pre-selected angular velocity when the subject applies force against the lever.

In the clinical setting in physiotherapy and neurological assessment the method of muscle testing is usually manual. However this may not be sensitive enough to assess changes in strength. Manual and isokinetic evaluation of shoulder muscles have been compared pre and post surgery[177]. According to manual testing the strength was improved significantly, but objective isokinetic techniques did not confirm this. This extended the objective tests available to clinical assessment and practice.

In tests of dynamometry for muscular performance the subject should provide a full maximum voluntary effort. Data obtained from tests with maximum voluntary efforts confirmed excellent reproducibility, unlike tests with sub-maximum efforts[126]. The average strength of the quadriceps muscles in normal male subjects was reported to be180 Nm, equal to 600 Nm at low velocity[177], which means 600 N of force.

It was found that the data acquired using similar isokinetic machines in different centres were not comparative, even if they were set in an identical testing mode. After reviewing about 200 research articles about the procedures on isokinetic measurements a few factors that affected the results were identified. They included weight, gender, age, athletic background, limb dominance and degree of disability[131]. Other factors that could also cause variations in results were the type of contraction, ROM, warm-up, stabilisation, gravity correction, axis alignment and lever-arm length. The conditions of test, such as speed, test sequence, rest intervals and feedback were also important.

It was also found that the measured isokinetic torques in 45-78 year old subjects were greater in the second testing session compared to the first. However the difference between the produced torques was not significant in subjects under 45 years old.

In a study looking at the eccentric/concentric ratio in subjects with normal and injured knee joints, cases with patellofemoral problems had significantly lower ratios compared to a control group[132] .

A strong association has been found in several investigations between functional ability and the peak torque measurement in isokinetic dynamometry. For example the association between functional testing and peak torque of knee extension was investigated in subjects with reconstruction of the anterior cruciate ligament and also in a control group [133]. It was concluded that a strong positive correlation exists between the result of isokinetic strength test and functional clinical tests. Similar findings were reported in a study looking at the relationship between functional ability and isokinetic peak torque in normal subjects [134]. Open and closed kinetic chain isokinetic dynamometry is strongly associated. Isokinetic peak torque was also compared to maximal ball velocity in youth football players [135]. This study demonstrated that isokinetic strength tests are positively and strongly correlated with functional ability. These studies suggested that the isokinetic results are reliable and valid for application in clinical sports medicine.

In athletic activities for example during landing the knee joint is under great force. The quadriceps muscles absorb the shock and impact of these forces during knee flexion by eccentric contraction and give stability to the joint [136 137]. This absorption is a negative force, which decelerates the body movement and maintains balance during activities. This negative work that is performed by eccentric contraction of the quadriceps muscles is efficient to keep the joint stable in functions, such as landing and also helps to maintain balance[137]. In the eccentric activity of the quadriceps both muscle strength and neuromuscular control are necessary[140]. With impaired neuromuscular control even very strong quadriceps muscles might not be able to perform this shock absorption properly in complex manoeuvres, such as landing. Therefore it is possible that the player may have sufficient muscle strength, yet may not be able to apply it appropriately when performing a complex movement such as landing.

The ratio of maximum hamstring torque/maximum quadriceps torque has attracted several researchers as well. The normative value of 0.60 is widely accepted among researchers in the field of rehabilitation. The values of eccentric and concentric H/Q ratio were reported as 0.646 and 0.553 at a velocity of 60°/s[138].

3.15 Method: Isokinetic dynamometry

A health questionnaire was completed prior to the application of the test. The suitability of the subjects for the tests was evaluated using the questionnaire and no subject was recruited who had any injury during the preceding six months or any sequel from a previous injury. Exclusion criteria also included the absence of pain at the session because it would have inhibited their performance and limited their full participation. The research project was approved by the ethics committee of the University of Glasgow and all participants signed an informed consent form and a health questionnaire including the information that their rights were protected.

Participants performed a warm-up consisting of an eight-minute treadmill run at a comfortable speed. The assessments were performed at the same hour of the day and under the same room temperature. The subjects were positioned sitting upright at the machine (REV 9000, Technogym, Italy) at a seat angle of 100°. They were stabilised on the seat securely then for the testing used two straps on their chest and also a thigh restraint roller just above the knee. The lever arm clamp was positioned at the distal part of the leg and immediately proximal to the lateral malleolus. Subjects were required to cross their arms over their chests to avoid any synergistic muscle actions in the upper limbs. The range of motion was set at 90° to 10° knee flexion. The anatomical axis of the joint (the lateral epicondyle of the femur at 90° flexion of the knee joint) was aligned with the mechanical axis of the dynamometer, and aligned with the knee using a laser beam provided in the machine. The torque was corrected for gravitational moments of the lower leg and the lever arm before each part of assessment.

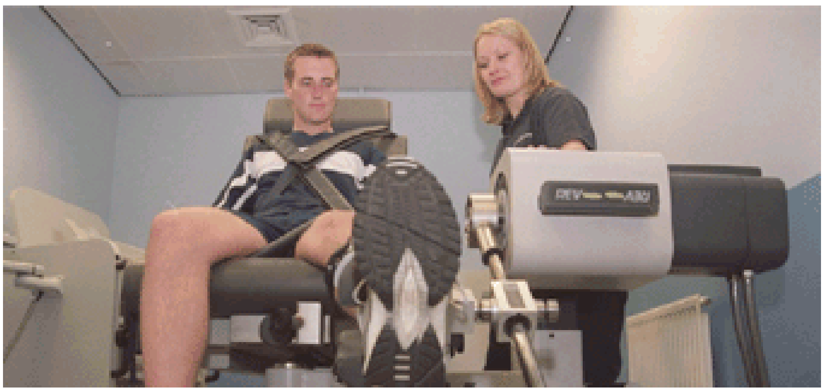

Figure 3-16 Isokinetic Dynamometer rev 9000

After the general warm up and one minute rest following it a specific warm up was performed, in which the subjects completed 2 sets of sub-maximal flexion/extensions of the knee joint. They were asked to push out and pull back their legs forwards and backwards. The first set included 4 concentric knee extension/flexion contractions, followed by 4 sub-maximal eccentric flexion/extension contraction of the knee joint at 30º/s. The second set was repeated afterwards at the velocity of 180º/s. All components of this specific warm-up were performed at 50-75% of estimated maximum effort. Apart from the first series for each test with about 50% of subject's maximum effort was considered as a specific and task related warm up and the main test was performed after a period of one-minute rest.

Subjects had a period of two minutes recovery after performing the specific warm up. The isokinetic test then started with the measurement of concentric peak torque of the hamstring and quadriceps muscle groups of the knee joint at the velocity of 30º/s from 4 maximal efforts. Following to a 90s rest period the same function was repeated at 180º/s. The subject then completed two sets of 4 maximal concentric-eccentric contractions of the hamstrings at the same velocities and with the same 90s rest period in-between. After a further one minute recovery, 4 maximal quadriceps muscle actions with the sequence of concentric-eccentric were performed at two testing speeds of 30º/s and 180º/s with a 90s rest in-between. After a 2 minute recovery period, the maximum isometric angle-specific torques for the hamstrings and quadriceps were tested at two angles of knee flexion (70° and 25°). Each isometric contraction lasted for 5s followed by 30s recovery periods. Finally the concentric peak torques of the hamstrings and quadriceps muscles were evaluated with fast movements which equate more to athletic performance. After a further 3-minute non-specific warm-up, the contralateral leg was then assessed using the same protocol outlined above.

3.16 Introduction: Comparative Study of strength and balance in Scottish Youth Footballers

The studies of the reproducibility of the Biodex Stability System and the review of the usefulness and reproducibility of the REV 900 isometric dynamometer in the first portion of study 2 provided tools which could be applied with confidence in the assessment of proprioceptive function and muscle strength in health and disease.

Football is the most popular sport with 200 million players in the world and female

And youth participation has increased rapidly in the last decades[139140] . In professional football, coaches look to identify the traits that discriminate between performers. They are seeking effective methods to identify talented young players. Youth academies can play a very important role in developing football players finding the most effective formula, however, are very difficult. Different factors may predispose young players towards successful performance in professional football. Typical studies in this field compare professional players with semi-professional players or with recreational players to find the effective characteristics that could distinguish the best performers.

With the long and strong history of football in Scotland and the current popularity of it in the younger generation, related authorities wish to boost the players' performance. Although there are studies in this respect from other countries, every nation needs to develop data from its own population[141].

Comparing fitness data with that of the other countries would provide meaningful information and may confirm that low fitness levels are a contributory factor to the decrease in standard of Scottish football. Fitter teams win more often, as reflected in a rank correlation between final league position and fitness in Hungary, and the differences between the top and bottom teams in the Norwegian league championship. While the two teams were at opposite ends of the table in terms of points, they were also at opposite ends of the spectrum in terms of endurance, strength and performance.

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3.17 The Aim of the comparative study in Scottish Youth Footballers

This extension of the second study was designed to compare strength and balance in professional, non-professional and non-football players to identify if differences exist within these characteristics which might determine a player's potential to progress to higher levels of football.

3.18 Literature Review: the Comparative Study in Scottish Youth Footballers

Several characteristics have been investigated as the predictors of success in professional youth football. These factors comprise physiological, anthropometric and psychological characteristics, as well as training and match experience, motor skills and techniques, and also injury risks. Maximal sprint speed, maximal anaerobic power, peak torque and jumping capacity may also discriminate across various age categories and/or playing positions between youth players who are successful or not in achieving the highest standards of play[142].

Previous reports on youth soccer players have disclosed significant differences in anthropometric and fitness measures between both different standards of play and across playing positions. In particular goalkeepers and defenders were differentiated in body size. This result supports the findings of Gil et al. who indicated that body size is an important criterion in talent selection[143].

Vaeyens et al. found that performance characteristics vary according to age groups, and contradicted to some extent factors observed in the only other study in young professional football players. Franks et al compared those from the Football Association's National Centre of Excellence who succeeded in playing at the professional level. Players could not be discriminated on the basis of anthropometry or sprint performance, although these players were clearly distinguished in level of talent from a non-professional, age-matched group[142].

Many studies in the field of sports injury and prevention have been carried out on adults. There are gaps in the studies focussing on adolescents. Looking for preventive research on adolescence in databases during last the 50 years, show few studies relating to adolescents. These studies have focused on validating the effectiveness of rehabilitation practices as prevention strategies. In one of them the intervention included training in strengthening techniques, plyometrics, and landing technique in female adolescents. These training techniques may reduce ground reaction forces and improve jumping technique. These methods may prevent major knee injuries in young football, basketball and volleyball players. Another article by the same research team showed that neuromuscular exercise techniques could improve jumping performance in female adolescent athletes[144] .

Noyes [174] trialled a six weeks training programme which consisted of flexibility, plyometrics and weight training in 366 women. The main focus of training was on the correct technique of landing after jumping. The intervention group and two control groups were recruited from volley ball, football and basket ball. The results found in 94% of the group showed that there were no serious knee injuries in the volleyball players in any of the groups. The results focusing on football and basketball, found that the untrained females had 5.8 times the number of injuries than men. Training lead to a significant reduction in injuries but even still the trained female group had 2.4 times the number of injuries than the men, suggesting that factors other than training are relevant.

3.19 Method: the comparative study of strength and balance in Scottish Youth Footballers

The main purpose of this study was to compare balance and strength, in elite, recreational and non-football players. Prior to any statistical comparison and tests, the results from the baseline data were explored. These results showed that groups were equivalent and comparable so all obtained variables from three groups were compared. Fifty four young subjects with an age range from 15 to 18 were recruited in three groups. Twenty of them were full-time Scottish Premier League players in the under 17 or 18 international teams with a mean age of 16.60 years. They were the first group in this study being elite youth football players (EFP). The second group were twenty one recreational youth football players (RFP) with the mean age of 16.5 years. They were recruited from three local high schools. The third group were non-football players (NFP) recruited from two local high schools with a mean age of 16.3 years Participants and their parents or guardians signed the consent forms.

3.19.1 Power and population size

This research was a part of a parallel study and the VO2-max of the subjects was measured as well. The power and population size were calculated based on the result of the Vo2-max and also isokinetic testing, because both are related to fitness and performance. The statistical analysis of one-way ANOVA was performed with a significance level of 0.05 and a required power of at least 80 %, the study required at least 13 subjects in each of the three samples.

3.20. Results: the Comparative Study of strength and balance in Scottish Youth Football

Data was provided from the isokinetic and balance assessment of fifty four young participants of this study. Their age range was from 15 to 18 (M= 16.61, SD= 0.70) they were recruited in three groups. Twenty subjects from full-time Scottish Premier League teams played in the under 17 or 18 international teams. The mean age was 16.60 years (SD= 0.3), the mean height was 176.2cms (SD=5.3) and the mean weight was 67.5 kg (SD=6.5). This group of subjects as youth football players (EFP) attended five formal training sessions per week at their clubs. This regular participation in training session was the rationale behind the hypothesis of this study that the professional group would be expected to present higher values in strength tests and better results in balance tests. The second group were twenty one recreational youth football players (RFP) with the mean age of 16.5 (SD=0.4), the mean height of 172.6 (SD=5.7) and the mean weight of 64.3 (SD=7.3). They were recruited from three local high schools. The RFP group trained two sessions per week or less at their schools and only played in their school teams. The third group were non-football players (NFP) recruited from two local high schools with the mean age of 16.3 (SD=0.4), the mean height of 173.7 (SD=7.4) and the mean weight of 67.0 (SD=3.3).

	N	Minimum	Maximum	Mean	Std. Deviation
Height	54	157.50	187.60	174.5889	6.87093
Weight	54	49.00	108.40	66.4037	8.58432
Age	54	15.00	18.04	16.6148	.70265
BMI	54	18.08	33.75	22.1087	2.29859
Valid N (list wise)	54				

Table 3-17 Descriptive Statistics of subjects' Anthropometric Data

3.20.1 Tests of normality

Statistical tests of normality (Kolmogorov-Smirnov and Shapiro-Wilk) were applied and showed that the distributions of height in all groups, weight in RF and age in EF were not significantly difference from the normal distribution (*P*>0.05). The distributions of weight in the EF and NFP groups, and the distribution of age in the RFP group are significantly different from that of the normal distribution, because p-values for Kolmogorov-Smirnov and Shapiro-Wilk are less than 0.05. Most of other variables were shown to be normally distributed. The groups in which the distribution was not normal were transformed, by log transformation or other appropriate modes of transformation.

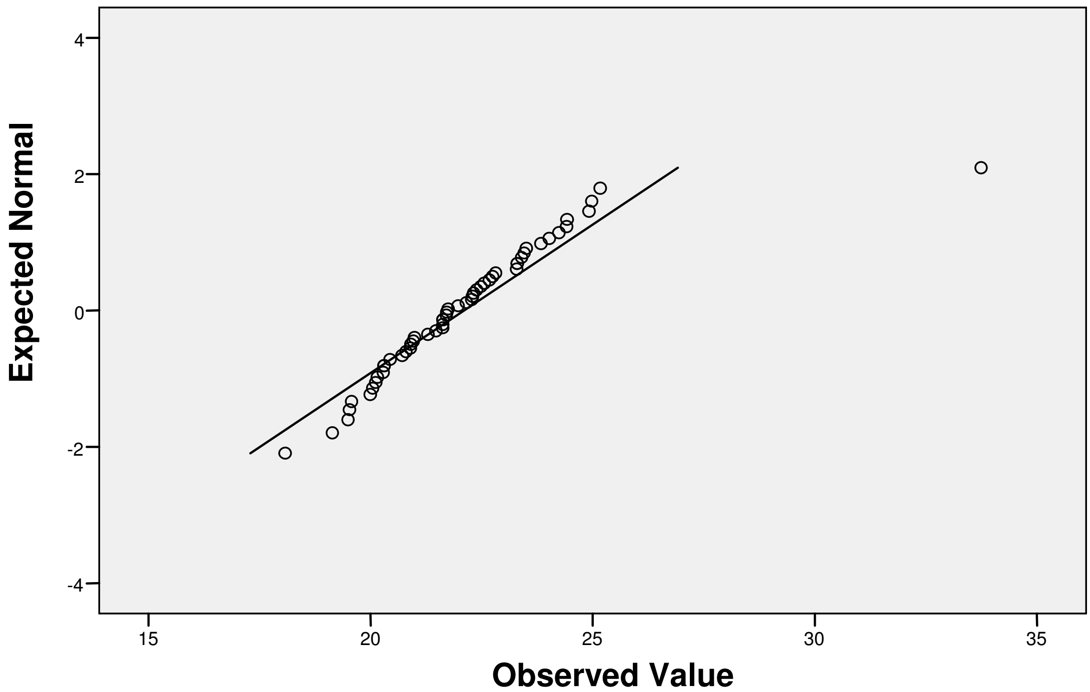

Figure 3-17 Normal Q-Q Plot of BMI

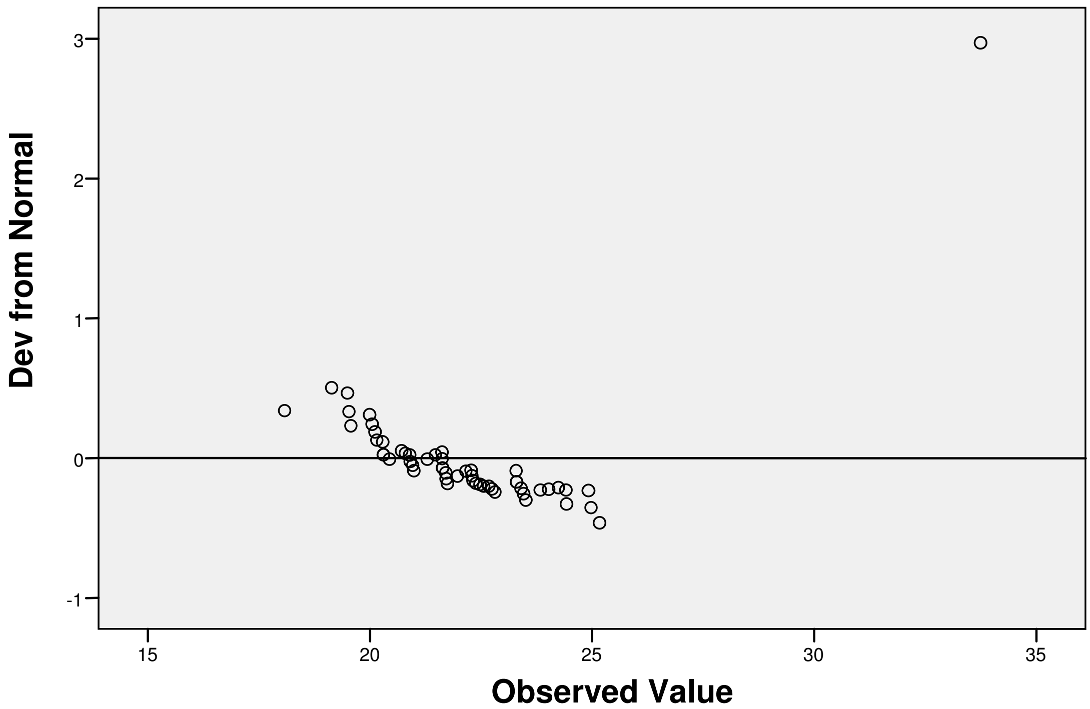

Figure 3-18 Detrended Normal Q-Q Plot of BMI-The quartile probability plot of the deviation from normal distribution

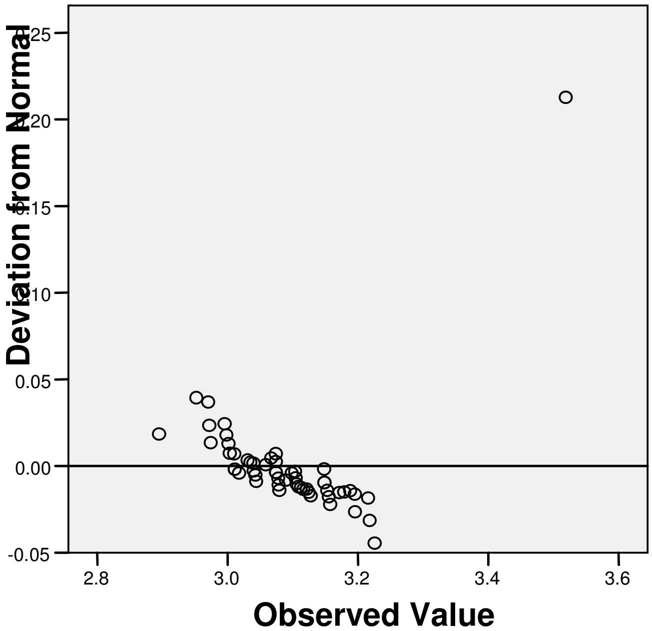

Figure 3-19 Detrended Normal Q-Q Plot of BMI (Transforms: natural log)

		Levene Statistic	df1	df2	Sig.
Height	Based on Mean	.224	2	51	.800
	Based on Median	.218	2	51	.805
	Based on Median and with adjusted df	.218	2	50.994	.805
	Based on trimmed mean	.232	2	51	.794
Weight	Based on Mean	.174	2	51	.841
	Based on Median	.093	2	51	.912
	Based on Median and with adjusted df	.093	2	31.568	.912
	Based on trimmed mean	.135	2	51	.874
Age	Based on Mean	.143	2	51	.867
	Based on Median	.629	2	51	.537
	Based on Median and with adjusted df	.629	2	44.654	.538
	Based on trimmed mean	.195	2	51	.824

Table 3-18 Test of Homogeneity of Variance

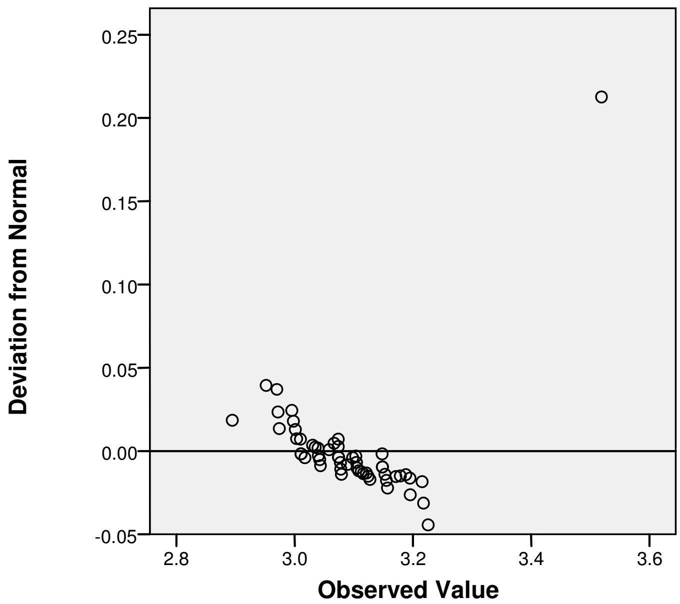

Figure 3-20 Detrended Normal Q-Q Plot of BMI

3.20.2 Results of the balance tests

Balance Tests	Minimum	Maximum	Mean		SD
	Statistic	Statistic	Statistic	Std. Error	Statistic
Bipedal Overall Stability Index	.90	9.10	3.1264	.19454	1.41627
Bipedal Anterior/Posterior Stability Index	.70	8.10	2.5566	.16592	1.20791
Bipedal Medial/Lateral Stability Index	.80	4.70	2.0057	.12323	.89709
Right Foot Overall Stability Index	1.40	6.40	3.3075	.16892	1.22974
Right Foot Anterior/Posterior Stability Index	.90	6.40	2.8245	.17181	1.25083
Right Foot Medial/Lateral Stability Index	.90	3.60	1.8113	.08884	.64679
Left Foot Overall Stability Index	1.60	9.90	3.2943	.22163	1.61345
Left Foot Anterior/Posterior Stability Index	1.10	9.70	2.8566	.21108	1.53667
Left Foot Medial/Lateral Stability Index	.80	4.40	1.7755	.10605	.77209
Limits of stability Completion Time	96.00	274.00	142.0577	4.13702	29.83248
Limits of stability Overall Control	4.00	36.00	15.4808	.84308	6.07951
Limits of stability Forward Control	3.00	60.00	17.4231	1.59263	11.48460
Limits of stability Backward Control	3.00	47.00	13.0000	1.15926	8.35957
Limits of stability Right Control	3.00	64.00	17.9808	1.37542	9.91827
Limits of stability Left Control	5.00	52.00	16.3846	1.22356	8.82322
Limits of stability Forward Right Control	2.00	37.00	15.9423	1.21343	8.75016
Limits of stability Forward Left Control	2.00	50.00	14.8846	1.26254	9.10431
Limits of stability Backward Right Control	2.00	43.00	15.4808	1.29464	9.33576
Limits of stability Backward Left Control	1.00	45.00	16.3462	1.38618	9.99585

Table 3-19 Descriptive Statistics for the Balance tests

3.20.3. Results of the ECC/CON ratio

Table 3-21 presents the ecc/con ratio for the hamstring and quadriceps muscles. All values are more than one ranging between 1.03 and 1.91 for hamstring muscles and between 1.11 and 1.22 for the quadriceps muscle.

Ecc/Con Ratios	Minimum	Maximum	Mean		SD
	Statistic	Statistic	Statistic	Std. Error	Statistic
Eccentric/Concentric Ratio of the Left Hamstrings at 30	.53	1.54	1.0745	.02694	.19794
Eccentric/Concentric Ratio of the Right Hamstrings at 30	.71	1.58	1.1334	.02592	.19049
Eccentric/Concentric Ratio of the Left Hamstrings at 180	.33	1.86	1.0321	.03911	.28739
Eccentric/Concentric Ratio of the Right Hamstrings at 180	1.16	3.00	1.9114	.05286	.38842
Eccentric/Concentric Ratio of the Left Quadriceps at 30	.78	1.50	1.1079	.02338	.17181
Eccentric/Concentric Ratio of the Right Quadriceps at 30	.71	2.01	1.1950	.03222	.23678
Eccentric/Concentric Ratio of the Left Quadriceps at 180	.85	1.72	1.1595	.02849	.20937
Eccentric/Concentric Ratio of the Right Quadriceps at 180	.67	1.92	1.2246	.03541	.26024

Table 3-20 Descriptive Statistics of the Eccentric/Concentric Ratio

3.20.4. Results of hamstring/ quadriceps ratio

The table3-22 shows the ham/quad ratio calculated in three velocities of 30º/s, 180º/s and 300º/s. The values obtained in the velocity of 30º/s were 59-60%, that of 180º/s was 65-69% and that of 300º/s was 74-78%. The ecc.ham./con.quad ratios are presented in table 3-19 They ranged from 63% to 69% for the velocity of 30º/s and from 67% to 77% for the velocity of 180º/s.

Ham/quad Ratio	Minimum	Maximum	Mean		SD
	Statistic	Statistic	Statistic	Std. Error	Statistic
Hamstring/Quadriceps Ratio of The Left Leg at 30	.38	1.18	.5907	.01854	.13626
Hamstring/Quadriceps Ratio of The Right Leg at 30	.41	.85	.6036	.01434	.10535
Hamstring/Quadriceps Ratio of The Left Leg at 180	.35	1.53	.6908	.03297	.24226
Hamstring/Quadriceps Ratio of The Right Leg at 180	.48	1.07	.6486	.01542	.11330
Hamstring/Quadriceps Ratio of The Left Leg at 300	.36	2.13	.7796	.04563	.31613
Hamstring/Quadriceps Ratio of The Right Leg at 30	.52	1.17	.7424	.01975	.13683

Table 3-21 Descriptive Statistics of the Hamstring/quadriceps Ratios

3.20.5. Results of eccentric hamstring /concentric quadriceps ratio

EccH/ConQ Ratios	Minimum	Maximum	Mean		SD
	Statistic	Statistic	Statistic	Std. Error	Statistic
Left Eccentric Hamstring: Concentric Quadriceps Ratio at 30	.34	1.14	.6267	.02157	.15848
Right Eccentric Hamstring Concentric Quadriceps Ratio at 30	.40	.99	.6870	.01989	.14619
Left Eccentric Hamstring Concentric Quadriceps Ratio at 180	.41	1.41	.6700	.02550	.18735
Right Eccentric Hamstring Concentric Quadriceps Ratio at 180	.49	1.24	.7727	.02041	.14999

Table 3-22 Descriptive Statistics Eccentric Hamstring/Concentric Quadriceps Ratios

3.20.6 Results of the isokinetic strength testing corrected values for weight

	N	Minimum	Maximum	Mean		Std. Deviation
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic
Concentric Hamstring Torque at 30 in Left Leg/weight	54	.76	2.37	1.4888	.04175	.30681
Concentric Hamstring Torque at 30 in Right Leg/weight	54	.78	2.56	1.5087	.04343	.31918
Concentric Hamstring Torque at 180 in Left Leg/weight	54	.72	2.70	1.5494	.05712	.41972
Concentric Hamstring Torque at 180 in Right Leg/weight	54	.84	2.12	1.4121	.03499	.25714
Concentric Quadriceps Torque at 30 in Left Leg/weight	54	1.6	3.6	2.567	.0628	.4616
Concentric Quadriceps Torque at 180 in Left Leg/weight	54	.90	3.73	2.3528	.07812	.57408
Concentric Quadriceps Torque at 30 in Right Leg/weight	54	1.39	4.61	2.5418	.07752	.56966
Concentric Quadriceps Torque at 180 in Right Leg/weight	54	1.24	3.72	2.2217	.06420	.47179

Eccentric Hamstring Torque at 30 in Left Leg/weight	54	.84	2.52	1.5820	.05151	.37854
Eccentric Hamstring Torque at 30 in Right Leg/weight	54	.78	2.65	1.7168	.05530	.40634
Eccentric Hamstring Torque at 180 in Left Leg/weight	54	.75	2.56	1.5185	.04752	.34917
Eccentric Hamstring Torque at 180 in Right Leg/weight	54	.92	2.27	1.6771	.04078	.29964
Eccentric Quadriceps Torque at 30 in Left Leg/weight	54	1.52	4.38	2.8524	.09753	.71669
Eccentric Quadriceps Torque at 30 in Right Leg/weight	54	1.37	5.45	3.0284	.11709	.86043
Eccentric Quadriceps Torque at 180 in Left Leg/weight	54	1.03	4.09	2.6772	.08331	.61217
Eccentric Quadriceps Torque at 180 in Right Leg/weight	54	1.52	4.10	2.6670	.08044	.59114
	N	Minimum	Maximum	Mean		Std. Deviation
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic
Maximum Isometric Hamstring Torque at 25 of The Knee Flexion in Left Leg/weight	54	.65	2.55	1.3756	.04832	.35505
Maximum Isometric Hamstring Torque at 25 of The Knee Flexion in Right Leg/weight	54	.74	2.54	1.4705	.05214	.38312
Maximum Isometric Quadriceps Torque at 25 of The Knee Flexion in Left Leg/weight	54	.54	1.74	1.1492	.03734	.27437
Maximum Isometric Quadriceps Torque at 25 of The Knee Flexion in Right Leg/weight	54	.58	1.55	1.1268	.02884	.21196
Maximum Isometric Hamstring Torque at 70 of The Knee Flexion in Left Leg/weight	54	.53	1.89	1.1851	.03223	.23681
Maximum Isometric Hamstring Torque at 70 of The Knee Flexion in Right Leg/weight	54	.76	2.06	1.2850	.03753	.27581
Maximum Isometric Quadriceps Torque at 70 of The Knee Flexion in Left Leg/weight	54	1.25	4.01	2.6018	.09397	.69051

Maximum Isometric Quadriceps Torque at 70 of The Knee Flexion in Right Leg/weight	54	1.47	3.82	2.5821	.07900	.58056
Concentric Hamstring Torque at 300 in Left Leg/weight	48	.53	3.24	1.5698	.07626	.52836
Concentric Hamstring Torque at 300 in Right Leg/weight	48	.85	2.17	1.4865	.04091	.28341
Concentric Quadriceps Torque at 300 in Left Leg/Weight	48	1.01	3.32	2.0817	.07577	.52494
Concentric Quadriceps Torque at 300 in Right Leg/Weight	48	1.08	3.05	2.0515	.06870	.47594
Valid N (list wise)	47					

Table 3-23 Descriptive Statistics the Isokinetic Corrected Values for Weight

3.20.7 Results of the angles of maximum contraction of concentric and eccentric contraction of the hamstring and quadriceps muscle

Table3.25 shows the descriptive analysis of the angles of the maximum contraction of concentric and eccentric contractions of the hamstring (table 5-42) and quadriceps (table 5-43). The range of mean for the angles related to the hamstring muscle is 29.06-48.89 with the average of 37.35 and that of quadriceps is 64.78-81.79 with the average of 73.20. It shows that the angle of peak torque for the quadriceps muscle is in close to the middle range of the knee flexion, but that of the hamstring is closer to the outer range of the knee joint.

Angle of Maximum Torque of Hamstring	Minimum	Maximum	Mean		Std. Deviation
	Statistic	Statistic	Statistic	Std. Error	Statistic
Concentric Contraction at 30 (Left)	10.00	90.00	29.0600	2.38454	14.86127
Concentric Contraction at 30 (Right)	10.00	66.00	32.3077	1.80529	13.01814
Concentric Contraction at 180 (Left)	10.00	83.00	37.1800	3.33671	23.59409

Concentric Contraction at 180 (Right)	10.00	84.00	40.2308	3.35468	24.19092
Eccentric Contraction at 30 (Left)	11.00	64.00	39.4000	1.84568	13.05092
Eccentric Contraction at 30 (Right)	11.00	82.00	36.7885	1.87774	13.54055
Eccentric Contraction at 180 (Left)	11.00	67.00	37.4400	1.83818	12.99790
Eccentric Contraction at 180 (Right)	11.00	60.00	33.5385	1.76536	12.73017
Concentric Contraction at 300 (Left)	10.00	84.00	40.6875	4.58955	31.79733
Concentric Hamstring at 300 (Right)	10.00	83.00	48.89	4.56	31.60

Table 3.24 Descriptive Statistics of the isokinetic testing affecting on the angle of maximum torque of the hamstrings

Angle of Maximum Torque of Quadriceps	Minimum	Maximum	Mean		Std. Deviation
	Statistic	Statistic	Statistic	Std. Error	Statistic
Concentric Contraction at 30 (Left)	45.00	89.00	74.4800	1.19223	8.43036
Concentric Contraction at 180 (Left)	51.00	90.00	76.2115	1.72776	12.45909
Concentric Contraction at 30 (Right)	13.00	90.00	73.9804	1.97861	14.13010
Concentric Contraction at 180 (Right)	54.00	90.00	78.7885	1.77492	12.79911
Eccentric Contraction at 30 (Left)	15.00	88.00	64.7800	2.07045	14.64030
Eccentric Contraction at 30 (Right)	21.00	88.00	69.0769	1.73093	12.48190
Eccentric Contraction at 180 (Left)	41.00	97.00	65.5000	1.81294	12.81939
Eccentric Contraction at 180 (Right)	31.00	90.00	67.1731	1.64489	11.86149
Concentric Contraction at 300 (Left)	21.00	90.00	80.2500	3.19137	22.11046
Concentric Contraction at 300 (Right)	23.00	94.00	81.7917	2.71520	18.81145
Valid N (list wise)					

Table 3.25 Descriptive Statistics of the isokinetic testing affecting on the angle of maximum torque of the quadriceps

3.20.8 Effects of velocity of the angle of maximum torque of the quadriceps and hamstring muscles

To find out if the velocity of the isokinetic testing affected the angle of maximum torque of the quadriceps and the hamstrings, a paired sample T test was performed between two different speeds (30º/s and 180º/s). Interestingly the difference between "the angle of maximum torque of the hamstring concentric contraction" at two speeds of 30º/s and 180º/s was significant in both left knee (P=0.006) and right knee

(P_e=0.028). The mean difference (MD) of the angles of maximum torque of the hamstring concentric contraction was 9.92 with 95% confidence interval of the difference (CID) of 2.94-16.90 for the right knee and 7.92 (CID:0.90-14.94). It means that the angle was on average 9.92 and 7.92 degrees more in the higher velocity in the right and the left knee respectively. These angles were not significantly different in the concentric contraction of the quadriceps between speeds of 30º and 180º/s in the left knee, however those of the right knee were significantly different (P=0.036, MD= 4.6, CID: 0.32-8.86).

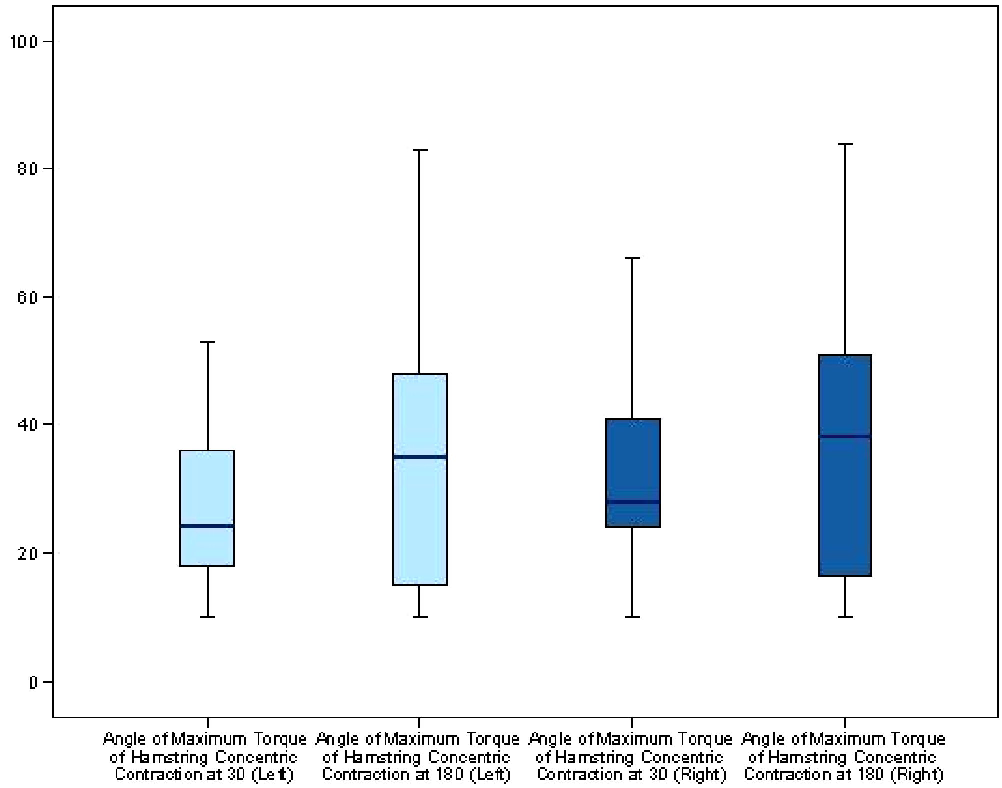

Figure 3-21 Comparison of The Maximum Torque of Hamstring Concentric Contraction between two velocities of 30º and 180º

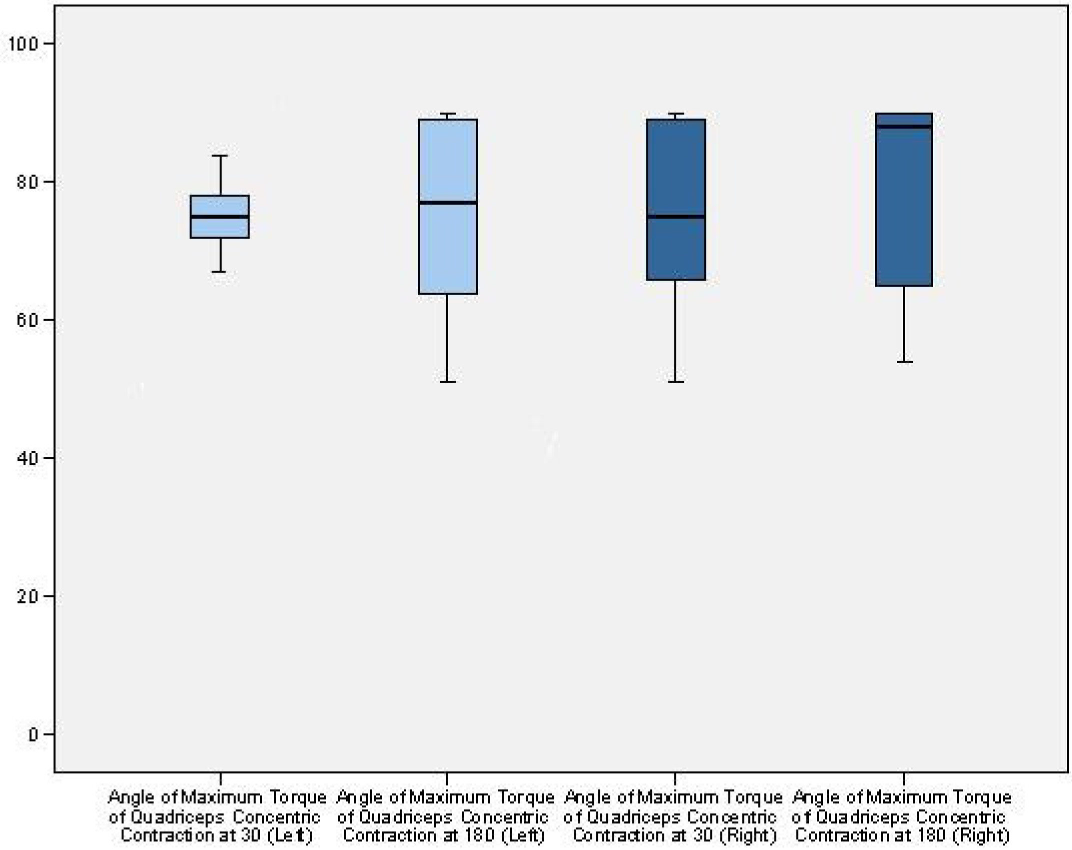

Figure 3-22 Comparison of The Maximum Torque of Quadriceps Concentric Contraction between two velocities of 30º and 180º

Tests of normality of eccentric concentric ratio (Kolmogorov-Smirnov and Shapiro-Wilk) for the hamstrings in both velocities and both knees were not significant so the distribution of these data were not significantly different from a normal distribution.

3.20.9 *Results of isokinetic variables in the three subject groups*

One-way ANOVA test was carried out to compare the means of all variables among the three groups EFP, REP and NFP. The one-way AVOVA post hoc table was also provided that listed the pair wise multiple comparisons of the group means for all selected post hoc procedures.

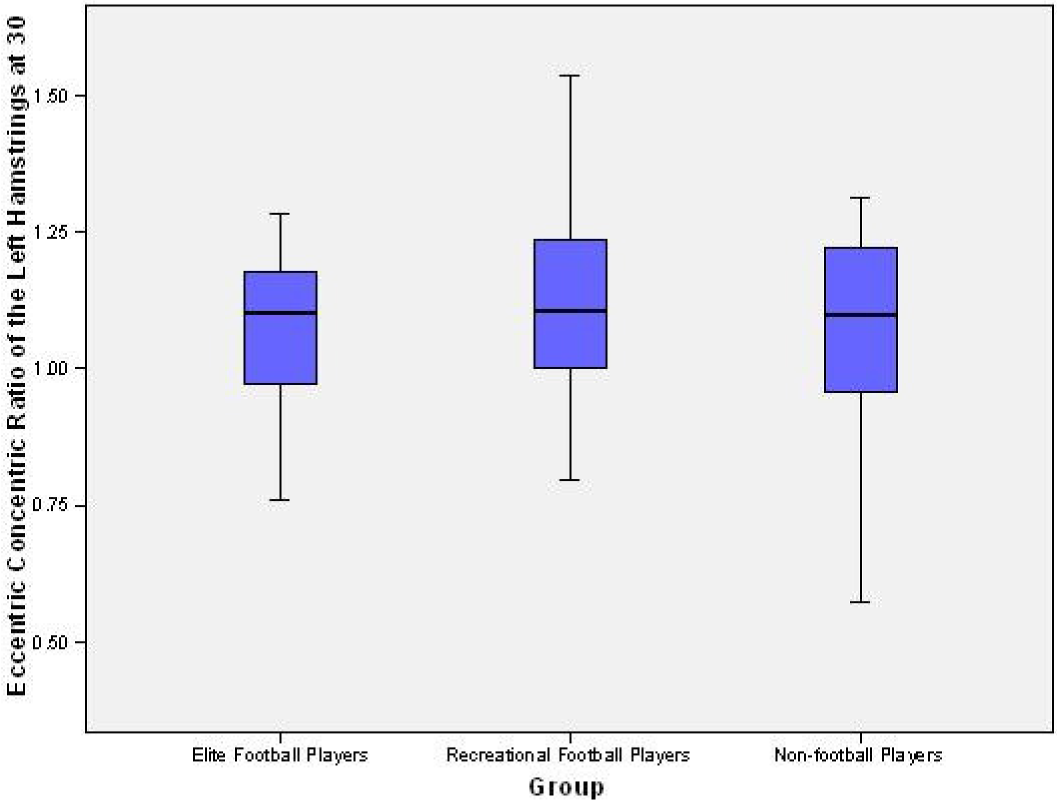

Figure 3-23 Comparison of Eccentric Ratio of the Left Hamstrings at 30 ° among three Groups

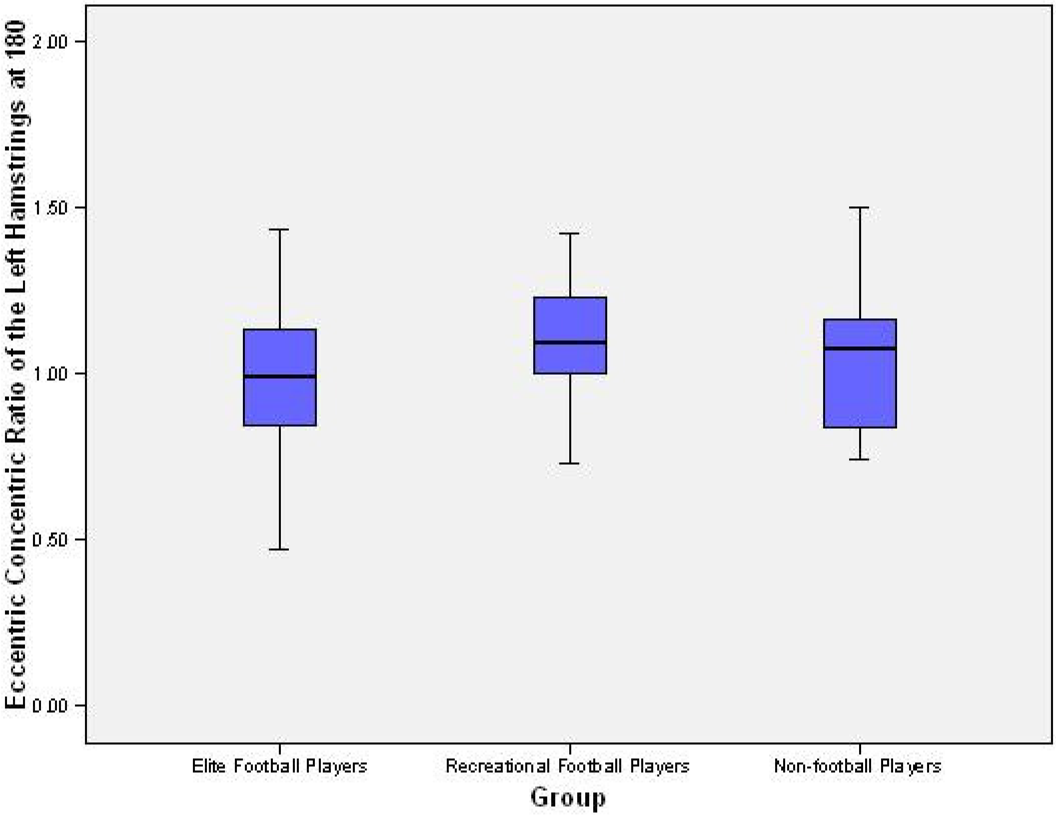

Figure 3-24 Comparison of Eccentric Ratio of the Left Hamstrings at 180 º among three Groups

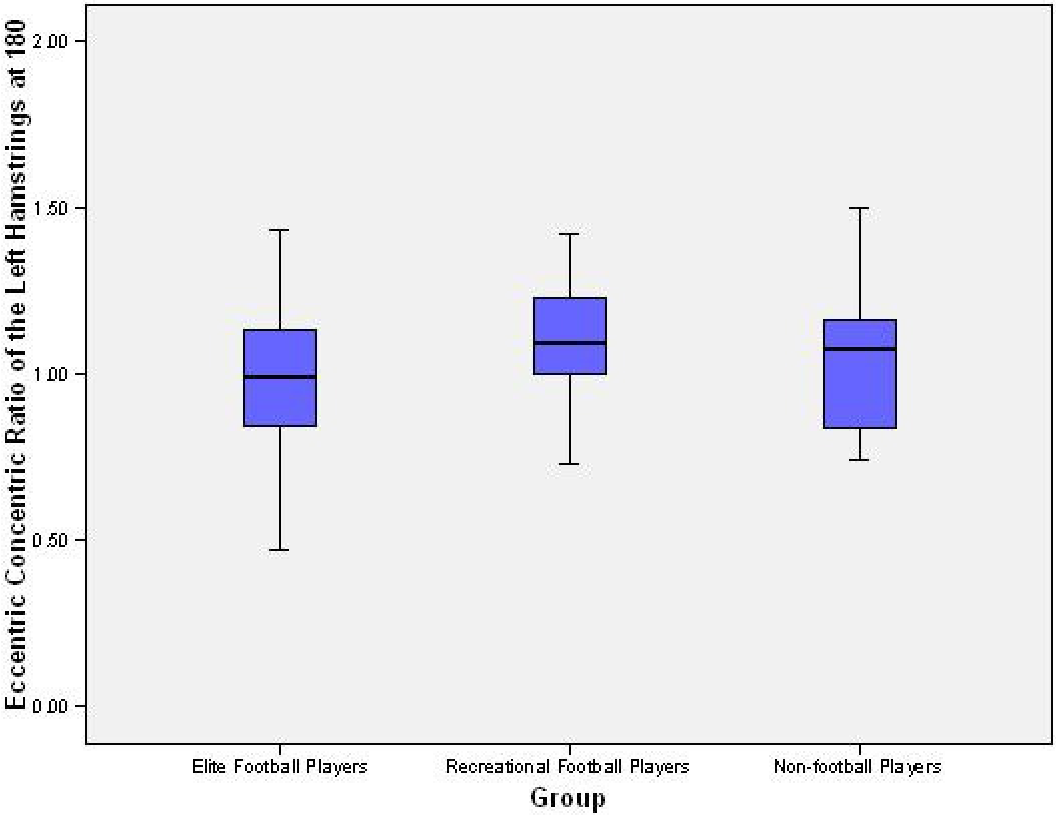

Figure 3-25 Comparison of Eccentric Ratio of the Right Quadriceps at 30 º among three Groups

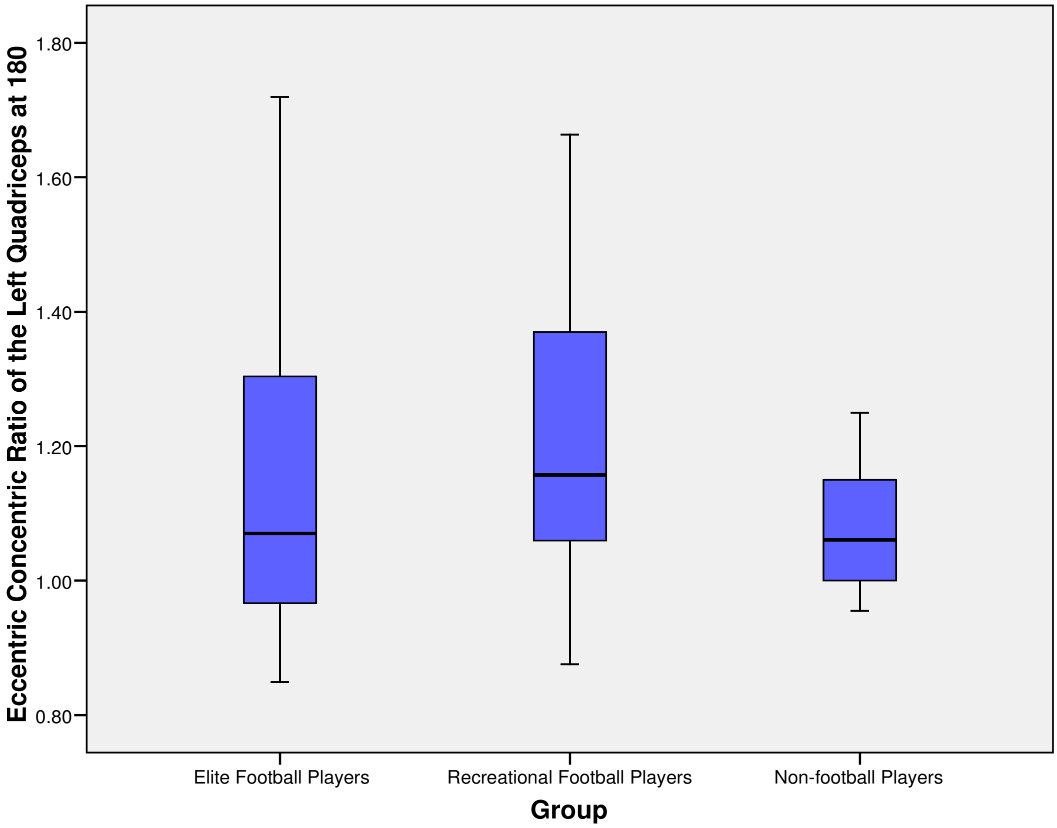

Figure 3-26 Comparison of Eccentric Ratio of the Left Quadriceps at 180 ° among three Groups

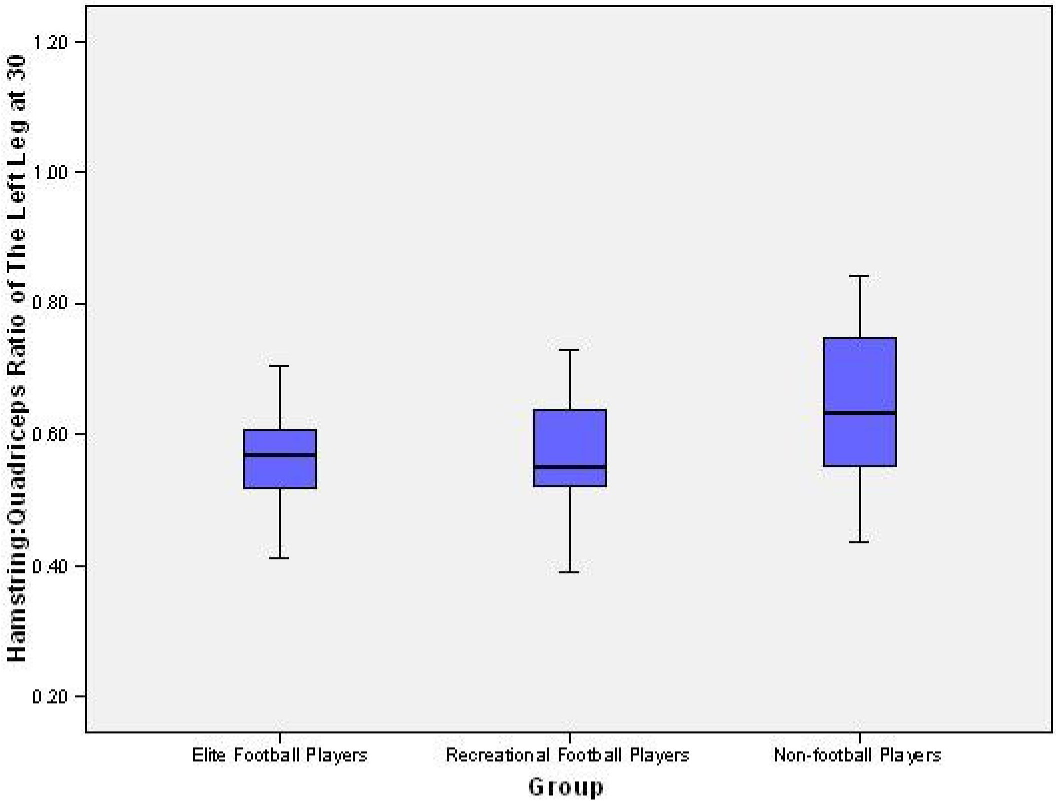

Figure 3-27 Comparison of Hamstrings: Quadriceps Ratio of the Left leg at 30 ° among three Groups

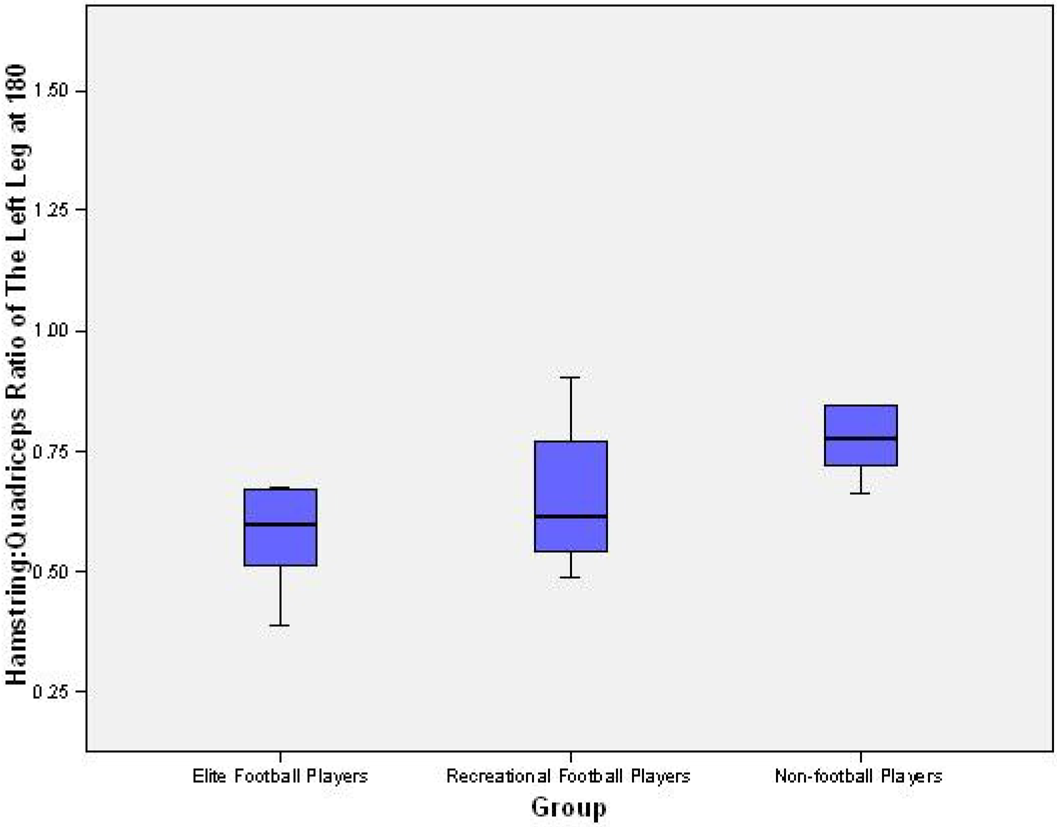

Figure 3-28 Comparison of Hamstrings: Quadriceps Ratio of the Left leg at 180 °
among three Groups

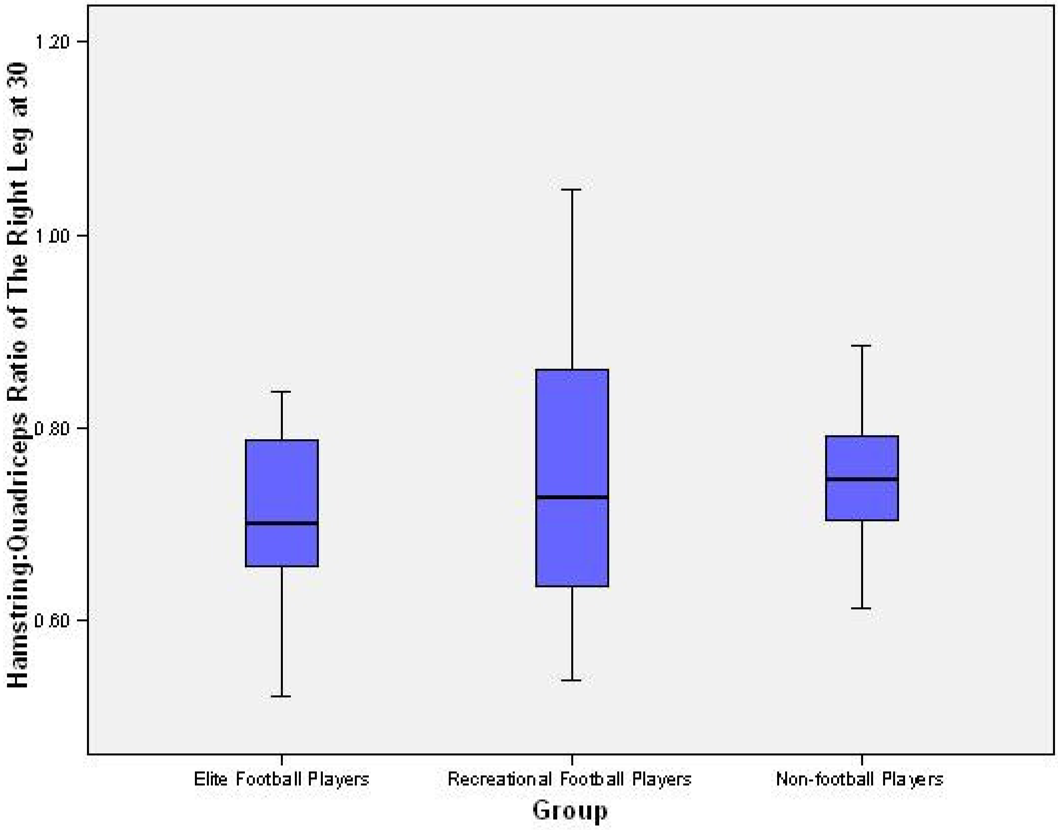

Figure 3-29 Comparison of Hamstrings: Quadriceps Ratio of the Right leg at 30 °
among three Groups

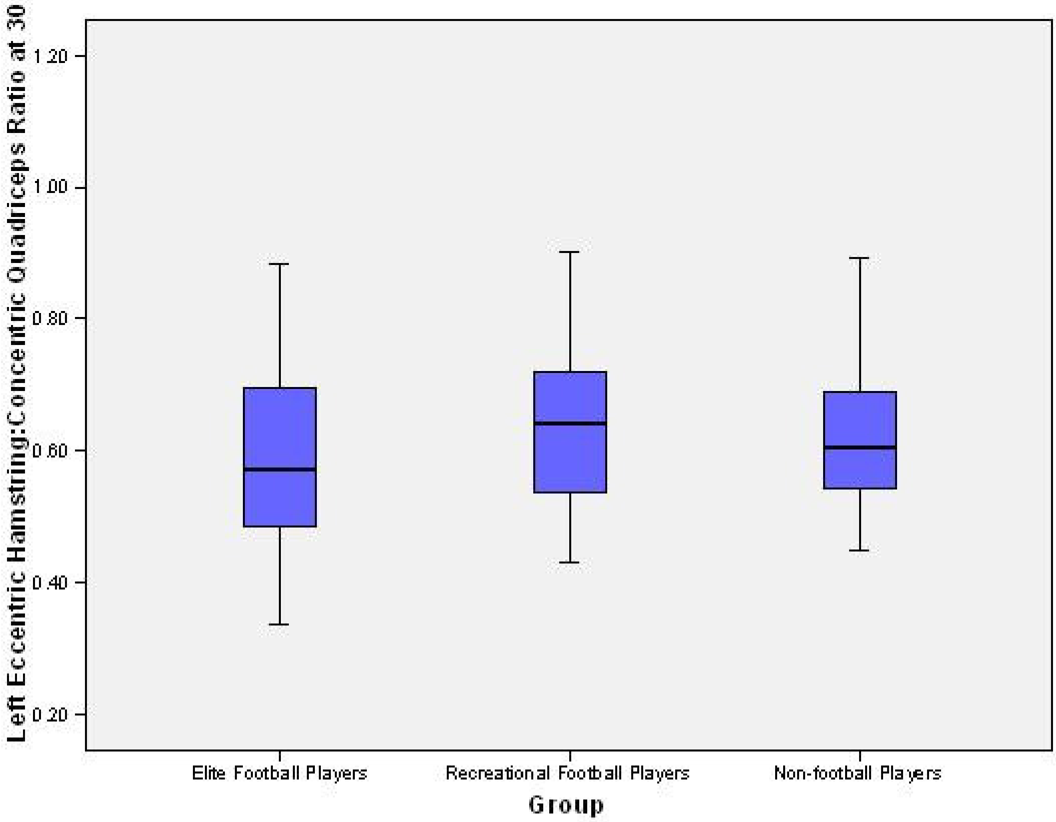

Figure 3-30 Comparison of Left Eccentric Hamstrings: Concentric Quadriceps Ratio at 30 ° among three Groups

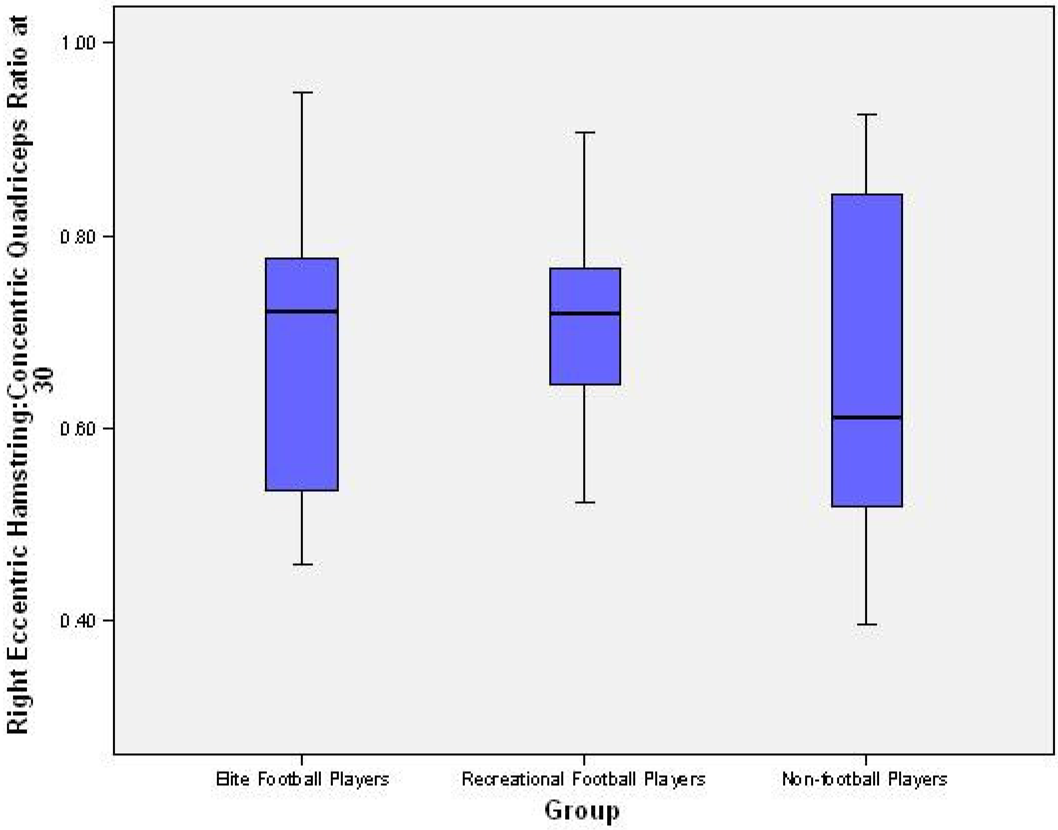

Figure 3-31 Comparison of Right Eccentric Hamstrings: Concentric Quadriceps Ratio at 30 ° among three Groups

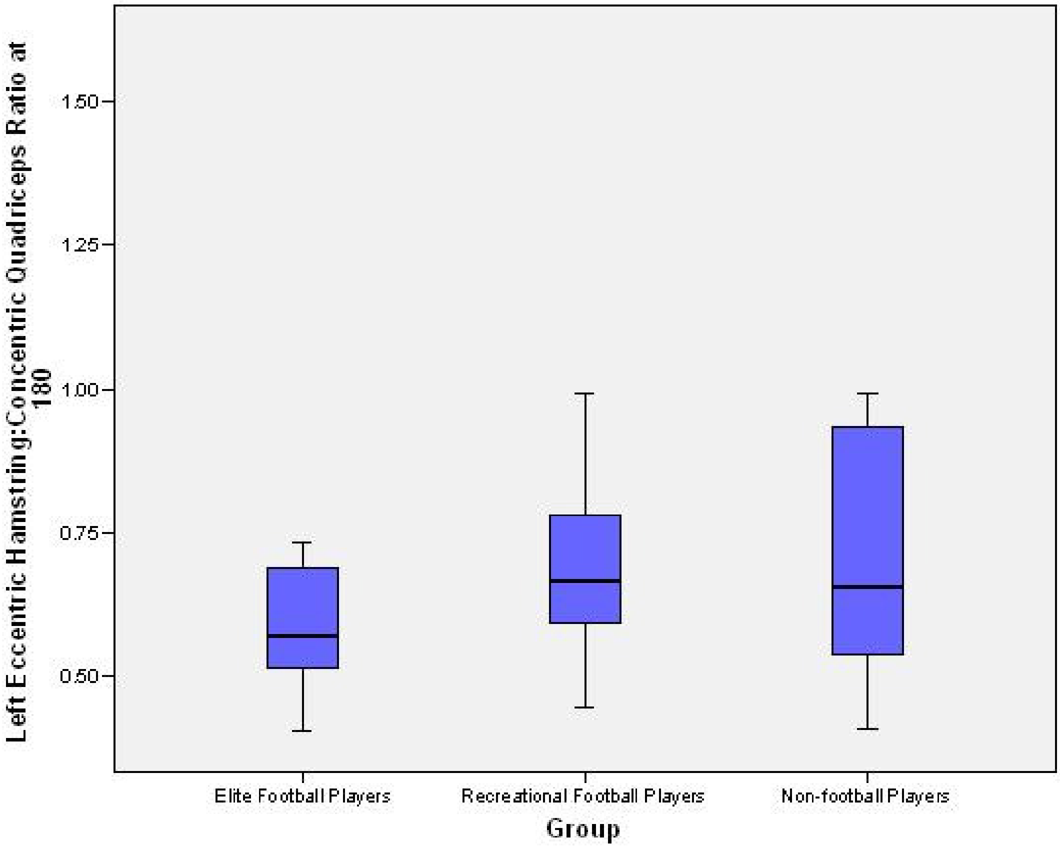

Figure3-32 Comparison of Left Eccentric Hamstrings: Concentric Quadriceps Ratio at 180 ° among three Groups

All of the variables related to the concentric and eccentric isokinetic contractions of the hamstring and quadriceps muscles were corrected for the weight of the subjects and then were compared using one-way ANOVA. The mean of the isokinetic concentric right hamstring peak torque at the speed of 30º/s (ICRHPT30) of the NFP group differed significantly from that of the EFP group (*P*=0.006). The pair wise comparison after post hoc test indicated that the mean difference of 0.339 NM/Kg (CI: 0.084-0.593) existed between the ICHPTR30 of the EFP group and that of the NFP (EFP ICHPTR30 > NFP ICHPTR30). The mean of the isokinetic concentric right hamstring PT at 180º/s (ICRHPT180) in the EFP group was on average 0.323 NM/Kg higher than that of the NFP group. This mean difference was significant with the (*P*=0.001, MD=0.323, CI: 0.123-0.519). There were in total 11 variables of isokinetic values that were indicated to be the subject of significant difference in Tukey-base pair wise multiple comparisons of means of two groups of EFP and NFP.

The next variable with a significant difference between elite group and non-footballers was the isokinetic concentric left quadriceps PT at speed of 30º/s (ICLQPT30). The mean difference that proved the EFP group was on average stronger at the ICLQPT30 was 0.495 NM/Kg with 95% confidence intervals of 0.131-0.859 (*P*=0.005). The EFP group on average was also stronger ICLQPT180 (isokinetic concentric left quadriceps PT at 180º/s) compared to the NFP (*P*=0.006, MD=0.608, CI: 0.155-1.062). There was evidence that the EFP group had on average stronger isokinetic concentric left quadriceps PT at 300º/s (ICLQPT300) compared to the NFP group (*P*=0.02) and the 95% the confidence intervals did not contain zero with the lower bound of 0.073 NM/Kg and the upper bound of 1.52 NM/Kg (MD=0.546). Isokinetic concentric right quadriceps PT at 180º/s (ICRQPT180) was also greatly different between two groups ($_e$=0.42, MD=0.395, CI 0.011-0.778).

The next five statistical analyses (3 eccentric tests and 2 isometric tests) also showed a significant difference between the results of the EFP group and that of the NFP group with the superiority of the elite group. The first three are related to the eccentric quadriceps isokinetic tests of the right and the left knees at the speed of 30º/s, as well as the same test of the left knee at the speed of 180º/s. These three eccentric tests indicated very low *P*-value and high magnitude of the mean difference compared to that of other variables. The one-way ANOVA post hoc analysis of the eccentric PK for the left quadriceps at 30º/s (IELQPT30) showed the mean difference of 0.605 NM/Kg (CI:0.011-1.198) between two groups (*P*=0.045). The same eccentric isokinetic test on the contralateral knee (right) was also significantly different between the two groups (*P*=0.018, MD=0.820, CI: 0.119-1.521). The last eccentric test was the isokinetic eccentric left quadriceps at the speed of 180º/s which was shown to be significantly different between the EFP and the NFP (*P*=0.0001 MD=0.822, CI: 0.362-1.281).

Among the eight isometric tests, two of them were significantly different. Both of them showed the EFP group showed higher values for the isometric tests of the hamstring muscle at 25 degree of knee flexion compared to that the NFP group. The mean difference for the maximum isometric left hamstring torque at 25 (MILHT25) was 0.358 NM/Kg (P=0.11, CI: 0.072-0.645) and the mean difference for the maximum isometric right hamstring torque at 25 (MIRHT25) was 0.362 (*P*=019, CI: 0.051-0.722).

The statistical analysis also indicated that the EFP group produced higher isokinetic values in three variables compared to that of the RFP group. The first variable was the isokinetic concentric left quadriceps peak torque at the speed of 30º/s (ICLQPT30) (*P*=0.005) with a mean difference of 0.328 NM/KG (CI: 0.008-0.647). The second significant difference that was calculated was between the isokinetic concentric left quadriceps peak torque at the speed of 180º/s, (ICLQPT180) of the EFP and RFP groups (*P*=0.046, MD=0.403, CI: 0.005-0.801). And finally the third variable that was significantly different between the EFP and RFP groups in pair wise comparison was the isokinetic concentric right quadriceps peak torque at the speed of 180º/s (ICRQPT180). The mean difference was 0.341 NM/Kg with the 95% confidence interval of difference of 0.005-0.677 (*P*=0.046). The measured value for the ICRHPT180 of the RFP was on average higher than that of the NFP significantly, as well. (*P*=0.011, MD=0.242, CI: 0.048-0.436)

When the EccH:ConQ ratios (Eccentric hamstring peak torque: Concentric quadriceps peak torque ratio) was investigated, the RFP group showed higher values in two variables related to this ratio compared to the EFP group. EccH:ConQ ratio of the left knee of the EFP group at the speed of 180º differed significantly from that of the RFP (*P*=0.044, MD=0.14, CID: 0.0029-0.2740). However the *P*-value was very close to the border line of 0.05 using the Bonferroni procedure. When the Tukey procedure was used the calculated *P*-value was 0.051 and the difference was not significant, however a trend was detected.

The EccH:ConQ ratio of the right knee at the speed of 180º/s for the RFP was on average slightly higher than that of the EFP group (*P*=0.048) when the Tukey procedure was used. The level of significance was and the Bonferroni procedure indicated a *P*-value of higher than 0.05 for the same variables (*P*=0.56).

Comparing the means of variables related to H/Q ratio (Hamstring maximum contraction/ Hamstring maximum contraction ratio) among the three groups indicated no significant differences, apart from one variable. The RFP group had a higher value of the H/Q ratio in the right knee at the speed of 180º/s, which was statistically significant (*P*=0.017, MD= 0.108, CID: 0.015-2.01). The mean of other five H/Q ratios were not different when the three groups were compared. These other five were H/Q ratios of the left knee in three speeds of 30º/s, 180º/s and 300º/s, and that of the right knee in two speeds of 30º/s and 300º/s.

From the results of eight variables related to Ecc/Con ratios only one of them, the Ecc/Con ratio of the right knee at a speed of 30º/s, was found to be different among the three groups. The trend indicated the NFP had on average a higher ratio compared to the EFP (MD=0.23, CI:0.77-0.371). The result from one-way ANOVA post hoc indicated also a significant difference between the NFP and RFP (*P*=0.02). The measured Ecc/Con values for the right hamstring of the NFP group was about 0.155 higher than that of the RFD group with 95% confident interval of difference between 0.008 and 0.30.

Measured values relating to the bipedal standing balance, the right and the left standing balance and the limits of stability were not significantly different when tested using one-way ANOVA post hoc procedure

3.20.10 Leg dominance

From the subjects of the third study 58.4% were right leg dominant, 18.6% were left leg dominant and 23.1% could use both legs as the kicking foot.

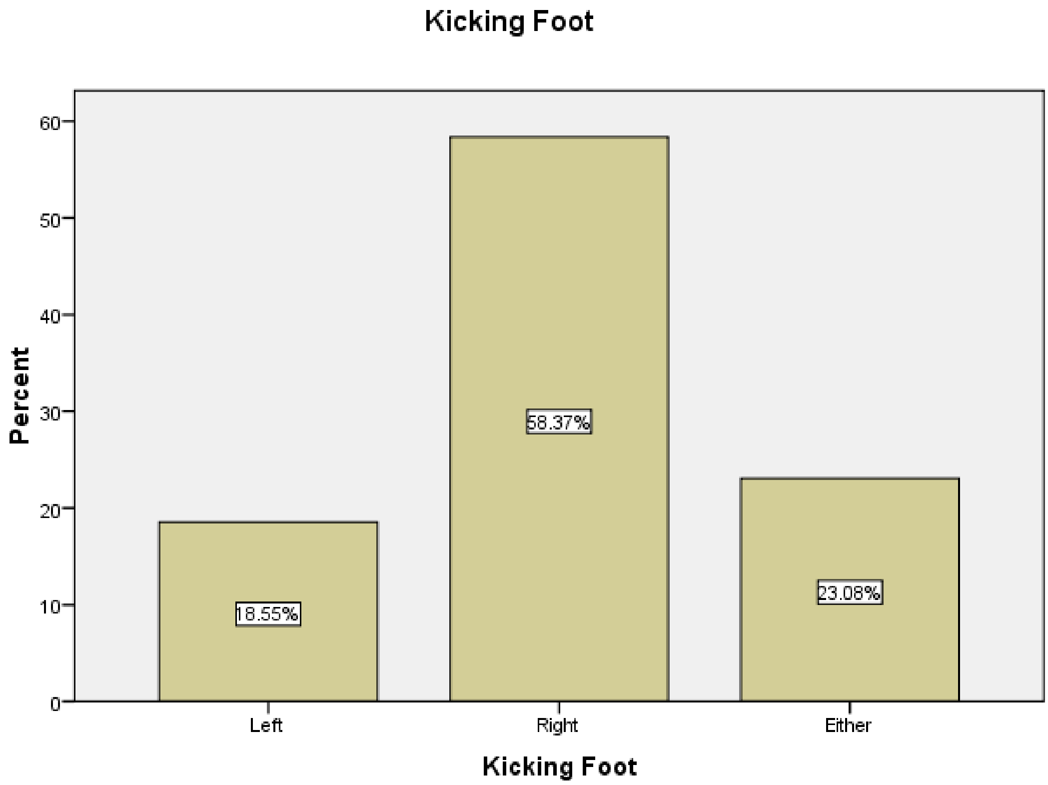

Figure 3-33 The percentage of the leg dominance

Different variables regarding balance and isokinetic assessments were compared pair wise, using pair t-test. Unipedal overall stability index was not significantly different in right and left legs. From twelve isokinetic tests five variables were significantly different when they were compared in the two sides. They were the concentric hamstring torque at 180 (*P*=.021), concentric quadriceps torque at 180 (*P*=.012), eccentric hamstring torque at 30 (*P*=.007), eccentric hamstring torque at 180 (P=.004) and eccentric quadriceps torque at 30 (*P*=.015). Two of them (concentric hamstring and quadriceps torque at 180) had higher values in the left leg. The rest of the variables, which were three eccentric isokinetic tests (eccentric hamstring torque at 30 and 180, and eccentric quadriceps torque at 30°/sec) had on average higher values in the right leg.

3.21 Discussion: the Comparative Study of strength and balance in Scottish Youth Football

According to the findings of this study, which is in line with the existing evidence[176], the angle of the peak torque for the hamstring muscle was in the outer range of the knee range and close to the full extension of the knee joint (M=37.35 degree). This angle was closer to the midrange for the peak torque of the quadriceps muscle (M=73.20). There was also evidence that showed the angle of peak torque was higher at faster speeds. This was the case in some isokinetic variables of this study, such as the concentric contraction of the hamstring muscle at two speeds of 30º/s and 180º/s in both legs and the concentric contraction of the quadriceps between speeds of 30º and 180º/s in the right leg.

All values of the ecc/con ratio were more than 1 ranging between 1.03 and 1.91 for the hamstring muscles and between 1.11 and 1.22 for the quadriceps muscle. These results were in line with the results of Griffin's study [127]. In this study the results of isokinetic strength tests for quadriceps and hamstring muscle showed the eccentric values were significantly more than the concentric values in both muscles[127] .So this ratio should be more than one. Shirakura et al reported values for quadriceps E/C ratio of normal and PCL injured knee were 1.30 and 1.29 respectively. In another research on normal subject the ratio was measured in normal subject 1.25–1.30 in the quadriceps and 1.25–1.35 in the hamstrings. The E/C ratio in this study was significantly different in the hamstring muscle of the PCL injured (1.09) knee and non-injured knee. This study showed an E/C ratio of 1.29 in the hamstrings on the non-injured extremity (1.29).

The ham/quad ratio that was measured between 59% and 60% in the velocity of 30º/s, between 65% and 69% % in the velocity of 180º/s and between 74% and 78% in the velocity of 300º/s. The ecc.ham./con.quad ratios ranged from 63% to 69% for the velocity of 30º/s and from 67% to 77% for the velocity of 180º/s. The trend was apparent in both ratios at various velocities with higher ratios obtained with higher velocities.

The reported normal values for E/C ratio ranges are between 0.95 and 2.05 in knee and shoulder. This ratio was less than 0.85 in low velocity test in patients with patellofemoral pain, it was suggested that this lower value compared to the normal range might have been due to the deficiency of neuromotor control of quadriceps muscle or an inhibitory effect on eccentric contraction of quadriceps muscle as a result of pain[138]. However there is evidence in literature that in subjects with no symptom the calculated ratio was less than 0.85. Interpretation of isokinetic test findings for ankle dysfunction has often been based on the principles of bilateral comparisons or comparison of dysfunctional with control groups.

The ratio between concentric torque and eccentric torque depends on the test velocity. Concentric strength tends to decline with increasing speed, unlike eccentric strength, which seems to increase or not change at all. An important factor that should be considered is the sequence of eccentric and concentric tests. The results of measured peak torque were about 10% lower when eccentric tests followed concentric tests compared to those produced using the eccentric-concentric sequence. This is possibly due to stretch-shortening facilitation by the eccentric-concentric sequence, which does not exist in a concentric-eccentric sequence. Eccentric testing also can put more impact on the joint. That is why the eccentric torque reduces significantly in painful conditions[177].

As it was noted in the literature the normal values for the ratio of maximum hamstring torque/maximum quadriceps torque were reported around 60%. An H/Q ratio of less than 0.60 has been associated with ACL injury. The values gained for eccentric H/Q ratios were significantly different between injured and non-injured side[138].

The reason was speculated as the neuromotor control of the quadriceps muscle. It was also suggested that the selective inhibition of eccentric contraction of the quadriceps as a result of pain might be the reason. The eccentric/concentric ratio of muscles around the ankle joint was also significantly lower in cases with chronic ankle instability compared to that of a normal group[145 146 176 147].

The reason of reduction in eccentric torque of the quadriceps in injured and even some non-injured knee could be its role as decelerator in bipedal activities. The eccentric strength of the quadriceps muscle is decreased after injury. This weakness was observed in injured subjects in activities, such as jumping, cutting and stair descent.

The professional group had significantly higher values of several isokinetic tests' values when compared to the non-football players group. These values were the concentric right hamstring peak torque (PT) at 30º/s and 180º/s, the concentric left quadriceps PT at 30º/s, 180º/s and 300º/s, the concentric right quadriceps PT at 180º/s, the eccentric quadriceps isokinetic tests of the right and the left knee at 30º/s, as well as the same test of the left knee at the speed of 180º/s. The same eccentric isokinetic test on the contralateral knee (right) and the eccentric test of the left quadriceps at the speed of 180º/s were also significantly different between two groups. Finally the isometric tests of the hamstring muscle at 25 degree of the knee flexion in both knees had on average higher values in EFP group compared to that of the NFP.

EFP group produced higher isokinetic values in three variables compared to that the RFP, including the isokinetic concentric left quadriceps peak torque at 30º/s isokinetic concentric quadriceps peak torque at of 180º/s in both sides.

Comparing the ecc.ham/con.quad. ratios and EccH:ConQ ratio of the right knee at the speed of 180º/s showed, the RFP group showed on average higher marginal values in two variables related to this ratio compared to the EFP group.

Interestingly the trend indicated the NFP had on average a higher ratio compared to the EFP and also Ecc/Con values for the right hamstring of the NFP group was higher than that of the RFD group.

It was anticipated that the EFP would have had higher scores than the other two groups, as they were involved in soccer training 5 days per week. While it was found that the elite sample had the highest quadriceps peak torque of the three groups on average, however the NFP group had better ratios.

There is a lack of an established equivalency in the literature between the strength assessment modes of the Technogym REV 9000 and other isokinetic testing devices, but in comparison with the literature the subjects tested in the present study are generally poor. Table 3-34 compares the results of the present study with football players on a Cybex machine and one with Australian Rules football players (one of the football codes) on a Kin-com. In all cases the peak torques have been standardised using body mass to allow as fair as a comparison across ages as is possible with different isokinetic equipment. Generally the subjects in the present study have lower values than the other studies cited in Table 3-10 but meaningful comparison may be complicated by differences in age .

Comparison of the results of the present study with football players on a Cybex machine and one with Australian Rules football.

	E	RS	NS	Bennell *et al* (1998) [1,2]	Kellis *et al* (2001) [3,4]	Kellis *et al* (2001)[5]
Quad Ecc L 180 (N.m/kgBW)	2.91±0.56	2.63±0.48	2.51±0.71	3.9±0.8	3.35±0.46	2.66±0.34
Quad Ecc R 180 (N.m/kgBW)	2.71±0.57	2.81±0.74	2.64±0.52	4.0±0.7	3.29±0.40	2.79±0.32
Ham Ecc L 180 (N.m/kgBW)	1.49±0.27	1.53±0.35	1.58±0.29	2.1±0.3	2.17±0.37	1.81±0.19
Ham Ecc R 180 (N.m/kgBW)	1.68±0.26	1.63±0.30	1.43±0.30	2.2±0.4	2.19±0.31	1.89±0.25
Quad Con L 180 (N.m/kgBW)	2.28±0.45	2.06±0.47	1.96±0.51	2.6±0.4	2.06±0.18	1.69±0.23
Quad Con R 180 (N.m/kgBW)	2.27±0.37	2.16±0.50	1.96±0.46	2.4±0.3	2.07±0.18	1.75±0.21
Ham Con L 180 (N.m/kgBW)	1.57±0.44	1.42±0.31	1.51±0.53	2.6±0.4	1.30±0.19	1.08±0.22
Ham Con R 180 (N.m/kgBW)	1.47±0.20	1.42±0.22	1.28±0.19	2.4±0.3	1.39±0.21	1.16±0.28

[1] Data for Australian Rules footballers (n=102, 22.8±3.6 yrs)
[2] In this case L = injured leg. R = non-injured leg
[3] Data given for n=18, 16.4±0.2 yrs, soccer players of Greek talent programme
[4] In this case L = non-preferred leg and R = preferred leg
[5] Subjects n=18, 13.4±0.2 yrs

Table 3-26 Isokinetic strength of selected populations of youth footballers

4.1 Introduction: Strength and proprioception following ACL reconstruction

The rate of sports injuries is significantly higher in the lower extremities, compared to the other parts of the body. The knee and ankle are the most commonly injured areas in sportspeople and in particular football. The knee is a complex joint which is stabilised by four main ligaments: two collateral ligaments (medial and lateral), and two cruciate ligaments (anterior and posterior). Injuries of the anterior cruciate ligament (ACL) and medial collateral ligament (MCL) are very common, due to the structure and the contour of the joint and are associated with the valgus movement or twisting [148].Over 250,000 athletes are diagnosed with ACL injury in each year and it is one of the most commonly injured ligaments in the knee [149]. The assessment of ACL deficient knees remain a major challenge in clinical sports medicine and in the rehabilitation of patients.

The treatment of sports-related ligament injuries is complicated and requires management of both the biomechanical and the sensorimotor changes. The biomechanical changes, such as instability after a ligament rupture, are well understood and are treated using physical training and ligament reconstruction, physical training and rehabilitation. The sensorimotor changes are much more difficult to understand, and treatment is a matter of debate. ACL injuries and lateral ankle sprains are common among ligament injuries and they may cause serious functional instability[150]. In the field of proprioception and balance, the major focus has been on the injuries of the knee and the ankle joints.

ACL injury causes the longest period of absence in football. The main way to prevent or manage an ACL injury is to increase knee stability.

4. 2 The Aim of the study of strength and proprioception in ACL reconstruction

This study was designed to examine potential impairment of the lower extremity, in particular the knee joint, after ACL reconstruction. It was hypothesised that the Biodex Stability System and isokinetic assessment of the stabilising muscles of the knee could differentiate the injured side of subjects with ACL injury from the opposite non-injured knee and help to develop a personalised menu based programme to aid rehabilitation.

4. 3 Background: ACL Injury

The main ligaments that support the knee joint as primary stabilisers are the anterior cruciate ligament (ACL), the posterior cruciate ligament (PCL), the medial collateral ligament (MCL), and the lateral collateral ligament (LCL). One of the most commonly injured ligaments is the ACL, which lies deep within the knee joint, connecting the femur with the tibia to prevent excessive forward tibial displacement relative to the femur. It provides rotational stability to the knee by preventing excessive twisting movements.

4.4 Epidemiology of ACL injury

Severe ACL sprain is a very important injury, which has serious consequences for the injured athlete. An ACL injury may cause long time absence from the sport or the injured athlete might not return to the same level in the sport than prior to the injury and in the worst-case scenario, the injury can end the athletes' career[151 152 153] .

Approximately 70% of anterior cruciate ligament injuries occur during some form of sports activity[154]. In the USA the rate of ACL injury is estimated at over 100 000 injuries per year. Complete ACL rupture may induce chronic knee instability, meniscal and chondral surface damage, and osteoarthritis in two thirds of subjects.

More than 100,000 knee arthroscopies and 50,000 knee replacements were carried out in Britain during 2005. Among skiers, knee injuries account for 25 per cent of all accidents on the slopes, with 1 skier in 2,000 sustaining ACL injury during one season. They are also common in those who play tennis, squash, netball and football. Health-mapping information reveals that areas of the country dominated by young families and recent graduates have high hospital admission rates for these types of recreational injuries[155].

Epidemiological studies have revealed that one of the most common injury mechanisms leading to knee injuries is landing from a jump[178]. In a study of 100 ACL injuries in 89, 72% were non-contact and 28% were contact injuries, which occurred during foot strike to the ground with the knee almost at full extension causing valgus collapse of the knee[156].

Male football has been reported as a sport with high rate of ACL injury (0.13/1000 exposures)[153]. The incidence is even more in female football players (0.31/1000 exposures)[153 157]. A study into the differences between ACL injuries in men and women in handball teams confirmed that women are more susceptible to the injury with a 5:1 risk ratio.

4.5 Mechanism of ACL injury

ACL injury is the commonest reason for knee operations. The cause of ACL injury is a compound mechanism. The main element is the stress of high speed pivotal movements in athletic activities[158].

Daily activities apply around 454 N of stress to the ligament, however an intact ACL can resist up to 1730N before it ruptures. The ACL is in a position of maximum stress when the knee is at full extension or at 90 degree flexion, due to normal stretch. Injuries most regularly occur when the knee suffers from valgus stress with lateral rotation in a foot planted position. The ACL provides 86% of the resistance to anterior displacement and 30% resistance to the medial displacement[159] Because of the amount of force required to damage the ACL, it is not uncommon for other structures within the knee such as the meniscus or medial ligament to also be damaged. An ACL injury may occur when the athlete suddenly decelerates and changes directions while running, pivoting, hitting the ground after a jump (heading the ball) or overextending the knee joint while kicking the ball with a hyper-extended knee. A blow to the side of the knee, which can occur during a football tackle, may also result in an ACL tear.

4.6 Literature review: balance and proprioception in knee injuries

A review of the literature on the prevention of knee injuries emphasised the value of neuromuscular training, including balance and proprioceptive exercises. In these articles neuromuscular control referred to the dynamic function activated by the unconscious organisation of the CNS, resulting from proprioceptive input, which helps in respect to the preparation, loading and joint motion to establish joint stability[99]. Intact neuromuscular responses are crucial in players, who practise high velocity sporting manoeuvres.

These proprioceptive signals are projected to the CNS for processing, which ultimately regulates reflexes and motor control[160]. Proprioception is the acquisition of stimuli by peripheral receptors, as well as the conversion of these mechanical stimuli to a neural signal that is transmitted along afferents pathways to the CNS for processing. Given this explanation, proprioception defines only the mechanism and process occurring in the afferent (sensory) pathway of the sensorimotor system. Further, this definition suggests that proprioception does not define any activity along the efferent (motor) pathway resulting in a motor response to the original sensorimotor system progresses Sherington's description of the proprioceptive system to include a more complex connection between sensory pathways and motor pathways than exclusively reflex. There is evidence that many parts of the nervous system are involved in this process, such as the spinal column, the basal ganglia and cerebellum. The reflexive components are also very complicated an integrated with visual, vestibular, and somatosensory elements.

Speculation on how sensory information from peripheral mechanoreceptors is transmitted to the CNS was originally based on a theory known as "labelled lines". The "labelled line" theory suggests that each type of mechanoreceptor has sensitivity to the single stimulus and transmits individual signals to the CNS for processing. However, Johansson in his experiments supported more complex patterns of afferent information transmitted by populations of mechanoreceptors, referred to as ensemble coding. This theory suggests that all of the afferents within the ensemble have the capacity to respond to the same stimulus. Research has established that a given ensemble contains afferents with varying ranges of sensitivity and different responses to the same stimulus. By using electrical stimulation of various joint nerves or physiological activation of joint receptors in animals, researchers have shown that joint afferents project to supraspinal centres through several ascending pathways, including the dorsal columns and the spinothalamic, spinoreticular, spinocervical, and spinocerebellar pathways [97].

Caraffa [161] and his co-workers investigated the application of balance training to examine if it could reduce the rate of knee injuries in different sports. Six hundred football players in 40 semi-professional or amateur teams were investigated to find if balance training could prevent the injuries in sports. They operated a progressive protocol on 4 different types of wobble-boards during three football training sessions. Three hundred of the players were asked to train for 20 minutes a day with 5 different phases of increased difficulty. The first phase consisted of balance training without a balance board; phase 2 of training on a rectangular balance board; phase 3 of training on a round board; phase 4 of training on a combined round and rectangular board; phase 5 of training on a less stable board. The other 300 were the control group. They followed their usual training regime with no extra balance training. They were monitored for 3 seasons. ACL injuries were assessed by clinical examination, KT-1000 measurements, magnetic resonance imaging or computer tomography and arthroscopy. These studies showed an incidence of 1.15 ACL injuries per team per year in the control group and 0.15 injuries per team per year in the balance training group. This suggested that balance training had a significant effect on the incidence of ACL injuries in players leading to successful prevention of this injury in sport.

A better postural sway in the lower limb has been shown to be associated with a lower rate of ankle injuries in athletes[162163 164]. Postural control is a multipart sensory motor coordination, which monitors and controls muscular force interacting external forces[165 166]. Any abnormal changes in the proprioception pathway or in motor control can cause abnormal postural sway. As a result there would be a lack of coordination of the movements of a section of body or balance of whole body.

As a response to any factors that cause disturbance in balance, the body tries to keep the balance and starts to sway with decreasing amplitude, until it is stabilised. This mechanism is optimised if the time to stabilisation and body sway are minimised [167 168]. BSS offers a type of balance test, which involves a complex coordination of the sensorimotor and biomechanical systems of human body. The neuromuscular responses lead to motor control of musculature and the stabilisers that are situated dominantly in lower limbs[169].

The respective contribution of the various peripheral afferents is also controversial. Traditionally, articular mechanoreceptors were thought to initiate protective reflexes directly to alpha motor neurons in response to load being placed on the joint. More recently, some researchers have suggested that articular mechanoreceptors have a very limited functional relevance in mediating reflexes, since they are thought to be important only under very high loads and physiological end ranges[170]. This would suggest that the tendomuscular mechanoreceptors are the structures that provide proprioceptive information that mediates reflex activity or provides joint position sense. Johnson and others however have suggested that the muscle afferents are indeed the crucial neural element for mediation of muscular control but that muscle spindles are heavily influenced by critical information delivered by articular afferents via the fusimotor system. Johansson extended this theory and describes a sophisticated articular tenomuscular link called the final common input. According to this theory the peripheral afferent information is integrated in muscle spindles, and then a final modified signal is transmitted to regulate the reflex[171].

In a study by Caraffa et al[161] it was found that proprioceptive (balance) training reduced the number of occurrences of ankle injuries in a variety of sports, and also aided in the rehabilitation of ACL injuries. The same study also found that by gradually increasing the difficulty levels of such as training over five phases in the proprioceptively trained group, the rate of ACL injuries in football players was significantlydecreased.

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4.7 Review of Rehabilitation of knee injuries

Quadriceps strengthening and isokinetic knee extension exercises.

Powerful quadriceps muscles are critical for good functional use of the lower extremity. Using isokinetic knee extension exercises can maximally contract the quadriceps. However, non-weight bearing resistance knee extension exercise may be deleterious to the repaired ACL in the terminal 50 degrees of knee extension. There is no posterior shear force produced from 90 to 50 degrees of knee extension. This implies that to protect the reconstructed ACL, the quadriceps can be safely exercised in the range from 90 to 50 degrees with isometric knee extension. Using isometric contractions also can strengthen the quadriceps. However, determining an appropriate knee joint position for the isometric contraction is important because a joint flexion angle of around 30 degrees might endanger the reconstructed ACL healing process. Based on the muscle overload principle, maximally resisted knee isometric extension exercise for strengthening the quadriceps is recommended about 50-60 degrees of knee flexion.

Hamstring strengthening and isokinetic knee flexion exercise.

For total hamstring force and, hence, strength gain, isokinetic knee flexion exercise is superior to knee extension exercises for prevention of ACL injuries. Strong hamstring muscles are needed by the patient to return to functional activities, such as walking and stair climbing. This is mainly due to the role of the hamstrings as a dynamic stabilizer. This stabilisation can help to resist anterior tibial translation relative to the femur during activity. Therefore, before a patient with an ACL deficient or an ACL reconstructed knee returns to activity, hamstring muscle strengthening exercise is advisable. No posterior shear force is produced during isokinetic knee flexion exercise from 0 to 90 degrees. For these reasons, isokinetic knee flexion exercise is highly recommended for patients undergoing ACL rehabilitation, particularly before they return to athletic activity.

The rehabilitation time following an ACL injury takes about six months[172 152 148]. The rehabilitation team should define the criteria and tests to the injured player before they can return to the training. A physiotherapist or team doctor who is expert in the area should lead the rehabilitation programme for a player who suffers from ACL injury. There are many articles, which have looked the time and criteria to return to light activities and contact sport activities after an ACL reconstruction. Most of the studies have stated that return to light activities should occur between 2-3 months after surgery and 6 months after for contact sport, but there are no specific regulations concerning this. Premature return to sport increases the re-injury risk and delayed return to sport increases the players and coaches' disappointment[152]. A recent study by Walden et al [172] supported that premature return to sport and inadequate rehabilitation after ACL reconstruction increased the risk of new, overuse, injury within the first month. The most common tests used to assess muscle strength and performance after an ACL reconstruction is isokinetic testing, the one leg jump test and thigh girth[152]. Criteria should be met before the injured athlete can return to sport. They should have completed a rehabilitation programme and performed functional tests successfully.

The purpose of ACL injury rehabilitation is to gain a good functional stability, reach the best possible functional level and to decrease the risk of re-injury. Most of the rehabilitation programmes for the injured ACL starts immediately with range of motion (ROM) exercises within pain free limits, strengthening exercises, cardiovascular fitness and weight bearing exercises such as walking with a cane[152]. Anderson et al stated four phases in the rehabilitation programme after a soft tissue injury, phase one: control inflammation, RICE, maintain ROM, flexibility, strength and endurance in the unaffected body parts, phase two: restore motion, phase three: develop muscular strength, power and endurance in the affected body part, phase four: return to sport activity.

Rehabilitation of the knee joint has focused on the quadriceps femoris muscle, in particular after PCL injury. The reason of this particular attention to the quadriceps muscle after PCL injury is the synergic action between them in stabilising the knee joint in the sagittal plane[173]. Baratta and Solomonow[173] emphasised co-contraction of flexors and extensors muscles of the knee in the rehabilitation of ligament injuries of the knee joint, regardless of the injury of any particular ligament. They suggested that co-activation of both the hamstring and quadriceps muscles are important in all types of knee ligament injury. During flexion and extension the antagonist muscle should also be submaximally contracted.

Several studies looked at quadriceps concentric strength in non-injured subjects and in those with posterior cruciate ligament (PCL) knee injuries and found a significant difference between the injured and non-injured legs. Other studies have shown no significant difference however between quadriceps strength in knees with ligament injury and the normal side[173]. The aim of muscular rehabilitation in PCL injured athletes should be to gain an injured/non-injured ratio of more than one for quadriceps strength. This can reduce the anteroposterior stress on the injured PCL and ultimately prevent ligament re-injury. Hamstring muscle strength was also significantly lower on the injured side and this weakness was more in eccentric contraction compared to concentric testing. The eccentric hamstring/quadriceps ratio was significantly different on the injured side compared to the non-injured side.

4.8 Method: Strength and Proprioception following ACL Reconstruction

The purpose of the present study was to compare the isokinetic and balance performance of two groups of ACL injured patients. The dynamic balance was assessed for injured and non-injured legs, using the Biodex Stability System (BSS).the background and use of the Biodex Stability system has been discussed in detail in the previous chapter. The test protocol had four stages, starting with the bipedal standing test, followed by the unilateral standing test for the injured and non-injured legs. The fourth part was the measurement of the limits of stability.

For a period of 30 seconds, subjects attempted to maintain the unstable platform in a level position. The value that was measured by BSS software for each balance test was a stability index that was calculated based on the duration of time and the degree

to which the platform was off level. One practice trial as familiarisation and two main test sessions were conducted.
Isokinetic strength tests were also performed using the Rev 9000 dynamometer. The protocol has been discussed in detail in the previous chapter. The measured values from the injured and non-injured legs were compared, to find out whether these methods of assessment could identify impairment after ACL injury. Previous studies in the clinical setting have examined the results of muscle testing and balance of the injured leg using the normal leg as control.

Fifty-two patients, who were under physiotherapy treatment at the Sport, Health and Injury clinic of the Scottish National Stadium after ACL reconstruction, were examined. The reconstruction for the ACL injury should not have been performed less than three months or more than two years prior to entry. Concentric isokinetic measurements of the hamstring and quadriceps muscles were performed for twenty-one subjects in group one. Protocol A was a gentle protocol with no maximum eccentric test .The protocol that was utilised for group two was more challenging than the first protocol and contained more tests including eccentric testing. This protocol was developed as being more challenging to the fit and athletic population. The tests were carried out for the injured and non-injured knee to provide comparison between two legs. Subjects of the group one were aged from 17-33 years. The age of group two ranged from 17-50 years.

4.8.1 Method: Isokinetic Testing

Isokinetic testing was undertaken as previously described. Two protocols were used on the direction of the physiotherapist or surgeon guiding the rehabilitation programme of the patient. All subjects performed protocol A which was a gentle protocol with no maximum eccentric test. This was determined by the phase of rehabilitation and the time from surgery. Protocol B contained more tests including eccentric testing and was more physically demanding.

Fifty-two ACL injured patients were examined. The method of the isokinetic testing has been fully explained, to avoid repetition the summary of the testing protocols are listed below:

After a warm-up, which was running on a treadmill for 8 minutes subjects sat upright on the isokinetic dynamometer (REV 9000, Technogym, Italy) at a seat angle of 100°. Subjects were stabilised by two crossed straps across their trunks and also by a thigh restrain roller above the knee joint. The axis of rotation of the dynamometer lever arm was aligned with the lateral femoral condyle of the knee joint at 90° knee flexion. The clamp pad was fastened just proximal to the malleoli. Clients were asked to cross their arms over their chests in order to avoid any influence of synergic muscles. The range of motion was set at 90° to 10° knee flexion. Once the test was begun the dynamometer corrected the torque for the gravity momentum. Then a specific warm-up was performed.

Protocol A: The warm-up protocol consisted of four sets of concentric knee extension and flexion at 50-75% of estimated maximum effort at 50 ^{o}/s – four times
After warm-up and a 2 minutes rest the main part of test was performed. The protocol included the following tests:

1. Peak isometric angle-specific torques for the quadriceps and hamstrings were completed at both 40° and 80° knee flexion using a 5s contraction time followed by 30s recovery periods.
2. Concentric peak torque of the quadriceps and hamstring muscles at a test velocity of 50 ^{o}/s for 4 maximal efforts, followed by a 90s recovery period.

3. Concentric peak torque of the quadriceps and hamstring muscles at a velocity of 150°/s, followed by a 90s recovery period.
4. Concentric peak torque of the quadriceps and hamstring muscles at a velocity of 250°/s, followed by a 90s recovery period.
5. Three minutes non-specific warm-up
6. The same procedures outlined above were performed for the contralateral knee.

Protocol B: The warm-up protocol consisted of:

- Four sets of concentric knee extension and flexion at 50-75% of estimated maximum effort at 30 °/s
- Four sets of sub-maximal eccentric quadriceps and eccentric hamstrings muscle contractions, at 50-75% of estimated maximum effort. This specific warm-up was then repeated at the other test velocity of 180°/s

After warm-up and a 2 minutes rest the main part of test was performed. The protocol consisted of the following tests:

1. Concentric peak torque of the quadriceps and hamstring muscles at a test velocity of 30 °/s for 4 maximal efforts, followed by a 90s recovery period.
2. Concentric peak torque of the quadriceps and hamstring muscles at a velocity of 180°/s, followed by a 90s recovery period.
3. Four maximal eccentric muscle torques of the hamstrings at a test velocity of 30 °/s for 4 maximal efforts, followed by a 90s recovery period.
4. Four maximal eccentric muscle torques of the hamstrings at a test velocity of 180 °/s for 4 maximal efforts, followed by a 90s recovery period.
5. Four maximal eccentric quadriceps muscle torques at a test velocity of 30 °/s for 4 maximal efforts, followed by a 90s recovery period.
6. Four maximal eccentric quadriceps muscle torques at a test velocity of 180 °/s for 4 maximal efforts, followed by a two minutes recovery period.
7. Peak isometric angle-specific torques for the quadriceps and hamstrings were completed at both 70° and 25° knee flexion by 5s efforts interspersed by 30s recovery periods.
8. Three minutes non-specific warm-up

The same procedures outlined above were performed for the contralateral knee.

4.8.2 Method: balance testing

The method of the balance tests performed in the comparative study in subjects following ACL reconstruction was similar to that explained in detail previously. The method had proved to be reproducible in the second study, and he same procedure was utilised on the extended study in the 54 participants from two levels of young football teams and the non-football player group. This gave confidence regarding the protocols for use in the patient group in the present study.

All measurements were carried out using the same instrument by the same researcher under the same environmental conditions. Subjects were instructed to hold the handrail and/or put their unsupported foot down on the stable corners of the BSS around the platform to prevent a fall in case of loss of balance. The examiner stood very close to the subjects to support them if necessary.

Study method

The inclusion criteria included a documented diagnosis of ACL injury and an auto graft reconstruction, which was performed beyond three months but within two years and the ability to keep the standing balance on one leg for the duration of 30 seconds. The exclusion criteria were bilateral injury; a sprain or an unstable joint other than the ligament injury of the knee joint and any major previous musculoskeletal injury to the lower limb or lumbar spine. In addition subjects should not have had any rheumatic disease, or neurological or musculoskeletal problems that could influence the measurements.

4.9 Results: Study of strength and proprioception after ACL reconstruction

The purpose of the present study was to compare the isokinetic and balance performance of patients with ACL injuries. The eccentric and concentric contraction, ratios between flexor and extensors of the knee joint were measured in all subjects. In addition unipedal standing balance was measured in group two. The results of the assessment of the injured and non-injured knees were compared. Fifty-two patients were evaluated in divided in retrospect into two groups. Fifty-two subjects, who were under physiotherapy treatment at the Sport, Health and Injury clinic of the Scottish National Stadium, were recruited after ACL reconstruction Their surgery was on average 11.35 months (2.60-21.53 months) before their participation in this research. All fifty two subjects were assessed through protocol A and thirty one subjects were assessed through protocol B. Subjects of the first group consisted of sixteen males and five females with the age range between 17 and 32 years old with a mean of 22.80 years (SD=5.6). The mean body weight was 77.14 kg (SD=13.4) and the mean body height was 178.66 (SD=8.7). Thirty-one subjects (26 males and 5 females) ranging from 17 to 50 years of age (Mean=32.38, SD= 10.48) took part in the second group. Their weight varied from 51 kg to 97 kg (Mean = 79.03, SD= 10.18) and their height ranged between 156 cm and 191 cm (Mean=175.5, SD= 7.84). Participants completed a health questionnaire regarding the history of injury and also a consent form. The location of the study was at the Performance Lab of the Sports, Health and Injury Clinics at the Scottish National Stadium at Glasgow Hampden Park.

Based on an expected effect size of 10% and the highest value of standard deviation that was obtained in the pilot study for bipedal and unipedal overall stability score as well as limit-of stability score, (SD7/26), for a statistical power of 90% for a two-tailed alpha level of 0.05 the number of 29 subjects was calculated.

	N	Minimum	Maximum	Mean	Std. Deviation
Height	21	161.00	197.00	178.6667	8.69099
Weight	21	53.00	111.00	77.1429	13.35397
Age	21	17.00	33.00	22.8095	5.60017
Valid N (list wise)	21				

Table 4-1Anthropometric Data for Patients in Group One

	N	Minimum	Maximum	Mean	Std. Deviation
Height	30	156.00	191.00	175.5667	7.83750
Weight	31	51.00	97.00	79.0323	10.17672
Age	31	17.00	50.00	32.3871	10.48388
Valid N (list wise)	30				

Table 4-2 Anthropometric Data for Patients in Group Two

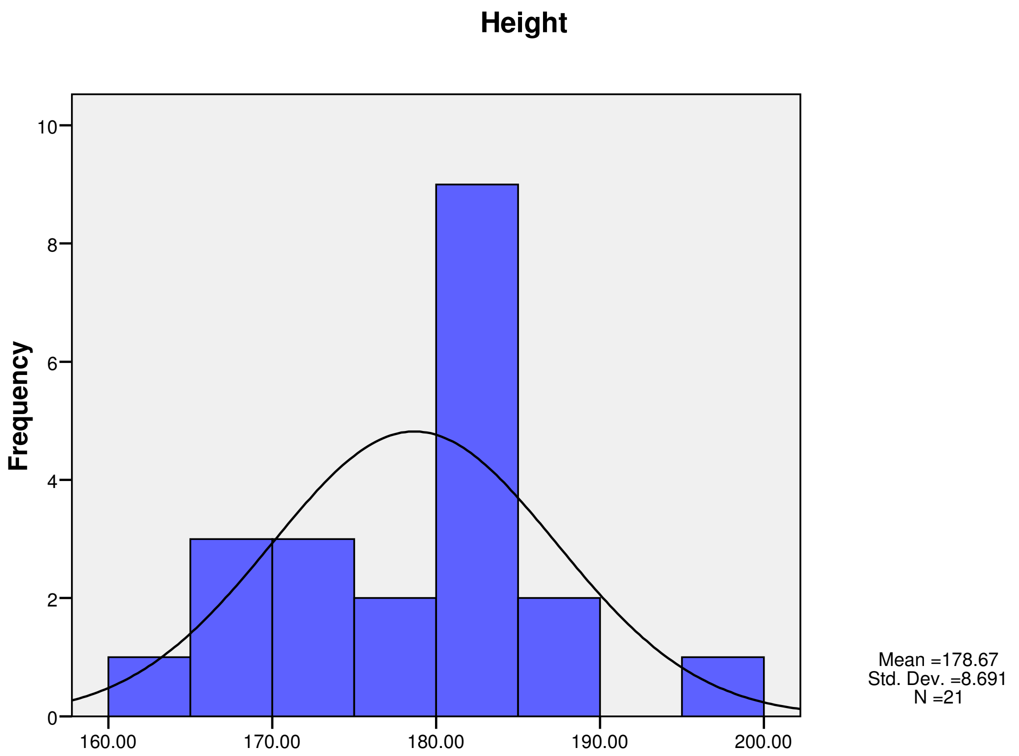

Figure 4-1 Histogram of the group one height with the normality curve

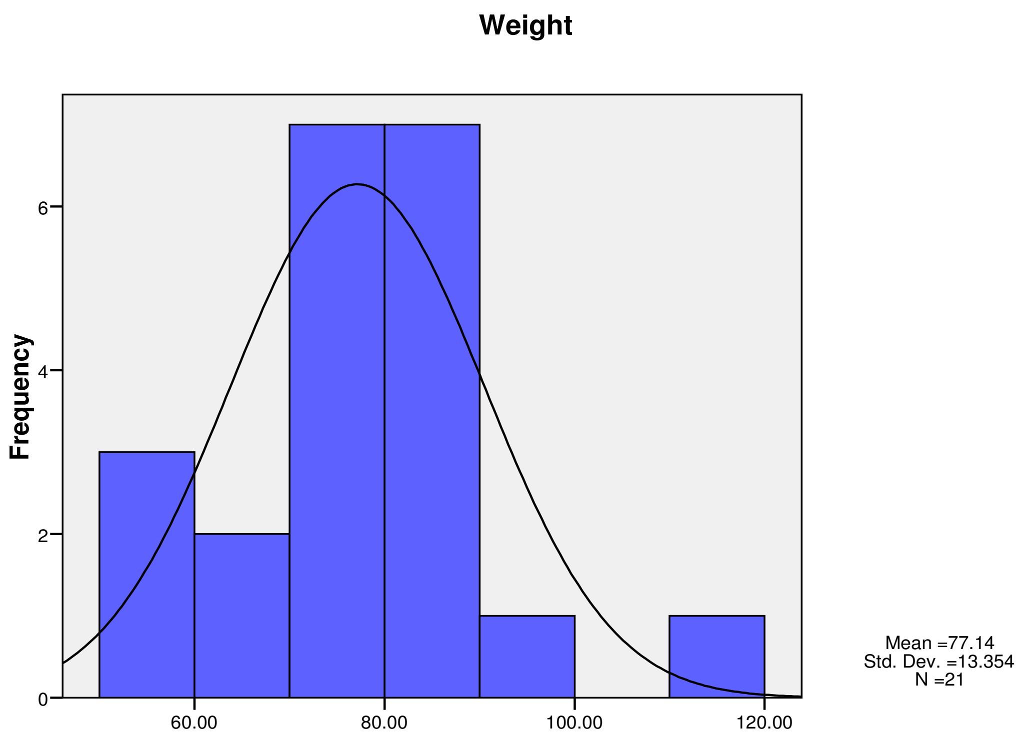

Figure 4-2 Histogram of the group one weight with the normality curve

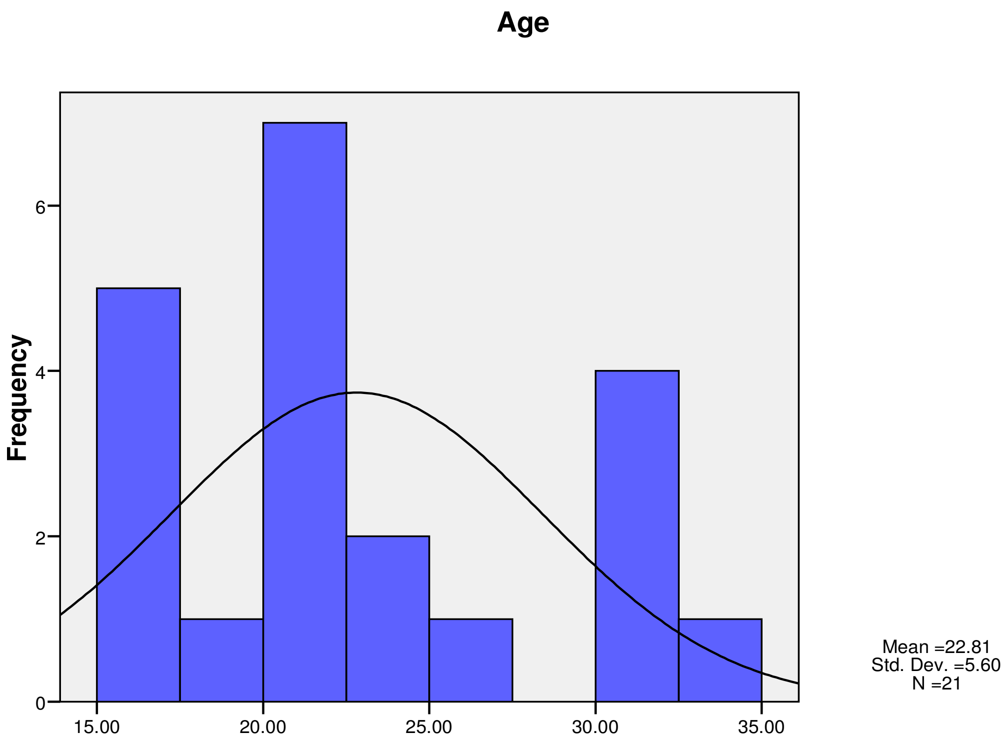

Figure 4-3 Histogram of the group one age with the normality curve

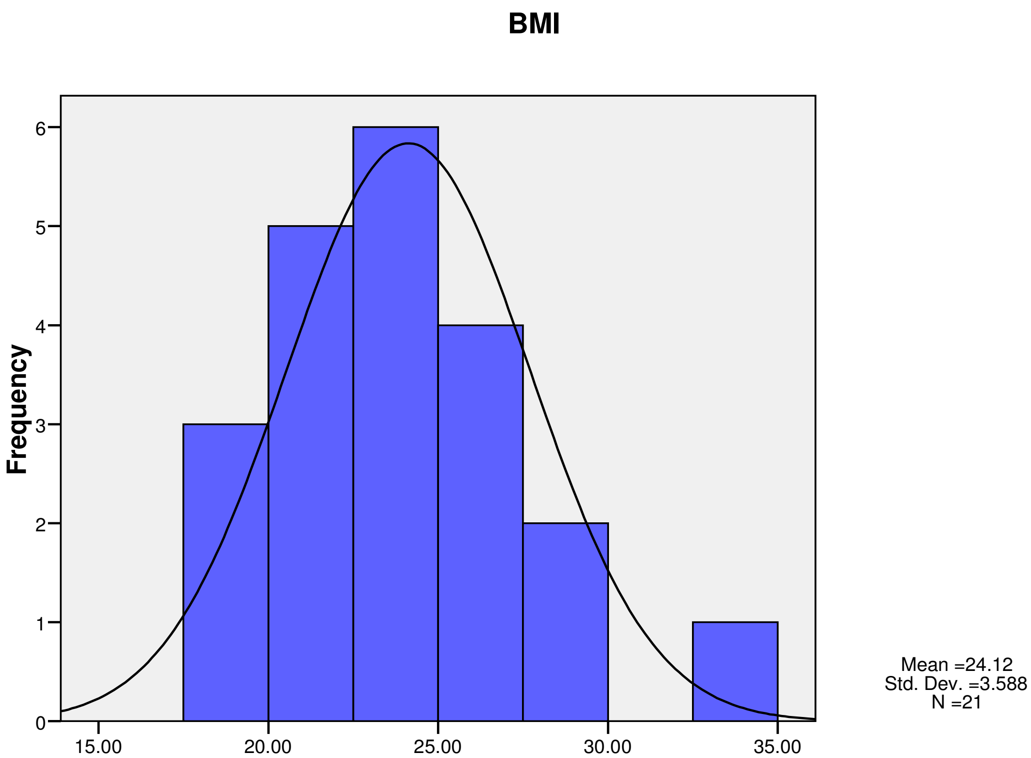

Figure 4-4 Histogram of the group one height with the normality curve.

The histogram charts of the anthropometric data of subjects of the group one with the normality curve indicated that their distributions are not different from a normal distribution. Normal Q-Q plot and the tests of normality of other variables also indicated similar results. It was possible to use one sample paired T test for the results obtained from group one to compare the ACL injured and the controlateral knee.

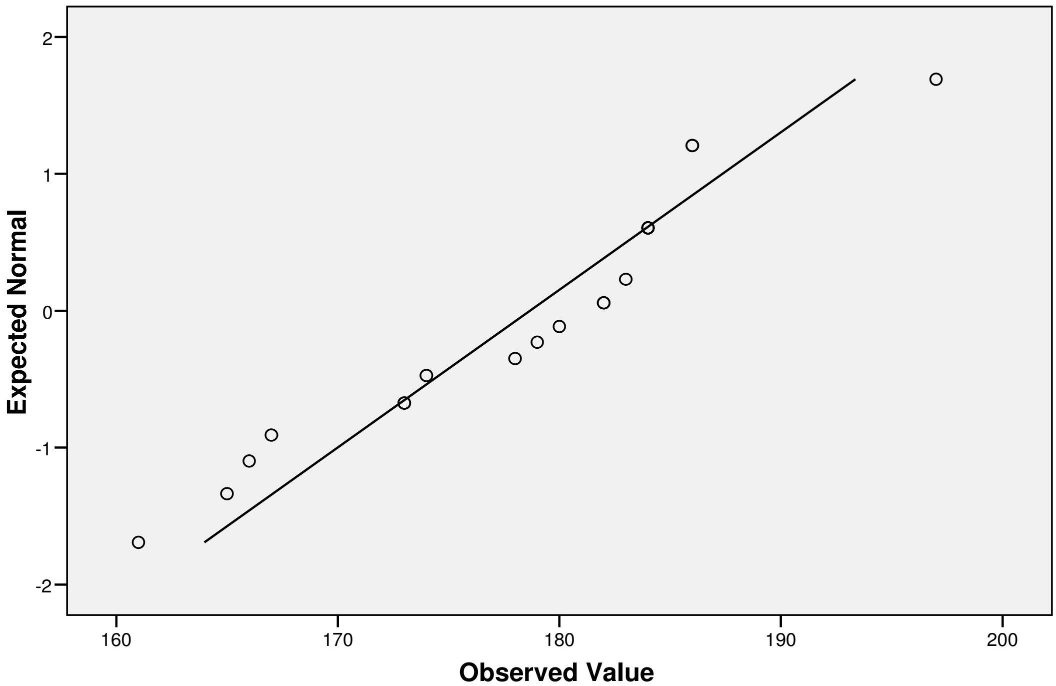

Figure 4-5 Normal Q-Q Plot of height for group one

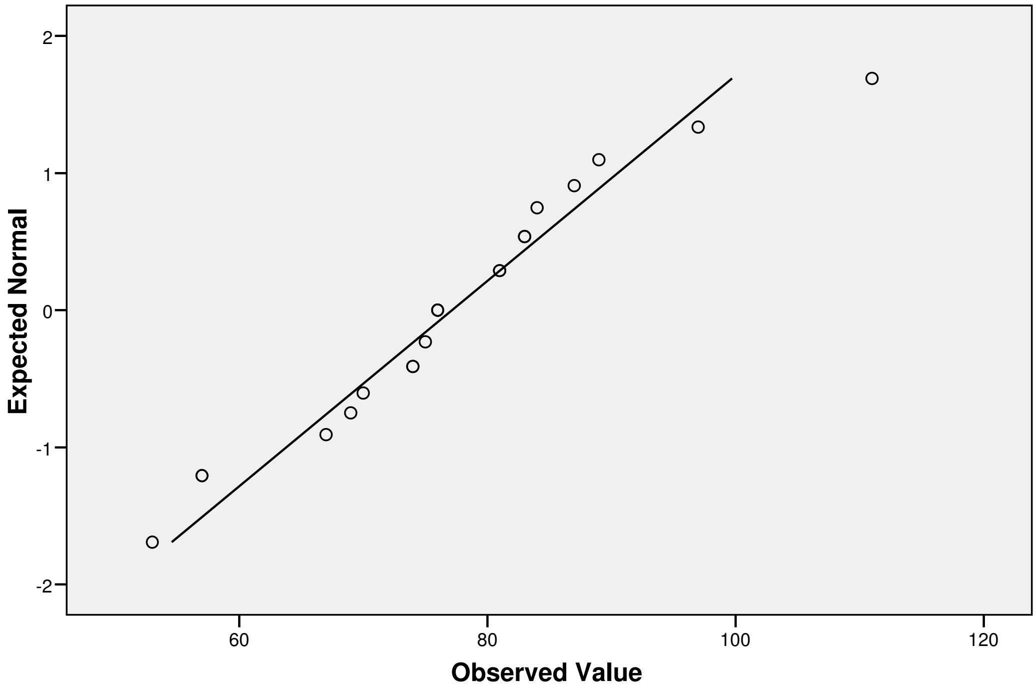

Figure 4-6 Normal Q-Q Plot of weight for group one

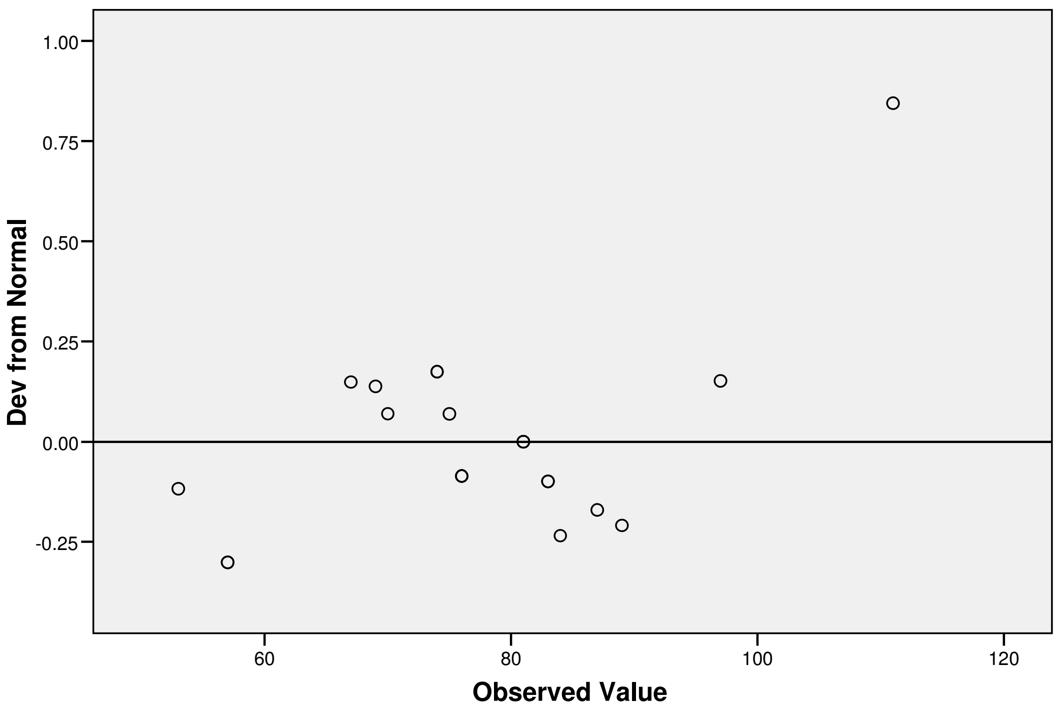

Figure 4-7 Detrended Normal Q-Q Plot of weight for group one

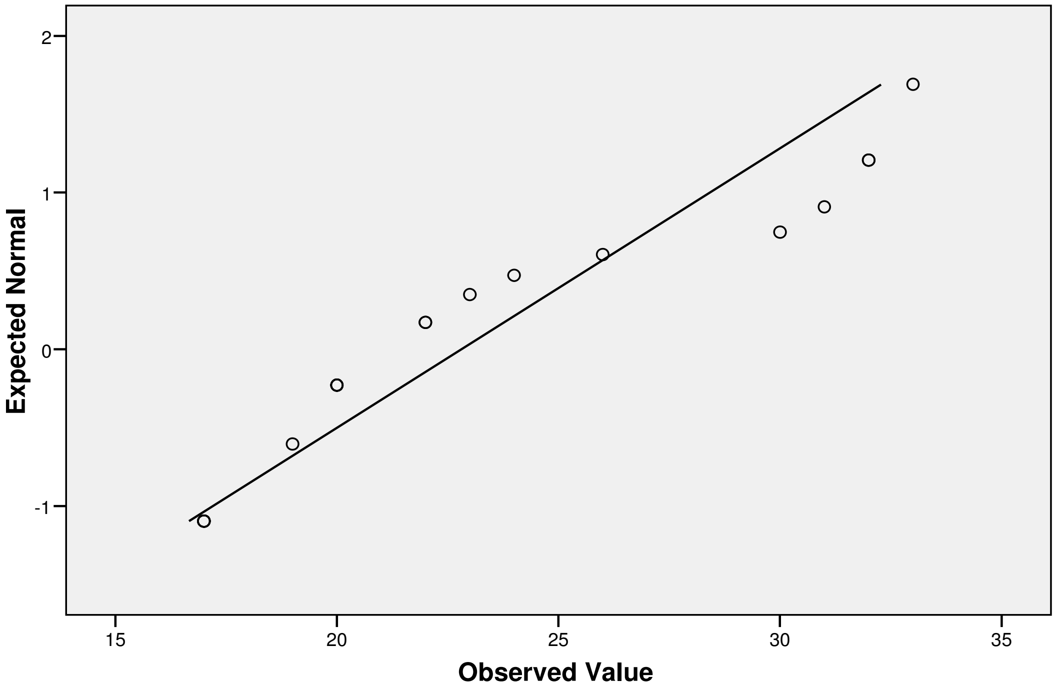

Figure 4-8 Normal Q-Q Plot of age for group one

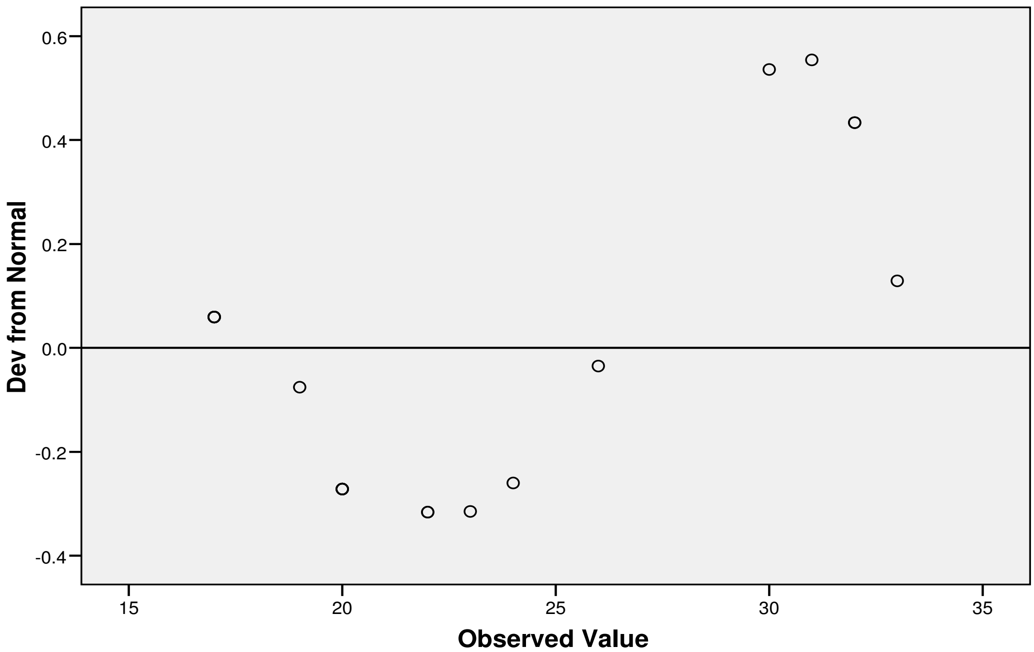

Figure 4-9 Detrended Normal Q-Q Plot of age for group one

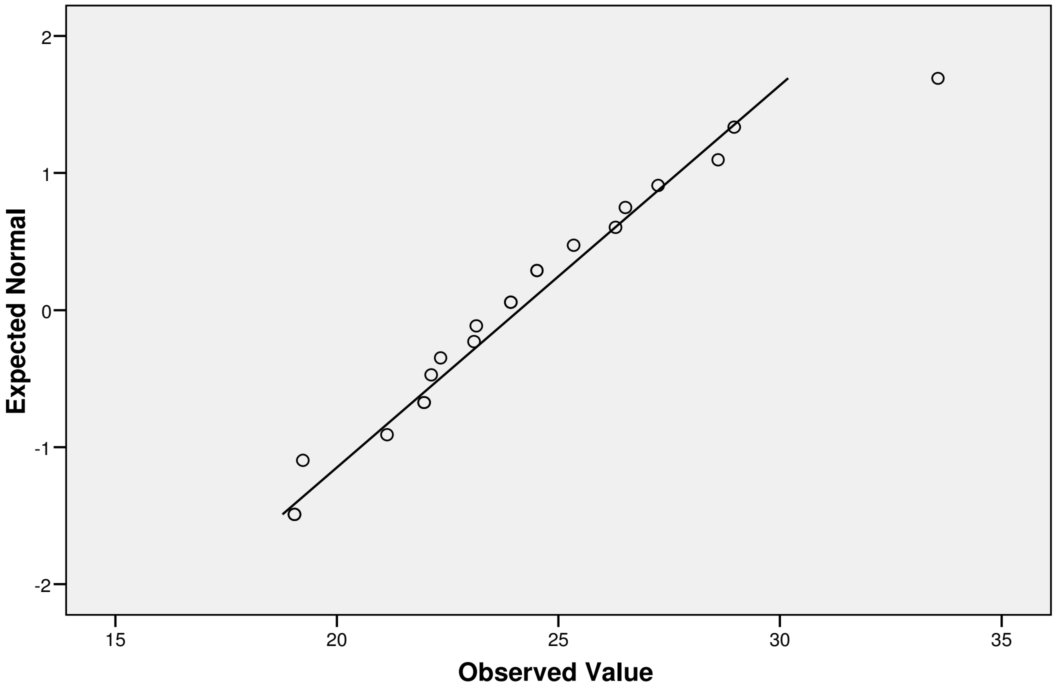

Figure 4-10 Normal Q-Q Plot of BMI for group one

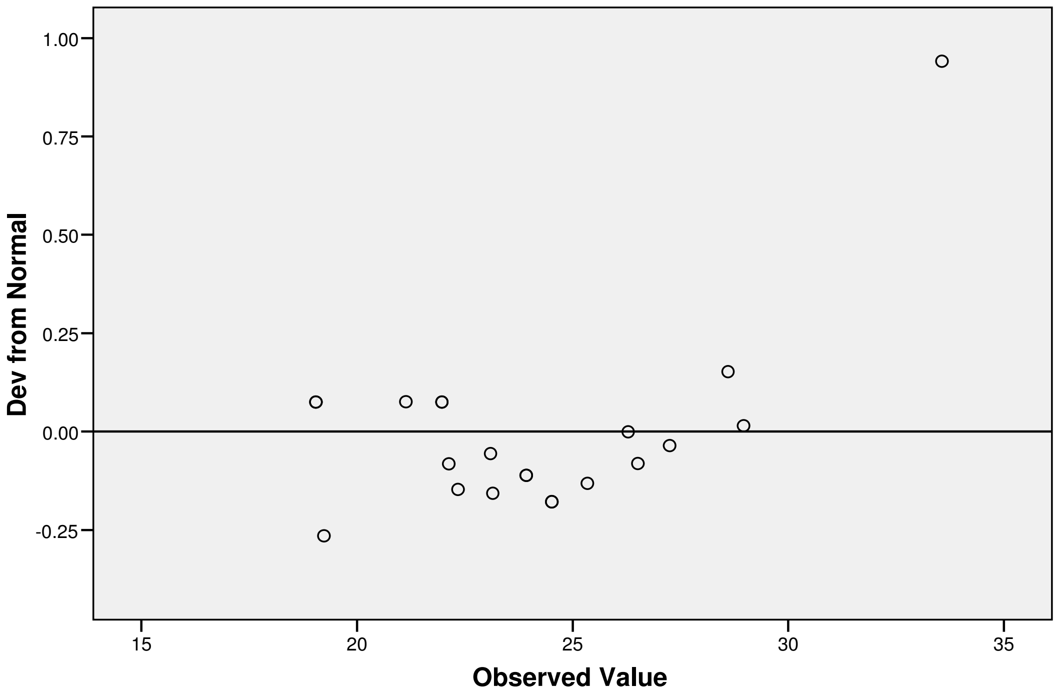

Figure 4-11 Detrended Normal Q-Q Plot of BMI for group one

	Min	Max	Mean		SD
	Stat	Stat	Stat	SE	Stat
Maximum Isometric Quadriceps Torque at 40º of The Knee Flexion in Uninjured Knee/Weight	1.19	2.20	1.7016	.06345	.29074
Maximum Isometric Quadriceps Torque at 40º of The Knee Flexion in Injured Knee/Weight	1.06	2.20	1.5393	.07640	.35013
Maximum Isometric Quadriceps Torque at 80º of The Knee Flexion in Uninjured Knee/Weight	1.99	4.23	3.1060	.15384	.70497
Maximum Isometric Quadriceps Torque at 80º of The Knee Flexion in Injured Knee/Weight	1.25	3.90	2.3163	.16926	.77563
Maximum Isometric Hamstring Torque at 40º of The Knee Flexion in Uninjured Knee/Weight	1.15	2.12	1.6105	.06543	.29262
Maximum Isometric Hamstring Torque at 40º of The Knee Flexion in Injured Knee/Weight	.61	2.15	1.3583	.10569	.47267
Maximum Isometric Hamstring Torque at 80º of The Knee Flexion in Uninjured Knee/Weight	.12	1.74	1.1945	.08328	.37245
Maximum Isometric Hamstring Torque at 40º of The Knee Flexion in Injured Knee/Weight	.50	1.64	.9906	.06863	.30693
Concentric Quadriceps Peak Torque at the Velocity of 50º in Non-injured Knee/Weight	1.24	3.28	2.6279	.10561	.48395
Concentric Quadriceps Peak Torque at the Velocity of 50º in Injured Knee/Weight	.91	3.39	2.1594	.14341	.65717
Concentric Hamstring Peak Torque at the Velocity of 50º in Non-injured Knee/Weight	.89	2.06	1.5527	.06066	.27800
Concentric Hamstring Peak Torque at the Velocity of 50º in Injured Knee/Weight	.85	2.36	1.3523	.08199	.37572
Concentric Quadriceps Peak Torque at the Velocity of 150º in Non-injured Knee/Weight	1.43	3.41	2.3189	.10518	.48199
Concentric Quadriceps Peak Torque at the Velocity of 150º in Injured Knee/Weight	.54	3.03	1.8722	.14004	.64174
Concentric Hamstring Peak Torque at the Velocity of 150º in Non-injured Knee/Weight	.85	3.08	1.5492	.09805	.44932
Concentric Hamstring Peak Torque at the Velocity of 150º in Injured Knee/Weight	.74	2.93	1.4042	.11621	.53252
Concentric Quadriceps Peak Torque at the Velocity of 250º in Non-injured Knee/Weight	1.38	3.39	2.2577	.14920	.61517
Concentric Quadriceps Peak Torque at the Velocity of 250º in Injured Knee/Weight	.54	3.24	1.9582	.15478	.65668
Concentric Hamstring Peak Torque at the Velocity of 250º in Non-injured Knee/Weight	.41	1.97	1.3289	.08270	.34100
Concentric Hamstring Peak Torque at the Velocity of 250º in Injured Knee/Weight	.80	3.21	1.5469	.14899	.63210

Table 4-3 Descriptive Statistics for the Isokinetic variables in group one

	Paired Differences					Sig. (2-tailed)
	Mean	SD	SE Mean	95% CI of Difference		
				Lower	upper	
Maximum Isometric Quadriceps Torque at 80º of The Knee Flexion/Weight	.790	.920	.201	.37	1.21	.001
Maximum Isometric Hamstring Torque at 40º of The Knee Flexion/Weight	.252	.361	.081	.083	.42	.006
Concentric Quadriceps Peak Torque at the Velocity of 50º/Weight	.469	.658	.142	.17	.77	.004
Concentric Hamstring Peak Torque at the Velocity of 50º/Weight	.201	.307	.067	.061	.34	.007
Concentric Quadriceps Peak Torque at the Velocity of 150º/Weight	.447	.582	.127	.182	.71	.002
Hamstring/Quadriceps Ratio	-.207	.351	.085	-.39	-.026	.028

Table 4-4 Paired Samples T Test for comparison of the Isokinetic variables in group one

In group one all variables' means in the injured legs and normal legs were compared, using the one sample paired T test (Table 4-2). The significance value was less than P <0.05 in six variables (table 4.3.). The differences of two isometric tests for the quadriceps at 80º of the knee flexion and for the hamstring at 40º of knee flexion were significant with *P*-values of 0.001 and 0.006 respectively. The mean difference between the injured and non-injured knees was 0.79 NM/Kg (CI: 0.37-1.21) for the isometric quadriceps test at 80º of the knee flexion and 0.25 NM/Kg (CI: 0.083-0.42) for the isometric hamstring test at 40º of the knee flexion. Concentric quadriceps peak torque at velocities of 50º/s and 150º/s were also significantly different between the normal and ACL injured knees of the subjects of the first group. The significance value for the speed of 50º/s was P 0.004 (MD=0.47, CI: 0.17-0.77) and for the speed of 150º/s was P 0.002 (MD=0.45, CI: 0.18-0.71). Concentric hamstring peak torque that was obtained with the test velocity of 50º/s was also significantly different in the two legs. (*P*=.007, MD=0.20, CI: 0.06-0.34) the last variable which was shown to be different in the two legs was the hamstring/quadriceps ratio with the *P* 0.028. (MD=-0.21, CI: -0.39-0.03). The upper limit of the 95% of confidence interval for this ratio was very close to zero and the range of mean difference was negative.

The histogram graphs of the anthropometric data of subjects of the second group with the normality curve showed that their distributions were not greatly different from normal distribution. The tests of normality also indicated the similar results. However as far as the distribution of the other acquired data are concerned, the values of skewness and kurtosis of a number of variables showed they were not normally distributed. The range of these values were exceeded significantly the expected range (-1 to 1) for a number of variables. So, nonparametric statistical analysis were applied to compare the obtained values from injured and non-injured legs. Specifically the Wilcox on signed-rank test was utilised as an alternative to the paired samples t-test.

This test, which is a nonparametric method of analysis for two related samples, indicated that most of concentric and eccentric quadriceps tests were significantly different between the values from injured and uninjured legs. Concentric quadriceps torques at the velocity of 30º/s and 180º/s were on average 3.974 NM/KG (P=0.008) and 2.63 NM/KG (P=0.000) less in injured knee, respectively. Eccentric quadriceps torque at the velocity of 30º/s and 180º/s were also on average 4.25 NM/KG (P=0.000) and 3.450 NM/KG (P=0.001) less in injured legs, respectively. In contrast, none of the values in relation to the hamstring muscle and no balance tests were significantly different between the injured and non-injured legs. The difference between the maximum isometric quadriceps torque of the injured leg and that of the non-injured leg was also significant (P= 0.006). This variable was on average 2.76 NM more in the non-injured side. The eccentric/concentric ratio of the quadriceps muscle of the injured leg differed from that of the non-injured leg (P=0.000) with a mean difference of 3.48.

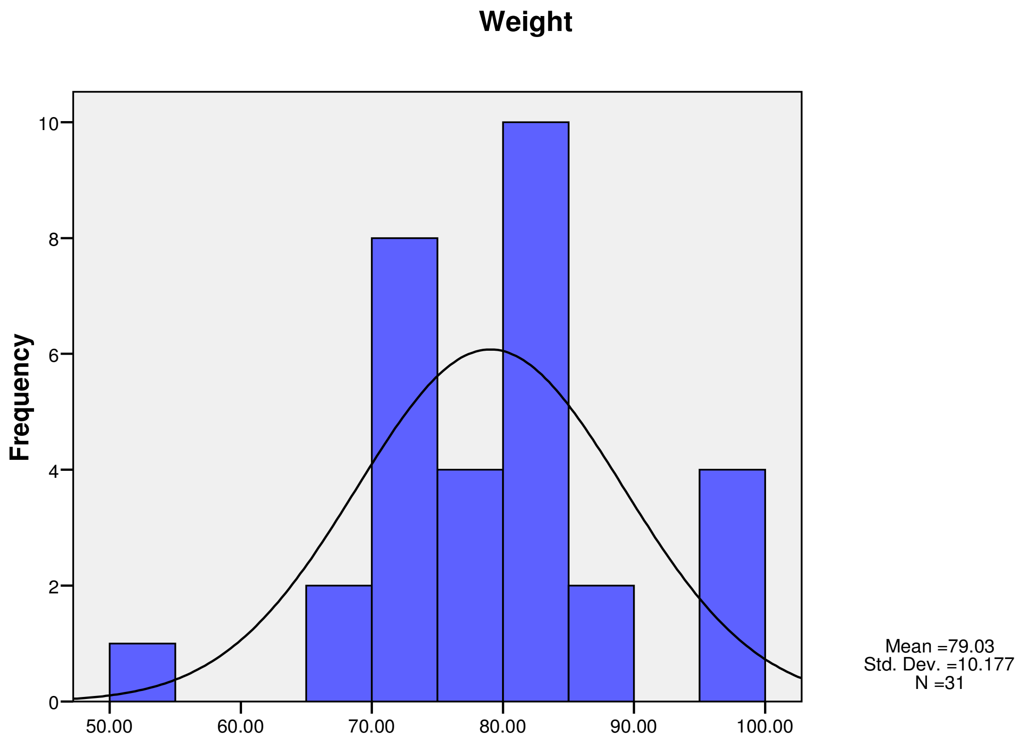

Figure 4-12 Histogram of the weights of group two with the normality curve

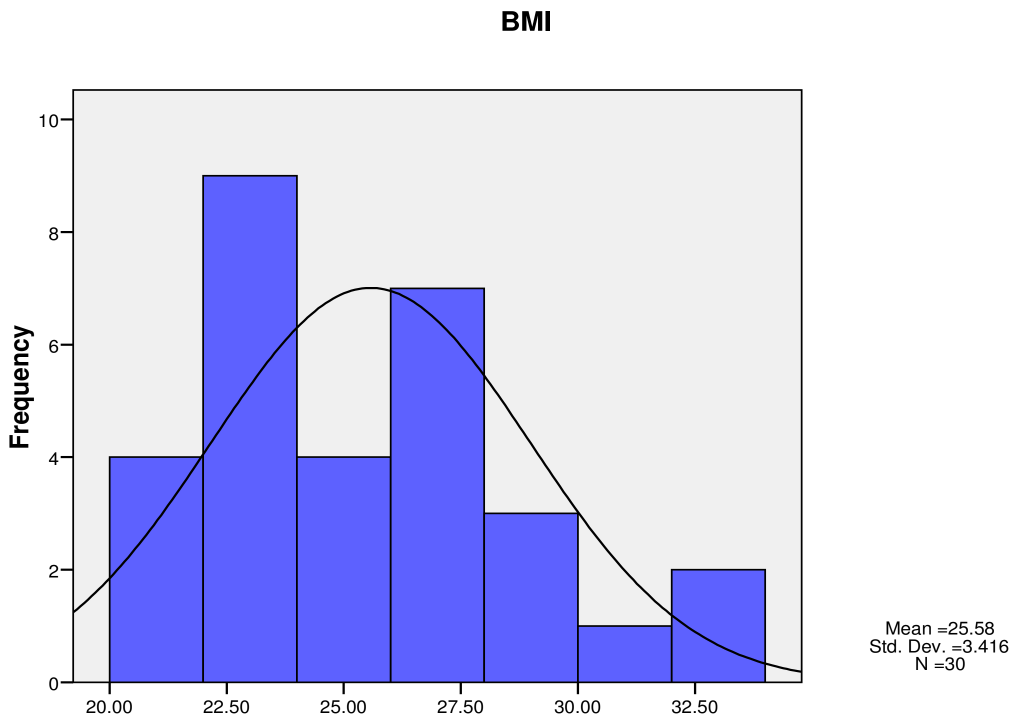

Figure 4-13 Histogram of the group two BMI with the normality curve

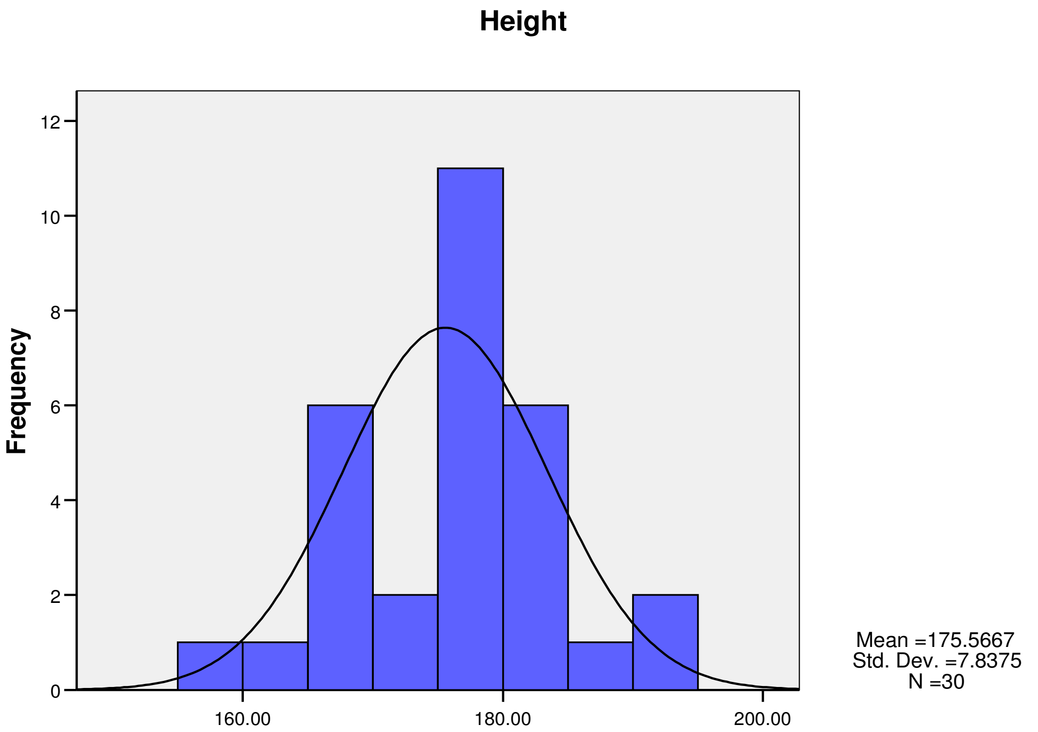

Figure 4-14 Histogram of the group two height with the normality curve

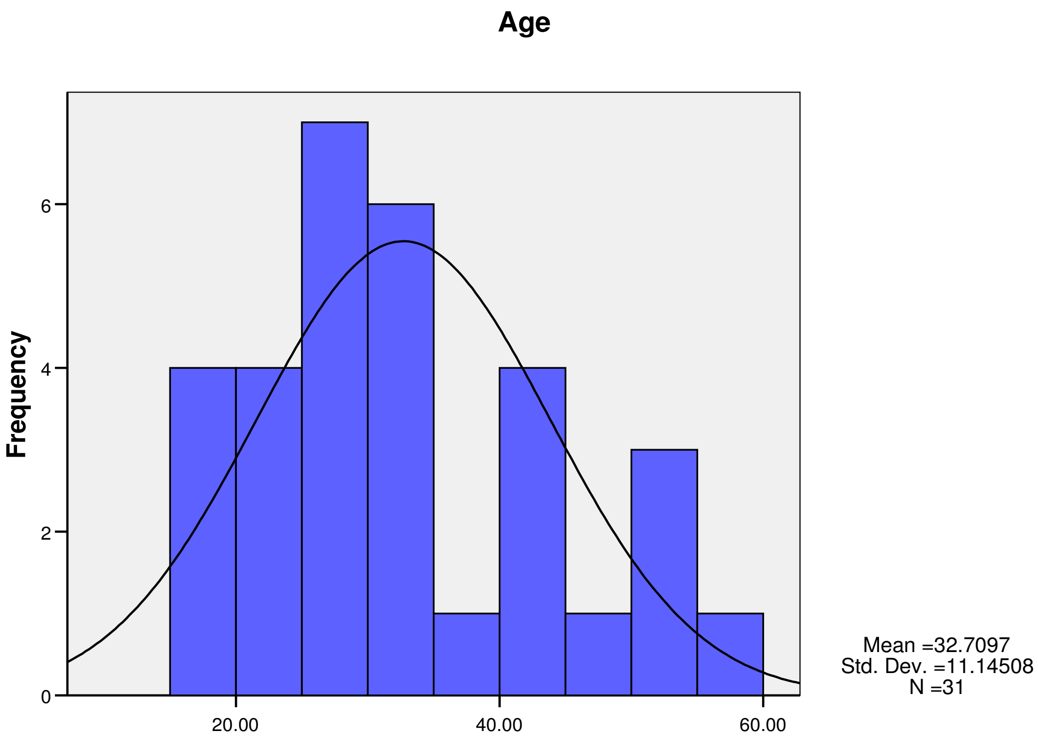

Figure 4-15 Histogram of the group two age with the normality curve

	Min	Max	Mean		SD
	Stat	Stat	Stat	SD	Stat
Concentric Hamstring Torque at 30 in Uninjured Leg/W	.76	2.37	1.489	.042	.307
Concentric Hamstring Torque at 30 in Injured Leg/W	.78	2.56	1.509	.043	.319
Concentric Hamstring Torque at 180 in Uninjured Leg/W	.72	2.70	1.549	.057	.42
Concentric Hamstring Torque at 180 in Injured Leg/W	.84	2.12	1.412	.035	.257
Concentric Quadriceps Torque at 30 in Uninjured Leg/W	1.6	3.6	2.567	.063	.462
Concentric Quadriceps Torque at 30 in Injured Leg/W	.90	3.73	2.353	.078	.574
Concentric Quadriceps Torque at 180 in Uninjured Leg/W	1.39	4.61	2.542	.078	.57
Concentric Quadriceps Torque at 180 in Injured Leg/W	1.24	3.72	2.222	.064	.472
Eccentric Hamstring Torque at 30 in Uninjured Leg/W	.84	2.52	1.582	.052	.379
Eccentric Hamstring Torque at 30 in Injured Leg/W	.78	2.65	1.717	.055	.406
Eccentric Hamstring Torque at 180 in Uninjured Leg/W	.75	2.56	1.519	.048	.349
Eccentric Hamstring Torque at 180 in Injured Leg/W	.92	2.27	1.677	.041	..3
Eccentric Quadriceps Torque at 30 in Uninjured Leg/W	1.52	4.38	2.852	.098	.717
Eccentric Quadriceps Torque at 30 in Injured Leg/W	1.37	5.45	3.028	.117	.860
Eccentric Quadriceps Torque at 180 in Uninjured Leg/W	1.03	4.09	2.677	.083	.612
Eccentric Quadriceps Torque at 180 in Injured Leg/W	1.52	4.10	2.667	.080	.591
Maximum Isometric Hamstring Torque at 25 of The Knee Flexion in Non-injured Leg/weight	.65	2.55	1.376	.048	.355
Maximum Isometric Hamstring Torque at 25 of The Knee Flexion in Injured Knee/weight	.74	2.54	1.471	.052	.383
Maximum Isometric Quadriceps Torque at 25 of The Knee Flexion in Non-injured Knee/weight	.54	1.74	1.149	.0373	.274
Maximum Isometric Quadriceps Torque at 25 of The Knee Flexion in Injured Knee/weight	.58	1.55	1.127	.029	.212
Maximum Isometric Hamstring Torque at 70 of The Knee Flexion in Non-injured Knee/weight	.53	1.89	1.185	.032	.237
Maximum Isometric Hamstring Torque at 70 of The Knee Flexion in Injured Knee/weight	.76	2.06	1.285	.038	.276
Maximum Isometric Quadriceps Torque at 70 of The Knee Flexion in Non-injured Knee/weight	1.25	4.01	2.602	.094	.691
Maximum Isometric Quadriceps Torque at 70 of The Knee Flexion in Injured Knee/weight	1.47	3.82	2.582	.079	.581
Concentric Hamstring Torque at 300 in Non-injured Knee/weight	.53	3.24	1.57	.076	.528
Concentric Hamstring Torque at 300 in Injured Knee/weight	.85	2.17	1.487	.041	.283
Concentric Quadriceps Torque at 300 in Non-injured Knee/Weight	1.01	3.32	2.082	.076	.525
Concentric Quadriceps Torque at 300 in Injured Knee/Weight	1.08	3.05	2.052	.069	.476

Table 4-5 Descriptive Statistics for the Isokinetic variables in group two

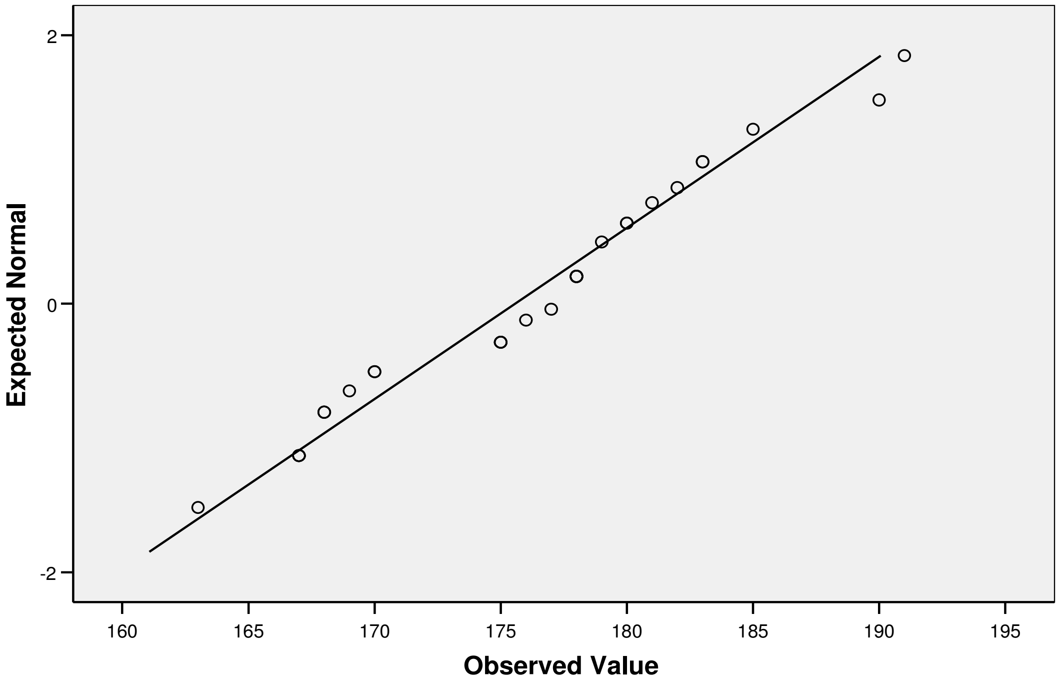

Figure 4-16 Normal Q-Q Plot of height for group two

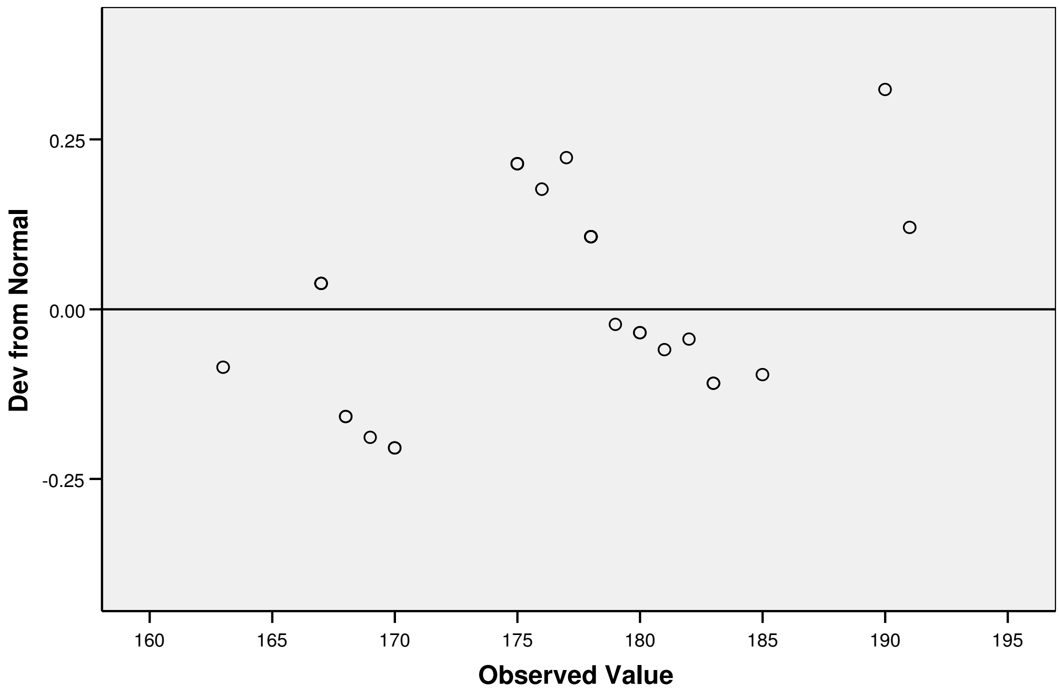

Figure 4-17 Detrended Normal Q-Q Plot of height for group two

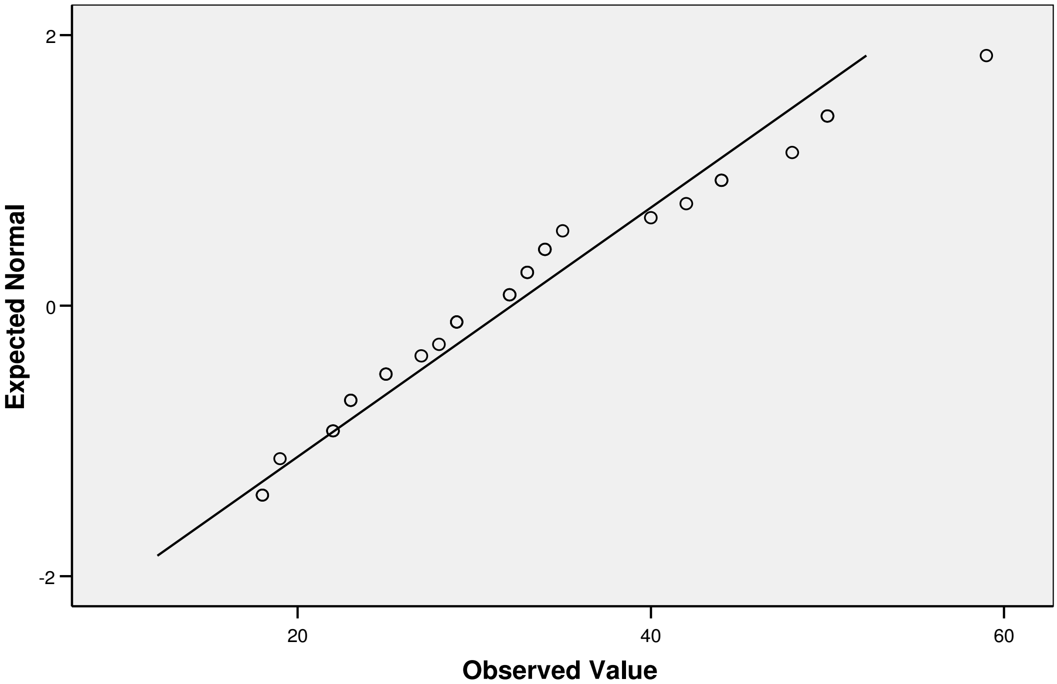

Figure 4-18 Normal Q-Q Plot of age for group two

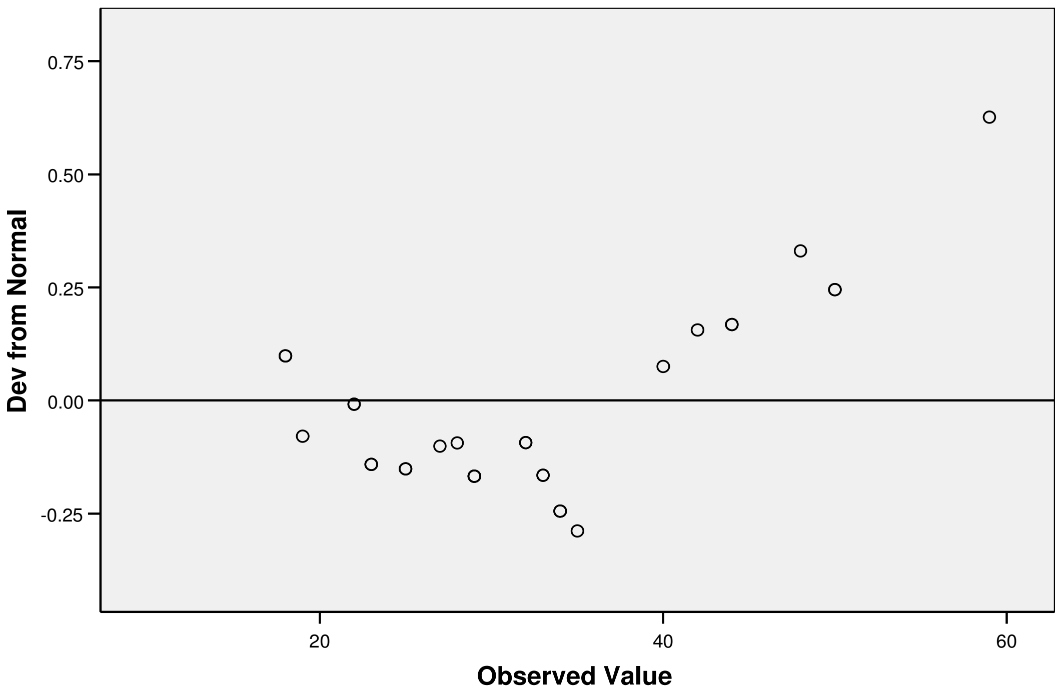

Figure 4-19 Detrended Normal Q-Q Plot of age for group two

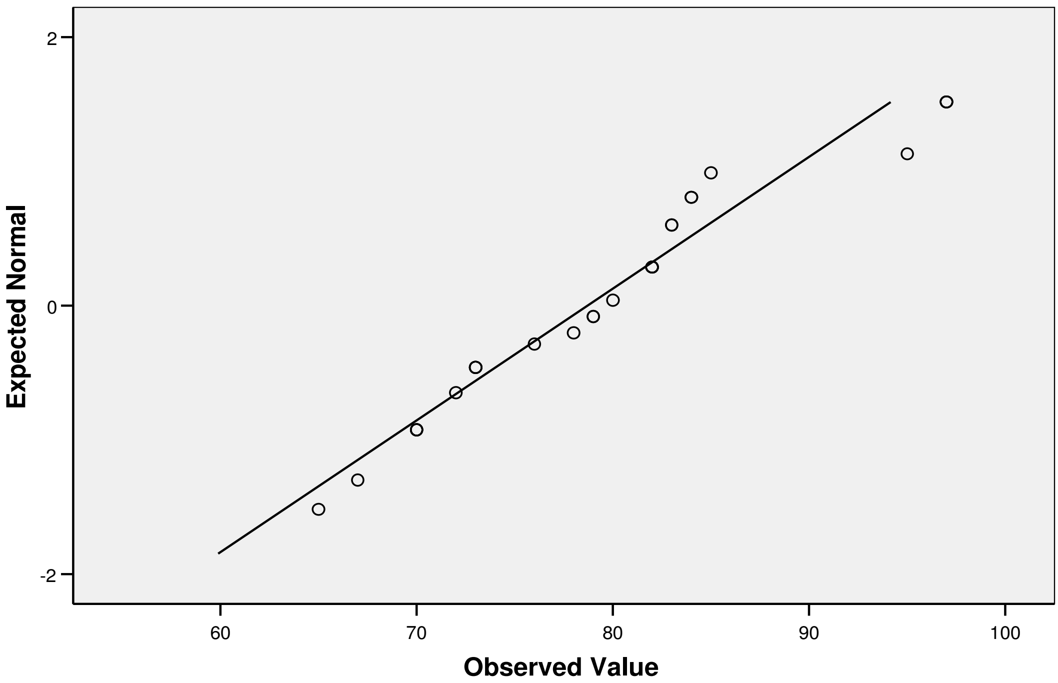

Figure 4-20 Normal Q-Q Plot of weight for group two

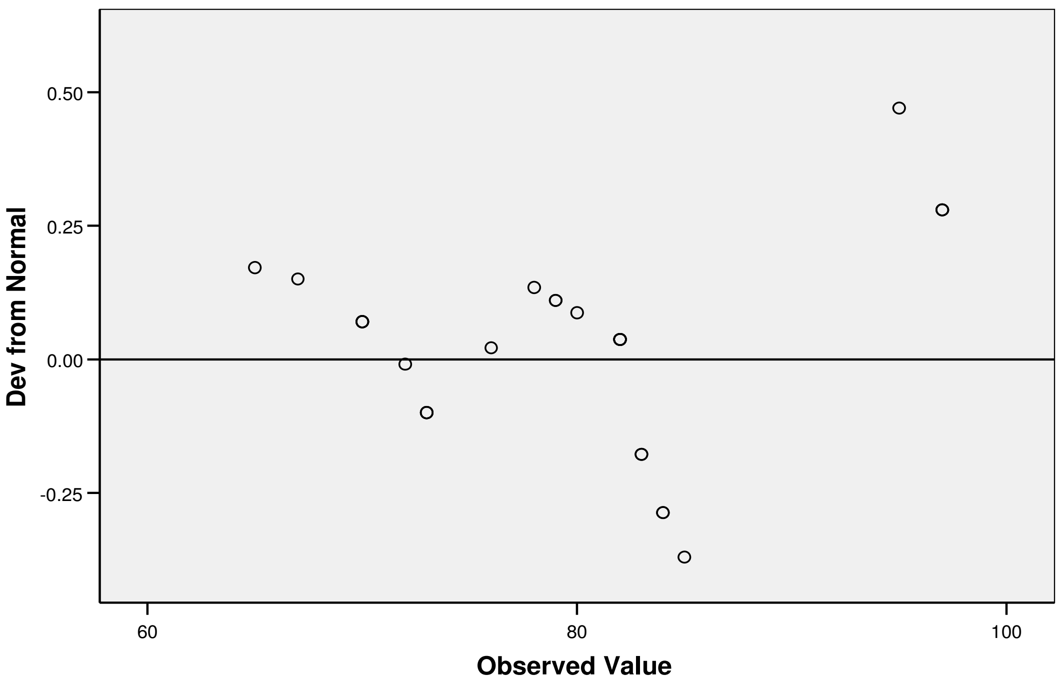

Figure 4-21 Detrended Normal Q-Q Plot of weight for group two

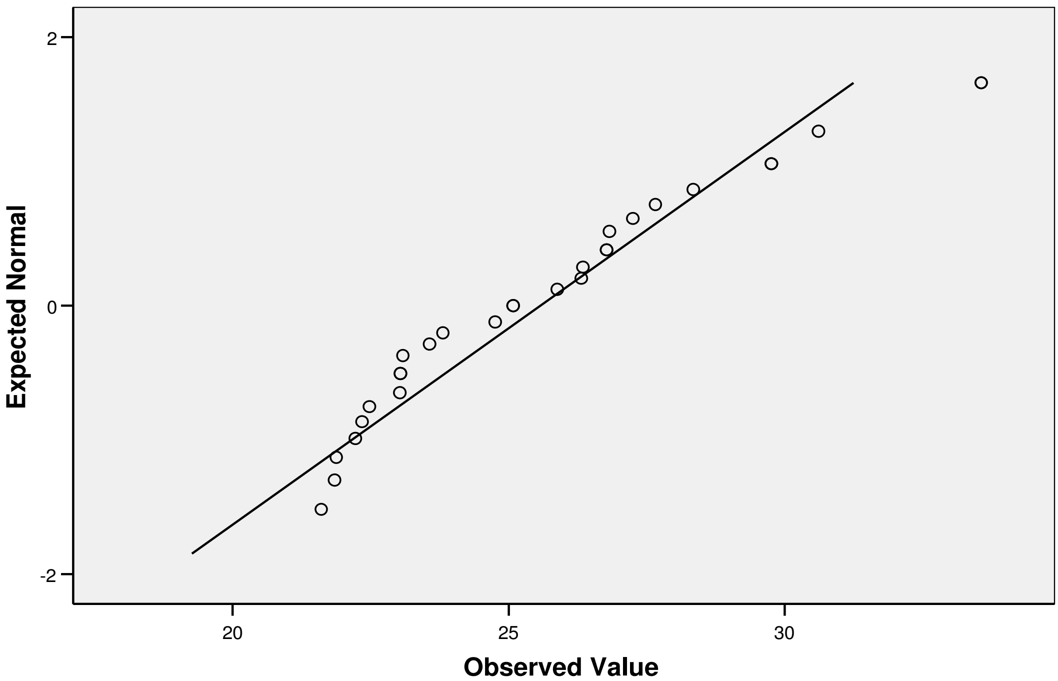

Figure 4-22 Normal Q-Q Plot of BMI for group two

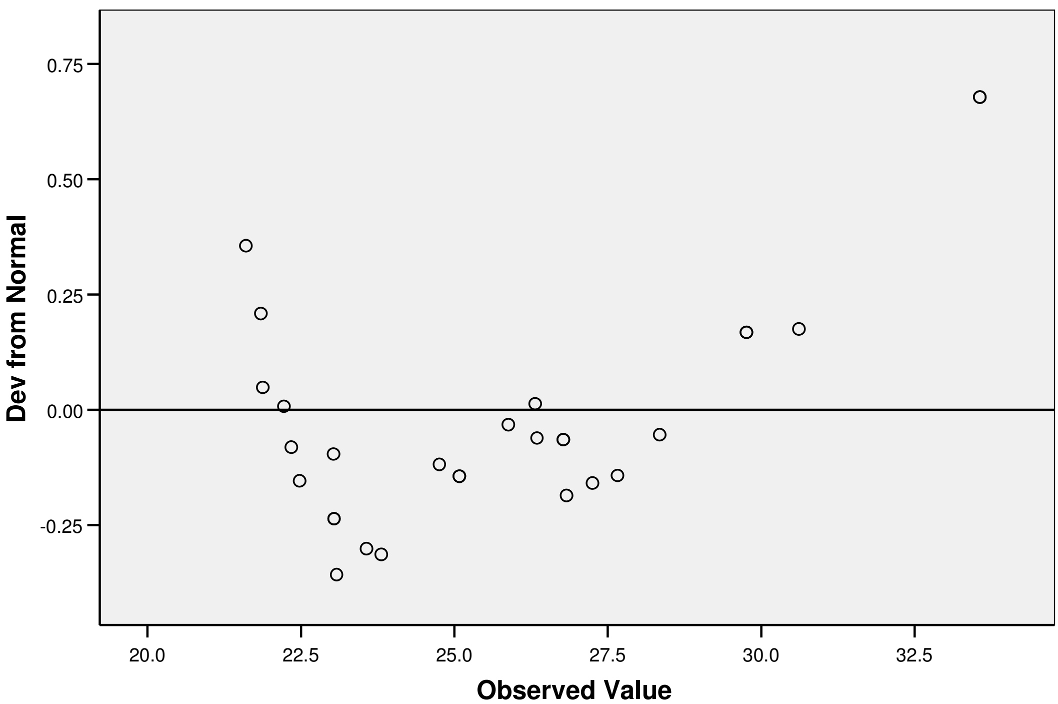

Figure 4-23 Detrended Normal Q-Q Plot of BMI for group two

	Paired Differences					Sig. (2-tailed)
	Mean	SD	Std. Error Mean	95% CI of the Difference		
				Lower	Upper	
Eccentric-Concentric Ratio at 180	.39	.58	.11	.17	.62	.001
Concentric Quadriceps Torque at 30	35.96	35.40	6.69	22.24	49.70	.000
Concentric Quadriceps Torque at 180	21.86	38.61	7.30	6.89	36.83	.006
Eccentric Quadriceps Torque at 30	53.54	42.87	8.10	36.91	70.16	.000
Eccentric Quadriceps Torque at 180	36.29	45.28	8.56	18.73	53.83	.000
Maximum Isometric Quadriceps Torque at 70 of The Knee	22.85	36.76	6.95	8.60	37.11	.003

Table 4-6 Paired Samples T Test for the Isokinetic variables in group two

Leg dominance

Subjects were divided into two groups, based on the whether the injury was in the dominant or non dominant leg. 51.6% of them had the ACL injury in their non-dominant side and 48.4% of them had ACL injury in their dominant side (Figure 4.24).

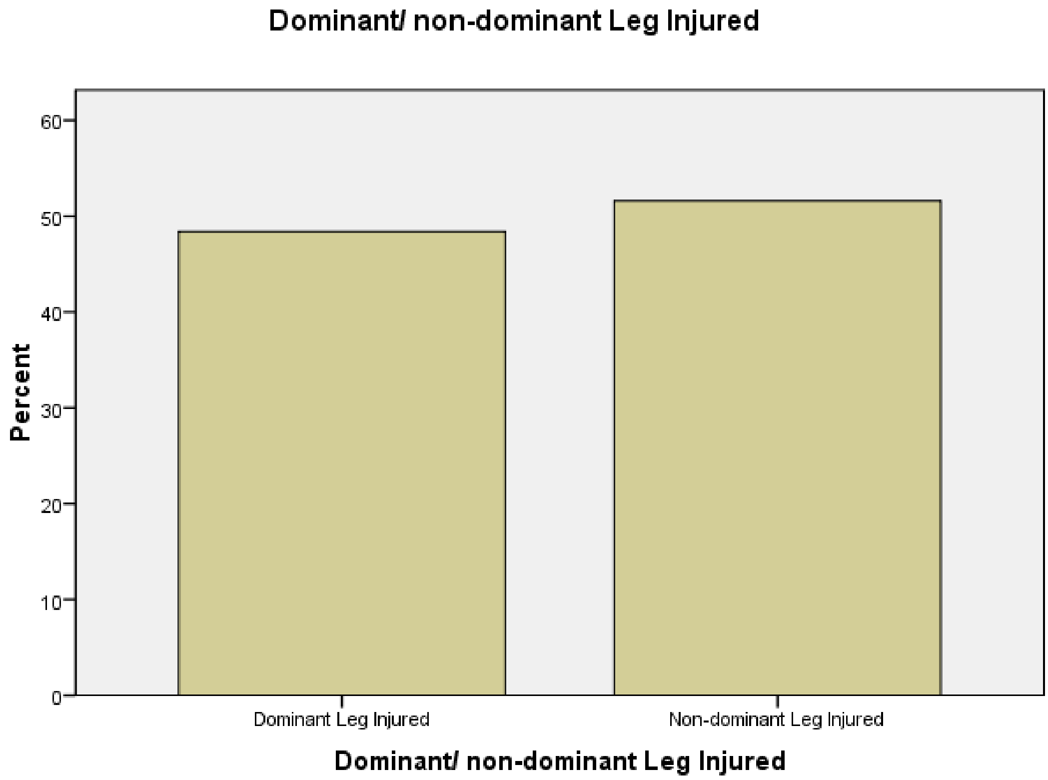

Figure 4-24 Injury at the dominant or non-dominant side.

There is no significant difference between the injury sites.

4 .10 Discussion Study of strength and proprioception following ACL reconstruction

The main purpose of the present study was to analyse whether there was any difference in postural control and isokinetic performance of the knee muscles between ACL reconstructed knees and the uninjured extremities.

In reference to the findings of the result sections, subjects gained higher values in some isokinetic measurements of the muscular performance of the non-injured knee compared to the injured knee. The non-injured knee of the patients of the first group had on average 0.79 NM/KG in the isometric quadriceps at 80º of the knee flexion and 0.25 NM/KG in the isometric hamstring at 40º of the knee flexion. The calculated concentric quadriceps peak torque at velocities of 50º/s and 150º/s were also on average 0.47 NM/KG and 0.45 NM/KG higher in the non-injured knee respectively. On average, the concentric hamstring peak torque that obtained with the test velocity of 50º/s was 0.20 NM/KG more in the normal side. Interestingly the hamstring/quadriceps ratio was on average, 0.21 more in ACL-injured knee. However, the Overall Stability Index (OSI) for bipedal stability test and, right and left legs' unipedal stability tests and test of limits of stability did not have any significant difference between the ACL injured and normal knees.

In the second group with a different isokinetic assessment protocol, more isokinetic variables were found to be different between the injured and non-injured extremities. The concentric quadriceps torques at the velocity of 30º/s and 180º/s were on average 3.974 NM/KG and 2.63 NM/KG more in the non-injured knee respectively. Eccentric quadriceps torque at the velocity of 30º/s and 180º/s were also on average 4.25 NM/KG and 3.450 NM/KG more in non-injured legs, respectively. Findings also indicated that none of the isokinetic measurements of the hamstring muscle and no balance test were significantly different between injured and non-injured knees. The maximum isometric quadriceps torque of the non-injured leg was on average 2.76 NM/KG higher than that of the injured leg. The eccentric/concentric ratio of the quadriceps muscle of the non-injured leg was also on average 3.48 NM/KG higher than that of the injured leg.

Knee joint injuries are common in both athletes and in the general population. Quadriceps and hamstring control and development can help prevention or be used in the treatment of such injuries. Most clinical studies assessing the treatment of muscle injuries in sports medicine are based on serial isokinetic measurement. Outcomes of different exercise protocols or different training programmes have been evaluated using an isokinetic dynamometer. Many studies are focused on the assessment of the strength of the thigh muscles because of their important role, both in athletic performance and also in their supportive role for the knee joint.

A previous study found three major causes of injury. These were stopping and changing direction (19%), landing with the knee in extension (28%) and sudden block (26%). The possibility of a meniscus injury is significantly higher in ACL injured cases, compared to the normal population. If the anterior cruciate ligament is injured due to an impact it is highly probable that the medial ligaments and menisci may also be injured. This study suggested that the frequency of ACL injuries could be diminished by 89 per cent with the use of the "three-step stop" with the knee bent instead of one-step stop with the knee hyper extended, all techniques designed to decrease the quadriceps cruciate interaction[172].

ACL injuries commonly occur when an athlete needs to do sudden cutting, turning, deceleration and landing in training or in a game. Although ACL injury is common in contact and pivoting sports, such as football, rugby, American football and ice hockey, many injuries occur without any contact, for example in sudden twists[156 157 174]. It was found out that 81 of 176 (46 per cent) ACL injuries were the result of a tackle and most of the tackles came from the side[153], therefore correct tackling technique could prevent some of the injuries. To prevent the ACL injuries risk factors should be identified first. The risk factors can be intrinsic and person related such as the anatomy and biology of the player, and extrinsic factors, environment related, such as the playing surface, equipment and rules[157 175]. There are about 16 football-specific playing actions including kicking, passing, dribbling and heading the ball; making a tackle and a charge; receiving a ball, a tackle and a charge, jumping to head, shot on goal, set kick, and throw in the ball goal catching, goal punching and goal throwing. Some of them are associated with higher injury risk; in particular, receiving a tackle or a charge, and making a tackle, was actions with a significant risk of injury.

Several motor control theories explained the process of learning neuromuscular skills, however there is not enough theories to support improvement in sports performance. The cognitive stage is one of the theories that present three levels of motor learning. It explained the process of performing a task, the stage of alteration and improvement of that task, which is related to skill and the stage that the skill develops as an automated task, which is called autonomous stage. Neuromuscular training is the learning process following practice that a complex task becomes an automatic function. For instance, to learn a manoeuvre in sports, such as safe landing, needs repetition by the player and correction by appropriate feedback from the coach. In theory motor improvement is a product of cognitive processes by practising the technique, but the process is yet to be understood completely [99]. According to the theories in motor learning a function is a resultant of a motor programme, which is recorded, based on previous experiences as motor commands. When a well-learnt motor programme implemented after adequate practice fewer corrections are required. The motor training in various techniques should also include preparation for perturbations happening in a real competition, otherwise the motor response time to joint instability will be longer and injury would occur. There is research conducted on correct techniques in landing that showed that even verbal feedback on the technique of landing from a jump could reduce ground reaction forces. This kind of training programme appears to improve the technique, which may cause an appropriate pre-activation of stabilising muscles in a feed forward motor control system to protect the knee joint against forces leading to injuries.

The results of both concentric and eccentric contractions are velocity dependent. The velocity of movement has a negative relationship with the magnitude of concentric contraction and positive relationship with that of eccentric contraction. However change of eccentric contraction with velocity is less than that of concentric contraction. Therefore the E/C ratio is also velocity dependent and increased with increasing of the velocity of movement[176 177]. Most of reported values for E/C ratio from the literature has been gained in isokinetic tests with moderate to low velocities, because using higher velocities for eccentric contraction may cause muscle injury.

Knee injuries commonly occur during sports activity and the consequences are more serious and costly compared to the injuries of other joints[178]. Football players in particular suffer from increased knee injury risk, due to consistent changes in pace and direction which place the neuromuscular system under strain, causing a reduction in knee strength and an increase in joint laxity. Among all injuries occurring in the knee joint the ACL injury is the most common one with very long absence from the sports and lengthy rehabilitation period. It has been suggested that ACL has a sensory role for the ACL .So the neural and proprioceptive action of the ACL in the stability of the knee joint is as significant as its biomechanical role. It was shown that postural control declined after ACL injury. Mechanical stability of the joint might be restored after an ACL reconstruction; however there is still controversy regarding the effect of this surgery to restore sensory input[179].

In a study that was conducted at Karolinska institute, postural control of 18 patients with chronic ACL insufficiency was compared with that of the control group. Results showed an impaired postural control in single-legged stance on both the injured and the uninjured leg even several years after injury[179].

There has not been a study similar to this research that the BSS was utilised to assess potential impairment of the ACL injured knee after reconstruction. In the valuable book of Lephart [97] the "Proprioception and neuromuscular control in joint stability", several studies were mentioned that were comparable to the present study. For instance in 1989, Barrack and co-workers observed a statistically significant increase in the threshold to detect passive motion in ACL-deficient subjects. Similar results were reported by Corrigan et al [as cited in 97] who demonstrated that after ACL injury the static position sense would be diminished. Barrack et al also noted an increased "threshold to detection of passive motion" (TTDPM) in many ACL-deficient knees with functional instability. This result was confirmed by Corrigan et al who also found reduced proprioception following ACL injury. Lephart et al demonstrated a reduction in the ability to detect motion, using a similar experimental approach in 1992. This was not improved after ACL reconstruction, using patellar tendon graft.

No significant difference in reproduction error was found between injured and intact limb in work of Co and co-workers on 10 subjects with reconstructed ACL. There was no meaningful difference between patients and normal group in reproduction error in detection of the position of the knee joint. Both injured and intact limbs of the patients were even more accurate in measuring the threshold compare to that of the control group. The accuracy of the result of the tests of the ACL-injured limb was less in TTDPM. Similar results were reported by Clark et al on 8 unilateral PCL-injured patients. The difference in TTDPM was significant between two sides[183]. In another research on 51 ACL-reconstructed knees by Harter et al no difference was reported between the normal and the injured knee. However their methodology was different. Instead of measuring the TTDPM, they used a less sensitive test, the passive positioning reproduction. As it explained in the literature review section of this chapter in the reproduction test in post reconstruction ACL injured patients Newberg reported a significant difference between injured and non-injured leg [160] .

Now it could be argued whether the non-significance results gained from the comparison of balance tests of injured and non-injured legs in this study were as a result of positive effect of surgery or the weakness of the Biodex Stability system. Oeffenger also showed that patients with reconstructed ACL-knees had a better coordination compared to non operated ACL-injured patients. Similar studies were conducted by Jerosch and Prymka on 25 ACL-injured subjects, 11 after reconstruction and 14 before reconstruction. They concluded that the coordination of post-operation group was significantly better than pre-operation group. Conversely Rasmussen did not find any significant difference between two groups of ACL injured patients with and with out ACL reconstruction[180]. If an ACL reconstruction operation is performed well followed by an appropriate rehabilitation program, proprioception will function close to normal. However, to what extent the proprioceptive ability after an ACL rupture can be fully restored has to be affected after an ipsilateral joint injury. Joint position sense was measured in another study in normal and instable ankles, no significant difference was found between normal and intact ankles[145]. However in a similar study the difference in detecting of joint position in active and passive movement was significant between normal and instable ankle joints[188] .

Perron et al measured the postural control of the patients with lateral ankle sprain, using the Biodex Stability System. They compared the limits of stability between injured and non-injured legs as well as between the injured ankle and the normal control group. Their main findings were that the Biodex Stability System had poor differentiating properties and that the overall dynamic limit-of-stability score did not relate to the subject's functional capacity. They suggested testing dynamic postural control on an unstable surface also evaluated other factors possibly contributing to impaired dynamic balance, such as strength deficits, pain, mechanical instability and inadequate control at the proximal joints.

Unlike the variables related to balance, some of the isokinetic measurements were found to be sensitive in terms of the differentiation of impairment after ACL reconstruction. These variables were isometric quadriceps maximum torque at 80º of the knee flexion, isometric hamstring maximum torque at 40º of the knee flexion, concentric quadriceps peak torque at velocities of 50º/s and 150º/s, concentric hamstring peak torque that obtained with the test velocity of 50º/s, concentric quadriceps torques at the velocity of 30º/s and 180º/s, and eccentric quadriceps torque at the velocity of 30º/s and 180º/s. Examining these findings shows that most of the variables are related to quadriceps strength. There is evidence that this muscle is very sensitive to injury and becomes atrophied and weak after even minor to moderate traumas. Even joint effusions influences sensorimotor activities and cause muscle atrophy. Joint effusion may occur in acute trauma, as well as in degenerative and inflammatory conditions. The inflammatory nature of the fluid in a chronic effusion may cause proprioception deficit[181] .

For years, knee surgeons have postulated that the sensory loss associated with ACL injury may affect the results of ACL repair and reconstruction. Certain reconstructive techniques have been advocated, in part, to increase afferent preservation... It is well known that unstable knees, due to ACL injury and particularly in cases with re-injury can lead to arthritis over time[97]. There is evidence that reduced proprioceptive following ACL injuries may be re-established after reconstruction procedures. The association between a proprioception deficit and the subsequent development of an arthritic knee is not proven, however there are some studies suggesting that, proprioceptive loss results in arthritis[182]. In reproduction tests on 35 patients after

ACL reconstruction Newberg observed a significant difference between the injured and intact legs[160]

There are some contradictions about muscle activity changes. The reason for at least some of the inconsistencies is the fact that the muscular activation patterns have been investigated during very different activities such as, for example, walking, running, cutting, and stair climbing. In a study by Sinkjaer et al [cited in 97] patients with ACL injury did not show any significant difference in EMG activity of muscles around the knee joint in normal walking, when compared with normal subjects. However the injured group had different EMG patterns in uphill walking. Muscles around the knee joint showed earlier onset and longer duration of activity compared to the control group. These alterations in EMG pattern were greater in the hamstring and gastronomies muscles. The early recruitment and prolonged activity of these muscles may be a dynamic compensation of muscles to an insufficient static stability. So this compensatory mechanism in ACL-injured patients could secure the functional stability of the knee joint[97]. In the case of swelling of the knee joint, due to haemarthrosis or effusion, there might be a disruption in EMG, with out any ligament injury. The receptors in ligaments and capsule are intact, but as a result of pressure or tension stimulus provide incorrect information. The function of the quadriceps (particularly the oblique fibres of the vastus medialis) can be inhibited up to 60% by a small (20-mL) knee infusion[183]. This inhibition can deactivate the neuromuscular pathway and result in insufficient or uncoordinated muscle group activation.

Reflex latencies may occur in ACL-injured athletes by stimulating episodes of anterior tibial translation, triggering hamstring activation through ACL feedback or from the receptors in muscle, tendon and capsule. Reflex hamstring latency in the involved leg was nearly twice that of uninvolved and controls limbs. Increased reflex latency may be due to proprioceptive deficits that may impair joint function. It was hypothesised that rupture of the ACL might interrupt the ACL-muscle reflex arc. So a slower pathway would be triggered from the receptors of other articular soft tissue, such as muscle and capsule. But the muscle activity in response to this second pathway would be an abnormal pattern that could reduce dynamic knee stability[184].

The EMG of athletes with ACL deficiency has characteristic patterns in walking and running. Early recruitment of an antagonist acts as a compensatory mechanism and the inhibition of the agonist occur under the feed forward process of motor. Several investigations have shown enlarged lateral hamstring activity during the stance phase of walking and also in cutting. This increase in hamstring activation is a compensatory mechanism for ACL deficiency. It reduces the anterior tibial translation and rotation. It has been shown that during the swing phase of gait, quadriceps activity is inhibited. The inhibition of the quadriceps muscle, prior to heel strike, prevents the anterior shearing forces at ground contact. Hamstring activation and quadriceps inhibition reflect preparatory mechanisms to anticipated joint loads that preserved joint equilibrium and stability[184].

Many investigators have studied the effects of joint effusions on sensorimotor activities and muscle atrophy, with different results. Proprioception deficit is reported in patients with joint diseases, such as rheumatoid arthritis, osteoarthritis, and Charcot arthropathy. In a study on the effect of joint effusion on proprioception MacNair et al injected saline into the knee joint and examined the results. But they did not find any significant difference. They suggested that the reason of the negative result was the short time of effusion. In pathologic conditions the inflammatory nature of the fluid and the chronic effusion may cause proprioception deficit[181] .

Many researchers measure the joint position sense to assess proprioception. There is inevitable relationship between proprioception and postural control; however they are not one entity. It was not possible for this research to work on each aspect independently, e.g. balance with the exclusion of proprioception. From three aspects of this thesis, the balance was explained more in chapter two, the isokinetic strength was analysed in chapter three and the proprioception has been discussed in this chapter. One might say the methodology of this chapter is more related to postural control and balance, in addition to isokinetic, rather than proprioception, however these are all related issues and with reference to the plan of the thesis each one has been dealt mainly in one chapter. The reason that the methodology of this research focused mainly on postural control, rather than proprioception was the clinical value of these tests.

Perron et al stated in respect to the results of proprioception studies: "Unfortunately, these results are of limited value for the clinician because no clear relationships between proprioceptive deficits and functional capacity were shown"[185]. Then Perron recommended the evaluation of the postural balance as a clinical alternative. As explained in chapter 3-1 of the recent equipments to assess neuromuscular control is the Biodex Stability System (New York, USA). This device measures the ability of a person to maintain dynamic postural stability on an unstable surface. Although there have been evidences that this device is reliable and also in chapter three the protocol for the present studies showed to be reliable, the measurement properties of the BSS are not known, in particular there is no study to allow differentiation between an injured and the contralateral non-injured side, using the BSS. So an objective of the present study was to assess some of the measurement properties of the BSS in subjects with ACL injury after reconstruction.

There are other functional assessments, which also test the balance and neuromuscular control such as tests of stance on a wobble board[186], single- leg stance balance[187], which could be performed with eyes open or closed[165] .These functional tests do not test just one joint. The advantage of these tests compare to measuring the position sense is their similarity to real functional activities; however the measurement of the position sense is specific to proprioception of an isolated joint. Functional activities of the lower limb are largely in weight bearing positions and these functional tests are also performed in closed kinematic chain. Tests of position test however are performed in open kinematic chain in a non-weight position[188] .

Neuromuscular training programmes can operate as pre-planned motor responses to enhance the feed forward system and reduce motor response time[189]. The body detects the disturbances in balance via proprioception and tries to maintain balance by fast motion responses. Body's responses could be in a close circuit in reaction to sensory inputs that are integrated in the CNS and/or in an open loop. So neuromuscular training can prepare the body to anticipate the perturbations in fast movements of sports activity in a feed forward control. Enhancement of this type of control provides a quicker response in body motion that lead to an in time reaction to stabilise joints and prevent the potential injury[97].

Proprioception insufficiency may be caused by muscle fatigue or inaccuracy of afferent and efferent input [190 132]. Mechanoreceptors, such as Ruffini's endings, Pacinian corpuscles and free nerve endings[190 169 191] provide the input for the afferent pathways. They adjust the response time of muscular activation, which is responsible to maintain the centre of balance of the body [191 192] .These receptors that are located in the muscles, joints and skin, detect the position of the joint. They also interpret an active or passive joint movement in open and closed kinetic chains. Mechanoreceptors, such as Golgi tendon organs and muscle spindles are located in tendons and muscles. They monitor muscle tension and changes in muscle length respectively. The information provided by mechanoreceptors is integrated in the CNS. The processing of this information leads to produce motor responses to maintain balance. Deficiency in mechanoreceptors and afferent system would increase the respond time of the balancing system, due to the late reaction of muscles[190 132 163 169] .

The aim of the proprioception programme is to allow the athlete to consciously or subconsciously control the pivot shift. This requires hamstring activation that minimises the forward movement of motion of the tibia from underneath the femur. If the knee rehabilitation program is to be successful the athlete must be able to control pivot shift by hamstring activation. This is an automatic action and can be very difficult for an athlete to master. A coach and medical specialist should work together with athletes who have had ACL injuries, or participating in a sport prone to ACL injuries, to ensure they complete proprioception exercises on a regular basis[193] .

5.1 Conclusion Chapter

The final chapter consists of the key findings, the conclusion and implication, as well as the limitations of the study and suggestions for future studies.

More and more adolescents are participating in organised sport. Such participation from a young age has become a popular culture in particular in Western countries. They tend to start in youth sport at a very early age, even before puberty, which is possibly due to the 'catch them young' philosophy[194].

The main areas of interest in the first part of this study included injury prevalence, injury severity, type and anatomical site of injuries. The main observations in this study on Scottish youth football players during one season can be summarised as follows:

- There was a high incidence of injuries in youth football suggesting that methods of prevention should be explored.
- The rate of the lower extremity injury was about 6 times more than that of the rest of the body.
- The knee and ankle joints were found to be the most affected anatomical sites.
- The absolute number of injuries was 3-fold greater in matches than in training. However, measuring the incidence of injury in 1000 hours of exposure although there was a trend for more injuries in competition, there was no significant difference between the two activities. The rate of injury was 6.31 per 1000 hours of total exposure.
- The rate of injury was not significantly different in the two levels of players whether at high school or professional level.
- About one fifth of injuries were minor, about one third were moderate and the remainder were severe injuries.
- There were slightly more injuries in the second half than occurred in the first half of competitive games.

- Contact injuries were more common than non-contact injuries. The most frequent type of injury was muscle strain followed by fracture, bruise and sprain. The high percentage of contact injuries, and in particular fractures, in youth football, should attract more attention to consider modification of the rules of the game in this age group. Less contact would reduce the advantage of physical size and strength in early developers and also allow the development of playing skills in players with smaller stature. As the rate of injury is high, regulations should be particularly enforced in these subject groups.
- A considerable number of injuries were managed by the coach. It indicates that the first administration of medical care by all touch line carers should be appropriate with training in sports first aid and the initial management of injuries

The descriptive and analytic results of this study, which identified the problem of sports injury in youth football players in Scotland, in conjunction with the findings of other epidemiologic investigations, can be implemented to establish in-depth preventive measures. The outcome of these studies could be used by authorities and governors who work in the field of football. As a result adequate protection against injuries and appropriate care for the injured players could be provided at high school football level. The administration of public schools and football coaches in Scotland should be informed and educated in this regard to evaluate the risk of injury and to develop and apply preventive strategies. Otherwise safe practice and participation in sport and in particular in football cannot be met. The coaches should prevent previously injured players from taking part in competition and high impact training sessions until the rehabilitation programme is completed.

Due to the high incidence of injury in young Scottish players and the susceptibility of this age range, the number of competitions should be reduced, in particular in November or April when the rate of injuries was higher. Intensive training of more than 20 hours per week seems to be too much for youngsters at school level. The results of the present study on a group of young players in Scotland showed that fracture accounts for about one fifth of all injuries in football. The suitability of youngsters for participation should be assessed, as their musculoskeletal system may not be matured enough when they are in the process of growth. Tripping over the ball and movements with the ball, such as turning and cutting in the category of non-contact mechanisms of falls are also common causes of fractures in football. Coaches should focus on these skills in training and make sure that adolescents are confident enough in these manoeuvres before they are recruited for competitions. Proprioception and balance exercises should be recommended to the coaches as part of their routine practice for adolescents

The process of injury prevention can be divided into four phases.

a) Phase one includes the description and classification of the level of the injury.

b) Phase two is identification of the injury mechanisms and the risk factors, which cause injuries.

c) Phase three is execution of preventive strategies founded on phase 1 and 2

d) Phase four is evaluation of the implemented strategies to assess their efficiency [195] [196]

The present study focused on the first two stages. The incidence and the severity of sports injury can describe the problem of sports injury. However, the method of this study was an injury prevalence study rather than an injury incidence one, as it was retrospective research. The application of results of research on the prevalence of sports injury depends on how the 'sports injury' is defined. As far as the comparability of the research data is concerned the definitions should be consistent. The second phase of injury prevention, as pointed out earlier, is identification of the causative factors, which should be considered in further research looking at aetiology and epidemiology of sports injury.

The results of the reproducibility study on two groups of subjects in two age ranges demonstrated good to excellent test re-test reproducibility for all four measures of the bipedal Overall Stability Index, the unipedal Overall Stability Index for dominant and non-dominant legs and the bipedal Limits of Stability using the Biodex Stability System. These strong reproducibility scores which were found in this study confirmed the consistency of the obtained results the subjects in this sample. It was possible to proceed and perform other studies, using the Biodex Stability System as the testing device in the sporting and patient groups.

The extension of the second study aimed to examine strength and balance characteristics in three groups of professional, non-professional and non-football players. The professional group had significantly higher values of several isokinetic test values when compared to the non-football players. These values were the concentric right hamstring strength, the concentric left quadriceps strength, the concentric and the eccentric quadriceps strength. The same eccentric isokinetic test on the contralateral knee and the eccentric test of the left quadriceps at the speed of 180º/s were also significantly different between two the groups. Finally the isometric tests of the hamstring muscle at 25 degree of knee flexion were significantly different. These key values regarding isokinetic muscle strength could be used to develop training programmes to improve imbalances of muscle strength which may prevent injuries and improve the performance level of young football players. In reference to the evaluation of players to select talented performers it is recommended that isokinetic assessment be utilised to distinguish the potential strength of players. The protocol that was used to evaluate balance, however, did not show changes within these groups. Both groups of players may be highly selected and under systematic training.

Biological maturity does not occur at the same age in all children. Adolescents competing in the same age group might not be at the same level of maturity. Within one chronological age group there might be early maturing players who compete with late maturing players in an unequal competition. Using only age group categories is therefore not always reliable. Individual physical differences should be considered using a method of maturity estimation.

The final study was conducted to find which methods of assessment could differentiate neuromuscular impairment and muscle strength after ACL reconstruction. Sensitive methods of evaluation are necessary to identify neuromuscular strength and functional impairment. Using the result of such evaluations, the next stage of rehabilitation could be identified and the physiotherapist could also decide on the criteria to allow a return to sport.

The findings of this study, confirm that various types of measurement of the quadriceps strength, using the isokinetic dynamometer may be employed for the purpose of evaluation and differentiation of impairment after ACL injury. The findings of this research did not confirm usefulness of the balance assessments, using the BSS. These tests could not identify differences between the injured and intact knees. This could have two explanations. The stability of the ACL-injured knees might have been very close to the normal condition after reconstruction and rehabilitation and/or the protocol of this study, using BSS was not sensitive enough to identify potential impairments in balance. Further serial studies in individuals with ACL injuries should be performed with the balance system compared to force plate or other methods of assessment.

The aim of rehabilitation of the knee joint should be to improve the function of whole lower limb, rather than just the function of the knee joint. Several studies which were reviewed in this chapter showed the positive effect of proprioception and balance exercises in the prevention and rehabilitation of sports injuries. Caraffa[161], for example, suggested that athletes should be trained with appropriate proprioceptive exercises, such as single leg drills and when ready for dynamic activities a 14-inch by 14-inch wobble board can be used, which could be advanced to a smaller size board. In addition to these activities the athlete should be taught sport specific manoeuvres[161 193]. With this in mind each coach should consider incorporating this type of exercise into everyday training with all athletes.

Preventative strategies are strongly supported by researchers who report on the prevalence of knee injuries. Half of all organized sports-related injuries among young players can be prevented. It is a very complicated issue to prevent sports injuries in the knee joint. Further studies are required of exercise programmes and rehabilitation strategies.

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5.2 Limitations

A low response rate to a questionnaire is a limitation in any study. The overall response rate of 55.25% means that selection bias may exist in this study. This may lead to the over-reporting or under-reporting of the incidence of injuries. However the results of this study were similar to the findings of other studies. This suggested that the effect of possible bias was not great. The results do stress the problems of performing research in sporting groups from an external source with no previous contact and recruitment improved in the later studies following the familiarity of the author with the sporting groups.

Recall bias is a possibility in a retrospective self administered questionnaire based study. This could have an impact upon the reliability of the data collected. To minimise the effect of recall bias this study was carried out just over one season. The true effect and incidence of overuse and carry over injuries could be extended by performing studies over a longer period. The infrequency of ACL injuries in the young population meant that a wider source of patients had to be sought and recruited.

There is a degree of controversy surrounding the definition of injury used in different studies. Although the most common definition was used in this study, it is possible that some injuries were not recorded. Serious injuries which required a player to leave the field of play and to miss training or a competitive match are easily remembered but this may omit players who were injured but decided to continue playing.

A bigger sample size could have been used for the two cross sectional studies. Longitudinal cohort studies could have been preferred for the study design. Lack of normative data for isokinetic assessment, using the Rev 9000 dynamometer and in particular balance data using BSS was a pre-study limitation. Finding the normal range for a large and variable specific population may require a very large sample size. The results could be extended to a larger population with varying heights, weights and body habitus.

For the study of the ACL injuries observations should be extended to subjects who had different operative procedures and be conducted serially at different phases of rehabilitation. This would need a large sample size, in order to include a satisfactory number of subjects in the different surgical groups. A group who had conservative rather than surgical management should also have been included.

5.3 Future Studies

There are many studies looking at the prevalence and incidence of football injuries. Some of them follow a similar methodology to collect data, but future studies are required in particular in young players to fill the gaps in present knowledge. Such research in a similar context to the current study may play a significant role in the development of programmes which may lead to the prevention of injuries. In general data collected would be more valuable if obtained prospectively.

Ideally enough funding should be available with a supporting research team including appropriate administration and sports specific members to work together in a prospective study over a few seasons. This would be more valuable using more detailed methods. The addition of video recordings of matches and an agreed method of reporting of injuries could add much to the present observational data and allow more detailed study of this challenging area in the young. .

Ongoing injury prevalence studies using a uniform definition of injury are required to extend the present data in Scottish youth football to detect changing patterns or trends of injury frequency, injury severity, anatomic injury sites, and mechanisms of injury. This kind of research could also be expanded to other age groups, including children and adolescents to compare the rate, pattern and trend of sports injury and the relationship of these parameters with continued high levels of activity in talented youngsters. The influence of the activities of Youth Academies should be monitored and such studies applied to different sports.

The definition of injury in future studies should be as specific as possible, but at the same time well accepted by the wide range of researchers. Overuse injuries, which have the potential for serious long-term effects, may have particular interest in the young.

The next step of the present study could be that having recognised the mechanisms and risk factors that cause the common injuries in youth football preventive strategies should be considered and introduced with a research protocol.

More research is also needed in talent recognition to identify the factors that determine potential players for future high standard performances. Injury prevention strategies on this player population may be an interesting avenue for further research, and prove worthwhile in limiting the extent of overuse and long term injury. Longitudinal studies are particularly important in this area.

There are limited studies into the efficiency of preventive strategies for sports-related injuries. Exercise programmes may be a good option in the prevention of specific knee injuries and are cost effective and practical. The wider application of extended cardiovascular fitness programmes seem to be promising in combating sports related injuries[161] .

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