Quantifying Eccentric Hamstring Strength in Elite Academy Footballers: Analysis of the NordBord and IKD

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STUDENT DECLARATION FORM

Type of Award – MA (by research) School of Health Sciences

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Abstract

Context: Hamstring injury is a prevalent muscle injury in sports, reduced hamstring strength is associated with such injury risk but has also been shown to impact on knee function. Hamstring injury-risk assessment and methods of quantifying eccentric hamstring strength for return to play criteria following injury have primarily been investigated using isokinetic dynamometry (IKD). However, practical issues such as cost and availability limit the widespread application of isokinetics for injury-risk assessment; thus, a field-based alternative for assessing eccentric hamstring strength (NordBord) has been developed. The use of the NordBord is growing within elite performance environments, but questions remain with regards the parameters utilised to quantify eccentric hamstring strength and whether it has the potential to replace the IKD as a gold standard alternative.

Objective: The aim of this study was to investigate the reliability of each device in elite youth soccer, whilst aiming to further investigate the correlation between the two pieces of equipment to see if similarities or differences occurred when comparing the parameters of average torque (AvT), peak torque (PkT), breaking angle/angle of PkT (ϴ). Intentions of the study were to guide practitioners in the use of each in an elite applied environment.

Participants: Thirty-four male elite footballers from Premier League Category 1 Academies (mean ± SD age 17.60 ± 0.76 y, height 179.23 ± 7.8 cm and body mass 72.7 ± 9.9 kg) acted as subjects for the study.

Methods: Participants underwent eccentric knee flexor testing on the IKD at varying testing speeds (60°·s-1 and 150°·s-1) to determine PkT, AvT, ϴ. Likewise participants completed the NordBord to determine results of PkT, AvT and break point angle. The Nordic break-point angle (the point at which the subject can no longer resist the increasing gravitational moment during a Nordic hamstring lower) was measured using video analysis. Study 1 was designed to determine the test-retest reliability of each modality of assessment. Study 2 continued to analyse the relationship between the results of the IKD and NordBord to determine where, if any correlations occurred.

Results: The results from study 1 revealed excellent test-retest ICC scores for the IKD across both testing speeds for all parameters (ICC = 0.87 - 0.91). In contrast to the NordBord which found fair to moderate ICC values for PkT and AvT (ICC = 0.56 – 0.76) yet excellent for break point angle (ICC = 0.92). In study 2, when identifying correlations between the two testing devices, the present study acknowledged very weak relationships between the NordBord and the IKD when analysing the parameters of AvT and PkT at the slower speed of 60°·s-1. This trend continues with the IKD at 150°·s-1 for the right leg, but interestingly a strong correlation was seen for the left leg.

Conclusion: Quantification of eccentric hamstring strength in elite academy footballers is a contemporary concern. Prior to identifying any potential injury risk, the outputs observed across the IKD and NordBord must be reliable and clearly relate to injury mechanism. In study 1 the IKD was demonstrated to be a reliable measure of all parameters observed (PkT, AvT and ϴ). In contrast parameters of PkT and AvT determined via the NordBord must be interpreted with caution. Contrastingly, break angle when performing the NHE on the NordBord displayed excellent reliability and should be considered in practice to determine the muscle architecture of elite academy footballers. The speed and ease of testing when utilising the NordBord is a huge advantage to practitioners in the field and study 2 identified clear relationships between ϴ and break angle. Highlighting, the use of the NordBord in practice for establishing the muscle architecture of individual athletes.

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List of Abbreviations

HSI – Hamstring strain injuries
NHE – Nordic Hamstring Exercise
ACL – Anterior cruciate ligament
RTP – Return to play
PkT – Peak torque
AvT – Average peak torque
Θ – Angle of peak torque
IKD – Isokinetic dynamometer
H:Q – Hamstring to quadricep ratio
BFlh – Biceps femoris long head
MOI – Mechanism of injury
MTS – Musculotendinous stiffness
MTJ – Musculotendinous junction
OSD – Osgood-Schlatter disease
ICC – Intraclass correlation coefficient

Chapter 1 - Introduction

1.1 Overview

There is a wide spectrum of hamstring-related injuries that can occur in an athlete, of these, hamstring strain injuries (HSI) are the most prevalent cause of lost playing and training time (Hägglund, Walden & Ekstrand 2009). Athletes are at an increased risk of acute hamstring strains in sports with large exposure to high velocity eccentric contractions, such as football, (Arnason et al., 2004; Ekstrand et al., 2011b; Elliott, Zarins, Powell, & Kenyon, 2011), Australian Rules (Gabbe, Bennell, Finch, Wajswelner, & Orchard, 2006), athletics (Alonso et al., 2010) and cricket (Orchard, James, & Portus, 2006). Although injury audits in Elite Academy football are not well documented in research, this limited research continues to identify the severity of hamstring injuries at a youth level. Price et al, (2004) identified that hamstring injuries account for 34% of all lower limb muscular strains. While a prospective cohort study including all registered players at one English Premier League Football academy over the 2012-2013 season found that posterior thigh injuries accounted for 13% of all injuries seen (Renshaw & Goodwin 2016). The force exerted from eccentric contractions may have other implications for lower limb injury not solely linked to hamstring conditions. Structural knee pathologies including anterior cruciate ligament (ACL) and meniscal injuries are linked to poor levels of eccentric hamstring strength as excessive anterior tibio-femoral translation may occur. This highlights the importance of the stability provided by the hamstring muscle group. Along with hamstring strains, ischial apophyseal injuries are another common condition associated with posterior thigh pain in youth athletes (Heyworth et al, 2014). Apophyseal avulsion fractures are usually the result of a sudden forceful concentric or eccentric contraction of the muscle attached to the apophysis. Like other paediatric fractures, apophyseal avulsion fractures fail through the physis with the primary age for these injuries to occur being between 14 and 25 years old (Salter & Harris 1963, Heyworth et al, 2014). Other hamstring-related injuries include hamstring strains, complete and partial proximal hamstring tendon avulsions, proximal hamstring tendinopathy, and referred posterior thigh pain (Sherry, 2012; Sherry, Johnston & Heidersch, 2015).

Hamstrings strains are clearly multifactorial and have been related to; poor functional muscle-strength imbalance, poor flexibility, muscle fatigue, inadequate warm-up, previous strains and inadequate rehabilitation (Opar, Williams & Shield 2012). Lower levels of eccentric hamstring strength have been reported as a key risk factor for HSI (Croisier, Ganteaume, Binet, Genty & Ferret 2008; Sugiura, Saito, Sakuraba & Sakuma 2008), indicating the importance of high eccentric strength for reduction in HSI incidence (Petersen, Thorborg, Nielsen, Budtz-Jør¬gensen & Hölmich 2011). Lee, Reid, Elliott & Lloyd (2009) demonstrated that, previously strained hamstrings display reduced levels of eccentric knee flexor strength compared to those in the uninjured contralateral limb, although some questions remain, this may give some explanation for why approximately one-third of hamstring strains will reoccur. The high recurrence of these injuries may be suggestive of an inadequate rehabilitation program, a premature return to sport, or a combination of both. With athletes return from injury being guided not only by the knowledge and clinical reasoning of a practitioner, but also by objective return to play (RTP) measures, quantification of eccentric strength performance may provide the answers to not only reduction of injury incidence but also re-injury. This becomes highlighted even further when the time and financial consequences of recurrence are high, with recurrent hamstring strains having been shown to result in significantly more time lost than first time (Lauren, Erickson, Marc & Sherry, 2017).

Due to the high occurrence of hamstring strain injuries there has been significant research interest in hamstring injuries in recent years and this has led to the development of new concepts and practices in injury prevention (Petersen, Thorborg & Nielsen 2011; van der Horst, Smits & Petersen, 2015) and rehabilitation (Sherry & Best 2004; Fyfe, Opar & Williams 2013; Askling, Tengvar & Tarassova 2015; Mendiguchia, Martinez-Ruiz & Edouard 2017). Unfortunately, it is not clear whether these research findings have had a significant impact on primary hamstring injury and recurrence rates in elite sport (Ekstrand, Hagglund & Kristenson 2013; Ekstrand, Walden & Hagglund 2016). This is highlighted with the number of hamstring injuries being on the rise in football with observations from UEFA’s Champions League football suggesting that the total number of hamstring injuries per 1000 h of exposure have increased by 2.3% per year over the past 13 years (Ekstrand, Walden & Hagglund 2016). Perhaps our improved understanding is only just keeping up with increases in training volumes and intensities that predispose athletes to risk. New broadcasting rights and developments in sponsorship within the sport have led to players being expected to play more frequently with less rest between games

(Barnes, Archer & Hogg 2014), highlighting the effects fatigue may be having on injury risk. The temporal pattern of injury during match play also indicates that fatigue might be a factor. In English professional soccer players, 47% of match-play hamstrings strains were incurred during the final 15 minutes of each half, (Woods et al., 2004). Low levels of eccentric strength have long been considered a major contributing factor towards hamstring injuries occurring. Grieg & Seigler (2009) outlined peak eccentric torque generally decreased as a function of exercise duration through each half when looking at the effects of soccer specific fatigue on eccentric strength ability. The levels of eccentric hamstrings strength noted following fatigue supports Woods et al, (2004) with hamstrings strains more likely to occur during the latter stages of match play. The greatest deficits of peak torque were noted at the fastest testing speed indicating that the risk of muscle strain injury increases during explosive actions such as sprinting.

Being able to quantify hamstring strength with knowledge of sound, reliable results is vitally important for researchers and practitioners to try and reduce such injury rates. These objective markers can highlight uninjured athletes with poor strength or large imbalances as ‘risk’ players at an increased chance of injury and likewise can be used to guide the rehabilitation process whilst being able to set clear and objective RTP markers. Using the same metrics for both injury prevention and rehabilitation is imperative in developing improved understanding. Injury prevention models require objective measures to analyse the success of an intervention. The injury prevention paradigm was first proposed by Van Mechlen (1992), who published a paper on the conceptual underpinnings of injury epidemiology in sports and has since been cited more than 420 times and has been a template for several hundred epidemiological studies on sports. The model proposes a four-step process to injury prevention: (1) Establish a system to capture injury events, and ideally exposure data, to determine the size of the problem, (2) analyse injury data to identify risk factors and mechanisms of injury, (3) develop and implement prevention strategies based on careful review of (2), and (4) evaluate the efficacy of (3) by capturing new data from (1). Eccentric hamstring strength has been through this process and highlighted throughout literature as a model to reduce hamstring injuries from occurring (Prior et al., 2009; Engebretsen et al., 2010; Freckleton & Pizzari, 2013; Opar et al., 2015; Timmins et al., 2015; van Dyk et al., 2016), quantifying hamstring strength then becomes the emphasis to give consistency and transparency to practitioners and researchers alike.

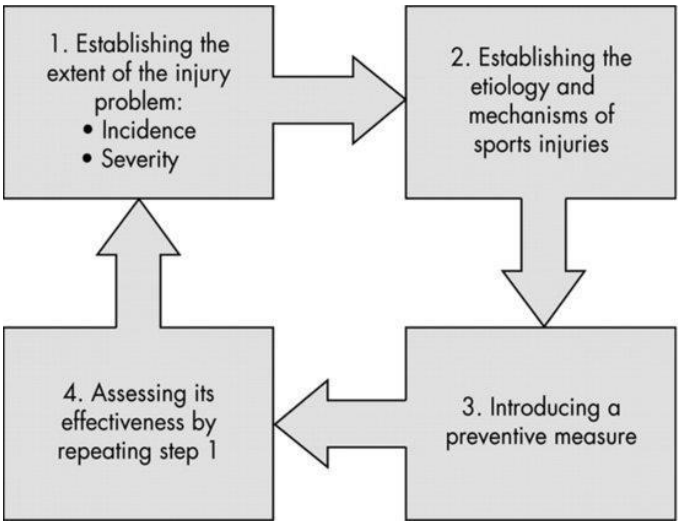

Figure 1.1 The Four-Step 'Sequence of Prevention' described by Van Mechelen et al., (1992).

The financial loss occurring from the high incident rates of hamstring injuries has highlighted the need to effectively monitor athletes to minimise modifiable risk factors associated with injury. Evidently reduction in eccentric strength (Mair et al., 1996; Small et al., 2008; Greig., 2008; Greig et al., 2009; Small et al., 2009; Delextrat, 2010) is a key contributory factor to hamstring injury however, importantly, is vitally significant in relation to common knee injuries seen in academy players. This is due to the role eccentric strength plays on the dynamic stability of the knee and in particular the ACL.

It is common place to screen and monitor athletes in elite sport, inclusive of academies, to guide injury prevention strategies and rehabilitation. Historically, isokinetic Dynamometry (IKD) testing has been commonly used to determine concentric muscle strength with an association with stronger athletes being less likely to become injured. However, in recent times some academic studies have claimed that strength assessments may provide a poor association with predicting injuries (Bakken et al., 2018). Therefore, contemporary examples of measures taken to inform injury prevention strategies for hamstring injury include eccentric Isokinetic Dynamometry (IKD) and the NordBord. Although similarities are evident with the outputs given to quantify hamstring function, individual interpretation of data and individual's preference of equipment may lead to confusion and contradictory information related to the data output from each device.

Quantification of eccentric hamstring strength within football is common practice and research highlights the isokinetic dynamometer as a gold-standard marker for functional hamstring strength. Literature highlights its use in RTP and injury prevention strategies. Although to date, this approach has seen no reduction in the incidence of these injuries (Aagaard, Simonsen, Magnusson, Larsson & Dyhre-Poulsen 1998). Opar, Piatkowski, Williams & Shield (2013), recently developed a novel field testing device for the assessment of hamstring eccentric strength known as the 'NordBord'. The device is based on the commonly employed Nordic hamstring exercise giving unilateral strength scores. The NordBord is commonly seen and utilised in some elite sporting environments. Justification for its use is its portability, ease of use and speed of data analysis. Consideration must be given to the data output of both the IKD and NordBord to identify whether comparisons can be made between the two pieces of equipment. As demonstrated, incidence of both these injuries are rising in sport despite previous research and gold standard methods potentially due to the limited use of the equipment required. Comparisons highlighted through this study may provide support for the use of the NordBord as a field-based assessment for eccentric hamstring strength overcoming some of the practical limitations of isokinetic testing.

1.2 Aims and Structure of Thesis

The aim of this thesis is to analyse two contemporary measures of functional hamstring strength in elite academy footballers, identifying if relationships exist between the data output of the IKD and NordBord. Of note, there is a lack of research associated with quantification of functional hamstring strength in elite academy footballers. Both the IKD and NordBord provide measures of PkT, AvT and ϴ. Identifying relationships within measures could provide justification for their use within an elite academy sports setting. Research identifies a variety of testing speeds within Isokinetic measures and has been consistently used demonstrating high levels of validity and reliability in determining the associated values (Svensson et al., 2005; Impellizzeri et al., 2007; Maffiuletti et al., 2007; Greig., 2008; Cesar et al., 2013; Ribeiro et al., 2015). Although, none of these have been carried out in elite academy footballers. In addition, the thesis will also identify the reliability of measures associated with the IKD and NordBord within elite academy footballers. The NordBord output of PkT, AvT and Ɵ will be compared against differing speeds completed on the IKD to identify if there are associated relationships.

The significance of this thesis is to develop the current body of work regarding the use of a portable device to determine similarities or confusion for the utilisation of IKD and NordBord in Elite Academy Footballers. As mentioned previously, hamstring injuries result in significant loss of playing time resulting in substantial time and cost implications. More importantly in youth athletes, this can lead to loss of development time which can contribute to the fine margins required to make it in the professional game. Conclusions drawn from this research will inform of the preventative strategies used to combat low eccentric strength as a risk factor for hamstring injuries occurring, informing practitioners which measures are best suited to inform decisions. Comparisons made will also inform and guide rehabilitation processes by providing a greater understanding of the reliability of each measure but also when they should be utilised throughout the RTP procedure. Less reliable measures may still have their place in the process used as training tools to give informative feedback and to track progress however, the decision to return an athlete to training and competition requires an objective and reliable input. As discussed previously, re-injury can have a detrimental effect on a young athlete’s career prospects by keeping them off the training pitch for substantial periods of time, emphasising the importance that useful information is used to guide both injury prevention and rehabilitation implemented in the future. With the rise in popularity throughout elite sport in the application of the NordBord as an alternative measure of eccentric hamstring strength to isokinetic dynamometry, the studies in the thesis aim to determine the reliability of each device in elite youth soccer. Study two then aims to further investigate the correlation between the two pieces of equipment, with intentions to guide the use of each in an applied environment.

Chapter 2 Literature Review

2.1 Anatomy and Pathophysiology

The hamstring muscle group is made up of three muscles; biceps femoris, semitendinosus and semimembranosus. Due to their anatomy the hamstring muscle group has a function over two joints working to extend the thigh at the hip, flex the knee and internal rotate the knee when the knee is flexed. A muscle is strained when some of the fibres fail to cope with the excessive tensile and/or shearing forces placed upon it. Muscle architecture is the single most important factor when it comes to determining a muscles function, force production capacity and contraction velocity, with these variations not only affecting the function of the muscle but also the exposed risk of injury placed upon it (Potier, Alexander, Seynnes 2009). Several architectural factors may increase the likelihood of hamstring strains occurring, including their anatomy over two joints and their forceful activation during eccentric contractions (Thelen, Chumanov, Hoerth, Best, Swanson, Li, Young, Heiderscheit. 2005; Opar, Williams & Shield, 2012). This information is also vitally important when trying to understand the nature of individual injuries and potential practical applications for use in rehabilitation (Fernandez, Blanco, Fernandez, 2017). Knowledge of the way the hamstring works in relation to function on a training/match pitch where injuries occur must be considered and replicated where possible when trying to quantify hamstring strength.

Yu et al, (2008) proposed that developing eccentric hamstring strength may help an athlete to have greater autonomous control over knee extension, meaning they are less likely to over extend and stress myofascial structures. The lack of strength is linked to the muscular architecture of the hamstrings group, in particularly the Biceps Femoris. Extensive research claims that much of the hamstring micro-structure is type IIb fast twitch glycolytic muscle fibres, (Hoskins and Pollard et al, 2004; Portier and Alexander, 2009; Timmins et al, 2015). Based upon this, Hoskins and Pollard, (2004) explained that in order to stop an over extension of the knee, near maximal eccentric contractions are initiated, which involve type IIb muscle fibres to decelerate knee extension. To bring this into context, Proske and Morgan, (2001) theorised that during eccentric contraction subjects non-uniformed lengthening of individual sarcomeres causing damage. Therefore, if an athlete lacks eccentric strength, then they are theoretically unable to produce eccentric contractions sufficient enough to decelerate the knee and hip extension, resulting in stress higher than the mechanical limits of the musculotendinous unit. Despite a lack of direct evidence, it has been proposed that hamstring muscle fascicle length may alter the risk for a future HSI (Fyfe et al., 2013). Although a retrospective study has shown BFlh fascicles are shorter in previously injured muscles than in the contralateral uninjured muscles (Timmins et al., 2015), due to the retrospective nature this available evidence, it is not possible to determine that these differences in fascicle length were either a result of the injury occurring or a causative factor in the first place. One cohort study of 152 elite male football players, concluded athletes that suffered a HSI contained shorter BFlh fascicle lengths than those that remained uninjured (Timmins, Bourne, Shield, Williams, Lorenzen, Opar, 2015), although they also linked this risk factor to reduced knee flexor strength recorded. Timmins et al., (2015) stated that the increased risk associated with non-modifiable factors can be mitigated with greater levels of eccentric knee flexor strength and longer BFlh fascicle lengths.

The anterior cruciate ligament (ACL) is the main source of knee stability. Alentorn-Geli et al., (2009), stated that excessive anterior tibio-femoral translation (ATFT) (>5mm) can be a risk factor for ACL injury. Greater hamstring musculotendinous stiffness (MTS) has been shown to display reduced anterior tibial translation during controlled perturbations (Blackburn, Norcross & Padua 2011). It is also associated with more favourable landing biomechanics in terms of ACL loading. This is evidenced by smaller anterior tibial shear forces and frontal plane knee moments, and greater knee flexion at the instants of peak kinetic ACL loading mechanisms (Blackburn, Norcross, Cannon, Zinder 2013). Blackburn & Norcross (2014), demonstrated that isotonic training increased hamstring stiffness by 13.5%, slightly less than that following isometric training (15.7%) although stated the isometric training used in the study would not be feasible in an elite performance setting and stated isotonic exercises such as Nordic hamstring exercises as used by Mjolsnes, Arnason, Osthagen, Raastad, Bahr (2004), would give similar benefit.

Osgood–Schlatter disease (OSD) is a traction apophysitis of the tibial tubercle caused by overload/microfractures in the attachment of the patellar tendon commonly seen in youth athletes (Read, et al. 2017). The repetitive strain, in turn, is caused by the strong pull produced by the quadriceps femoris muscle during sporting activities. (Nakase, Goshima, Numata, Oshima, Takata & Tsuchiya, 2015). The rectus femoris muscle contracts eccentrically during the stance phase of running until the beginning of propulsion, when the knee reaches its highest level of flexion (Sarcevic 2008). Shortening of the rectus femoris may substantially affect the biomechanical function of the knee with respect to the lever arm, peak torque, and discharge of compressive forces at 30° and 60° (Gholve, Scher, Khakharia Widmann, Green, 2007). It is argued that OSD develops when the muscular strength involved in performing a knee extension increases in the presence of shortening of the quadriceps femoris muscle (Nakase et al., 2015). Although not documented in research it may be argued that weak hamstring muscles during this period of growth may be potential contribution factors for OSD. Decreased hamstring strength has been shown to alter knee biomechanics (Blackburn et al., 2013), increasing stress/load through the knee. The combination of strong quadriceps and weak hamstring muscles may potentially result in greater eccentric load through the quadriceps during the stance phase of running causing more stress on tibial tuberosity.

2.1.1 Mechanism of Injury:

Acute hamstring strain injuries are generally divided into two types based on the localisation of the injury and injury mechanism. The first is the most prevalent and occurs during high-speed running where the hamstring musculature is required to perform high velocity eccentric actions. These injuries commonly involve the long head of biceps femoris (BFlh), with most strains occurring proximally at the musculotendinous junction (MTJ) (Slider Heiderscheit, Thelen, Enright, Tuite 2008; Silder, Reeder, Thelen, 2010). This mechanism is of particular interest, as they constitute over 80% of all hamstring strains (Kouloris and Connell, 2003; Ekstrand et al., 2012).

Tosovic, Muirhead, Brown & Woodley (2016), used ultrasound to look at the anatomy of the BFlh, this has given an insight into a reason why such high incident rates occur at this site. They concluded that the distal-most part of the muscle contained shorter fascicles which were more pennated than its proximal most site. This arrangement is typical of muscles designed for force production, where the pennated orientation allows for a relatively greater number of fascicles to be packed in the muscle, parallel to each other (Wickiewicz, Roy, Powell, Edgerton, 1983; Aagaard, Andersen, Dyhre-Poulsen, Leffers, Wagner, Magnusson, Halkjaer-Kristensen, Simonsen. 2001). This therefore appears that the proximal segment of BFlh has larger excursive potential compared to its distal region which appears better suited to force generation. A three-dimensional muscle model created by Rehorn and Blemker (2010) demonstrates that non-uniform stretching occurs within BFlh, with the largest degree of muscle stretch localised near the proximal MTJ during activated muscle lengthening (eccentric contractions) (Tosovic, et al., 2016). In order to produce high amounts of horizontal ground reaction force and impulse at high running speeds, intense backward movements of the lower limb are necessary during both stance and late swing phases of running mechanics. The hamstring muscles are responsible for producing very high forces during both phases (Morin, 2013; Sun, Wei, Zhong, Fu, Li & Liu 2015). High levels of eccentric hamstring strength are required during sprinting for the actions mentioned above, individuals with poor eccentric strength therefore heighten the chances of such injury occurring (Van Hooren et al., 2016). Although the exact moment of injury occurrence is commonly debated between the end of swing or stance phase (Chumanov et al., 2007, 2011; Yu, Queen, Abbey, Liu, Moorman & Garrett 2008; Orchard, 2012; Ono, Higashihara, Shinohara, Hirose & Fukubayashi 2015), most share the sprint action as the main injury mechanism (Arnason et al., 2004; Woods et al., 2004; Ueblacker, Müller-Wohlfahrt & Ekstrand 2015). Due to the overall speed of motion throughout the lower limb, the transition between swing and stance phases are very short with typical total swing and stance times between 100ms and 300ms recorded (Morin, Gimenez, Edouard, Arnal, Jimenez-Reyes, Samozino, Brughelli & Mendiguchia, 2015), some researchers have started to combine the two (Clark & Weyand 2014). It has been suggested that the amount of knee elevation achieved late in the swing phase of sprinting while hamstrings are actively lengthened, an eccentric force >6–8 times body weight (BW) occurs (Sun, et al. 2015).

The second type otherwise known as a stretching type occurs during slow speed movements where extensive lengthening of the hamstrings occurs. These actions such as sagittal splits, sliding tackles and high kicking occur when in increased hip flexion combined with knee extension (Askling, Lund, Saartok, & Thorstensson, 2002; Askling, Tengvar, Saartok, & Thorstensson, 2000; Askling, Tengvar, Saartok & Thorstensson 2007a, 2007b; Askling & Thorstensson, 2008). These injuries are typically located close to the ischial tuberosity with involvement of the proximal free tendon of the semimembranosus (Askling et al., 2007b; Askling, Tengvar, Saartok, & Thorstensson, 2008). Some studies looked into the consequences of involvement of the proximal free tendon of semimembranosus and found prolonged return time to sport versus the proximal muscle-tendon junction of the long head of biceps femoris (Askling et al., 2007b, 2008;

Askling & Thorstensson, 2008). The closer the site of maximum pain palpation was to the ischial tuberosity, the longer the rehabilitation period. The proximal free tendon of the semimembranosus has a length of more than 10 cm, so the stretching type of hamstring strain can in fact be considered a tendon injury (Woodley & Mercer, 2005).

Knowledge of these mechanisms becomes vitally important when trying to quantify hamstring strength for both injury prevention and rehabilitation. It is known that a combination of excessive hip flexion and knee extension exposes the hamstring to a maximal stretch and combined with numerous architectural factors exposes an athlete to injury risk. Quantifying hamstring strength needs to replicate these with functional strength relating to MOI, with the hip in a flexed position while the knee extends. The NordBord consists of an athlete kneeling with the hip in a neutral position while extending from the knee, this action is very different to that seen on the IKD where an athlete sits with the hip in a flexed position while eccentrically resisting extension of their knee.

2.2 Epidemiology

The number of prospective injury studies in football is limited (Anglietti, Zaccherotti, De Biase 1994; Woods et al., 2004; Ekstrand et al., 2011b; Ekstrand et al., 2016) and, in relation to injuries in youth football, is greatly restricted (Nilsson & Roaas 1978; McCarroll, Meaney, Sieber 1984; Dvorak & Junge 2000; Price et al., 2004). Ekstrand et al, (2011a) conducted a study looking into injury incidence in professional football with participants as young as 15, hamstring strain injuries accounted for 12% of all injuries and represented 37% of all muscle injuries sustained. Ekstrand et al., (2016) carried out a longitudinal study over a thirteen-year period and concluded that on average, 21.8% of all players sustained at least one hamstring injury during a season. A football team with 25 players typically suffers 5-7 HSI each season, equivalent to between 80-90 days lost due to injury. These injuries require extensive treatment and long rehabilitation periods (Woods et al., 2004) with an average HI burden of 19.7 days per 1000 h (Ekstrand et al., 2016), this results in substantial financial losses for elite football clubs (Woods, Hawkins, Hulse, & Hodson, 2002). The average cost of a first-team player in a professional team being injured for 1 month is calculated to be around €500,000 (Ekstrand 2013). Ekstrand et al, (2016) showed an annual average 2.3% increase in the total hamstring injury rate over the 13-year period with the increase most pronounced in the training injury rate, with a yearly 4.0% increase noted.

Potential reasons for such high incidence rates occurring in the sport can be linked to the fact that football requires great energy capabilities, characterised by constant changes, high speed, acceleration, deceleration and jumps (Ekstrand et al, 2011; Michalis & Apostolos, 2016). Most hamstring strains occur through non-contact mechanisms, either over stretching or more commonly associated with running and sprinting activities occurring during sport. During the terminal swing phase of the running gait cycle, the hamstrings incur the greatest stretch and are active, eccentrically contracting to decelerate the lower limb in preparation for foot contact (Chumanov, Heiderscheit & Thelen, 2007). Approximately one-third of hamstring strains will recur; with the highest risk for injury recurrence being within the first two weeks of return to sport (Sherry et al, 2015; Dalton et al, 2015). This high recurrence rate is suggestive of an inadequate rehabilitation program, a premature return to sport, or a combination of both. The consequences of recurrence are high with recurrent hamstring strains to have been shown to result in significantly more time lost than the first time (Lauren, Erickson, Marc & Sherry, 2017).

Although research is severely limited, in the most recent injury audit in academy football, the most commonly injured area was the thigh with a significant 79% of these thigh injuries being muscle strains, 57% of these injuries were to the posterior thigh (Price et al., 2004). Of all of the recurrent muscle strains noted over this two-year period, 33% of these effected the hamstring muscle group. In professional football, the impact of injury on a club can be measured in terms of competitive matches missed and therefore costed against a player’s wages or the performance of the team. In academy football, however, the impact of injury must be considered from the point of view of the player’s development and skill acquisition. On average, each injury stopped the player participating in normal activities for 21.9 days, and each player was injured on average 0.40 times per season. This equates to the player missing about 6% of the season and therefore a large proportion of his development time. Osgood Schlatter Disease has been shown to affect as many as one in five youth footballers throughout their development (Domingues 2013), poor hamstring function increases the pull on the quadricep due to the co contraction increasing the problem.

Although in comparison with studies on professional players the amount of injuries sustained in academies was less. Price et al., (2004) stated that at the time of this research, players up to the age of 17 usually only trained twice a week and played competitive matches at weekends. This decrease in playing frequency may be causative factor and without any research to make a comparison between injuries in relation to time on the pitch it is impossible to make a true comparison. Since this research has been published the Football Association (FA) has since enrolled a youth development scheme known as the Elite Player Performance Plan (EPPP). This has increased the amount of contact time academy footballers now train at elite academies, as injuries are often displayed per 1000 hours, it can be assumed that injury rates will have likewise increased since this publication.

2.3 Aetiology

Several different studies have examined the risk factors for HI in sport. Multiple potential unalterable factors have been suggested such as age (Orchard, Marsden, Lord, 1997; Orchard, 2001; Gabbe, Bennell & Finch, 2006; Hagglund et al., 2006; Woods et al., 2004; Brooks, Fuller, Kemp, 2006), ethnicity (Friden & Lieber 1992; Verrall, Slavotinek, Barnes, Fon & Spriggins 2001; Woods et al, 2004; Brooks, Fuller, Kemp, & Reddin 2006; Foreman, Addy, Baker, Burns, Hill, & Madden 2006; Prior, Guerin & Grimmer 2009; Freckleton & Pizzari 2013), previous HI (Orchard, 2001; Verrall Slavotinek, Barnes, Fon & Spriggins 2001; Arnason et al., 2004; Gabbe, Bennell, Finch, Wajswelner & Orchard 2006; Koulouris, Connell, Brukner, & Schneider-Kolsky, 2007; Prior, Guerin & Grimmer 2009; Warren, Gabbe, Schneider-Kolsky & Bennell, 2010; Fousekis, Tsepis, Poulmedis, Athanasopoulos, & Vagenas, 2011; Tol Hamilton, Eirale, Muxart, Jacobsen & Whiteley 2014), higher level of competition (Varrall et al., 2001; Arnason et al., 2004; Woods et al., 2004; Ekstrand et al., 2011a; Barnes, Archer, Hogg, Bush & Bradley, 2014; Ekstrand et al., 2016) and fatigue (Woods et al., 2004; Bangsbo, Iaia, & Krustrup, 2007; Rampinini, Impellizzeri, Castagna, Coutts, & Wisloff, 2009; Greig and Siegler 2009; Ekstrand et al., 2011b). These unalterable factors have often been associated with an increased risk of hamstring injury. However, it would seem that the effects of these can be reduced with an effective injury prevention strategy with a key component of injury prevention being appropriate and reliable outcome measures. The effect of fatigue driven from higher levels of competitive play and fixture congestion may relate to poor hamstring strength function and injury risk as result of the fatigue. Implications of this are not exclusive to the hamstring, poor hamstring function under fatigue leads to increased stress on stabilising structures of the knee and can therefore be presented in ACL injuries or as commonly seen in youth sport Osgood Schlatter.

A number of modifiable factors has also been discussed including; flexibility (Witvrouw, Danneels, Asselman, D'Have & Cambier 2003; Foreman et al., 2006; Bradley & Portas, 2007; Fousekis, Tsepis, Poulmedis, Athanasopoulos, Vagenas, 2011; Timmins, Bourne, Shield, Williams, Lorenzen & Opar, 2015), H:Q ratio (Cameron, Adams & Maher, 2003; Croisier, Ganteaume, Binet, Genty, & Ferret 2008; Henderson, Barnes & Portas 2010; van Dyk, Bahr, Whiteley, Tol, Kumar, Hamilton, Witvrouw 2016), concentric strength (Freckleton & Pizzari 2013; Van Dyk et al., 2016) and eccentric strength (Prior et al., 2009; Engebretsen et al., 2010; Freckleton & Pizzari, 2013; Opar et al., 2015; Timmins et al., 2015; van Dyk et al., 2016).

2.4 Unalterable Factors

2.4.1 Higher age:

Age has been considered in literature as an intrinsic risk factor for HI, however most studies did not consider the reasons behind this and instead made vague hypotheses. Limited research can reason age alone as a risk factor and this is usually associated with weight or body mass index (BMI). A cohort study by Gabbe, Bennell & Finch (2006), investigated 448 Australian male amateur and professional football players. The results showed that increased body weight and decreased hip flexor flexibility were significant predictors of HI in players aged ≤25 years, but not in the younger players (aged ≤20 years). The cohort study by Orchard (2001), looking at 2255 matches/83 503 playermatches in the Australian Football League between 1992 and 1999, supports the finding of greater body weight (expressed as body mass index) as a predictive factor for HI in older players (<23 years). However, the study showed that body mass index correlated highly with player age and previous injury, being a possible confounding factor.

It is well accepted that there is a progressive reduction in muscle strength during the aging process known as Sarcopenia (Roig, MacIntyre, Eng, Narici, Maganaris, Reid, 2010). It is thought that physically inactive people lose as much as 3%-5% of their muscle mass each decade after the age of 30, with even the most active individuals still having some muscle loss (Clark, Condliffe, Patten 2006). Interestingly, when the age-related reduction of contractile capacity is considered in terms of different types of muscle contractions, the degree to which concentric and isometric strength is reduced is more pronounced than eccentric strength. Previous studies have reported a relative preservation of the capacity to produce eccentric torque (Horstmann et al, 1990; Pousson, Lepers, Van Hoecke (2001). Although the deficit in eccentric strength has been shown to be not as significant as concentric strength, this reduction of eccentric capacity occurring throughout the ageing process may provide some answers for an increased risk of hamstring strain injury. The importance in the ability to quantify eccentric hamstring strength consistently with precision is emphasised in the ability to reduce hamstring injury risk.

Hagglund et al (2006), found age to be a significant risk factor, while Woods et al (2004) found 17–22 year old age groups sustained fewer hamstring strains than the older soccer players ($p<0.01$). Two studies reported that age was not a significant factor for injury (Orchard, Marsden, Lord, 1997; Brooks, Fuller, Kemp 2006). Interestingly, to date, there is no research on the effect of age on a younger athlete and hamstring injury incidence. It would seem that during peak height velocity (PHV), when the femur grows in length, the hamstring muscle would be placed under an increased stretch while this catches up. In theory this increased stretch would predispose the young athlete to either muscle strains or apophyseal avulsion injuries.

2.4.2 Ethnicity:

Three cohort studies (Verrall et al., 2001; Woods et al., 2004; Brooks et al., 2006), two systematic reviews (Foreman et al., 2006; Prior et al., 2009) and one meta-analysis (Freckleton & Pizzari, 2013) have evaluated the ethnic origin of athletes as a potential intrinsic risk factor for HI. Verrall et al. (2001) found an increased risk of HI in players of Aboriginal descent, while Woods et al. (2004) showed identical risk in players of black origin. These findings are supported by the systematic review of Prior et al. (2009). Both excessive anterior pelvic tilt (Woods et al., 2004) and high proportions of type II fibres (Friden & Lieber, 1992) have been suggested as possible risk factors for HI in these populations. The cohort by Brooks et al. (2006) showed that the incidence of injury among people with Black African or Caribbean descent was almost four times that of people with white origin, but the difference was not significant.

2.4.3 Previous HSI:

Previous HI as a potential risk factor for a new HI has been long documented in research with 14 studies discussing the association (Orchard, 2001; Varrall et al., 2001; Arnason et al., 2004; Foreman et al., 2006; Gabbe et al., 2006; Hägglund et al., 2006; Koulouris et al., 2007; Prior et al., 2009; Engebretsen et al., 2010; Henderson, Barnes & Portas 2010; Warren et al., 2010; Fousekis et al., 2011; Freckleton & Pizzari, 2013; Hägglund et al., 2013). All of these studies looked at players participating in elite sport in either football or Australian Rule Football of which, only three studies did not find an association between previous HI and a new HI (Koulouris et al., 2007; Henderson et al., 2010; Fousekis et al., 2011). Fousekis et al. (2011) even showed that a history of HI could be protective against recurrent HI demonstrated through extensive rehabilitation programs.

Several studies have examined the effect that a HSI has on eccentric knee flexor strength, along with making comparisons between previously injured and uninjured limbs and have identified substantial deficits in the previously injured hamstring strength (Croisier, 2004a, 2004b; Lee et al., 2009; Opar, Williams, Timmins, Dear, & Shield, 2013; Tol et al., 2014). The majority of these studies used isokinetic strength measurements months to years after a HI occurred and a long time after return to sport however, deficits of up to 22-24% were found (Croisier et al. 2002). These findings suggest that possible inadequate rehabilitation following a HI may contribute to future injury or in fact that if reduced strength is associated with previous injury, this may be long lasting (Fyfe, Opar, Williams, & Shield, 2013). The ability to quantify eccentric hamstring strength throughout the rehabilitation process would provide the ability to ensure eccentric strength levels return and surpass pre-injury data ensuring asymmetries are resolved throughout rehabilitation prior to return to play decisions being made. This in turn may therefore minimise the effects of the aetiological factor previous injury history has on hamstring injury risk.

An important factor is that none of these studies differentiated between injury grades and location with HSI being seen as quite generic. The British athletics muscle injury grading has been proposed by Pollock, James, Lee (2014), proposes five grades of muscle injury ranging from Grade 0 associated with DOMS through to Grade 4, a full thickness tear based on specific MRI features. Grades 1-4 are further subdivided into groups (a, b or c) based on the site and extent of the injury (Patel et al. 2015). The injury is classified as a number and letter as determined by the injury characteristics. The suffix “a” denotes a myofascial injury at the muscleefascia interface at the peripheral aspect of the muscle. A “b” injury is predominantly within the muscle belly or the muscleetendon junction (MTJ), but with no intratendinous involvement. A “c” denotes extension of an injury into the tendon which has been demonstrated to be associated with a poorer prognosis (Slavotinek 2010).

Pollock, Patel, Chakraverty, Suokas, James & Chakraverty (2015), used the British Athletics Muscle Injury Classification to determine that different categories of hamstring injuries had different time to return to full training (TRFT) and significantly different recurrence rates. Hamstring injuries that extend into the tendon (‘c’) are more prone to re-injury with re-injury rates as high as 63% noted for 2’c’ injuries (Pollock et al, 2015). Future prospective research using this grading system may give us a better understanding in terms of the importance of specific injuries and the effect this will have on the risk factor for future HI.

2.4.4 Higher Level of Competition and Match Play:

In two cohort studies (Verrall et al., 2001; Woods et al., 2004) of 2490 professional footballers in total from England and Australia, the prevalence of HI was greater at higher levels of competition. The study by Verrall et al. (2001) showed a difference in prevalence by more than 20% between players at the highest level of play and players at the lower level of competition. In the study by Woods et al. (2004) HI were the most common in the English Premier League (EPL) and became less common in the lower leagues. Football as a sport over the last decade has undergone substantial change with the distances covered at high-intensity and sprinting increasing by 30-50% and the number of passes rising by 40% (Barnes, Archer, Hogg, Bush, & Bradley, 2014). A substantial large increase in the total number of sprinting actions has also been found for all Tiers from the 2006-07 to 2012-13, it is known that the hamstring is required to perform forceful eccentric contractions at high velocities during these actions and the increase in eccentric stress places on the hamstring may potentially be a contributing factor to the annual 4% rise in HI shown by Ekstrand et al., (2016).

The cohort study by Ekstrand et al. (2016) and Ekstrand et al. (2011a), looking at 36 and 51 European football teams respectively, found match play to be a risk factor for HI. Ekstrand et al. (2016) showed that playing a match gave a 9.4 times greater risk of getting a HI compared to completing a training session (4.77 vs 0.51 injuries per 1000 h). A lot of the reason behind this has been given to the high-intensity running distance and actions occurring during matches (Barnes et al., 2014). Arnason et al. (2004), found in contrast, no association between match play and an increased risk of HI.

Although not specified by an explanation for why HI rates are in the increase in training could be that the focus of training sessions included more repeated high-intensity actions that replicate the evolving nature of the game. Many top-level coaches want the training sessions to mirror the demands of a match, with similar intensity and movement patterns. If training sessions are becoming better at mimicking matches, the players may therefore be better prepared for match situations although might increase the incidence of training injuries, on the other hand, the players who are fit will be better prepared for match intensity, which might reduce the match injury risk (Ekstrand et al., 2016).

2.4.5 Fatigue:

The cohort study by Ekstrand et al. (2011b) looking into 23 European professional football clubs over a seven year period from 2001-2008 showed that the incidence of HI during matches increased during the latter stages of each half. These findings suggest that fatigue may be a predisposing factor for hamstring injuries occurring. These results are supported by the earlier findings of Woods et al. (2004), who looked at 91 football clubs from England from 1997-1999. This study concluded demonstrated that 47% of HI sustained during matches occurred during the last third of each half during a match. Studies of physical demands in football have found that fatigue is developed towards the end of a match, combined with the fact that the amount of high-intensity running and technical performance is lowered (Bangsbo, Iaia, & Krustrup, 2007; Rampinini et al., 2009). A laboratory study by Greig and Siegler (2009) of 10 male professional footballers showed that the eccentric knee flexor strength reduced over time and, in particular, after the half-time interval. Given the associated between eccentric knee flexor strength weakness and HI risk, athletes who exhibit greater levels of eccentric hamstrings fatigue would be expected to be at a higher risk of a HI with prolonged activity (Opar et al., 2015; Timmins et al., 2015; van Dyk et al., 2016). Agre (1985) suggested that the association between fatigue and the increased risk for HI might be because muscle fatigue influences the neural system, specifically the dual innervation of the two heads of biceps femoris, which can cause a mistimed contraction of the muscles and a possibly reduced ability to generate sufficient force.

The systematic review by Prior et al. (2009) showed conflicting evidence regarding fatigue as an intrinsic risk factor for HSI. Arnason et al. (2004) and Orchard et al. (1997) both found no association between poor aerobic capacity (described as decreased VO2 max), which could be involved with general fatigue, and the risk for HI. Although fatigue is an unalterable factor, with appropriate strength training and objective monitoring, increasing an athlete’s fatigue resistance can occur by exerting appropriate force in a functional position of knee extension and hip flexion may make them more functional and less likely to get injured as they can demonstrate an improved functional control.

2.5 **Alterable Aetiological Factors**

2.5.1 Decreased flexibility:

A number of cohort studies (Witvrouw et al., 2003; Bradley & Portas, 2007; Fousekis et al., 2011; Timmins et al., 2015) investigated 407 football players in total from England, Belgium and USA all identified decreased hamstring flexibility as an intrinsic risk factor for HSI. The methods and body positions used to measure hamstrings flexibility are different, however between the studies, making comparisons more difficult. While Witvrouw et al. (2003) measured hamstrings flexibility with a goniometer in a passive straight-leg raise test, Bradley and Portas (2007) used a 2- dimensional image-based analysis in a sitting position with the knee flexed. Timmins et al. (2015) showed that biceps femoris long head fascicle length below 10.56 cm increased the risk of HI 4.1 fold. Timmins et al. (2015) measured hamstrings flexibility through fascicle length of the biceps femoris longhead using ultrasound with the person in prone and the knee fully extended. A fascicle length below 10.56 cm was used as a definition of decreased hamstrings flexibility, while Witvrouw et al. (2003) used perhaps a more practical definition, showing that a hamstring flexibility less than 90° in a passive straight-leg raise correlated significantly with HSI. Fousekis et al, (2011) concluded this increased HI risk appeared to come from structural inequality altering the kinetic patterns of the lower extremity function during the production of excessive and asymmetrical forces in explosive sports activities, such as kicking and cutting in football.

A systematic review (Foreman et al., 2006) and meta-analysis (Freckleton & Pizzari, 2013) showed conflicting evidence regarding decreased hamstrings flexibility as an intrinsic risk factor for HSI. Although a number of studies have found no association between decreased hamstring flexibility and an increased risk of HI (Orchard et al., 1997; Gabbe et al., 2005; Gabbe, Bennell, & Finch, 2006), according to Foreman et al. (2006) only Arnason et al. (2004) used reliable measures of hamstring flexibility in demonstrating no association in 306 Icelandic football players.

Although increased flexibility has been shown to reduce hamstring injury risk (Freckleton & Pizzari, 2013), it is important to highlight that flexibility alone may be ineffective at reducing injury risk (Aaltonen et al., 2007). O'Sullivan et al, (2012) suggest that an altered length-tension curve, and not just reduced flexibility, is what may increase injury risk. Reduced flexibility increases injury risk secondary to the inability of the muscle to produce adequate force in a lengthened position which exposes the muscle to damaging lengthening forces. Interestingly, stretching does not seem to positively influence lengthtension relationships in the same fashion as eccentric training, which improves the ability of a muscle to produce force in a lengthened position (Proske & Morgan et al., 2001) highlighting the importance of eccentric strength in reducing hamstring injury risk.

2.5.2 Strength imbalance (H:Q strength ratio):

The cohort study by Croisier et al. (2008) followed 462 football players from professional teams in Belgium, Brazil and France for one season identifying athletes with strength imbalances had a 4.7 times greater risk of suffering a HI compared with players showing no imbalance. Values of H:Qconv strength ratio below 0.45-0.47 Nm and H:Qfunc strength ratio below 0.80-0.89 Nm, also increased the risk of HI . (Croisier et al., 2008). Similar findings had the cohort by Cameron et al. (2003), looking at 20 elite players of Australian football for one season, with their results showing that a reduced H:Qconv strength ratio gave an increased risk of HI. These results were supported by Orchard et al. (1997), who studied a cohort of 37 professional Australian Rule footballers over one season. Cameron et al. (2003) also developed cut-off values based on their findings and a H:Qconv strength ratio of 0.66 Nm was determined to be an optimum cut-off value. It is important to consider however, that the study by Cameron et al. (2003) and Orchard et al. (1997) are small studies. Bahr and Holme (2003) suggests that prospective studies require 20-50 injured subjects to detect small to moderate associations between risk factors and injury risk.

Two cohort studies (Henderson et al., 2010; van Dyk et al., 2016) examining 650 football players concluded that reduced H:Q strength ratio was not an associated with and increased risk factor for HI. Van Dyk et al. (2016) measured both H:Qconv and H:Qfunc strength ratios, while Henderson et al. (2010) only measured H:Qconv. This finding was supported by the meta-analysis of Freckleton and Pizzari (2013) which included studies that used a number of different methods to measure H:Q strength ratio.

2.5.3 Concentric Strength:

A cohort study of 614 initial participants carried out over of four year period (Van Dyk et al., 2016), found lower quadriceps concentric strength as a risk factor for HSIs, which had not been described previously as an independent risk factor for HSIs. Previous studies have presented conflicting results, which have led to different interpretations of the role of strength. In contrast to these results a recent systematic review and meta-analysis (Freckleton & Pizzari 2013) identified increased quadriceps concentric strength as being a risk factor for HSI. However, it is important to note that the study by Van Dyk et al.,

(2016) was carried out on Qatari athletes, with limited research carried out comparing the demands and characteristics of football between the two nations, arguably these results are not a true reflection of athletes participating in elite football as differences in training history, emphasis on strength training and quality of coaching will all impact results. As discussed earlier, an increased level of competition (Verrall et al., 2001; Woods et al., 2004), has been associated with an increased risk of HSI occurring. Distances covered at highintensity and sprinting have increased by 30-50% over the past decade (Barnes, Archer, Hogg, Bush, & Bradley, 2014), potentially being associated with the annual 4% rise of HSI (Ekstrand et al., 2016).

2.5.4 Reduced eccentric knee flexor strength:

Three cohort studies (Opar et al., 2015; Timmins et al., 2015; van Dyk et al., 2016) have found that reduced eccentric knee flexor strength is associated with an increased risk of HSI. Timmins et al. (2015) examined 152 elite Australian football players during the preseason and in-season period, measuring eccentric knee flexor strength using the NordBord. Their results demonstrated a reduced eccentric hamstring strength being associated with an increased risk of HSI, stating that athletes with eccentric knee flexor strength below 4.35 N/kg had 2.5 fold greater risk of HSI than stronger players. Although the correlations noted may have been significant, it is only representative of one sporting population of which makes it difficult for comparisons to be made, also no consideration was made regarding the anthropometrical variances previously highlighted and how these may influence the results obtained.

The study by Opar et al. (2015) followed 210 elite Australian Rule Footballers for one season and measured eccentric knee flexor strength again using the NordBord at the beginning and end of preseason training along with the midpoint of the season (Opar, Piatkowski, et al., 2013). Opar et al. (2015) reported eccentric knee flexor strength both in absolute terms (N) and corrected for bodyweight (N/kg) and found that eccentric knee flexor strength below 3.16 N/kg at the start of preseason and 3.45 N/kg at the end of preseason increased the risk of HI 3.1 fold and 5.0 fold, respectively. Interestingly, they noted that between-limb asymmetries of as high as 20% in eccentric knee flexor strength did not increase the risk of HSI. Opar et al., (2015) also agreed with comments made earlier that with appropriate injury prevention programs, the modifiable factor of high eccentric knee flexor strength appeared to offset non-modifiable factors such as increasing age and previous HSI. Due to different sporting populations utilised in these two studies, although associations can be made with football, further extensive research is needed to make true comparisons. While Opar et al. (2015) and Timmins et al. (2015) used the NordBord for measuring eccentric knee flexor strength, van Dyk et al. (2016) used isokinetic testing procedures. This study of 614 elite football players from the Qatar Stars League, found that players with eccentric knee flexor strength adjusted for bodyweight below 1.37, were at a higher risk of obtaining a HSI (van Dyk et al., 2016).

Two systematic reviews (Foreman et al., 2006; Prior et al., 2009), two cohort studies (Bennell et al. 1998; Engebretsen et al., 2010) and one meta-analysis (Freckleton & Pizzari, 2013), showed conflicting evidence. They all used isokinetic testing procedures as measurements of eccentric knee flexor strength and found no association between eccentric knee flexor strength and increased risk for HSI. Opar et al. (2015) considered the different testing methods to be the most likely explanation of the contrasting findings between their study and the work from Bennell et al. (1998). However, van Dyk et al. (2016) used similar testing procedures as Bennell et al. (1998) and still found reduced eccentric knee flexor strength to be an intrinsic risk factor for HSI. Different methods of measuring eccentric knee flexor strength and their validity and reliability are to be discussed further in section 2.7.

Bourne, Duhig, Timmins, Williams, Opar, Najjar, Kerr, Shield (2016) completed the first study to explore the architectural and morphological adaptations of the hamstrings in response to different strength training exercises, concluding that eccentric hamstring exercises, such as the NHE, stimulate significant increases in BFLH fascicle length. Fascicle lengthening is one possible mechanism by which the NHE and other eccentric hamstring exercises protect muscles from injury. Observations of increased fascicle length following eccentric hamstring exercise are largely consistent throughout literature. For example, Potier, Alexander & Seynnes (2009), reported a 34% increase in BFLH fascicle length following 8 weeks of eccentric leg curl exercise. While Timmins et al., (2015) reported a 16% increase in BFLH fascicle length after 6 weeks of eccentric training on an isokinetic dynamometer. Bourne et al., (2016) reported a 20% increase in BFLH fascicle length following a 10 week Nordic hamstring exercise programme and a 13% increase following a similar program of hip extension exercises.

These adaptations most likely result from the addition of in-series sarcomeres, as has been shown to occur within rat vastus intermedius muscle after 5 days of downhill running (Lynn & Morgan 1994). It has been proposed that this increase in serial sarcomeres accounts for both a rightward shift in a muscle's force-length relationship, while also reducing its susceptibility to damage (Brockett, Morgan & Proske 2001; Reeves, Narici & Maganaris 2004). However, it is also at least theoretically possible that fascicle lengthening occurs as a result of increased tendon or aponeurotic stiffness and further research is needed to clarify the precise mechanism(s) responsible for these architectural changes (Bourne et al, 2016). Establishing muscle architecture is a key component to enhance an injury prevention approach as demonstrated prospectively by Timmins et al., (2015). They stated that professional soccer players with fascicles <10.56 cm were ~4 times more likely to suffer a hamstring strain than athletes with longer fascicles and that the probability of injury was reduced by ~74% for every 0.5 cm increase in fascicle length. Despite this high knowledge of anatomy, MOI, aetiological factors, intervention strategies the fact remains these injuries have increased in the last decade.

2.6 Eccentric Strength

As demonstrated in the high incidence rates of hamstring injuries seen in sport, prevention, reduction and control of sports injuries are important goals for clinicians and researchers alike (Ekstrand et al, 2016). A crucial part of injury prevention in sport is the understanding of injury risks and injury aetiology. Since the early 1990s, several theoretical models have been put forward that have aided clinicians and researchers towards a better understanding of injury aetiology and, ultimately, the development of preventive measures. Arguably, the most widely accepted and used models are those discussed by van Mechelen et al, (1992) and Meeuwisse (1994).

Injury prevention research has been described by van Mechelen et al, (1992) as a four step sequence (fig. 1.1). Firstly, the magnitude of the problem must be identified and described in terms of the incidence and severity of sports injuries. Secondly, the risk factors and injury mechanisms that play a part in the occurrence of sports injuries must be identified. The third step is to introduce measures that are likely to reduce the future risk and/or severity of sports injuries. Such measures should be based on information on the aetiological factors and the injury mechanisms as identified in the second step. Finally, the effects of the measures must be evaluated by repeating the first step, which can be achieved by time trend analysis of injury patterns or, preferably, by means of a randomised clinical trial. A critical step in the sequence is to establish the causes of an injury occurring including obtaining information on the risk factors why a particular athlete may be at risk in a given situation and the injury mechanisms of how injuries happen.

Meeuwisse (1994) developed a model to account for the multifactorial nature of sports injuries. Although an injury may appear to have been caused by a single inciting event, it is more likely to be a result of a complex interaction between internal and external risk factors. Internal factors such as age, sex, and body composition may influence the risk of sustaining injuries, predisposing the athlete to injury, and are therefore by definition risk factors. In addition, external factors such surface conditions and boot type may modify injury risk, making the athlete even more susceptible to injury. It is the presence of both internal and external risk factors that renders the athlete susceptible to injury, but the mere presence of these risk factors is not sufficient to produce injury (Bahr & Krosshaug 2005). It is suggested that the associated risk factors together combined with the interaction between them ‘‘prepares’’ the athlete for an injury to occur in a given situation,

Meeuwisse describes the inciting event as the final link in the chain that causes an injury.

More recently, a comprehensive model for injury causation was proposed by Bahr and Krosshaug (2005). This model is a further expansion of the epidemiological model by Meeuwisse (1994) that describes the interplay between different factors along the path to injury. Stating that it is necessary to expand the traditional biomechanical approach to a description of the inciting event if the objective is to prevent injuries. They also discussed the importance of understanding complete description of the mechanisms for a particular injury type in any given sport as these will often differ between sports with the need to account for the events leading to the injury situation (playing situation, player and opponent behaviour), as well as to include a description of whole body and joint biomechanics leading up to, and at the time of injury. To address the potential for prevention, the information on injury mechanism must be considered in a model that also reflects how internal and external risk factors can modify injury risk (Meeuwisse 1994).

One common factor of the models referred to here is that they are based upon clinical, biomedical and biomechanical research focus.

As discussed in section 2.5.4, eccentric strength has been linked as a modifiable factor which can contribute towards injury prevention, not only for HSI but also for common injuries seen in academy players due to the structural role this has on knee stability. Reduced eccentric strength has been shown to correlate with increased injury while strength being shown to reduce post injury. Due to this, it has continually been recommended that eccentric training, which is continual repeated lengthening under load specific exercise, should be incorporated into an uninjured footballer's schedule, to develop eccentric hamstring strength, to reduce HSI risk (Hoskins and Pollard, 2004; Grieg, 2008; Opar, 2016). These methods also form the key focus of rehabilitation following an injury. The Nordic hamstring exercise (NHE) is one of the most common forms of exercise which targets the hamstring group through eccentric contraction (Opar et al, 2015; Timmins et al, 2015; Van der Horst et al, 2015). Mjølsnes et al, (2004) pioneered the NHE, which is a bodyweight exercise, where athletes are positioned in a kneeling position with their ankles fixed, from there athletes gradually lower themselves to the ground, utilising the hamstrings through eccentric contraction, to slow knee extension as they descend to the ground. The NHE has been shown to improve both eccentric strength and induce neuromuscular adaptations, which have been linked to HSI mechanisms (Mjølsnes et al, 2004; Guex et al, 2016; Timmins et al, 2015; Opar et al, 2016).

It has been frequently attempted in literature, to theorise why such improvements are observed when NHE is performed. Eccentric based training is commonly said to cause changes to the hamstrings architecture, in terms of increasing fascicle length and reducing the pennation angle (Seynnes et al, 2007; Timmins et al, 2015; Guex et al, 2016). The nature of effective eccentric based training is characterised as slow to moderate angular velocity eccentric contractions performed at the knee joint (Guex and Millet, 2013). NHE are an acceptable candidate for effective eccentric training, as they are performed at moderate angular velocities with movement focused at the knee joint. In recent literature, Portier and Alexander, (2009) witnessed a 33.5% or 2.5 mm increase in fascicle length of the hamstrings in professional footballers following an 8-week NHE programme. Similarly, Timmins et al, (2015) identified a 15% increase in fascicle length following a

3-week protocol utilising IKD. Timmins et al, (2016) related changes in fascicle length to HSI risk, outlining a subtle 0.5mm increase in fascicle length resulted in a reduction in HSI risk by 74%. During analysis, Guex et al, (2016) reasoned why HSI may decrease due to fascicular changes, explaining that by increasing fascicle length, more sarcomeres are working in series allowing the hamstrings to work over greater ROM.

Over the past two decades injury prevention models have been widely adopted in sports injury research with no doubt this has led to a wide array of preventative measures for a variety of injuries within different sports. However recently, more of a discussion around the 'true' effect of preventative measures in real-life sports settings have occurred (Finch 2006; Timpka, Ekstrand & Svnastrom 2006). As stated by Finch (2006), only research outcomes that are adopted by athletes, coaches, other intermediaries and sporting bodies will actually 'prevent' injuries. For this reason, Finch (2006) introduced the Translating Research into Injury Prevention Practice (TRIPP) model as an expansion of the original sequence of prevention (van Mechelen et al, 1992). The TRIPP approach aims to gather a better understanding of the implementation context for injury prevention, stressing the importance of understanding both behavioural inputs and outputs in relation to sports injury prevention. An example of how this is demonstrated is that despite literature has shown the success in reducing hamstring strain injuries using eccentric training methods, the adoption of the NHE in elite European soccer has been reported to be poor with only ∼11% of Norwegian premier league and UEFA teams deemed to have adequately implemented NHE programmes (Arnason et al, 2008; Petersen et al, 2011; van der Horst et al, 2015).

Recent advances, such as the TRIPP model, have been an important step forward for sports injury prevention as they underline the important role of behaviour in injury risk and consequently, injury prevention. A recent systematic review by McGlashan and Finch (2010) revealed only 11 out of 100 published injury prevention studies specifically used behavioural and/or social sciences theories. This shows that although conceptual ideas incorporating a more behavioural approach of sports injury prevention have been postulated, the role of behaviour within this specific field remains under-researched (Verhagen, van Stralen & van Mechelen 2010). Verhagen et al, (2010) provided an overview on the types of relationships that can exist between behaviour and injury risk. Although this was just a starting point for further research, it encouraged authors to consider all behaviours whether they be conscious, unconscious or a combination and how these may influence injury risk in both positive and negative manors, instead of solely considering the nature of the injury alone.

A common feature used in each model is the importance of using appropriate outcome measures to evaluate the effectiveness of an intervention. As discussed previously, in order to prevent hamstring injuries, establishing a depth of knowledge around muscle architecture, the effect this has on injury risk and how this adapts with specific eccentric training modalities has been shown to be of great importance in reducing injury risk. Despite this, confusion must still remain with hamstring injuries remaining on the rise, quantification of evaluating hamstring strength to be applied for both injury prevention and RTP strategies in rehab continue to require further explanation.

2.7 Quantification of Functional Hamstring Strength and Muscle Function

Various measures have been used throughout research to quantify hamstring muscle strength; these include 1RM (1 rep max) single leg and double leg squats, isometric testing and isokinetic testing for both concentric and eccentric measures (Dauty et al., 2001; Drouin et al., 2004; Maffiuletti et al., 2007; Impellizzeri et al., 2007; Greig., 2008; Hazdic et al., 2010; Houweling et al., 2010; Findikoglu et al., 2011; Anastasi et al., 2011; Cesar et al., 2013; Riberio et al., 2015). These tests are carried out to give outcome measures which can either be compared to normative values or asymmetrical differences which may be associated with an increased risk of non-contact musculoskeletal injury.

1RM testing was a traditional method of measuring hamstring strength, it required an athlete to perform a concentric contraction on a leg-curl machine in order to achieve their maximum strength ability (Kaminski et al, 1998). Individuals were required to perform a warm up set of light weight resistance for 10 repetitions, followed by a set of 5 repetitions after adding 10- 20% of weight. A 3 to 5-minute rest period was allowed between each successive set. After increasing the weight 20-30%, the 1RM was attempted on the third trial. For each successful trial 10-20% of weight was added, if unsuccessful, one trial was attempted after 5-10% of the weight was subtracted (McCurdy et al, 2004). Due to the fact that no more than 5 trials were allowed including the warm-up sets to attain the 1RM, the validity of the results remain questionable. Firstly, depending on the weight resistance started on, and the incriminations of weight prescribed, some individuals may not reach their maximal potential in the repetitions allowed (McCurdy et al, 2004). Likewise, the increments between repetitions may be too great to determine small deficits/improvements in strength to be monitored for injury prevention purposes and throughout the rehabilitation process. It is also possible that the carry over effect of fatigue during previous trail attempts for the 1RM may hinder the strength ability, having a negative effect on the strength profile given. More importantly, 1RM testing for the hamstring has traditionally been carried out via concentric contractions, knowledge around the importance of eccentric strength in reducing hamstring injury risk has taken practitioners away from that line of investigations (Hoskins and Pollard, 2004; Grieg, 2008; Opar, 2016). That saying, it had been hypothesised that there may be a correlation between 1RM and isokinetic peak torque values determined through concentric IKD assessments, providing some use to the interpretation of the results given during 1RM testing. However, Gentil et al, (2017) highlighted results obtained by PkT and 1RM are not equivalent when evaluating muscle strength, as the results obtained show large variations and can be even conflicting.

An alternative simple and practical test proposed in literature is an isometric test of hamstring muscle force initially using a sphygmomanometer (Schache, Crossley, Macindoe, Fahrner, & Pandy, 2011), but more recently, force plates (McCall et al., 2014). This simple and quick test is able to determine an objective measure of isometric muscle strength in a given range of motion. The test has previously been utilised monitoring the level of fatigue and muscle damage of the hamstring muscles following match play along with in the ability to quantify distinction between dominant and non-dominant limbs for injury prevention and rehabilitation purposes (McCall et al., 2014). Additionally, isometric contractions have been shown to result in little or no structural muscle damage (Faulkner, Brooks, & Opiteck, 1993; Leiber, Woodburn, & Friden, 1991; Nosaka, Newton, & Sacco, 2002) and therefore can be considered as a safer alternative test mode of contraction than eccentric which in comparison has been shown to result in more profound muscle damage (Nosaka et al., 2002). This method has been shown to have good to high reliability when measured with twenty-nine professional football players and may therefore provide some insight into unilateral hamstring function. That saying it is important to note that this method of testing isolates one range of hamstring muscle function and therefore lacks the ability to give a full profile of muscle capacity's through its functional range. Although points have been raised regarding this method being safer due to the isometric nature of the test, this in turn raises concerns over the functionality of the test and its relation to athlete performance. Footballers are required to repeatedly perform high speed actions requiring large eccentric contractions of the hamstring musculature (Morin, 2013; Sun et al., 2015), simply getting an isometric measure of midrange strength does not give practitioners enough knowledge to be making decisions over injury prevention and rehabilitation, especially with the previous knowledge in the importance of eccentric hamstring strength in hamstring injury risk (Ekstrand et al, 2016). It is also important to note that although eccentric testing may result in increased muscle damage to isometric testing, this replicates actions performed during competitive sport related activities and therefore not detrimental to well-trained athletes.

2.7.1 Isokinetic Dynamometry:

Due to the significant cost of hamstring injuries in football (Rahnama et al., 2002; Murphy et al., 2003; Woods et al., 2004), the reliance of the hamstring muscle group on stabilisation of the knee and the mechanism of injury associated with hamstring and knee injuries, the use of Isokinetic dynamometers has become progressively popular in sports, research, and clinical settings (Dauty et al., 2003; Svennson et al., 2005 Impellizzeri et al., 2007; Houweling et al., 2010; Findikoglu et al., 2011; Anastasi et al., 2011). The reliable test results, particularly for muscles of the lower extremity, have made IKDs the gold standard for measuring muscle strength over hand held dynamometry, mainly because the results are not influenced by a strength imbalance between the participant and the examiner, whereby a maximal torque can be generated throughout the whole range of motion (Chamorro et al., 2017).

Bakken et al., (2018) concluded that muscle strength is a poor screening test for predicting lower limb injuries in professional football following a study using 369 participants. They used IKD assessments to compare to trends in relation to injury data over a two year period. Although a large sample size was used, all participants were from the Qatari League meaning comparisons to the English Premier League cannot really be made. Mainly concentric measures were taken in the assessment with only a single slow speed eccentric hamstring measure at $60°\cdot s^{-1}$ being completed. In addition, no reference is made to what metrics have been analysed following testing other than PkT. Svennson et al., (2005) states in their review of testing procedures in football, that the IKD is focussed on one muscular area of the joint which limits the functionality of the testing. Although this may be true, it is important to note that this limitation can be overcome by how the data is collected and applied. Although PkT provides a snapshot of muscle strength this is very limited as only at one specific point throughout a dynamic assessment, a combination of tests carried out on the IKD may provide more applied functional data for practitioners. The consistent use of this method of measurement throughout rehabilitation to quantify the improvements in athlete's strength profile, indicates the importance the clinicians put on this as a tool to progress an athlete. The information gathered tends to be heavily focussed on the eccentric knee flexor torque at varying speeds (Dauty et al., 2003; Askling et al., 2008; Hazdic et al., 2010; Delextrat et al., 2010; Fousekis et al., 2010) due to the IKD showing good test-retest reliability (Steiner et al., 1993; Gaines et al 1999; Svensson et al., 2005; Impellizzeri et al., 2007; Maffiuletti et al., 2007; Greig., 2008; Cesar et al., 2013; Ribeiro et al., 2015). However, it is important to note that this reliance on using the measure of PkT alone is limited. To increase the functionality of the measures gained from the IKD, clinicians can also incorporate the ϴ, AvT in relation to the speed of testing and the range of angle to which the torque is achieved (Svennson et al., 2005; Greig., 2008; Greig et al., 2009; Small et al., 2009). Analysing these as a whole, would provide a more informed view of the strength profile of the hamstring and allow assumptions to be made about the individual's potential to sustain injury when performing functionally.

Various ratios in relation to hamstring strength in comparison to quadriceps strength (H:Q) have been obtained via IKD to profile athletes in relation to injury risk. The differences between methods comes from changes in the type of muscle contraction used and the speed of testing (Freckleton & Pizzari, 2013). The conventional hamstrings to quadriceps strength ratio (H:Qconv), which describes the concentric strength imbalance, has traditionally been the measurement of choice (Heiser, Weber, Sullivan, Clare, & Jacobs, 1984; Orchard, Marsden, Lord & Garlick 1997). However, in more recent times, due to an increased knowledge in the importance of the eccentric contraction of the hamstrings during the terminal swing phase of gait (Chumanov, Heiderscheit & Thelen, 2007; Chumanov, Heiderscheit & Thelen, 2011), a more functional strength ratio (H:Qfunc) has been postulated. Otherwise known as the dynamic control ratio, this method describing the ratio between the eccentric hamstrings to concentric quadriceps strength has been popularised (Engebretsen, Myklebust, Holme, Engebretsen & Bahr 2010; van Dyk, Bahr, Whiteley, Tol, Kumar, Hamilton & Witvrouw, 2016). Furthermore, the angle of peak torque has been discussed in relation as a risk factor for hamstring injuries (Brockett, Morgan & Proske 2004; Proske, Morgan, Brockett & Percival, 2004). An angle achieved at shorter muscle lengths has been associated with an increased risk factor for hamstring injury as the muscle is vulnerable for a longer period (Proske et al, 2004).

Two of the most common isokinetic dynamometers utilised in practice are the Cybex and Biodex systems. Ribeiro et al., (2015) analysed 770 knee flexor and extensor isometric, concentric and eccentric measures of strength and indicated testing on the machines had high to very high reproducibility of measures (r = 0.88 - Cybex and 0.92 - Biodex). They also concluded peak torque measures between machines did not show great differences amongst them. There have been several pieces of research discussing the reliability and validity of the IKD as a strength measurement tool and it is consistently highlighted that it has high reliability r = 0.9 – 0.98. (Steiner et al., 1993; Gaines et al 1999; Svensson et al., 2005; Impellizzeri et al., 2007; Maffiuletti et al., 2007; Greig., 2008; Cesar et al., 2013; Ribeiro et al., 2015). All of this research was completed on both eccentric and concentric strength profiles at a variety of speeds ranging from 30°·s-1 to 180°·s-1.

The high cost of the device combined with its lack of portability in the field are both limitations to its widespread use throughout sport and research carried out in practice. In high level elite sport, due to the financial backing of such organisations, the cost limitation may be less appropriate. That said, further limitations remain in terms of the time restraints required to test individuals being extensive, the need for a skilled operator of the equipment and then likewise the extensive time needed for appropriate analysis. Furthermore, isokinetic testing has been sometimes regarded as a non-functional assessment in regards to most sporting actions. Often assessments are performed in a seated position (Aagaard, Simonsen, Magnusson, Larsson & Dyhre-Poulsen, 1998; Croisier, Forthomme, Namurois, Vanderthommen & Crielaard, 2002; Brockett, Morgan & Proske, 2004), which may further limit the investigation of relationships to functional activities with the hip in an extended position.

2.7.2 NordBord:

The NordBord is a recently developed field testing device, designed specifically to obtain objective measurements of eccentric knee flexor strength and overcome the limitations of isokinetic dynamometry (Opar, Piatkowski, et al., 2013). The device is able to record various eccentric knee flexor strength values in the form of peak torque, peak power, average torque and average power whilst calculating between-limb imbalance (Opar, Piatkowski, et al., 2013). Although the device is not able to calculate the angle of peak torque, the breaking angle has been discussed as an alternative method for this (Sconce et al., 2015). Theoretically, the greater range achieved by an individual during a Nordic hamstring lower reflects the individual's eccentric hamstring strength, as the gravitational moment progressively increases throughout the range of the exercise. Therefore, the "break point" (the angle at which the individual can no longer resist the increasing gravitational moment and falls to the floor) could hypothetically be used as an assessment of eccentric hamstring strength correlating to the angle of peak torque commonly in assessing hamstring capabilities (Sconce, Jones, Turner, Comfort & Graham-Smith, 2015).

Figure 1.2 Image of the NordBord device being used to quantify eccentric hamstring strength.

The time of an assessment has been found to take less than 2 minutes per athlete (Opar et al, 2015). The reliability and case control injury study by Opar et al, (2013) found the NordBord to have moderate to high test-retest reliability (ICC= 0.83 - 0.90) for measurements when the NHE was performed bilaterally, but poor reliability during unilateral testing. Regarding measurements of absolute eccentric knee flexor strength, the NordBord showed moderate reliability only when the NHE was completed bilaterally and peak force was averaged across six trials (two sets of three repetitions) (Opar, Piatkowski, et al., 2013). Compared to measurements made with an isokinetic (Drouin et al., 2004; Impellizzeri et al., 2008; Maffiuletti et al., 2007) or hand-held dynamometer (Whiteley et al., 2012), the NordBord showed similar or slightly lower levels of reliability (Opar, Piatkowski, et al., 2013). In conclusion it was found that the NordBord offered a reliable method to measure eccentric knee flexor strength and strength asymmetry's, providing an alternative to IKD (Opar et al, 2013).

It is however clear, that the device lacks the ability to change the speed and angle of peak torque at which the hamstrings perform, which is possible through isokinetic dynamometry. Following the initial research, Timmins et al, (2015) performed NHE with 152 professional footballers in an attempt to determine whether short Biceps Femoris fascicles and eccentric knee flexor weakness increase HSI risk. Utilising the NordBord, Timmins et al, (2015) identified that players who displayed low levels of eccentric hamstring strength in pre-season were 4 times more likely to incur HSI, Although, the study doesn't outline whether these conclusions can be generalised to in-season screening values. Furthermore, the study outlined that an athlete with high levels of eccentric strength obtained through repeated eccentric loading, offset the risk of injury associated with older age and previous injury (Timmins et al, 2015). Therefore, this suggests that risk factors of age and previous injury, which where once classed as unalterable, can now be offset, by increasing knee flexor strength. As exemplary as the research is, one major limitation, is that the study is conducted on the Biceps Femoris only, which may mean that results impact on HSI risk for the other hamstring muscles, could well be different.

The device is not surprisingly receiving an exponentially increasing interest in the field today, and although some interesting applications have recently been published, some areas remain unresearched. Absolute strength profiles have been discussed by Opar et al, (2013) demonstrating that there may be an eccentric knee-flexor-strength threshold of which injury risk may be substantially increased if not attained, specifically 265N in AFL players. Buchheit, Cholley, Nagel & Poulos (2016) were the first to theorise that absolute thresholds for eccentric strength without taking other factors into consideration, may be questionable. Their study on 81 footballers ranging from youth to professional level observed unclear to large correlations between eccentric knee-flexor strength and body mass (BM). While correlations do not imply causality, the likely effect of BM on eccentric knee-flexor strength may be linked to the fact that when leaning forward during the Nordic exercise, players' BM may affect the force applied to the dynamometers, at least partially independent of players' true strength (Buchheit et al, 2016). It was suggested that eccentric knee-flexor strength is likely to increase by 4 N per increase in 1 kg of BM with the following equation formulised to give estimated guidelines (Eccentric strength [N] = 4 x BM [kg] + 26.1). This theory however can be said to be generic and only takes into consideration the one factor of body mass, further research is needed to individualise and obtain sport/position specific guidelines.

It is important to note that there is very little research surrounding the NordBord other than that published by the creators of the equipment along with very little emphasis given into the anthropometrical elements to the action. Findings regarding the correlation between the NordBord and isokinetic dynamometry have not been reported on especially in an elite applied setting, further research such as this study is required in order for true comparisons to be made.

2.7.3 Summary

Isokinetic dynamometry testing is widely considered as the gold standard measure for assessing eccentric hamstring strength with a vast array of research from laboratory settings. Throughout sport, generally the high cost of the device combined with its lack of portability in the field are both limitations to its widespread use. In high level elite sport, due to the financial backing of such organisations, the cost limitation may be less appropriate. That said, a further limitation is as a restraint to the time implication associated with testing each individual athlete which can be extensive. Likewise, organisations may have other restrictions for its use with the need for a skilled operator of the equipment and then likewise the extensive time needed for appropriate analysis. Furthermore, isokinetic testing has been sometimes regarded as a non-functional assessment in regards to most sporting actions. Often assessments are performed in a seated position (Aagaard, Simonsen, Magnusson, Larsson & Dyhre-Poulsen, 1998; Croisier, Forthomme, Namurois, Vanderthommen & Crielaard, 2002; Brockett, Morgan & Proske, 2004), which may further limit the investigation of relationships to functional activities with the hip in an extended position.

The NordBord may provide a solution to these restrictions as a portable device that can be carried out quickly in as little as two minutes per athlete (Opar et al, 2015). Little has been documented regarding the anthropometric variances associated with the device as hypothetically, both limb length and body mass may influence the amount of force required to be exerted by an athlete to remain in the required position and control the forward lean eccentrically with their hamstrings. Another potential limitation without previous recognition is the fact that unlike the IKD, although unilateral scores are given, the action completed is bilateral with both legs performing simultaneously. Theoretically, it may be impossible to determine if this is a true measure of unilateral strength as an athlete may be compensating through the contralateral leg. With little, if any, research making like for like comparisons between the two testing modalities, practitioners are restricted in their application of the NordBord for both training and rehabilitation interventions.

As discussed, there remains limitations for the applied use of both pieces of equipment, whether that be usability of the kit or potentially in the results due to way the test is performed. In elite sport where implications are so large from injury, with the effect of loss of playing time being vastly costly financially to a club and developmentally to an athlete, these unanswered questions need clarification. Practitioners need to be able to quantify hamstring strength appropriately with confidence in the results being given to guide injury prevention, use as a monitoring tool throughout strength training and ultimately be used as a RTP marker during rehabilitation.

Chapter 3: General Methodology

3.1 Introduction

Evidence has shown the negative impact that non-contact musculoskeletal injuries sustained by players have on football club's performance due to days missed and the financial implications associated with them (Woods et al., 2002; Orchard et al., 2009; Rahnama et al., 2009; Fisher et al., 2011; Yoon et al., 2011). Decreased eccentric hamstrings strength has been highlighted as a main contributory factor to lower limb noncontact musculoskeletal injuries such as; hamstring strains and ACL sprains/rupture (Opar et al., 2012). Evidence also highlights that soccer fatigue causes a decrease in dynamic stabilisation and eccentric hamstrings function due to the high eccentric loads experienced in game play (Greig 2008; Small et al., 2009; Thomas et al., 2010; Gioftsidou et al., 2011; Changela et al., 2012).

As discussed in the previous chapter, there are various means of measurement that can be utilised to quantify these measures of muscle function. The most reliable and valid measure of quantifying eccentric hamstrings strength is the IKD (Steiner et al., 1993; Gaines et al 1999; Svensson et al., 2005; Impellizzeri et al., 2007; Maffiuletti et al., 2007; Cesar et al., 2013; Ribeiro et al., 2015). The novel NordBord device is becoming widely used throughout elite sport as an alternative measure of eccentric hamstring strength (Opar et al, 2013). The studies in the thesis are to determine the reliability of each device in elite youth soccer and then to look at the correlation between the two pieces of equipment in order to guide their use in an applied environment.

3.2 Participants

Thirty-four elite footballers from one Premier League Category 1 Academy were recruited across both studies contained within the thesis with a mean age 17.60±0.76 years, height 179.23±7.8 cm and body mass 72.7±9.9 kg. Participants were required to carry out testing as part of the Football Club's Sports Science and Medical physical profiling. All participants were given clear guidance of the procedures of each study and these were clearly explained before any ethical approval was obtained. All participants were asked to ensure they were appropriately hydrated with water leading up to testing and had not eaten 3 hours prior to testing.

3.2.1 Sample Size:

A priori power calculation was conducted using familiarisation trials and pilot data completed by participants matching the criteria described above. A sample size of ≥ 14 players was required to evaluate the interactions associated with all independent variables (for statistical power > 0.8; $P < 0.05$). A minimum of 14 participants were utilised within each study. However, more were used (18 in study 1 and 16 in study 2), as players completed this testing as part of the clubs screening protocols. As part of their contractual agreements players are required to complete all pre-identified screening and testing required by the club.

3.2.2 Ethical Considerations:

Ethical approval was granted by University of Central Lancashire Ethics Committee and adhered to the guidelines outlined in the University's Research Ethics Framework, British Association of Sport and Exercise Science Testing Guidelines (2007) and in accordance with the Helsinki Declaration (2014) for medical research on human participants.

Each participant was provided with a participant information sheet, which comprehensively outlined the study structure and requirements of participants. Additionally, participants where made aware of any possible risks and discomforts associated with the studies. Following this, informed consent was obtained from all participants to acknowledge that they understood the information provided and consented to participation within the relevant research. Participants had the right to withdraw from the study at any time.

Following the completion of the written informed consent, the participants were allocated a unique ID number. This number in turn was then used to identify the participants on all other documentation excluding the consent form. Participants were given the right to withdraw their data within four weeks of the completion of the final testing sessions by providing their unique ID number (the researchers details were provided following the completion of the written informed consent form). It must be recognised that the participants consent forms were stored separately from the other data collected and following the completion of the informed consent the unique ID number was the only method used to identify the participants. Although all data was coded using these ID numbers, the data sets were stored on a password protected mass storage device and PC in line with the Data Protection Act (1998).

3.2.3 Inclusion/Exclusion Criteria:

All participants were to be aged between 16 and 18 at the time of testing and were required to be signed at a Premier League Category 1 Academy. All participants had to be free of any current lower limb injuries, as well as being fully active in current training and competition. Any subject with a history of previous hamstring injury in the previous twelve months was excluded from the study. If at any time during the study, one of the players became injured or unable to train through illness/personal reasons they would be removed from any further testing and excluded from the results. If players could not complete the tests, for example, if they could not match the isokinetic speeds of the IKD, then they were excluded from the study.

3.2.4 Pilot Study:

Confirmation of the final experimental design was only made once the relevant pilot work had been completed. Due to the participants recruited for the study all being elite youth footballers they had all, at some stage, completed testing on the IKD and NordBord.

During the pilot study it was realised that the landmarks recommended by the ‘Nordic’s’ Application in order to work out breaking angle was; 1) lateral malleolus, 2) lateral femoral condyle, 3) greater trochanter at the nordic break-point angle. This gave a range of up to 180° of movement, compared to between 90° – 100° often seen with knee extension on the IKD. In order to combat this, the landmarks used were changed. The athletes were positioned using a goniometer into 95° of knee flexion where landmark 1) was placed on the greater trochanter in the start position, following the completion of the NHE the following landmarks remained as before; 2) lateral femoral condyle and 3) greater trochanter (see Fig. 1.2) enabling the working available range of movement to be set at 95° which was replicated during the range of knee extension on the IKD. These changes resulted in test becoming comparable with the IKD as the working angle of motion repeated for both tests remained consistent.

Although faster speeds better replicate the mechanism of injury within hamstring and ACL injuries, as these are more commonly sustained at high velocity (Bollen 2000; Arnason et al., 2008; Engebretsen et al., 2010), it became apparent during the pilot study that youth athletes may not have been able to sustain an eccentric contraction through the range at $300^{\circ/s-1}$ resulting the IKD failing on a number of occasions. This finding led to the faster eccentric speed on the IKD being removed for the purpose of the research.

3.3 Experimental Design

Prior to any familiarisation or testing within the experimental studies each player's height and weight measures were taken. The height of each participant was measured in centimetres, to the nearest millimetre, using the Seca Road Rod Stadiometer 214. The stadiometer was assembled and placed on a flat floor next to a wall to ensure it was kept up straight. Participants were required to remove their shoes prior to measurement and stand neutrally facing forward. Following obtaining height measures, the weight of each participant was then taken. Weight was measured in kilograms to the nearest 0.1kg, using the Seca 761 flat mechanical scales. The scales were calibrated to 0kg and were placed on a flat floor. Again, all participants were required to remove their shoes prior to measuring.

Participants were required to complete a familiarisation trial on the IKD and NordBord to negate potential learning effects (Heinmann et al, 2009). All participants involved in the studies completed all testing between 13:00 and 17:00 hrs to account for the effects of circadian rhythm (Drust et al., 2005; Nicolas et al., 2008; Bougard et al., 2010; Sedliak et al., 2011) and in accordance with regular training and competition times. Familiarisation of the testing equipment was completed in one session, 7 days prior to testing beginning. The familiarisation trials were consistent with the testing procedure completed in the studies. The participants completed testing procedures on the IKD at the varying testing speeds (60°·s^{-1} and 150°·s^{-1}), similarly participants were subjected to 3 NHE on the NordBord, so they were aware of expectations when testing began. Some participants were required to complete more than one familiarisation trial to ensure that they were completing the task correctly. Verbal encouragement was provided throughout the testing process as this replicated the encouragement they traditionally receive during performance (Enoka., 1992; Mcnair et al., 1996; Kim et al., 1997; Gandevia 2001; Knicker et al., 2011).

Study 1 comprised of the test retest reliability study of both testing devices, this was carried out throughout preseason as part of the club's pre-season testing battery. Study 2 was completed during the in-season, again extraneous variables were controlled where able. The testing in this study was completed during a period in the season where no competitive fixtures take place, this was it was able to have control over the training in the weeks going into the testing in order to ensure the athletes physical demands on the pitch had been replicated prior to testing.

3.3.1 Isokinetic Dynamometry:

Participants were required to attend for testing in full training kit and athletic trainers that they would wear when completing gym sessions or runs at the club. Data collection on the IKD consisted of 2 x 5 sets of eccentric hamstrings work, which was followed by passive movement back in to knee flexion guided by the IKD at 10°·s-1. Each subject completed a bilateral isokinetic eccentric protocol where dominant leg as defined as preferred kicking leg carried out first. Gravity-corrected isokinetic peak torque (PkT), average peak torque (AvT) and angle of peak torque (ϴ) of the knee flexors was assessed at 60°/s-1 and 150°/s-1 using a Biodex isokinetic dynamometer (System 3, Biodex Medical Systems, Shirley, NY, USA). Five repetitions were performed on each limb at each speed allowing 10 seconds recovery between efforts (Baltzopoulos, 2008) and a rest period of 30 seconds remained between each set. Participants were instructed that each repetition should be a maximal contraction throughout the entire range of movement.

The dynamometer setup was modified to be subject specific following the manufacturer's guidelines, with the setup maintained throughout the exercise protocol. The crank axis aligned with the axis of rotation of the knee joint, and the cuff of the dynamometer's lever arm secured around the ankle, proximal to the malleoli. Restraints applied across the test thigh, proximal to the knee joint so as not to restrict movement, and across the chest. The range of motion was pre-set from full extension to a 95° range of flexion (Greig 2008). The seated position was chosen due to the consistent approach used in several previous studies (Croisier et al, 2002, Askling et al, 2003, Greig 2008). The order of speeds performed was in line with recommendations that isokinetic dynamometry protocols should be progress from slower to faster speeds (Wilhite et al, 1992).

Figure 1.3 Image of the setup of the IKD for the testing protocol.

3.3.2 NordBord:

The NordBord is a 90 cm long and 60 cm wide padded board with two ankle hooks (see Fig. 1.2). Since the exercise used for testing is the commonly employed NHE, the device has a special set-up (Opar, et al., 2013). The ankle hooks are connected to two force cells that measure the force (in Newton) at which the ankle hooks are being pulled. The force measured by the two force cells is transmitted in real time to a host computer/tablet via a USB cable. Each subject also performed three trials of Nordic hamstring lowers on the NordBord. To ensure consistency, markers were placed on the floor for which the NordBord to set on to ensure the angle of which the action was recorded remained the same. Each trial was recorded from the sagittal plane using a Canon XA35 camera. The camera was placed on a fixed stand set 3m away and 0.5m from the floor. Three reflective circular markers were attached to the right greater trochanter, right lateral femoral condyle, and right lateral malleolus to calculate knee joint kinematics. Minimal clothing was recommended to avoid movement of markers. Participants knelt on the padded section of the NordBord with each ankle secured superior to the lateral malleolus by individual braces. Participants were instructed to gradually lean forward at the slowest possible speed, maximally resisting this movement with both limbs, while holding their trunk and hips in a neutral position throughout, with their hands across their chest (Buchheit et al, 2016). Individual's knee position on the NordBord was recorded using the integrated knee position guides with the ankle restraints at 90^o 2cm superior to the lateral malleolus to ensure the body position remain consistent between tests.

The Nordic hamstring exercise completed on the NordBord was analysed using a variation of the motion analysis protocol adopted from a previous study (Lee, Li, Yung & Chan 2017). Video clips were digitized and transformed into a two-dimensional space using motion analysis application software (IOS Nordics Application). Each participants' break point angle (lowest, closest to the floor) was calculated using the reflective markers placed on the landmarks previously set with the best repetition used for the purpose of the research.

Figure 1.4 Image of the standardisation of the camera used in order to determine the break point angle of the NHE.

3.4 Data Analysis:

The IKD data was analysed to quantify gravity corrected peak torque measures for the hamstring muscle group when performing eccentric knee extension at 2 speeds ($60°\cdot s^{-1}$ and $150°\cdot s^{-1}$). Gravity correction is applied based on the anthropometric measures input in to the Isokinetic Dynamometer when completing the testing. If the correct anthropometric measures are not input on testing the athlete, then a gravity correction is not applied and could potentially affect the reliability and validity of the measures obtained. The IKD is the main testing procedure utilised within research to quantify functional strength of the hamstring muscle group (Gaines et al., 1999; Dauty et al., 2001; Dauty et al., 2003; Drouin et al., 2004; Svennson et al., 2005; Maffiuletti et al., 2007; Impellizzeri et al., 2007; Greig., 2008; Small et al., 2010; Houweling et al., 2010; Findikoglu et al., 2011; Anastasi et al., 2011; Cesar et al., 2013; Riberio et al., 2015). Measures of functional hamstring strength have been shown to have good-high reliability (ICC = 0.76-0.97) when analysing measures at speeds between $60°\cdot s^{-1}$ - $300°\cdot s^{-1}$ (Steiner et al., 1993; Gaines et al 1999; Drouin et al., 2004; Svensson et al., 2005; Impellizzeri et al., 2007; Maffiuletti et al., 2007; Greig., 2008; Cesar et al., 2013; Ribeiro et al., 2015).

Mean PkT, mean AvT and mean Θ values were calculated by identifying the two repetitions of similar values with a set of 5 repetitions for each testing speed. Measures of Θ, AvT alongside PkT measures have been shown to increase the functionality of scores exhibited (Svennson et al., 2005, Greig., 2008, Greig et al., 2009, Small et al., 2009). PkT for each individual within each study was determined by identifying where they could consistently achieve similar torque values, but also replicate this within the same angle through range, which represented the Θ. These two reps out of the 5-rep set were then taken and an average value calculated. This was repeated for the angle of peak torque. The average peak torque was then calculated taking the average torque score through the relevant isokinetic phase and then these two values were then averaged against each other. It is important to note that the torque values were only analysed where the participants were meeting the isokinetic testing speeds. On completion of data collection for all subjects within the study an overall average for each measure of Mean PkT, mean AvT and mean Θ values was calculated. These values were then utilised in statistical analysis for the group.

Throughout the data analysis, testing speeds were represented as $150^{\circ}\cdot s^{-1}$ and $60^{\circ}\cdot s^{-1}$ with eccentric exercise being represented as 'ecc' and hamstrings or knee flexor work indicted with 'H'. Peak Torque was represented as PkT, Average Peak Torque as AvT and Angle of Peak Torque as Θ. So for example, average peak torque of the knee flexors at an eccentric speed of $150^{\circ}\cdot s^{-1}$ would be $\text{AvgPkT}_{\text{eccH150o/s}}{}^{-1}$. It is important to note that these values were only taken during the isokinetic phases of eccentric knee extension for each speed tested.

During a NHE completed on the NordBord force is measured by the two force cells, meaning the device is able to record various unilateral eccentric knee flexor strength values in the form of peak torque, peak power, average torque and average power whilst calculating between-limb imbalance (Opar, Piatkowski, et al., 2013). Data is transmitted in real time to a host computer/tablet via a USB cable using the ScoreBord (Valdperformance) recording system and exported into an Excel results sheet. As the method for completing a NHE is a bilateral exercise and taken from the single recording of the exercise, a single measure is obtained for breaking angle without unilateral differences determined. The best angle of the three was used and added to the Excel results sheet.

3.5 Statistical Analysis

Initial Q-Q and box plots were completed to determine that the data satisfied normal distribution for all outcome variables within IKD and NordBord measures. Potential outliers detected in the boxplots were included in each of the data sets, as they were considered true data representative of sports injury data in elite professional football and thus should be included. Pairs of measurements from each participant were compared to assess test-retest reproducibility of eccentric strength measures using each piece of equipment in elite academy footballers. The descriptive statistic of intraclass correlation coefficient (ICC) was used to describe how strongly the pairs of quantitative measurements resemble each other. Qualitative interpretation of ICC values are as follows: 0– .20 = poor; 0.21–0.40 = fair; 0.41–0.60 = moderate; 0.61–0.80 = good; and 0.81–1 = excellent (McCunn et al, 2017). For test-retest reproducibility, these metrics were calculated separately for each athlete, and then the metrics from the athletes were averaged.

Once all data cleaning had occurred and all data was normally distributed, analysis of a linear correlation was used in Study 2 to investigate the variance in peak torque values obtained at slower isokinetic speeds and medium isokinetic speeds, (60°·s-1, 150°·s-1) against that of the NordBord peak torque values following NHE. In order to establish the distribution of peak torque values from each individual parameter, box plots and Q-Q normative plots were constructed. To determine a relationship between the normative values, a Pearson correlation coefficient was calculated. Significant differences between values were also identified using a paired T-test, with significance set at P<.05. Statistical analysis of data distribution was identified utilising box plots, of which all data was normally distributed.

NordBord test performance data and all isokinetic parameters are quantified as mean ± standard deviation. Linear regression analysis was used to quantify the relationship between performance on each NordBord test parameter with peak torque, average torque and with angle of peak torque at each discrete testing speed (60, 150^{o}·s-1), in terms of eccH. Multiple linear regression analysis was then used to model NordBord test performance as a function of peak torque across all testing speeds collectively for eccH. This process was repeated for average torque and angle of peak torque across both speeds. In all cases the correlation coefficient (r) was used to quantify the relative contribution of each factor to agility performance. The value r^2 was subsequently calculated to quantify the percentage variation in NordBord performance that can be accounted for by variation in the isokinetic variable. Finally, and in order to develop a hierarchical ordering of the strength parameters influencing the NordBord test results, a forward stepwise regression model was utilized. Stepwise linear regression provides a means of including multiple variables within a model while simultaneously removing those variables that are not important. The forward selection model employed is initiated with no variables included, and subsequently adding the variable whose insertion gives the most statistically significant improvement of the correlation. This process is repeated until no additional variables improve the model to a statistically significant extent. This process allowed for identification of the singular most important isokinetic torque and angle of peak torque for eccentric hamstring strength at each testing speed.

Chapter 4: Study 1 – Test retest reliability

4.1 Introduction:

Quantification of eccentric strength with elite sport is well documented (Greig., 2008; Small et al., 2009; Ribeiro et al. 2015). Of note, the focus of the current evidence is based on senior athletes in football and not academy players. Functional strength has been highlighted as a key aetiological factor associated with hamstring and knee injuries (Opar et al. 2012; Ekstrand 2013; Schuermans et al. 2016). Current injury prevention strategies have incorporated eccentric strengthening through range, with a recent emphasis on the Nordic Hamstring Exercise (Sayers et al., 2008; Petersen et al., 2011). It has been well documented that the inclusion of Nordic Hamstring Curls within an elite athlete's programme has been shown to result in a reduction of hamstring injuries across a range of sports (Opar et al., 2014; Van Der Horst et al., 2015; Bahr et al., 2015). Thus highlighting the importance of establishing a player's functional strength profile.

Similarly, to the IKD, the NordBord predominantly quantifies an individual's functional hamstring profile through the following parameters peak torque (PkT) and Average Peak Torque (AvT) (Greig., 2008; Small et al., 2009; Opar et al., 2013). Information regarding the muscle architecture can be determined by establishing the angle of peak torque (Ө) on the isokinetic dynamometer. Equivalent conclusions could be drawn by assessing an individual's break angle on the NordBord, something that is not well documented within the current literature (Sconce et al., 2015). The introduction of the NordBord in to practice and ultimately research has provided a quick analysis of the eccentric hamstring profile of players and allows teams to complete a series of athletes in a short space of time. Heightening its appeal for use within an elite sporting environment where practitioners have significant time constraints associated with athlete profiling. This said to date, the IKD is considered the gold standard piece of apparatus for establishing the functional profile of the hamstrings and is utilised within rehabilitation to determine an athlete's readiness for return to play (De Carlo et al., 1992; Silva et al., 2012).

Research has debated the functionality of the IKD as a test to establish the hamstring function (Svennson et al., 2005) due to its isolation of one muscular area of the joint. However, the authors of this work only considered PkT as a measure and consideration of other parameters would have countered this argument, due to a broader view being presented of the muscles function. In addition to this the IKD is capable of testing at a variety of speeds from slow to fast (commonly 60°·s^{-1} – 300°·s^{-1}), again increasing the functionality of measures (Drouin et al., 2004; Greig., 2008). Similar arguments could be presented for the NordBord, particularly as this is limited to the athlete's control of the lower, which determines the speed of decline to the floor. Although, these factors should be taken in to consideration with any equipment/exercise prescribed to determine an athlete's functional hamstring strength profile. It is important to note that the IKD and NordBord are currently used at the forefront of contemporary research and approaches to hamstring profiling in elite sport. They are also being utilised within rehabilitation to determine an athlete's readiness for functional activity, particularly the IKD (De Carlo et al., 1992; Silva et al., 2012). However, this does present the question is one piece of equipment better than the other for hamstring profiling in academy footballers or does it not matter which piece of kit is used by clinicians.

The reliability of both the IKD and NordBord has been well documented within research as discussed in section 2.6.1, with high to very high reproducibility (ICC= 0.90 – 0.98) associated with the IKD (Ribeiro et al. 2015) and moderate to high test-retest reliability (ICC= 0.83 - 0.90) associated with the NordBord (Opar et al, 2013). In professional footballer's test-retest of IKD has been shown to have good reliability, with intraclass coefficients of 0.76 – 0.78 for the 3 testing speeds utilised (Greig., 2008). Although the sample utilised within the study closely represented the participants in the current thesis, they were not academy players and the sample size was relatively small (n = 10). It is understood that there is currently no data produced within elite footballers with regards the NordBord. Evidence suggests that both the IKD and NordBord are reliable tools in the assessment of hamstring function in sport. However, it is important to stress the need to establish their reliability in specific academy populations within elite football, as this will help guide the design of establishing the functional profile of players to guide injury prevention strategies. Considering this, the aim of the present study was to determine the reliability of the IKD and the NordBord considering parameters of PkT, AvT, ϴ and break angle.

4.2 Experimental Design:

Participants:

Sixteen elite youth footballers from a Premier League Category 1 Academy (age 17.57+/- 0.54 years, height= 178.44+/- 7.5cm, mass= 72.9+/- 4.01kg) participated in the study which involved evaluating the test re-test reliability of IKD and NordBord in assessing eccentric hamstring strength over a four-week period. The participants met the inclusion/exclusion criteria outlined in section 3.2.3.

Sample Size:

The sample utilised in the present study was determined using a priori power calculation, as detailed in section 3.2.

Ethical Considerations:

All participants provided written informed consent in accordance with Department and Faculty Research Ethics committees at the University of Central Lancashire, and in accordance with the Helsinki Declaration, as outlined in section 3.2.2.

Experimental Design

Participants height, weight and age was recorded before any testing took place. They were then familiarised with each piece of equipment, as highlighted in section 3.3 of the General Methodology.

All testing throughout each week was completed at the same time of day to account for the effects of circadian rhythm (Drust et al., 2005; Bambaeichi et al., 2009; Bougard et al., 2010; Blonc et al., 2010; Malhorta et al., 2014). Participants performed an identical warm up protocol before testing on each piece of equipment. This was led by the clubs Sports Science staff and consisted of a 10-minute of stationary cycling (60 rpm) on a cycle ergometer (Wattbike Ltd, Nottingham, UK). Followed by 10 full weight bearing bilateral squats, 10 unilateral left and right lunges, finishing with a dynamic hamstring stretching routine.

Participants were randomly assigned into two groups of eight (group 1 = 8, group 2 = 8). Each testing period was separated by 7 days before it was repeated. On the first testing week, each participant from group one performed a knee flexor eccentric strength testing protocol on the IKD (as outlined in section 3.3.1). This testing was then repeated again on week 2, with exactly 7 days between testing periods. During these two weeks, each participant from group 2 completed the NHE on the NordBord for (as outlined in section 3.3.2). Participants from each group then went on to complete the opposing piece of equipment during week three and four. All NordBord assessment was filmed as described in section 3.3.2, so that break angle could be assessed and compared against Ɵ.

4.3 Statistical Analysis:

Initial Q-Q and box plots were completed to determine that the data satisfied normal distribution for all outcome variables within IKD and NordBord measures. Potential outliers detected in the boxplots were included in each of the data sets, as they were considered true data representative of sports injury data in elite professional football and thus should be included. Pairs of measurements from each participant were compared to assess test-retest reproducibility of eccentric strength measures using each piece of equipment in elite academy footballers. Reproducibility was assessed using the intraclass correlation coefficient (ICC). Qualitative interpretation of ICC values are as follows: 0–.20 = poor; 0.21–0.40 = fair; 0.41–0.60 = moderate; 0.61–0.80 = good; and 0.81–1 = excellent (McCunn et al, 2017). For test-retest reproducibility, these metrics were calculated separately for each athlete, and then the metrics from the athletes were averaged.

4.4 Results:

4.4.1 IKD:

Figure 1.5 displays the variance in the data collected in terms of peak torque values collected through eccentric knee flexor IKD testing at 60°·s^{-1} and 150°·s^{-1} over the two week period. The graph displays mean peak torque values, differentiating between limb differences for the 16 participants along with the standard deviation (±) of each.

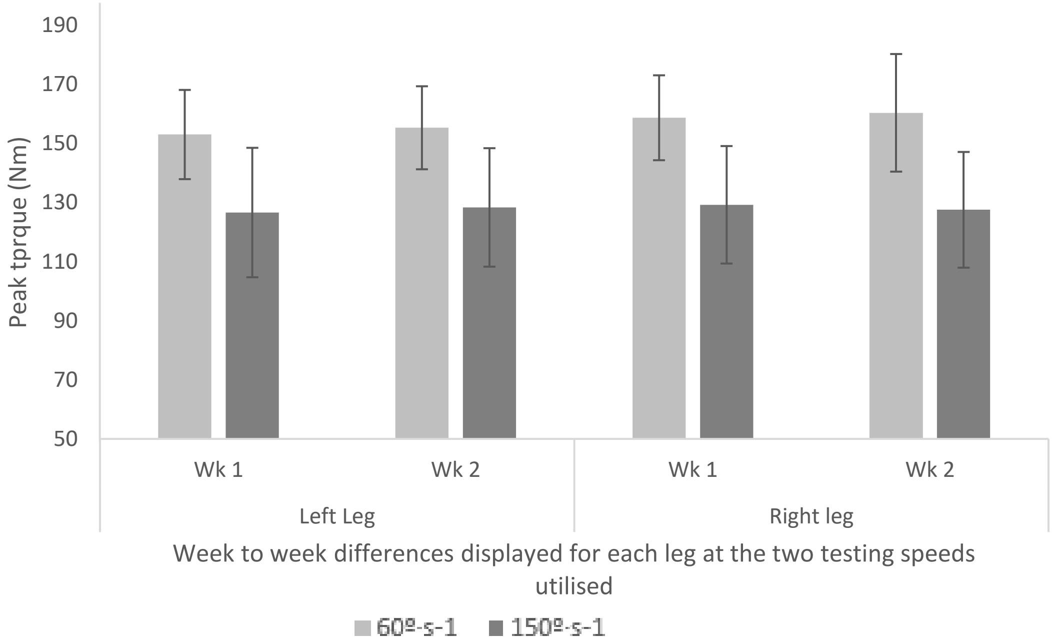

Figure 1.5 The variance in data associated with the peak torque values of both the left and right leg obtained through eccentric knee flexor IKD testing at 60°·s^{-1} and 150°·s^{-1}over a two-week period.

The mean peak torque value for the left leg obtained from the sixteen participants at week one at 60°·s^{-1} was 153.01 ± 15.10 and 155.30 ± 14.05 for week two. The mean peak torque value obtained for the right limb at week one at 60°·s-1 was 158.69 ± 14.37 and 160.36 ± 19.90 for week two. In terms of the testing speed of 150°·s^{-1}, a mean peak torque value of 126.61 ± 21.91 was noted for week one of testing on the left limb with 128.34 ± 20.05 in week two. Mean peak torque for the right limb at 150°·s-1 was 129.23 ± 19.89 for week one and 127.54 ± 19.58 for week two.

Figure 1.6 displays the variance in the data collected in terms of average peak torque values collected through eccentric knee flexor IKD testing at 60°·s^{-1} and 150°·s^{-1} over the two-week period. The graph displays mean average peak torque values, differentiating between limb differences for the 16 participants along with the standard deviation (±) of each.

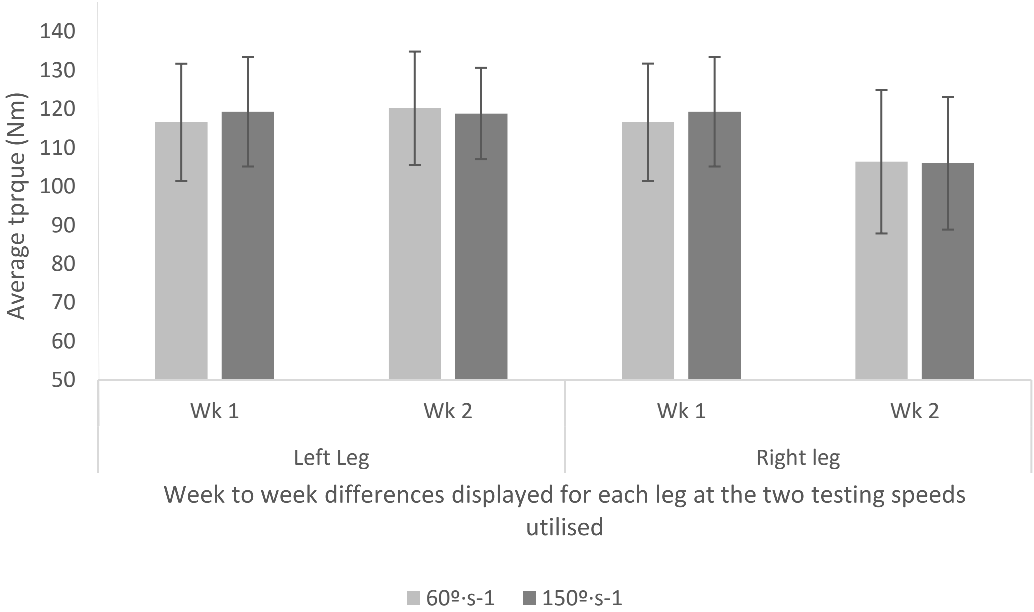

Figure 1.6 The variance in data associated with the average peak torque values of both the left and right leg obtained through eccentric knee flexor IKD testing at 60°·s^{-1} and 150°·s^{-1} over a two-week period.

The mean average peak torque value for the left leg obtained from the sixteen participants at week one at 60°·s^{-1} was 116.57 ± 15.13 and 119.28 ± 14.13 for week two. The mean average peak torque value obtained for the right limb at week one at 60°·s^{-1} was 120.20 ± 14.63 and 118.83 ± 11.81 for week two. In terms of the testing speed of 150°·s-1, a mean average peak torque value of 109.85 ± 15.71 was noted for week one of testing on the left limb with 110.85 ± 18.93 in week two. Mean average peak torque for the right limb at 150°·s^{-1} was 106.36 ± 18.50 for week one and 106.01 ± 17.13 for week two.

Figure 1.7 displays the variance in the data collected in terms of the angle of peak torque values collected through eccentric knee flexor IKD testing at 60°·s^{-1} and 150°·s^{-1} over the two-week period. The graph displays mean angle of peak torque values, differentiating between limb differences for the 16 participants along with the standard deviation (±) of each.

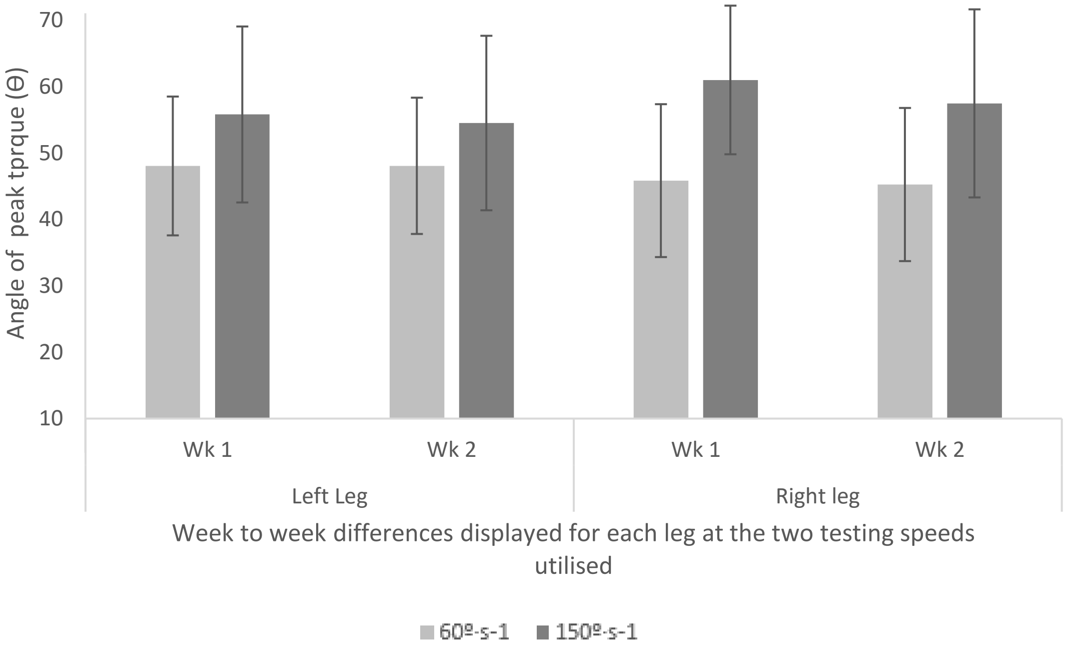

Figure 1.7 The variance in data associated with the angle of peak torque values of both the left and right leg obtained through eccentric knee flexor IKD testing at 60°·s^{-1} and 150°·s^{-1} over a two-week period.

The mean angle of peak torque value for the left leg obtained from the sixteen participants at week one at 60°·s^{-1} was 48.07 ± 10.46 and 48.09 ± 10.27 for week two. The mean angle peak torque value obtained for the right limb at week one at 60°·s^{-1} was 45.86 ± 11.51 and 45.27 ± 11.56 for week two. In terms of the testing speed of 150°·s-1, a mean angle of peak torque value of 55.83 ± 13.26 was noted for week one of testing on the left limb with 54.54 ± 13.15 in week two. Mean angle of peak torque for the right limb at 150°·s^{-1} was 61.03 ± 11.20 for week one and 57.50 ± 14.17 for week two.

Table 1.1 below displays the intraclass correlation coefficient (ICC) scores obtained through the test re-test reliability study for the IKD ranged between 0.87-0.91. Peak torque values showed consistent reliability between the two utilised speeds displaying excellent reliability (>0.81) findings for both limbs. This picture is continued and replicated with the other two units of measurement obtained via the IKD with all findings considered as excellent >0.81.

Table 1.1 Intraclass correlation coefficient (ICC) associated with the test re-test reliability of the use of IKD for measures of eccentric knee flexor strength in Category 1 Premier League elite youth footballers.

60deg/sec	**Left**	**Right**
PkT	0.88	0.92
AvT	0.88	0.91
Ɵ	0.91	0.91
150deg/sec	**Left**	**Right**
PkT	0.88	0.88
AvT	0.87	0.88
Ɵ	0.90	0.90

4.4.2 NordBord

Figure 1.8 displays the variance in the data collected in terms of both peak torque and average torque values collected through the NordBord testing over the two-week period. The graph displays mean values, differentiating between limb differences for the 16 participants along with the standard deviation (±) of each.

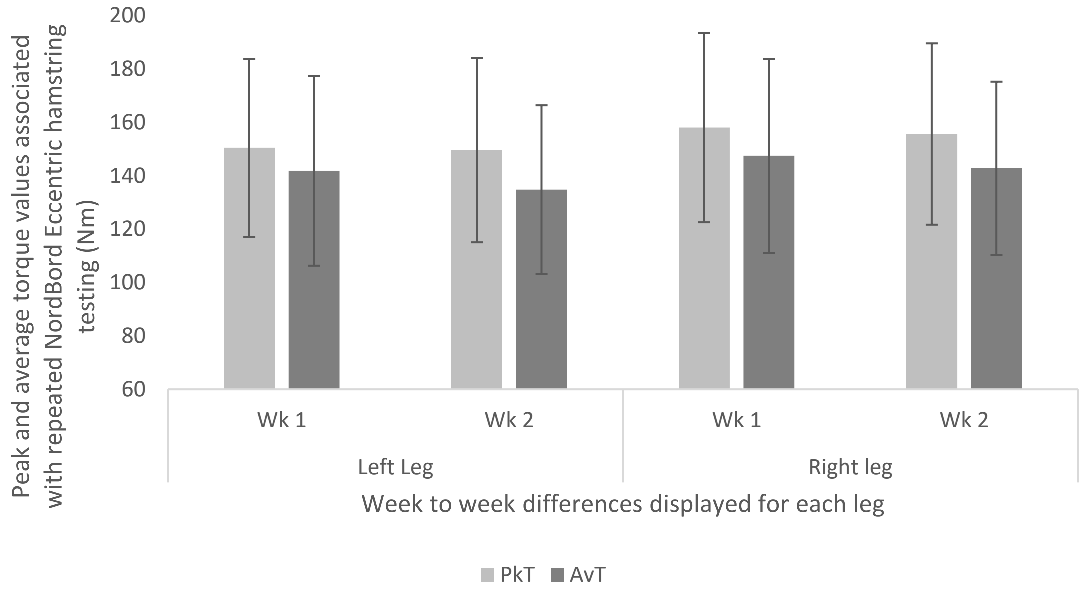

Figure 1.8 The variance in data associated with both peak torque (PkT) and average torque (AvT) of both the left and right leg obtained through eccentric knee flexor testing on the NordBord over a two-week period.

The mean peak torque value for the left leg obtained from the sixteen participants at week one was 150.4 ± 33.36 and 149.55 ± 34.53 for week two. The mean peak torque value obtained for the right limb at week one was 157.98 ± 35.45 and 155.57 ± 33.93 for week two. In terms of average torque, a mean value of 141.77 ± 35.49 was noted for week one of testing on the left limb with 134.74 ± 31.58 in week two. Mean average torque for the right limb was 147.4 ± 36.23 for week one and 142.74 ± 32.44 for week two.

Figure 1.9 below displays the variance in data collected in terms the breaking angle calculated using video analysis of the NordBord testing over the two-week period. Due to the bilateral nature of the test, only a single score is given each week, the graph displays mean values for the 16 participants along with the standard deviation (±).

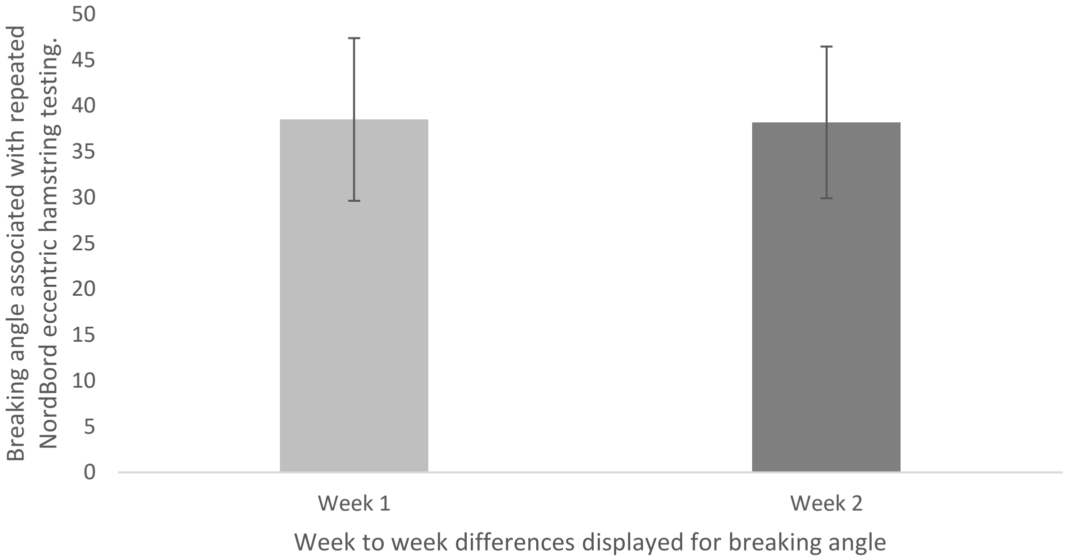

Figure 1.9 The variance in data associated with the breaking angle values of the right leg obtained through eccentric knee flexor testing on the NordBord over a two-week period. ICC = 0.92

The above figure displays the variance in the breaking angle data obtained through eccentric hamstring testing on the NordBord. In week one a mean angle of 38.5 ± 8.87 was determined with an angle of 38.18 ± 8.28 in week two. Table 1.2 below displays the intraclass correlation coefficient (ICC) scores obtained through the test re-test reliability study for the NordBord, results ranged between 0.56-0.92.

Table 1.2 Intraclass correlation coefficient (ICC) associated with the test re-test reliability of the use of the NordBord for measures of eccentric knee flexor strength in Category 1 Premier League elite youth footballers

NordBord	**Left**	**Right**
PkT	0.76	0.61
AvT	0.57	0.56
	Bilateral	
Breaking Angle	0.92	

4.5 Discussion:

The aim of the present study was to determine the reliability of the IKD and the NordBord considering parameters of PkT, AvT, ϴ and break angle in elite academy footballers. Recent research in this area is limited in relation to the population observed. However, contemporary evidence exists describing the test-retest reliability of both pieces of equipment in adult populations across a range of differing sports (Greig., 2008; Ribeiro et al., 2015). It is common practice within elite academies to screen and establish a player's eccentric hamstring strength profile due to the increased incidence of hamstring and knee injuries within the sport (Cesar et al., 2013; Riberio et al., 2015). The IKD and NordBord are contemporary pieces of equipment utilised to establish the parameters listed in the present study, to provide information on hamstring function and the muscle architecture (Findikoglu et al., 2011; Anastasi et al., 2011; Opar, Piatkowski, et al., 2013). Identification of the reliability and repeatability of these outputs and measures is essential within the specific population, as it will provide vital information for practitioners working within sports medicine departments that will guide injury prevention and conditioning approaches.

Much of the previous research has considered a variety of speeds within isokinetic testing, with some research detailing isokinetic testing at $300°\cdot s^{-1}$ (Greig., 2008). This was considered with the current group of academy players, due to its link within research to increased functionality (Engebretsen et al., 2010). During the pilot study it was identified that a number of players were unable to either initiate the dynamometer or alternatively unable to match the speed of testing, causing the IKD to fail. Resulting in no data being able to be obtained at this velocity. This could potentially indicate that this specific group of players could be at a higher risk of sustaining muscular or knee joint injury, due to the relationship of high velocity and high load movements being associated with many noncontact musculoskeletal injuries (Van Hooren et al., 2016).

Results displayed in the present study identify excellent test-retest ICC scores for the IKD across both testing speeds and all parameters (PkT, AvT, ϴ), reporting ICC values of 0.87 - 0.91. These findings are consistent with research conducted within adult populations and elite footballers (Greig., 2008; Ribeiro et al., 2015). Thus, indicating that the IKD is a reliable test to utilise within the current population tested and should be considered when trying to ascertain a functional profile of the hamstring to advise injury prevention or conditioning protocols. In addition to this it would also support its use when determining player progression within rehabilitation, which is consistent with previous research in adult populations (Greig et al., 2009; Small et al., 2009). In contrast testing completed on the population utilised in the present study on the NordBord identified fair - moderate ICC values for the parameters of PkT and AvT (0.56 - 0.76). Interestingly, excellent ICC scores were displayed for break angle (0.92), suggesting that the NHE performed on the NordBord was an excellent tool for identifying muscle architecture. Considering, specifically the MOI associated with hamstring related injuries and noncontact knee injuries players (Sconce et al, 2015), information regarding the break angle could be a potential indicator of likelihood of sustaining injury. Eccentric profiling of athletes on the NordBord is a time efficient process. However, caution must be taken when interpreting the data presented. The findings in the present study contradict previous literature. Opar et al, (2013) described ICC values for the NordBord of 0.83 - 0.90 for PkT and AvT. This study did not present data describing the reliability of break angle measures during the NHE. Although these results display conflicting evidence, one trend between the two studies is the variation of scores between limbs for peak torque. Careful consideration must also be given to limb variance when quantifying eccentric hamstring strength in athletes. The present study reports limb variance scores of 0.61 – 0.76 (15% variance), whereas Opar et al., (2013) reports a variance of 0.83 – 0.90 (7% variance). The variance when analysing AvT for the present study is 0.56 – 0.57 (1% difference) and 0.85 – 0.89 (4% difference) in Opar et al., (2013) work. Arguably, the variance displayed in both studies is insignificant, as current evidence identifies unilateral asymmetries of <10%, as a marker of a reduced chance of sustaining a non-contact musculoskeletal injury related to the hamstring or knee.

Injury burden in elite football is said to cost on average €500,000 a month for a first-team player in a professional team to be injured (Ekstrand 2013), and with an influx in revenue seen in the past five years from broadcasting rights and inflation in player values being astronomical this number will only have risen. Objective data used to help guide clinical decisions regarding injury prevention and throughout the rehabilitation process require high levels of interpretation on an individualised basis, practitioners are required to have tremendous confidence in the objective information being given to them to help guide this process.

4.6 Conclusion:

Quantification of eccentric hamstring strength in elite academy footballers is a contemporary concern. The IKD is shown to be a more reliable measure to identify function of the hamstring across a range of parameters (PkT, AvT and ϴ). The ICC scores reported within the present study are consistent with previous research (Greig., 2008; Ribeio et al., 2015). In contrast measures taken on the NordBord do not display strong ICC values and therefore reliability of measures taken in relation to PkT and AvT must be interpreted with caution. Interestingly break angle reports excellent ICC values when performing the NHE and provide a reliable measure that can be utilised to indicate muscle architecture. Careful consideration from practitioners working within sports medicine teams in elite academy football should proceed with caution when designing athlete profiling and rehabilitation progression protocols.

Chapter 5: Study 2 – Quantifying Eccentric Hamstring Strength

5.1 Introduction:

Hamstring and knee injuries within elite football are a contemporary concern, with both reported to be on the rise (Ekstrand et al, 2016). The cost implications to clubs has also risen, providing pressure on sports medicine professionals working within the game to present a resolution. Current developments in injury prevention strategies and the regular introduction of contemporary pieces of equipment to quantify key components such as strength (Opar et al. (2015), stability (Malliou, Gioftsidou & Pafis, (2004) and player load (Gabbett, Whyte, Hartwig, Wescombe, Naughton 2014; Gabbett 2016) to name a few, has led to confusion. Questions are raised within departments as to which approaches provide the best information. Potentially creating an environment where a 'collect all philosophy is developed', often duplicating measures or collating data for the same factor that can be contradictory.

Van Mechlen (1992) presents a simplistic injury prevention model that highlights the need for strategies to align to the MOI. Identifying the need for quantification to analyse the effectiveness of the interventions applied (see figure 1.1). Poor eccentric hamstring strength has been cited within literature as a key aetiological factor contributing to athletes sustaining hamstring and knee injuries in football (Opar et al., 2015; Timmins et al., 2015; van Dyk et al., 2016). Quantification of functional hamstring strength is well documented across literature (Maffiuletti et al., 2007; Impellizzeri et al., 2007; Greig., 2008; Hazdic et al., 2010; Houweling et al., 2010; Findikoglu et al., 2011; Anastasi et al., 2011; Cesar et al., 2013; Riberio et al., 2015). Contemporary approaches to detailing the functional profiles of athletes in relation to eccentric strength commonly consider two approaches the IKD (Findikoglu et al., 2011; Anastasi et al., 2011; Greig 2008) and the NordBord (Opar, et al., 2013). Obvious differences exist between the two pieces of equipment. Most notably the Nordic hamstring being dependent on player weight to provide load and tension through the muscle when performing the exercise. Buchheit et al, (2016) have detailed that player anthropometrics can have a significant impact on the force production generated when performing NHE on the NordBord. However, the study did not consider the effect of this on other parameters like PkT, AvT break angle. This said, parameters presented in IKD data are comparable to those on the NordBord, as they are also inclusive of PkT, AvT and Ѳ. Other key differences between the two testing modalities relate to the testing position, IKD assessments are often completed in a seated position with the hip in a flexed position, this differs from a hip extended position associated with a NHE, this difference in biomechanical difference may alter the force length relationship of the hamstring musculature. The IKD has been questioned in literature in relation to its functionality (Svensson., et al 2005), with specific reference made to it being an open kinetic chain exercise. The use of varying speeds from slow to fast, most commonly $60°·s^{-1}$ - $300°·s^{-1}$ (Greig., 2008). This has increased the functionality of the IKD and allowed a greater load and velocity through the hamstring that closely relate to the MOI (Chumanov et al, 2011). Another factor yet to be discussed in research and an area required for further research is the potential for how an individual's height may influence their results. Taller athlete's will have their centre of mass further away from the pivot at the knee. As the athlete leans forwards, the centre of mass will fall further outside the midline of the body, theoretically, this potentially with change the amount of eccentric force required by the athlete to resist falling. This highlights questions over the specificity of testing on the NordBord and continues to highlight the strengths of testing using the IKD where athletes are tested in a seated position with gravity corrected, the readings are less likely to be influenced by the body mass/height of a participant and are therefore reflective of true eccentric hamstring strength.

It is important to consider the findings from study 1 (section 4.4), which compares the reliability of the IKD and NordBord. Findings in this study present that the NordBord has excellent ICC values for break angle, but for PkT and AvT these ICC values were only fair – moderate. These results identify that the NordBord displays strong reliability in relation to breaking angle of which can be used to indicate the muscles force length relationship. Contrastingly the IKD displays excellent ICC values, for all parameters PkT, AvT and Ѳ. This provides interesting debate in practice in relation to speed of analysis and establishing an overview of an athletes functional hamstring strength, against the reliability of measures. The MOI of hamstring injuries is commonly associated with a high eccentric load through the hamstrings during the late swing phase of sprinting (Thelen et al., 2005; Heiderscheit et al., 2005; Yu et al., 2008; Schache et al., 2009). This presents the argument that the muscle architecture is the most important aspect to analyse when assessing hamstring function. This said, when performing the NHE and assessing break angle it is assumed that the force output from the muscle is reducing drastically as it reaches breaking point, hence the failure to maintain the exercise against the force exerted. Providing justification to compare the PkT or AvT against the ϴ, to see where and at what point through range maximum force is exerted. An ideal scenario would be for it to occur as close to full length as possible, replicating the MOI.

Test re-test reliability scores obtained and discussed in section 4.4 demonstrated the variance between the two pieces of equipment. This information alone may give some information for both practitioners and researchers alike into potential limitations of using data obtained from both the IKD and NordBord to inform clinical decisions on athletes. To take this forward and give improved depth and understanding there is a need to look at quantifying eccentric strength measures thus giving further insight for practitioners to make informed decisions in terms of both injury prevention and rehabilitation. As discussed in chapter 2.6, a variety of methods have been used previously to quantify eccentric hamstring strength (Impellizzeri et al., 2007; Greig., 2008; Hazdic et al., 2010; Houweling et al., 2010; Findikoglu et al., 2011; Anastasi et al., 2011; Cesar et al., 2013; Riberio et al., 2015) and with injury rates continuing to rise (Ekstrand et al, 2016) confusion remains throughout practitioners in the application of these methods but also in the interpretation of results. Isokinetic testing provides the most well recognised and objective method of measuring eccentric hamstring strength although as previously discussed potential limitations to its widespread use remain (Croisier et al, 2002; Brockett, Morgan & Proske, 2004). This label of being a ‘gold standard’ measure used throughout the field of sports medicine lead to a logical step of any new method being compared too. The NordBord is a novel device and further understanding and evidence of how these two methods compare when assessing eccentric hamstring muscle function will only allow for an improved application of when/how/why they are used in the injury prevention and rehabilitation process. The IKD is identified as a highly valid and reliable method for identifying eccentric hamstring function, whilst uncertainty of this remains with the NordBord within specific parameters. Therefore, if comparisons of these parameters can be identified against IKD data then this could potentially still be utilised in practice to save time when assessing an athletes eccentric hamstring strength. Therefore, the aim of the present study was to identify any relationships between the parameters PkT, AvT, ϴ and break angle from the IKD and NordBord.

5.2 Experimental Design:

Participants:

Sixteen elite youth footballers from a Premier League Category 1 Academy (Age= 17.63+/- 0.76 years, height= 180.02+/- 6.1cm, mass= 72.5+/- 9.9kg) participated in the study which involved assessing the correlation between peak torque, average peak torque and angle of peak torque values measured through eccentric hamstring testing on the IKD to peak torque, average peak torque and breaking angle values associated with a NHE on the NordBord. The participants met the inclusion/exclusion criteria outlined in section 3.2.3.

Sample Size:

The sample utilised in the present study was determined using a priori power calculation, as detailed in section 3.2.

Ethical Considerations:

All participants provided written informed consent in accordance with Department and Faculty Research Ethics committees at the University of Central Lancashire, and in accordance with the Helsinki Declaration, as outlined in section 3.2.2.

Experimental Design

Participants height, weight and age was recorded before any testing took place. They were then familiarised with each piece of equipment, as highlighted in section 3.3 of the General Methodology.

All testing throughout each week was completed at the same time of day to account for the effects of circadian rhythm (Drust et al., 2005; Bambaeichi et al., 2009; Bougard et al., 2010; Blonc et al., 2010; Malhorta et al., 2014). Participants performed an identical warm up protocol before testing on each piece of equipment. This was led by the clubs Sports Science staff and consisted of a 10-minute of stationary cycling (60 rpm) on a cycle ergometer (Wattbike Ltd, Nottingham, UK). Followed by 10 full weight bearing bilateral squats, 10 unilateral left and right lunges, finishing with a dynamic hamstring stretching routine.

Each testing period was separated by 7 days before it was repeated. Participants were assigned a number and then randomly assigned into two groups using a random number generator, group 1 (n=8) and group 2 (n=8). On the first testing week, each participant within group 1 performed a knee flexor eccentric strength testing protocol on the IKD (as outlined in section 3.3.1). Whilst, group 2 participants performed a strength testing protocol, comprised of NHE repetitions utilising the NordBord for strength measurement (as outlined in section 3.3.2). Precisely one week later the groups switched, with Group 1 completing the NordBord testing and Group 2 completing the IKD assessment. All NordBord assessment was filmed as described in section 3.3.2, so that break angle could be assessed and compared against ϴ.

5.3 Statistical Analysis

After inspection of normality had occurred and all data was normally distributed, analysis of a linear correlation was used to investigate the variance in peak torque values obtained at slower isokinetic speeds and medium isokinetic speeds, ($60°·s^{-1}$, $150°·s^{-1}$) against that of the NordBord peak torque values following NHE. In order to establish the distribution of peak torque values from each individual parameter, box plots and Q-Q normative plots were constructed. To determine a relationship between the normative values, a Pearson correlation coefficient was calculated. Significant differences between values were also identified using a paired T-test, with significance set at $P<.05$. Statistical analysis of data distribution was identified utilising box plots, of which all data was normally distributed,

NordBord test performance data and all isokinetic parameters are quantified as mean ± standard deviation. Linear regression analysis was used to quantify the relationship between performance on each NordBord test parameter with peak torque, average torque and with angle of peak torque at each discrete testing speed ($60\ °·s^{-1}$ / $150°·s^{-1}$), in terms of eccH. Multiple linear regression analysis was then used to model NordBord test performance as a function of peak torque across all testing speeds collectively for eccH. This process was repeated for average torque and angle of peak torque across both speeds. In all cases the correlation coefficient (r) was used to quantify the relative contribution of each factor to agility performance. The value r^2 was subsequently calculated to quantify the percentage variation in NordBord performance that can be accounted for by variation in the isokinetic variable. Finally, and in order to develop a hierarchical ordering of the strength parameters influencing the NordBord test results, a forward stepwise regression model was utilized. Stepwise linear regression provides a means of including multiple variables within a model while simultaneously removing those variables that are not important. The forward selection model employed is initiated with no variables included, and subsequently adding the variable whose insertion gives the most statistically significant improvement of the correlation. This process is repeated until no additional variables improve the model to a statistically significant extent. This process allowed for identification of the singular most important isokinetic torque and angle of peak torque for eccentric hamstring strength at each testing speed.

5.4 Results:

5.4.1 Peak Torque

Table 1.3 shows the correlation between NordBord right leg peak torque values against right eccentric hamstring peak torque values generated by the IKD running at $60°\cdot s^{-1}$. Analysis of the Pearson Correlation identifies a very weak relationship between the values, with a significant difference between values (r=.143 P=.001). Correlation between NordBord left leg peak torque values against left hamstring peak torque values generated by the IKD running at $60°\cdot s^{-1}$. Analysis of the Pearson correlation identifies virtually no relationship between values, again with significant difference (r=-.006 P=0.001). Correlation between NordBord right leg peak torque values against right hamstring peak torque values generated by the IKD running at $150°\cdot s^{-1}$ with analysis of the Pearson correlation identifying no existing correlation between the values, as well as a significant difference between peak torque values, (r=.034 P=0.003). The correlation between NordBord left leg peak torque values against eccentric left hamstring peak torque values, generated by the IKD running at $150°\cdot s^{-1}$ with analysis of the Pearson correlation and paired T-test, identifies a strong correlation between values, with a significant similarity between readings from the two pieces of equipment, (r=.898 P=0.002). Similarly, analysis of Pearson correlations revealed a strong correlation between eccentric left hamstring peak torque values generated by the IKD at 60°·s^{-1} and 150°·s^{-1} but not significant (r =.808 P=.450). Whilst, a moderate correlation was observed between eccentric right hamstring peak torque values generated by the IKD at 60°·s^{-1} and 150°·s^{-1}, which was also calculated as non-significant (r =.551 P.843).

Table 1.3 Correlation value (r) and effect size (P value) between PkT values from the IKD and NordBord. Significance was set at P=0.005.

NB Right / IKD Right 60°·s-1	r = .143 P= .001
NB Left / IKD Left 60°·s-1	r = -.006 P= .001
NB Right / IKD Right 150°·s-1	r = .034 P= .003
NB Left / IKD Left 150°·s-1	r = .898 P= .002
IKD Left 60°·s-1 / IKD Left 150°·s-1	r = .808 P= .450
IKD Right 60°·s-1 / IKD Right 150°·s-1	r = .551 P= .843

5.4.2 Average Peak Torque

Table 1.4 shows the correlation between the NordBord left leg average torque values against left eccentric hamstring average torque values obtained by IKD at 60°·s^{-1}. Analysis of the Pearson correlation identifies a weak relationship between the values, with no significant difference between values (r=-.028 P=.094). Correlations between the NordBord left leg average torque values against left eccentric hamstring average torque values obtained by IKD at 150°·s^{-1} displayed analysis of the Pearson correlation identifying a very weak relationship between the values, again without a significant difference between values (r=.151 P=.025). The correlation between the NordBord right leg average torque values against right eccentric hamstring average torque values obtained by IKD at 60°·s^{-1} are shown below with analysis of the Pearson Correlation identifying a weak relationship between the values, without significant difference between values (r=.220 P=.079). The correlation between the NordBord right leg average torque values against right eccentric hamstring average torque values obtained by IKD at 150°·s^{-1} with analysis of the Pearson correlation identifies a weak relationship between the values, again without a significant difference between values (r=.200 P=.025). Analysis of Pearson correlations revealed a strong correlation between eccentric left hamstring peak torque values generated by the IKD at 60°·s^{-1} and 150°·s^{-1}, (r =.729) but not significant. Whilst, a weak correlation was observed between eccentric right hamstring peak torque values generated by the IKD at 60°·s^{-1} and 150°·s^{-1}, (r =.388), which was also calculated as non-significant.

Table 1.4 Correlation value (r) and effect size (P value) between AvT values from the IKD and NordBord. Significance was set at P=0.005.

NB Right / IKD Right 60°·s-1	r = .220 P= .412
NB Left / IKD Left 60°·s-1	r = -.028 P= .094
NB Right / IKD Right 150°·s-1	r = .200 P= .457
NB Left / IKD Left 150°·s-1	r = .151 P= .025
IKD Left 60°·s-1 / IKD Left 150°·s-1	r = .729 P= .120
IKD Right 60°·s-1 / IKD Right 150°·s-1	r = .388 P= .249

5.3.3 Angle of Peak Torque

Table 1.5 displays the correlation between the NordBord breaking angle to the angle of peak torque value associated with the left leg obtained by IKD at 60°·s^{-1}. Analysis of the Pearson correlation identifies a moderate relationship between the values, without significance between values (r=.504 P=.047). Analysis of the Pearson correlation between the NordBord breaking angle to the angle of peak torque value associated with the left leg obtained by IKD at 150°·s^{-1} identifies a moderate relationship between the values, without a significance between values (r=.485 P=.057). Analysis of the Pearson correlation between the NordBord breaking angle to the angle of peak torque value associated with the right leg obtained by IKD at 60°·s^{-1} identifies a moderate relationship between the values, without significance difference between values (r=.546 P=.029). Analysis of the Pearson correlation between the NordBord breaking angle to the angle of peak torque value associated with the right leg obtained by IKD at 150°·s^{-1} identifies a weak relationship between the values, without significance difference between values (r=.327 P=.217). Analysis of Pearson correlations revealed a moderate correlation between left sided angle of peak torque values generated by the IKD at 60°·s^{-1} and 150°·s^{-1}, (r =.583 P=.018) but not significant. Whilst, a moderate correlation was observed between eccentric right hamstring peak torque values generated by the IKD at 60°·s^{-1} and 150°·s^{-1}, (r =.451), which was also calculated as non-significant (P=.080).

Table 1.5 Correlation value (r) and effect size (P value) between Θ values from the IKD and NordBord. Significance was set at P=0.005.

NB / IKD Right 60°·s-1	r = .546 P= .029
NB / IKD Left 60°·s-1	r = .504 P= .047
NB / IKD Right 150°·s-1	r = .327 P= .217
NB / IKD Left 150°·s-1	r = .485 P= .057
IKD Left 60°·s-1 / IKD Left 150°·s-1	r = .583 P= 081
IKD Right 60°·s-1 / IKD Right 150°·s-1	r = .451 P= .080

5.4.4 Stepwise hierarchical ordering for predicting IKD from NordBord

Table 1.6 Hierarchical linear regression model of NordBord eccentric hamstring strength factors influencing IKD test performance using a forward stepwise approach.

	Step 1	**Step 2**	**Step 3**
IKDPkT60L	NB Breaking angle $R^2 = 0.30$ P = .022		
IKDAng60 L	NB Breaking angle $R^2 = 0.28$ P = .028		
IKDPkT60R	NB Breaking angle $R^2 = 0.17$ P = .094		
IKDAng60R	NB Breaking angle $R^2 = 0.29$ P = .016	NB AvT L $R^2 = 0.45$ P = .068	
IKDAvT60L	NB Breaking angle $R^2 = 0.29$ P = .026	NB PkT L $R^2 = 0.35$ P = .239	NBAvT R $R^2 = 0.60$ P = .013
IKDAvT60R	NB PkT L $R^2 = 0.16$ P = .112		
IKDPkT150L	NB Breaking angle $R^2 = 0.35$ P = .016		
IKDAng150L	NB Breaking angle $R^2 = 0.23$ P = .059	NB PkT L $R^2 = 0.32$ P = .079	NB AvT L $R^2 = 0.42$ P = .190
IKDPkT150R			
IKDAng150R	NB Breaking angle $R^2 = 0.10$ P = .217		
IKDAvT150L	NB Breaking angle $R^2 = 0.38$ P= .013	NB PkT L $R^2 = 0.46$ P= .096	NB AvT L $R^2 = 0.54$ P= .182
IKDAvT150R	NBPkT L $R^2 = 0.16$ P= .108	NB Breaking angle $R^2 = 0.25$ P=.242	

Table 1.6 presents the hierarchical ordering of NordBord factors influencing each metric on IKD testing. Stepwise modelling produced a hierarchical model of determinants, with NordBord parameters able to account for between 10% (IKDAng150R) and 60% (IKDAvgT60R) of the variation in IKD test performance. NordBord breaking angle was the only predictor of AngPkT60L, PkT60R, AvgPkT60R, PkT150L and AngPkT150R. Breaking angle was also the primary predictor for AngPkT60R with NB AvPkTL subsequently added producing a cumulative $r^2 = 0.45$. The same trend continues with breaking angle as the primary predictor of AvgPkT60L with both NB PkTL and NB Av PkTL added to give the highest value noted of a cumulative $r^2 = 0.60$. Again, breaking angle continues to be highlighted as the most important value in predicting IKD performance being the primary predictor of AngPkT150L with both NB PkTL and NB Av PkTL added to produce a total $r^2 = 0.42$. The NordBord breaking angle remains the prime factor predicting AvgPkT150L with NB PkTL and NB AvPkTL added producing a cumulative $r^2 = 0.54$.

5.4.5 Stepwise hierarchical ordering for predicting NordBord from IKD

Table 1.7 A hierarchical linear regression model of IKD eccentric hamstring strength factors influencing NordBord test performance using a forward stepwise approach.

	Step 1	**Step 2**	**Step 3**	**Step 4**	**Step 5**
NB breaking angle	AvgPkT150L $R^2 = 0.38$ P = .011	AngPkT60R $R^2 = 0.52$ P = .079	AngPkT60L $R^2 = 0.60$ P = .140	PkT150R $R^2 = 0.69$ P = .111	
NB PkF L	AvgPkT60R $R^2 = 0.16$ P = .125				
NB PkF R	AvgPkT60R $R^2 = 0.14$ P = .148				

NB PkT L	AngPkT60R R^2 = 0.16 P = .123				
NB PkT R	AngPkT60R R^2 = 0.13 P = .178				
NB AvgF L	AngPkT60R R^2 = 0.15 P = .142				
NB AvgF R	AngPkT60R R^2 = 0.12 P = .184				
NB AvgT L	AngPkT60R R^2 = 0.19 P = .094				
NB AvgT	AngPkT60R **R** R^2 = 0.16 P = .127	AngPkT150R R^2 = 0.25 P = .288	AvgPkT150R R^2 = 0.34 P = .219	PkT150R R^2 = 0.57 P = .034	AvgPkT60R R^2 = 0.71 P = .136

Table 1.7 presents the hierarchical ordering of IKD factors influencing each metric on NordBord testing. Stepwise modelling produced a hierarchical model of determinants, with IKD parameters able to account for between 12% (NB AvgF R) and 71% (INB AvgT R) of the variation in NordBord test performance. IKD AvgPkT60R was the sole predictor of NordBord PkF R, PkT L, PkT R, AvgF L, AvgF R and Avg T L. IKD AvgPkT60R followed a similar trend of the primary predictor for NB AvgT R with AngPkT150R, AvgPkT150R, PkT150R and AvgPkT60R subsequently added producing a five step sequence and a cumulative $r^2 = 0.71$. NordBord breaking angle was the only metric to have the primary IKD metric influencing performance being of the faster testing speed of 150°·s-1, AvgPkT150L gave an initial $r^2 = 0.38$ with a further three steps of AngPkT60R, AngPkT60L and PkT150R subsequently added to give a total $r^2 = 0.69$.

5.4 Discussion

The aim of the present study was to identify any relationships between the parameters PkT, AvT, ϴ and break angle from the IKD and NordBord in elite academy footballers. Recent research in this area is limited in relation to quantifying eccentric hamstring strength across two pieces of equipment and comparing their relative outputs, making comparisons to previous literature difficult. The main focus of the previous literature in adult populations has been orientated around the reliability and validity of the equipment (Greig., 2008; Cesar et al., 2013; Opar et al, 2013; Ribeiro et al., 2015) and the influence of anthropometry on force output (Bucheit et al, 2016), with little consideration around comparison of the data output and implications of this of athlete profiling in elite sport. Identification of any relevant relationships could guide injury prevention and rehabilitation protocols in elite academies and provide justification of when and where to implement specific strategies.

Much of the previous research in the use of the IKD and NordBord in elite sports has been focussed on adult populations (Grieg, 2008; Opar et al, 2013) and comparisons have not been made between the outputs from the two pieces of equipment. Arguments exist as to the effect of anthropometry when performing the NHE on the NordBord, but the literature only compares force output and not parameters of PkT, AvT and Ɵ. Literature reports these as some key parameters in establishing eccentric hamstring function and the importance of these are argued throughout literature (Greig et al., 2009; Small et al., 2009). The present study displays very weak relationships between the NordBord and the IKD when analysing the parameters of AvT and PkT at the slower speed of $60°\cdot s^{-1}$. This trend continues with the IKD at $150°\cdot s^{-1}$ for the right leg, but interestingly a strong correlation was seen for the left leg, questions remain over the possible cause of this. One presented argument could be limb dominance and future research in this area should consider identification of players limb dominance and the effect of this on potential relationships between data outputs between the IKD and NordBord.

Stronger correlations were observed between the two testing speeds on the IKD. Dvir., (1991) and Ayala et al., (2012) do not advocate the use of a range of speeds on the IKD to assess function. However, the faster velocities completed on the IKD have been related to the MOI of sustaining hamstring injuries (Van Hooren et al., 2016). Interestingly the academy footballers within the present study were unable to perform testing at $300°\cdot s^{-1}$, which was also indicated in the findings of the study completed in section 4. Previous research has attributed good control of high velocity assessment on the IKD with a reduced risk of sustaining hamstring and knee injuries (Whiteley et al., 2016) and consideration of training protocols/design to improve this function should be considered.

This said, care must be taken in assuring that academy players are not exposed to excessive high velocity/high load movements due to the effect these could have on the immature skeleton and implications to injury risk (Price et al., 2004).

Moderate to strong correlations were observed when comparing ϴ (IKD) and break angle (NordBord). These relationships were observed bilaterally at 60°·s-1. However, at the faster speed of 150°·s-1 relationships between the two parameters were weak. When performing the NHE the athlete has to provide control within the lowering phase and this is observed to be at a relatively slow speed. It is suggested that this slow speed is comparable to the 60°·s^{-1} performed on the IKD and replicates a slow controlled deceleration in performance. Further analysis through the stepwise hierarchical ordering model for predicting the IKD from NordBord performance presented that the NordBord breaking angle was the main contributing factor for predicting IKD scores within most parameters. This suggests that the NordBord could be utilised in practice to provide a more time efficient method of establishing academy footballers muscle architecture. Considering the short time required to perform testing on the NordBord there would be potential to integrate this testing in to fatigue monitoring protocols within footballers, due to the strong relationship between fatigue and reductions in eccentric hamstring function (Greig., 2008; Small et al., 2009). Applying the same stepwise model to see if IKD eccentric hamstring strength parameters had any influence on NordBord test performance identified that all of the low speed IKD analysis, as the main predictors for NordBord performance. This again highlights the influence of the slow movement when performing NHE, and consideration must be given to the lack of functional specificity of this slow velocity performance in relation to the injury mechanism (Engebretsen et al., 2010).

Research within football identifies that hamstring and knee injuries are on the rise (Agel et al., 2005; Walden et al., 2011; Serpell et al., 2012). The common mechanisms related to sustaining these injuries are associated with high velocity accelerations/decelerations during a linear motion (Alentorn-Geli et al., 2009; Opar et al., 2012). Injury prevention strategies highlighted by Van Mechlen (1992) identify the need to be able to carefully monitor interventions or training influences on muscle function. In order to be able to achieve this the testing completed in elite sport must be time efficient and outputs clearly relate to the potential MOI. Failure to do this will result in clubs generating data that provides an overview of hamstring function, with parameters that do not clearly relate to the MOI. Potentially generating data that provides very little information in relation to injury prevention strategies. Consideration must be given to the relevance of testing at slow speeds and does this provide practitioners in sports medicine with the best platform for injury prevention strategies or outcome measures within rehabilitation.

5.5 Conclusion

Isokinetic dynamometry has long been regarded as the gold standard measure for assessing athlete’s eccentric hamstring muscle strength and function. The results of this study have displayed weak to moderate correlations between the NordBord compared to that of the IKD, within the parameters of PkT and AvT. These differences could potentially be attributed to the influence of anthropometry on NHE performance. This said, the relationships identified between ϴ and break angle provide a platform for identifying the athletes muscle architecture quickly and efficiently utilising the NordBord. Prior to identifying any potential injury risk the outputs observed across the IKD and NordBord must be reliable and clearly relate to the MOI.

Chapter 6 – Discussion

6.1 Introduction:

As highlighted throughout the thesis, confusion remains in elite football regarding quantifying eccentric hamstring muscle strength, the most appropriate methods to use, when to use them, and how to interpret the data in helping to inform important clinical decisions around injury prevention and return to play markers used in rehabilitation (Greig., 2008; Findikoglu et al., 2011; Riberio et al., 2015). This has been highlighted with hamstring injury rates increasing over the past decade (Ekstrand et al, 2016) throughout an era where more time and effort is being spent on testing, screening and profiling athletes to mitigate such injury risk. The ability to quantify eccentric hamstring strength is vital for practitioners to develop injury prevention strategies. Individuals with bilaterally weak scores in comparison to baseline values, their norm or squad averages may be predisposed to an increased risk of hamstring injuries occurring. This theory is mirrored for individuals with large asymmetries from dominant to non-dominant limbs, these ‘at risk’ athletes also heighten the likelihood of other structural knee pathologies such as ACL ruptures and meniscal tears with these injuries linked to poor levels of eccentric hamstring strength resulting in excessive anterior tibio-femoral translation occurring (Alentorn-Geli et al., 2009). As seen with such high injury incidence (Woods et al., 2004; Ekstrand et al., 2011b; Ekstrand et al., 2016), hamstring injuries remain common place in elite sport. During rehabilitation, objective markers will be set to guide to process and be used as criteria to allow an athlete to return to competitive sport. The ability to quantify eccentric hamstring strength accurately and reliably therefore essential in allowing practitioners confidence in the results and in the decisions being made.

Isokinetic dynamometry is well regarded as the gold standard method for assessing hamstring strength and commonly utilised within injury prevention strategies and return to play markers (Aagaard et al, 1998, Maffiuletti et al., 2007; Impellizzeri et al., 2007; Greig., 2008; Hazdic et al., 2010; Houweling et al., 2010; Findikoglu et al., 2011; Anastasi et al., 2011; Cesar et al., 2013; Riberio et al., 2015) However, the introduction of the NordBord has provided and alternate method of quantification of eccentric hamstring strength and has become common practise in sport due to the portable nature of the equipment and reduced financial implications allowing it to be accessible to more clubs

(Opar, et al (2013). Another perceived advantage is the ability to test each athlete in around two minutes (Opar et al, 2015), allowing for whole squad testing on a more regular basis in team sports such as football. Nevertheless, questions remain over the functionality of the NordBord due to the slow speed of the test performed and if this can be really compared to injury mechanisms? The speed at which a NHE is commonly performed has not been previously documented in research although the correlations shown in study two highlight the slow speed nature of the NordBord. During high speed running, of which has long been associated as the injury mechanism for HSI, intense backward movements of the lower limb are necessary during both stance and late swing phases of running mechanics. During these phases the hamstrings are required to produce high eccentric forces (Morin, 2013; Sun, Wei, Zhong, Fu ,Li & Liu 2015), with it being suggested that the amount of knee elevation achieved late in the swing phase of sprinting combined with the hamstrings being actively lengthened at high velocity, an eccentric force >6–8 times body weight occurs (Sun, et al. 2015). Other questions remain over the specificity of the NordBord in isolating the hamstring musculature as the test completed is a multi-joint CKC exercise compared to the OKC nature of the IKD in isolating the hamstring. The ability to isolate the hamstring and gain greater insight into the functional strength of the muscle replicated at speeds similar to the sport specific requirements needed by athletes; may give more detailed information for practitioners to inform decisions over injury prevention and rehabilitation. An objective review of the practical application of both modalities of quantifying eccentric hamstring strength may therefore provide some answers to these questions and help towards a consistent approach used throughout elite football and may in turn help to provide some answers to such high injury incidence.

The IKD has a long history of academic literature which supports the longstanding validity and reliability of the equipment (Gaines et al 1999; Svensson et al., 2005; Impellizzeri et al., 2007; Maffiuletti et al., 2007; Cesar et al., 2013; Ribeiro et al., 2015). The results from Study 1 displayed in Chapter 4 reiterate this with excellent interclass correlation coefficient scores seen for all of the IKD metrics taken during the test re-test reliability study of elite youth footballers (ICC=0.87-0.91). Although these results are for youth athletes and all previous studies carried out in adult populations, the results are comparable to previous testing completed on professional footballers (ICC=0.76-0.78) and a wider population (ICC=0.90-0.98) (Greig, 2008; Riberio et al, 2015). The differences in populations used for the studies and the constancy in reliability results given emphasise the reliability of the equipment in varied age groups of footballers. Isokinetic eccentric hamstring peak torque values obtained during the study in youth footballers are also concurrent with previously reported findings, (Impellizzeri et al, 2008; Willigenburg et al, 2015; Carvalho et al, 2016). The findings outlined average peak torque values of (154.16+-14.6 at IKD 60°·s^{-1} left leg) and (159.5+-16.6 at IKD 60°·s^{-1} right leg). In 2015, Willigenburg et al., reported values of (140-150N +-28) at 60°·s^{-1} for freshman footballer's eccentric hamstring. Similarly, Caravlho et al, 2016, reported values of (156+-28) at 60°·s^{-1} on the IKD with Impellizzeri et al, (2008) reported eccentric hamstring figures of (169N+-52). Although small, there will always be variation between strength values in the study completed in academy players to previous literature as predominantly research focusses on senior squads. to a certain extent, there will even be variation between strength values in adult populations meaning there are no 'gold standard' value of eccentric peak torque for an athlete to achieve. This will vary from each participant group based on the level of hamstring training performed, level of competition and compliance to training. Another main reason for this variance is the volume and workload each participant group undergoes on a regular basis. If participants are frequently participating in hamstring strengthening programmes, then eccentric hamstring strength will be greater, (Mjølsnes et al, 2004; Timmins et al, 2015; Guex et al, 2016; Opar et al, 2016). Nevertheless, the study is concurrent with previous results witnessed in footballing populations, (Impellizzeri et al, 2008; Willigenburg et al, 2015; Carvalho et al, 2016).

In contrast, the NordBord has very limited previous data or research for practitioners and researchers to make comparisons too. One documented metric is the test re-test reliability of the equipment with Opar et al, (2013), stating the device displays excellent reliability (ICC=0.83-0.90). The findings of Study 2 displayed in Chapter 5 contradict these findings with substantially less reliability shown in the athletes tested (ICC=0.61-0.76). These conflicting results may be linked to the fact that academy footballers were used in Study 1 compared to Opar et al, (2013) using an adult population. However, as seen above results for youth and senior footballers when comparing IKD reliability provided similar results implying other factors may be the cause of these differences. The action of the Nordic hamstring curl completed on the NordBord is a complex whole-body exercise, the learning effects from completing the movement repeatedly could mean it be argued that the results stated by Opar et al, (2013), may have been conducted by athletes who are considered ‘experts’ at completing the Nordic hamstring exercise giving more consistent results (Heinmann et al, 2009), however it is important to note that all athletes participating in the study had been fully familiarised with the equipment prior to testing and used the NordBord frequently for objective testing. Narouei et al, (2018) demonstrated that the Nordic Hamstring Exercise is a multi-joint action which may not exclusively tell us about hamstring function. Using surface EMG it was concluded that high levels of erector spinae and oblique muscle activation was required to control the trunk in performing the exercise likewise gluteus maximus and erector spinae remained important in pelvis stabilisation allowing for improved hamstring performance. This is important as the results being given are not solely informative of hamstring function but also synergist muscles and could therefore begin to use anthropometrical differences to provide answers for the differences seen. Potential further research is required in order to determine the correlation between stabilising muscles and eccentric hamstring performance on the NordBord, if such correlations do exist, this may provide further questions over the specificity of the test in isolating hamstring muscle performance and highlight the multi-joint nature of the test.

Findings of Study 1 displayed large variation between specific findings for the NordBord test re-test reliability, firstly between limb differences for PkT ranged between ICC= 0.61-0.76. This is a large difference to say that the action performed is a bilateral assessment and becomes interesting when compared to AvT values which although showed considerably reduced levels of test re-test reliability were much closer between limb differences (ICC=0.56-0.57). Furthermore, breaking angle was shown to demonstrate significantly higher interclass correlation coefficient (ICC=0.92). The differences in metrics for each measure combined with poor test retest results in difficulties in obtaining a clear strength profile for athletes. As the hamstring profile is inconsistent, this may therefore result in the injury prevention strategies employed being poor and therefore may not achieve what is required to mitigate injury risk. In contrast the IKD displayed consistent reliability scores between dominant and non-dominant limb and across the two testing speeds for PkT, AvT and Ө providing a clear profile of hamstring function across the testing resulting in specific and accurate injury prevention programs being given to athletes. When referring to Van Mechelen (1992) injury prevention model in order to develop and implement prevention strategies based on careful review of risk factors and mechanisms associated to an injury, it is clear that eccentric hamstring strength is an associated risk factor for a hamstring injury occurring. A lack of reliability displayed from the NordBord could be argued that this method of quantifying the associated risk factor results in a poor injury prevention model with likewise poor outcomes derived from these. This trend continues in relation to RTP markers, with poor test re-test reliability associated with the NordBord practitioners must raise question marks over the application of the equipment in making such important decisions especially with such high reinjury rates as highlighted throughout the thesis.

Correlations between peak torque values associated with testing on the NordBord and through isokinetic testing at $60°\cdot s^{-1}$ displayed very weak relationships irrespective of limb dominance (r= -0.006-0.143). Interestingly as discussed previously this speed of testing on the IKD, although research does not exist to reference, would seem most replicable to the speed of which a NHE is performed in which case, hypothetically, if a correlation was to occur it may be expected to occur at this speed. The trend of a poor correlation between the two testing modalities continues when analysing average torque, with relationships ranging between virtually none too weak displayed across the two testing speeds for both limbs (r= 0.028-0.220). Overall, the relationship between the results of PkT and AvT for the IKD and NordBord were very poor raising question marks over the ability to compare data from each source. The breaking angle obtained through the video recording and analysis of the NHE performed on the NordBord may have provided more of a comparable result. When looking to see the relationship between the Ө from the IKD at $60°\cdot s^{-1}$ to the breaking angle, moderate correlations were seen (r= 0.504-0.546). Emphasising the slow speed at which a NHE is performed, when looking at the IKD Ө at 150°·s-1, decreased relationships were seen between NordBord breaking angle, this improved relationship at slow speeds may help to provide some ability in comparing NHE performance to IKD at slow speeds.

The hierarchical linear regression model was used to analyse the eccentric strength factors of one device influencing the test performance of the other device using a forward stepwise approach. This method highlights the primary metric influencing the performance and allows to see if trends appear through the data set. When using the eccentric hamstring strength measures obtained via the NordBord to predict IKD measures, the NordBord breaking angle was the primary factor in all but two of the variations. This is interesting when added that the NordBord breaking angle also provided an increased relationship through Pearson's Correlation calculations giving some argument to say that the NordBord breaking angle is the best predictor of eccentric hamstring strength ability when compared to IKD. The same model was calculated this time using the IKD eccentric hamstring strength to see which would influence NordBord test performance. All the primary predictors throughout the data came from slow speed IKD analysis, this continues to highlight the slow movement of the NHE, raising questions to its functional specificity in relation to the high speeds associated with injury mechanism as discussed in Chapter 2.3.1. The theory behind the angle of peak torque being used to predict HSI risk stems from the basis that the measure corresponds with fascicle length and in-series sarcomere strain (Morgan 1990). Longer muscle fascicles are thought to have less sarcomere lengthening per unit of in-series strain when compared with shorter muscle fascicles. As a result, this will reduce the proportion of their range of motion that is spent on the descending limb of the force–length relationship, limiting its susceptibility to eccentrically-induced muscle damage and potentially reducing the risk of injury. The basis of this hypothesis is that possessing longer muscle fascicles results in the angle of peak knee flexor torque occurring at longer muscle lengths, where the opposite is thought to occur with shorter muscle fascicles (Brockett, Morgan & Proske 2004).

6.2 Isokinetic Dynamometry:

Several epidemiologic studies have reported that many lower limb injuries occur while athletes engage in activities with a high intensity of stretch–shortening cycles; in particular, during sudden acceleration and deceleration, rapid changes of directions, jumping and landing tasks (Cochrane et al., 2007; Croisier et al., 2008; Alentorn-Geli et al., 2009). It has been suggested that strength impairment of the knee is one of the most important risk factors for lower limb injuries in recreational and competitive athletes (Worrel & Perrin,1992; Croisier, 2004, Ayala et al, 2013). In addition, changes in the length–tension relationship of the muscles around the knee (knee flexor and extensor muscles) expressed as peak force occurring at a joint angle corresponding with a muscle length that is not optimal may also predispose the athlete to be more prone to lower limb injuries (Brockett et al., 2004).

Isokinetic testing provides an insight into the angle-torque relationships of the knee flexors and can be used as a global indicator of the length-tension relationship (Ayala et al, 2013). Variables such as peak torque, average peak torque and angle of peak torque displayed by the isokinetic angle–torque curve may provide useful insight on muscle function by not only giving torque values but a deeper understanding of where these occur during the functional range required by an athlete. Isokinetic dynamometry is a method commonly used in the assessment and monitoring of muscle performance used both in research and in clinical practice regarding injury prevention and rehabilitation.

Testing on an isokinetic dynamometer consists of a unilateral, open kinetic chain exercise isolating the muscle in question to perform the action being required. This difference when compared to a NordBord assessment where an athlete is required to lean forward resisting bilaterally while able to use other muscles to assist to stabilise and control the movement as discussed previously may help to give more of an understanding to differences in the results shown. The specificity of isokinetic testing is imperative for practitioners, enabling them trust in the results and allow them to be used to guide clinical decisions regarding injury prevention and return to play criteria highlighting how this method remains the best approach to date (Houweling et al., 2010; Findikoglu et al., 2011; Anastasi et al., 2011).

Several studies have examined the absolute reliability of the most common isokinetic parameters under knee flexion and extension muscle actions (McCleary &Andersen, 1992; Li et al., 1996; Pincivero et al., 1997; Dauty & Rochcongar, 2001; Lund et al., 2005; Dervisevic et al.,2006; Maffiuletti et al., 2007; Sole et al., 2007; Impellizzeriet al., 2008). Although some authors have theoretically suggested that to assess muscle function of the knee, an isokinetic protocol where athletes adopt a prone position (10–20° hip flexion) would be the most ecologically valid method, surprisingly, all of these studies have determined the absolute reliability of PkT, APkT and ϴ isokinetic parameters using a seated position with the hip at 90^{o} of flexion. A prone position used for testing may be more functionally relevant as it closely simulates the hip joint angle in a running/sprinting position and theoretically more closely replicates the knee flexor and extensor muscle length–tension relationships which occur during the late swing and early contact phase of sprinting, closely correlating with the main injury mechanism for HIS (Arnason et al., 2004; Woods et al., 2004; Ueblacker, Müller-Wohlfahrt & Ekstrand 2015).

The prone position of testing was considered for the protocol used in the thesis due to the reasons stated above however, questions remain over the reliability of findings when carried out this way. Although to current date, no study has been carried out to make a direct comparison between seated and prone testing protocols, individual reliability studies have been documented. Ayala et al, (2013), concluded moderate ICC scores >0.70 for knee flexion and extension in both concentric and eccentric actions and a variety of velocities (60, 180 and $240°\cdot s^{-1}$). Absolute reliability results have been reported in previous studies using recreational athletes in a seated testing position have shown increased levels of reliability (Li et al., 1996; Dauty & Rochcongar, 2001; Dervisevic et al., 2006; Maffiuletti et al., 2007; Sole et al., 2007; Impellizzeri et al., 2008). In addition, concerns have been raised over the variation in results seen, for example, Impellizzeri et al. (2008) reported within-subject variation expressed throughout standard error of measure (SEM, 68% likely) of 5.2% for concentric knee flexion PT measured at $180^{°/s-1}$, whereas the results of the current study have shown a within-subject variation of 12.3% for the same isokinetic index. Ayala et al, (2013) concluded that using the prone testing position may be acceptable to detect the large changes usually observed after rehabilitation programmes, but not an acceptable method to examine the effect of preventative training programmes in healthy individuals.

The decision was therefore made to stay in line with other studies and use the seated position for testing. A conscious effort was made however to ensure a consistent range of motion used from both the IKD and NordBord in order to allow a direct comparison to be made. It is important to note the difference in position in which the two actions are performed may be a substantial contributing factor for the differences seen. During a NHE, participants are positioned in 0 degrees of hip flexion, whereas during IKD protocols, participants are place in 80-90 degrees of hip flexion. Therefore, this places the hamstring group in a longer architectural position. Based on previous research by Guex et al, (2016), which outlined that greater hamstring fascicle adaptations were observed during 80 degrees hip flexed position compared to 0 degrees and of Bourne et al, (2016), stating that increased hip flexion angles during IKD protocols resulted in greater excursion of the hamstrings; this may provide some reasoning for the differences observed. Whilst performing the IKD protocol, the hamstrings are able to provide resistance over larger knee ROM due to the increased hip flexion angle as opposed to shorter knee ranges available whilst performing NHE therefore being able to produce higher peak torque values performed during IKD protocols, similar to those observed in this thesis.

Common injury mechanics for the hamstrings and ACL are related to high loads and high speeds as discussed in section 2.1.1, where control needed during an acceleration/deceleration phase or change of direction. Eccentric IKD measures at 300°·s^{-1} have been questioned in relation to how much of the ROM represents ‘true’ isokinetic measures however this may be the key indicator and preventative measure associated with reducing hamstring and ACL. The high velocity of the test may replicate the characteristics of the high velocity mechanisms in relation to hamstring and ACL injuries and therefore, a lack of control or poor performance during this test may highlight that a participant is are more prone to sustaining such injury. Theoretically if an athlete cannot meet the demands of high velocity eccentric IKD testing, then maybe it would suggest that the player is not functionally ready to return to game play, as these would be similar if not slightly less than loads experienced during game play (Gaines et al., 1999; Greig., 2008). It has been highlighted that any measures up to 300°·s^{-1} have shown good reliability and validity, (Drouin et at, 2004; Greig, 2008), which further raises concerns over the lack in the ability in elite youth footballers to initiate the movement and control throughout the range during testing, resulting in the high velocity test of 300°·s^{-1} being removed from the study. Further research is required to confirm whether this is representative of this age population across clubs and sports however, if this test replicates similar if not less loads required during performance (Greig, 2008), and the athletes could not perform the test, this may result in the athletes being more susceptible to hamstring and ACL injuries when playing (Pincivero et al., 2000; Sangnieer et al., 2007; Wright et al., 2009; Small et al., 2009; Small et al., 2010; Thomas et al., 2010; Rampinini et al., 2011). This is because the hamstrings would not respond to the changes in length at pace making them more susceptible to overstretch; nor would they be able to apply enough functional control to stabilise the knee through fast, high load movements (Ribeiro et al., 2008; Torres et al., 2010; Changela et al., 2012).

The number of repetitions used during testing remains inconsistent across literature, although this may be dependent on the test being carried out with some focussing on maximal strength values and others looking more into the effects of fatigue, some researchers use use peak values while others an average of multiple values. Portney & Watkins (2009), used the average of best two trials at each velocity through the testing concluding the magnitude of the error component decreased in doing so this way. In addition, Sole et al. (2007) reported better reproducibility when they used the average value from three trials rather than the single highest value from the three repetitions for concentric and eccentric PkT. It was decided for the study PkT, AvT and ϴ values were calculated by identifying two repetitions of similar values with a set of 5 repetitions for each testing speed in line with Greig., (2008), Greig et al., (2009) and Small et al., (2009) to reduce the error in the results.

6.3 NordBord:

The NordBord remains to have significant questions over the specificity and reliability of the test. The device has been advocated throughout literature since 2013 with Opar et al, (2013), concluding that the portable device offers an alternative to current dynamometry based techniques for the assessment of eccentric knee flexor strength. However, this study was completed on 30 amateur and 20 professional athletes, of which all competed in a variety of sports in Australia, this relatively low sample size combined with the fact that they are split across a number of sports including Australian football, soccer, rugby union, and differing track and field events makes it difficult to generalise the results for a specific athletic population. In addition, no specific ages of athletes were given for the participants used in the study, this again results in it being difficult to practically apply the results to specific athletic populations. The above combined with the significant difference seen in the results of test re-test reliability displayed in Study 1 when compared to previous research continue to raise questions over the reliability of the device.

Similarly, there remains a lack of clarity over the validity of the test without any literature published around this topic to date. Anthropometric variances have been touched on previously in this chapter already raising concerns over the validity of results by highlighting the fact the Nordic exercise is a whole-body exercise of which the performance depends not solely on hamstring strength ability but also other stabilising muscles (Narouei et al, 2018). This indicates that the results of testing are unable to comprehensively isolate hamstring muscle function and is therefore difficult to make imperative decisions regarding injury prevention and rehabilitation. Other questions arise from the fact that while being tested, an athlete is required to lean forward resisting bilaterally, although the devise has unilateral force cells able to detect left and right strength ability while completing the test, the fact that the test is bilateral in nature indicates that the results given may not be a direct result of unilateral strength due to the cross over effect of the contralateral limb.

Differences seen between the results of the two testing modalities may be explained and linked to the influence of the anthropometrical characteristics while performing the NHE. Unlike the IKD which uses calculations of body mass or limb weight in order for testing to be gravity corrected producing consistency in results, anthropometrical variances may influence the NordBord greatly. Theoretically, body mass may have a large effect on the results given, as an athlete begins to lean forward they begin to exert force onto the receptors around the ankles, participants who are heavier will place greater strain on the receptors which in turn, will alter readings that are not a true reflection of the player's actual eccentric peak torque strength. Bucheit et al, (2016) identified a moderate correlation between eccentric hamstring strength and body mass whilst testing on the Norbord (r=.55). Although only a moderate correlation was determined, Bucheit et al, (2016) continued further, outlining that for every 1kg of body mass increase there may be a 4N increase in torque values, further research is required in this area before being implemented by practitioners. Another factor yet to be discussed in research and an area required for further research is the potential for how an individual's height may influence their results. Physics states that a taller athlete will have their centre of mass further away from the fulcrum which in this example is at the knee. As the athlete performs the NHE the centre of mass will fall further outside the midline of the body, theoretically, this potentially with change the amount of eccentric force required by the athlete to resist falling. This highlights again the questions remaining over the specificity of testing on the NordBord and continues to highlight the strengths of testing using the IKD where athletes are tested in a seated position with gravity corrected, the readings are less likely to be influenced by the body mass/height of a participant and are therefore reflective of true eccentric hamstring strength.

The influence of ankle position on NHE performance is another factor of which has limited research carried out into the area. As discussed in chapter 2.3 the biceps femoris (BF) which is the most lateral muscle of the three hamstrings is injured more frequently than the semimembranosus and semitendinosus musculature (Silder, Reeder, Thelen, 2010; Ekstrand et al., 2012). Considering the biarticulation of the BF, this muscle is more susceptible to mechanical strain during rapid actions of hip flexion and knee extension (Comfort et al, 2017). Changing the position of the ankle will affect the length of the gastrocnemius, which could influence force production due to inherent length–tension characteristics of the muscle and, therefore, affect muscle activity of both the BF and gastrocnemius. Although Comfort et al, (2017) found no significant difference in peak EMG amplitude when performing a NHE with both the ankle in a dorsiflex (DF) and plantarflex (PF) position, this was carried out with a small sample size of 15 participants of which amateur in ability. With elite athletes, a change in ankle position may contribute towards a lack of reliability in results and may be another area where consistency between practitioners or between tests of the same athlete may be lacking.

Further potential questions associated with the practical implication of the NordBord is related to the speed at which the test is performed. To current date, no research has been carried out to state actual speed most commonly used by an athlete to perform a NHE, with the speed differing depending on the individual. That saying the movement of a NHE is a slow speed action in comparison with the demands of elite level sport. This theory is evidenced in Chapter 5.4 where interestingly when using the hierarchical linear regression model for predicting IKD performance from the NordBord, all the main predictors were from low speed IKD analysis, highlighting the slow movement of the NHE and raising question marks over the lack of functional specificity in relation to injury mechanism. An initial hypothesis expected to see that that values obtained from the IKD running at slow speeds (60°·s-1) and NordBord may be similar, whereas faster speeds of (150°·s-1 and

300°·s-1), which focus on the more functional strength aspects of eccentric hamstring mechanics, (Bucheit et al, 2016; Bourne et al, 2016), would be vastly different. Interestingly, Willigenburg et al, (2015) outlined that speeds greater than 180°·s-1, reflects eccentric muscle function during athletic activity, with a greater level of neuromuscular influence/control. Whilst speeds lower than 180°·s-1 specifically reflects muscular strength-based values. Therefore, the chosen speeds of 60°·s-1 and 150°·s-1 in the study, may be more reflective of muscular strength and if it had been able to incorporate the faster speed of 300°·s-1, greater differences may have been seen again between the IKD and the NordBord. Future research is required to examine the direct relationship NordBord performance and the speed of which the NHE is performed.

With the knowledge of the above it is important for practitioners to choose how to use and interpret data obtained via the NordBord. The portability combined with the ease of use may advocate the use of the device throughout the rehabilitation process as a training tool, providing instantaneous visual and informative feedback for both the athlete and practitioner. That saying, although an athlete may be seeing improved performance in NordBord strength scores, a NHE only trains the hamstring musculature throughout a small range of the muscle capabilities at a slow speed which may not be representative to functional activities out on the pitch. This improvement in NordBord ability may therefore provide false security for a practitioner that the athlete is ready to return to participation in sport without stressing the muscle close to the demands required when returning to sport. Likewise, when used for injury prevention strategies, a NordBord assessment may be appropriate in team-based sports where time is limited, to highlight individuals with significant deficits in strength compared to peers or large asymmetries. Nevertheless, the depth of knowledge and understanding of the slow speed nature of the NordBord is essential for practitioners across sport in order to use this information to highlight individuals but then follow up with further in-depth strength analysis, more representable of the eccentric physical demands required of the hamstrings functional activities.

6.4 Limitations and Directions for Future Research:

The main aim of the study was to examine and analyse two contemporary measures of eccentric hamstring strength used in elite academy footballers and how this can affect their application in professional sport. The findings above have displayed the differences that have been found and provided explanations on potential reasons why such differences may have occurred. To date there is no previous research which has made a direct comparison between the two testing modalities, several limitations remain from the current study therefore further studies may be required to attempt to explain why such differences in reliability and poor correlation between the two may have occurred. Although all attempts were made for the athletes to have as similar training week as possible in terms of volume and intensity between testing weeks, with the same number of training sessions with consistent themes during the week, it is impossible in an elite environment for this to be perfectly consistent. This is due to the natural variation of sessions led by coaches and differences in the competitive match. Although this may be slight variation, it is a true representation of the environment and gives a real insight into elite academy footballers.

The sample demographic provides another limitation to the wider generalisation of the results. As the study was performed in elite male youth footballers from one academy, questions remain whether this is a true representative of category one Premier League youth footballers. As the players are all from one club it is possible that the previous training history, injury prevention strategies and emphasis placed on strength training may all effect the nature of the results, in order to get a wider representative of this participant group it would be required to gain participants from a number of clubs across the country to remove these extraneous variables. Likewise, it remains to be seen if these results can be generalised and applied to a senior population in football or likewise to other sports. Further research is required to be carried out to see if such trends continue. Another limitation to the study is that measurements were displayed in terms of left and right limb rather than dominant or non-dominant. Football is an asymmetrical sport with athletes commonly favouring one leg for certain actions, this may predispose them to certain strength asymmetries due to repetitive actions performed in training and competition. Displaying the results in terms of dominance may provide a greater insight into the test retest reliability of each testing device and how results compared when comparing devices. Further research is required to be completed in order to determine if limb dominance changes how the results are presented. Further research is also required to be carried out into the NHE completed on the NordBord and how anthropometrical variances such as body mass and height effect the results obtained

6.5 **Implications for Practice:**

Although aware of the limitations in relation to the study there are several implications that can be taken and applied to practise. First of all, as highlighted previously, objective data used to help guide clinical decisions regarding injury prevention and throughout the rehabilitation process requires high levels of interpretation on an individualised basis of which practitioners are required to have large amounts of confidence in the objective information being given to them to help guide this process. The poor test re-test reliability associated with the NordBord indicates for practitioners to analyse results with caution when making informed decisions regarding injury prevention and return to play in elite athletes. The portability and ease of use of the NordBord may have combatted some of the limitations regarding isokinetic testing and led to the widespread use of the device. The study has also given guidance into the practical application of the NordBord in elite athletes, all be it in youth athletes, of which could be generalised to a wider population. The slow speed of the test and limited range of muscle function assessed by the NordBord raise questions over the functional specificity in relation to injury mechanics and therefore to the application of the device in regard to decisions over injury prevention and return to play. In team sports where limited time is available to screen athletes for injury prevention, the NordBord may provide a way to get a ‘snapshot’ in eccentric hamstring ability, highlighting gross asymmetries and weakness. This study would then advocate the need to further strength analysis more representable to functional activities. Isokinetic testing may take increased periods of time to test and analyse however this method has a long history of reliability and validity (Lund et al., 2005; Dervisevic et al.,2006; Maffiuletti et al., 2007; Sole et al., 2007; Impellizzeriet al., 2008) in isolating eccentric hamstring muscle function in a way that no other method has been shown to do.

Therefore, in order to make informative decisions regarding elite athletes where injuries have already been shown to be so detrimental both for development and financially, IKD testing is essential in this process.

Chapter 7 – Conclusion

Although hamstring injuries are known to be multi factorial with several risk factors associated with the injury as discussed in Chapter 2.2, eccentric hamstring strength is commonly accepted throughout sports medicine as a significant factor of which can be monitored and trained to reduce injury incidence. In elite level sport where such huge consequences occur over injury and reinjury with the substantial loss of playing time caused by these injuries having huge financial implications for clubs and detrimental developmental implications for youth athletes, the need to quantify eccentric strength accurately and appropriately is essential. From the results of this thesis, questions must arise regarding the practical application of the NordBord in making clinical decisions regarding injury prevention and as a return to play marker. The lack of test re-test reliability shown, combined with the poor correlation for peak torque to that of the IKD, result in questions of trust from practitioners in the objective results being given.

While the topic around screening for injury prevention remains debatable, reduced eccentric hamstring strength has been shown to increase the risk of likewise injuries occurring. The practicality of screening a whole squad on the IKD to raise concerns over weakness and asymmetry may not be feasible in a sporting setting due to the time demands this would take. Therefore, this may advocate the use of the NordBord as a tool to screen a squad quickly and to give some information regarding eccentric hamstring strength. In order to fully achieve this, further research is essential on the anthropometry when performing Nordic curl and its effect on PkT and AvT. Bucheit el al, (2016), predicted changes in force output in relation to BW, but nothing further. Study 2 highlights the relationship between break angle and angle of PkT of which gives an insight into the architecture of the muscle which can be related to the force lengthening capabilities of a muscle and relate to MOI. The differences seen here are supported with the excellent ICC of break angle from study 1 and the inconsistent values of PkT and AvT displayed. It is important for a sports medicine department or individual analysing the results to have a good understanding of the limitations of the results being given and if they had access, would strongly advocate for therapists to use clinical reasoning to highlight individuals potentially at risk and follow this up with IKD testing. Those without access may want to use findings of this study to say that breaking angle as a single measure may provide more of an insight into hamstring muscle function as displayed in study 2.

Following an injury and throughout the rehabilitation process it is important to have detailed objective markers used to determine when an athlete is prepared to progress to the next stage of rehabilitation. These methods require objectivity and consistency to assist practitioners with this process. That said, the NordBord does have some advantages over the IKD in that it is accessible throughout all levels of sport, the test is much quicker and can therefore be implemented into a program more frequently without the need for a skilled operator to carry out the test and then analyse the results. This may lead to the NordBord being most appropriately used throughout the rehabilitation stage as a training tool, providing instantaneous feedback for an athlete and coach which can be repeated regularly throughout the process. In contrast, it remains imperative for practitioners to understand the demands of the test being completed and to have the knowledge that the action of a NHE consists of a slow speed eccentric contraction throughout a relatively small range, although strength may be increasing while using this testing modality, does this really prepare them for the demands of the sport they are returning to?

The decision of returning an athlete to training and competitive competition is a complex decision with multiple factors needed to be taken into consideration. With hamstring injuries seeing such significant reinjury rates, it is imperative that this decision is made with the best clinical judgement. It is concluded from this research that the high levels of reliability demonstrated through IKD testing, combined with the specificity of IKD in isolating the specific muscle in question and the ability to test that muscle at significantly faster speeds which much closer replicate the demands of the returning sport, ensure this method remains the most useful tool to be utilised for return to play decisions for both hamstring and knee injuries.

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Appendix A

Participant information sheet

Hamstring Strength Study (Everton Football Club) – Participant Information

We would like you to take part in a small research study. Before you decide to take part, we would like you to understand why the research is being done and what it would involve for you.

Who is doing the research? The research is being led by Joshua Jeffery, a full time Sports Therapist who works for Everton Football Club.

Why is the study being carried out? This study aims to help reduce hamstring strain injuries in youth football by being able to identify risk factors associated with the injury easier and more efficiently.

What is involved in this study? Everton Football club are already undertaking Sports Science and Medicine testing on all players. This research study will simply analyse the test results of all players unless you contact the researcher to state that you do not wish your results to be included. All personal information will be removed and participants will remain completely anonymous.

What will happen if I don't want my results to be included in the study? You can decide for your results to not be included in the study by informing us on the contact details below before 01/11/2017. You don't have to tell us why you have decided this and your decision not to take part will not affect you in any way. However, I must inform you that all information will remain completely anonymous.

How will the study results be used? The data collected may be published in a journal and/or presented at a conference. The data collected will not contain any identifiable information. The findings will form future recommendations used in elite youth football sports medicine.

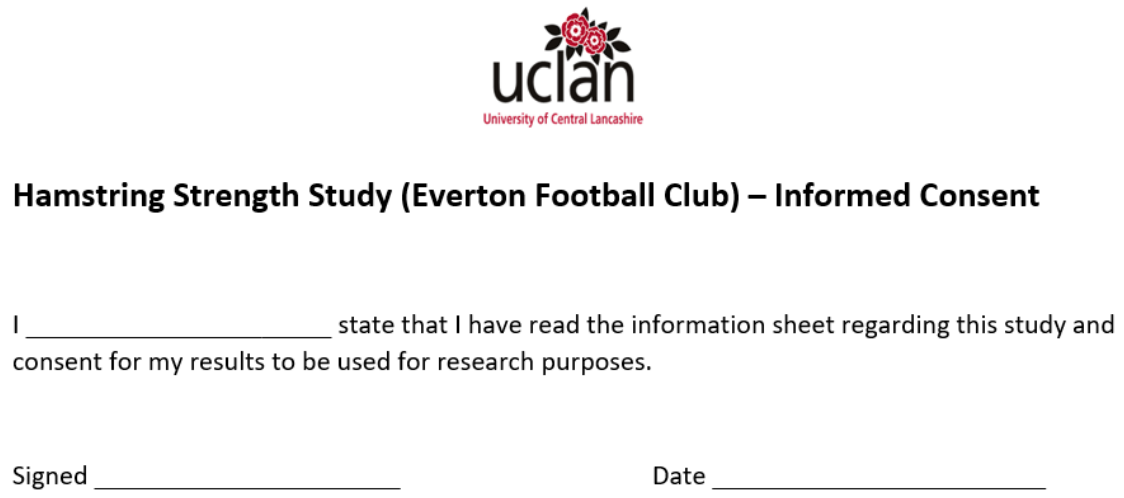
What can I do if I am not happy with the study? If for any reason you are not happy with any aspect of the study, or require any further information, please contact Josh Jeffery who will answer any questions.

Email: Josh.jeffery@evertonfc.com
Telephone: 07538153201

If you are unhappy or have concerns about any aspect of the project, and do not wish to contact the researcher, you can contact the University Officer for Ethics (officerforethics@uclan.ac.uk) who is entirely independent of the research and will respond to your concerns.

Appendix B

Informed Consent Form



uclan
University of Central Lancashire

Hamstring Strength Study (Everton Football Club) – Informed Consent

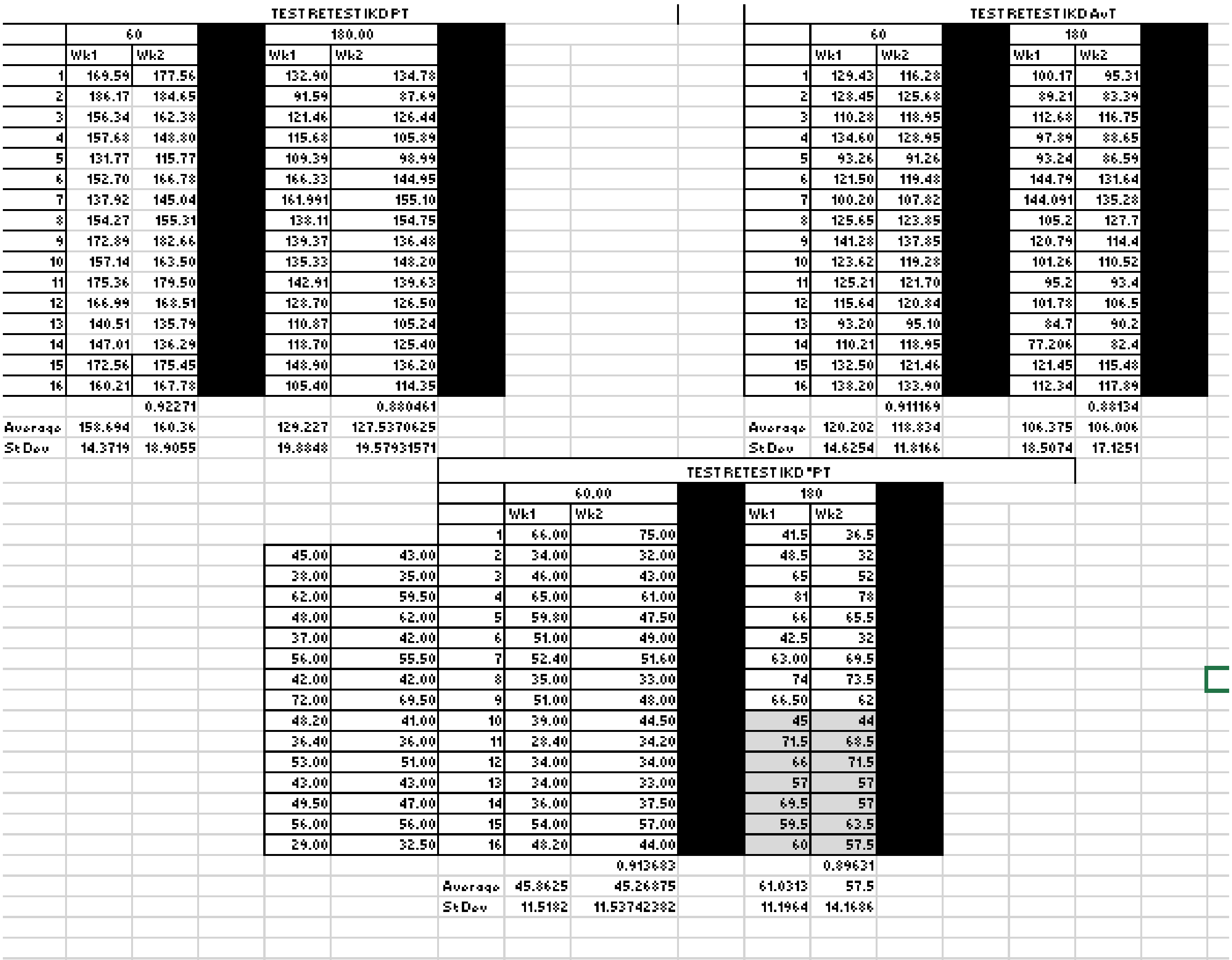
I ________________________ state that I have read the information sheet regarding this study and consent for my results to be used for research purposes.

Signed ________________________ Date __________________________

Appendix C

Raw Data

Right leg IKD data



TEST RETEST IKD PT

	60		180.00	
	Wk1	Wk2	Wk1	Wk2
1	169.59	177.56	132.90	134.78
2	186.17	184.65	91.59	87.69
3	156.34	162.38	121.46	126.44
4	157.68	148.80	115.68	105.89
5	131.77	115.77	109.39	98.99
6	152.70	166.78	166.33	144.95
7	137.92	145.04	161.991	155.10
8	154.27	155.31	138.11	154.75
9	172.89	182.66	139.37	136.48
10	157.14	163.50	135.33	148.20
11	175.36	179.50	142.91	139.63
12	166.99	168.51	128.70	126.50
13	140.51	135.79	110.87	105.24
14	147.01	136.29	118.70	125.40
15	172.56	175.45	148.90	136.20
16	160.21	167.78	105.40	114.35
		0.92271		0.880461
Average	158.694	160.36	129.227	127.5370625
St Dev	14.3719	18.9055	19.8848	19.57931571

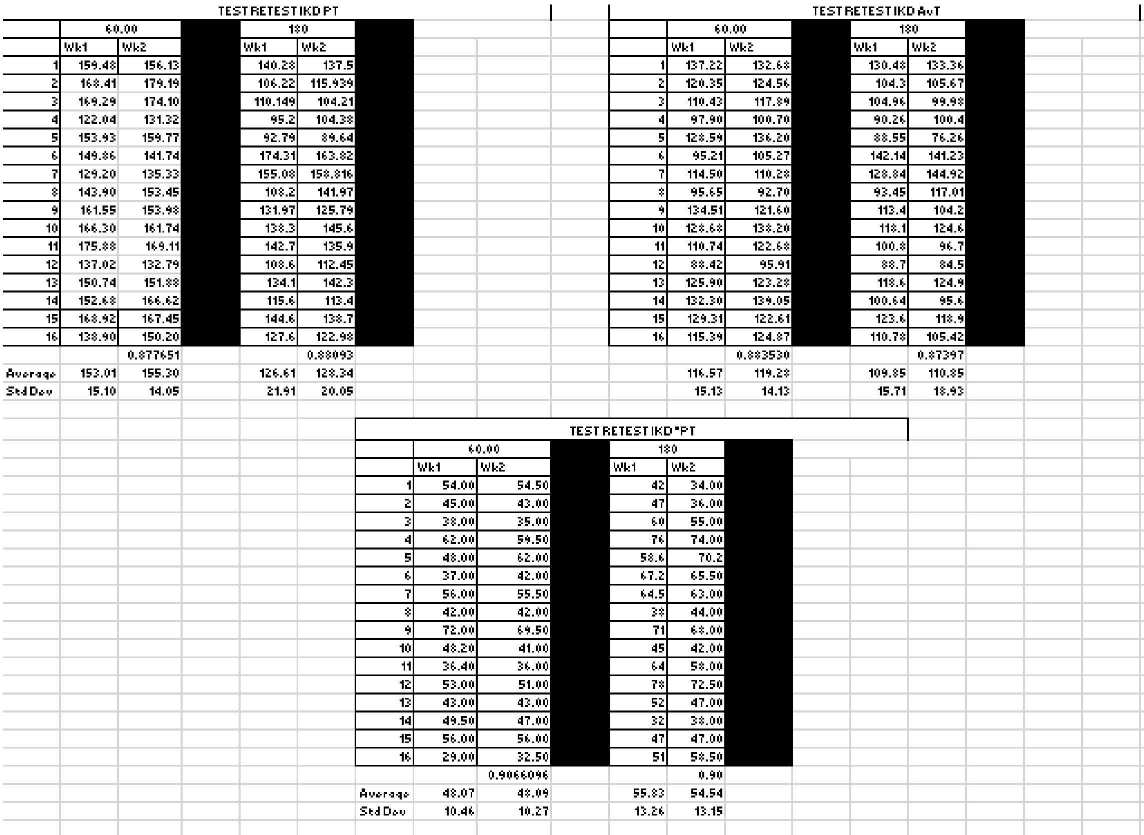
TEST RETEST IKD AvT

	60		180	
	Wk1	Wk2	Wk1	Wk2
1	129.43	116.28	100.17	95.31
2	128.45	125.68	89.21	83.39
3	110.28	118.95	112.68	116.75
4	134.60	128.95	97.89	88.65
5	93.26	91.26	93.24	86.59
6	121.50	119.48	144.79	131.64
7	100.20	107.82	144.091	135.28
8	125.65	123.85	105.2	127.7
9	141.28	137.85	120.79	114.4
10	123.62	119.28	101.26	110.52
11	125.21	121.70	95.2	93.4
12	115.64	120.84	101.78	106.5
13	93.20	95.10	84.7	90.2
14	110.21	118.95	77.206	82.4
15	132.50	121.46	121.45	115.48
16	138.20	133.90	112.34	117.89
		0.911169		0.88134
Average	120.202	118.834	106.375	106.006
St Dev	14.6254	11.8166	18.5074	17.1251

TEST RETEST IKD "PT

			60.00		180	
			Wk1	Wk2	Wk1	Wk2
		1	66.00	75.00	41.5	36.5
45.00	43.00	2	34.00	32.00	48.5	32
38.00	35.00	3	46.00	43.00	65	52
62.00	59.50	4	65.00	61.00	81	78
48.00	62.00	5	59.80	47.50	66	65.5
37.00	42.00	6	51.00	49.00	42.5	32
56.00	55.50	7	52.40	51.60	63.00	69.5
42.00	42.00	8	35.00	33.00	74	73.5
72.00	69.50	9	51.00	48.00	66.50	62
48.20	41.00	10	39.00	44.50	45	44
36.40	36.00	11	28.40	34.20	71.5	68.5
53.00	51.00	12	34.00	34.00	66	71.5
43.00	43.00	13	34.00	33.00	57	57
49.50	47.00	14	36.00	37.50	69.5	57
56.00	56.00	15	54.00	57.00	59.5	63.5
29.00	32.50	16	48.20	44.00	60	57.5
				0.913683		0.89631
		Average	45.8625	45.26875	61.0313	57.5
		St Dev	11.5182	11.53742382	11.1964	14.1686

Left leg IKD data



TEST RETEST IKD PT

	60.00		180	
	Wk1	Wk2	Wk1	Wk2
1	159.48	156.13	140.28	137.5
2	168.41	179.19	106.22	115.939
3	169.29	174.10	110.149	104.21
4	122.04	131.32	95.2	104.38
5	153.93	159.77	92.79	89.64
6	149.86	141.74	174.31	163.82
7	129.20	135.33	155.08	158.816
8	143.90	153.45	108.2	141.97
9	161.55	153.98	131.97	125.79
10	166.30	161.74	138.3	145.6
11	175.88	169.11	142.7	135.9
12	137.02	132.79	108.6	112.45
13	150.74	151.88	134.1	142.3
14	152.68	166.62	115.6	113.4
15	168.92	167.45	144.6	138.7
16	138.90	150.20	127.6	122.98
		0.877651		0.88093
Average	153.01	155.30	126.61	128.34
Std Dev	15.10	14.05	21.91	20.05

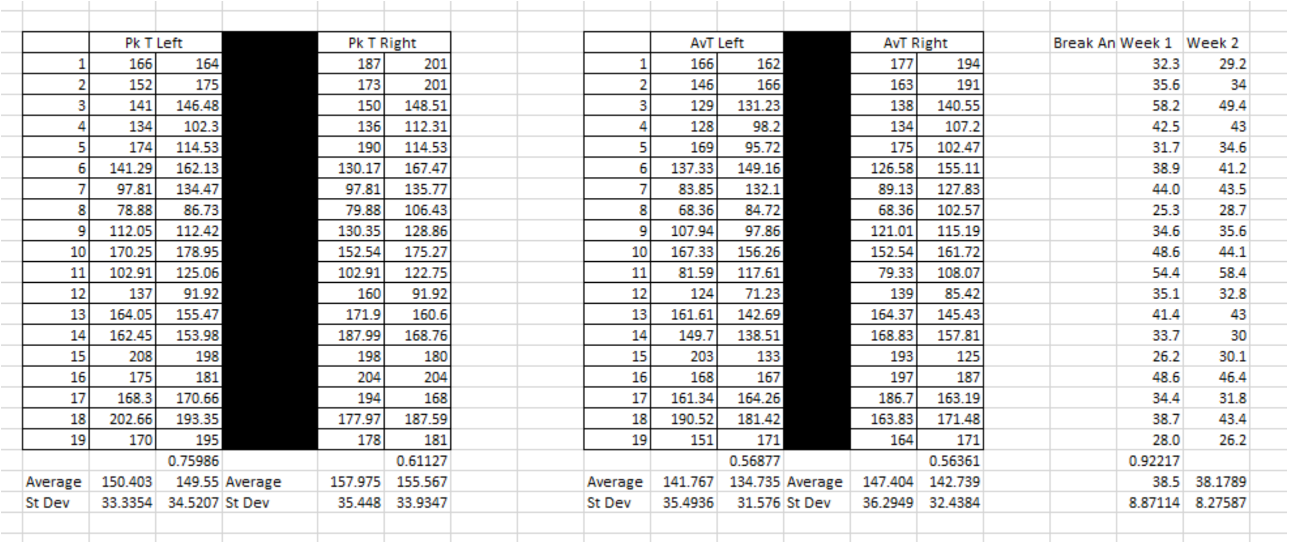
TEST RETEST IKD AvT

	60.00		180	
	Wk1	Wk2	Wk1	Wk2
1	137.22	132.68	130.48	133.36
2	120.35	124.56	104.3	105.67
3	110.43	117.89	104.96	99.98
4	97.90	100.70	90.26	100.4
5	128.59	136.20	88.55	76.26
6	95.21	105.27	142.14	141.23
7	114.50	110.28	128.84	144.92
8	95.65	92.70	93.45	117.01
9	134.51	121.60	113.4	104.2
10	128.68	138.20	118.1	124.6
11	110.74	122.68	100.8	96.7
12	88.42	95.91	88.7	84.5
13	125.90	123.28	118.6	124.9
14	132.30	139.05	100.64	95.6
15	129.31	122.61	123.6	118.9
16	115.39	124.87	110.78	105.42
		0.883530		0.87397
	116.57	119.28	109.85	110.85
	15.13	14.13	15.71	18.93

TEST RETEST IKD °PT

	60.00		180	
	Wk1	Wk2	Wk1	Wk2
1	54.00	54.50	42	34.00
2	45.00	43.00	47	36.00
3	38.00	35.00	60	55.00
4	62.00	59.50	76	74.00
5	48.00	62.00	58.6	70.2
6	37.00	42.00	67.2	65.50
7	56.00	55.50	64.5	63.00
8	42.00	42.00	38	44.00
9	72.00	69.50	71	68.00
10	48.20	41.00	45	42.00
11	36.40	36.00	64	58.00
12	53.00	51.00	78	72.50
13	43.00	43.00	52	47.00
14	49.50	47.00	32	38.00
15	56.00	56.00	47	47.00
16	29.00	32.50	51	58.50
		0.9066096		0.90
Average	48.07	48.09	55.83	54.54
Std Dev	10.46	10.27	13.26	13.15

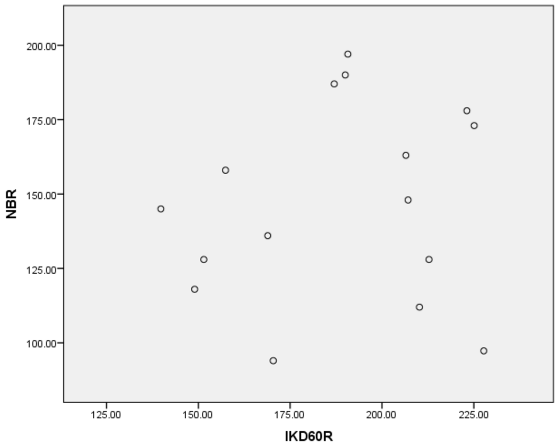
NordBord data



	Pk T Left			Pk T Right	
1	166	164		187	201
2	152	175		173	201
3	141	146.48		150	148.51
4	134	102.3		136	112.31
5	174	114.53		190	114.53
6	141.29	162.13		130.17	167.47
7	97.81	134.47		97.81	135.77
8	78.88	86.73		79.88	106.43
9	112.05	112.42		130.35	128.86
10	170.25	178.95		152.54	175.27
11	102.91	125.06		102.91	122.75
12	137	91.92		160	91.92
13	164.05	155.47		171.9	160.6
14	162.45	153.98		187.99	168.76
15	208	198		198	180
16	175	181		204	204
17	168.3	170.66		194	168
18	202.66	193.35		177.97	187.59
19	170	195		178	181
		0.75986			0.61127
Average	150.403	149.55	Average	157.975	155.567
St Dev	33.3354	34.5207	St Dev	35.448	33.9347

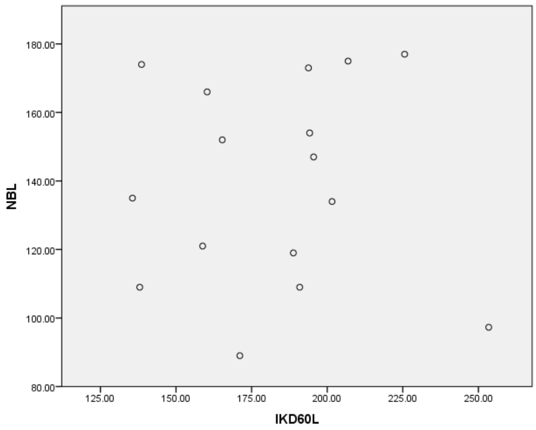
	AvT Left			AvT Right	
1	166	162		177	194
2	146	166		163	191
3	129	131.23		138	140.55
4	128	98.2		134	107.2
5	169	95.72		175	102.47
6	137.33	149.16		126.58	155.11
7	83.85	132.1		89.13	127.83
8	68.36	84.72		68.36	102.57
9	107.94	97.86		121.01	115.19
10	167.33	156.26		152.54	161.72
11	81.59	117.61		79.33	108.07
12	124	71.23		139	85.42
13	161.61	142.69		164.37	145.43
14	149.7	138.51		168.83	157.81
15	203	133		193	125
16	168	167		197	187
17	161.34	164.26		186.7	163.19
18	190.52	181.42		163.83	171.48
19	151	171		164	171
		0.56877			0.56361
Average	141.767	134.735	Average	147.404	142.739
St Dev	35.4936	31.576	St Dev	36.2949	32.4384

Break An	Week 1	Week 2
	32.3	29.2
	35.6	34
	58.2	49.4
	42.5	43
	31.7	34.6
	38.9	41.2
	44.0	43.5
	25.3	28.7
	34.6	35.6
	48.6	44.1
	54.4	58.4
	35.1	32.8
	41.4	43
	33.7	30
	26.2	30.1
	48.6	46.4
	34.4	31.8
	38.7	43.4
	28.0	26.2
	0.92217	
	38.5	38.1789
	8.87114	8.27587



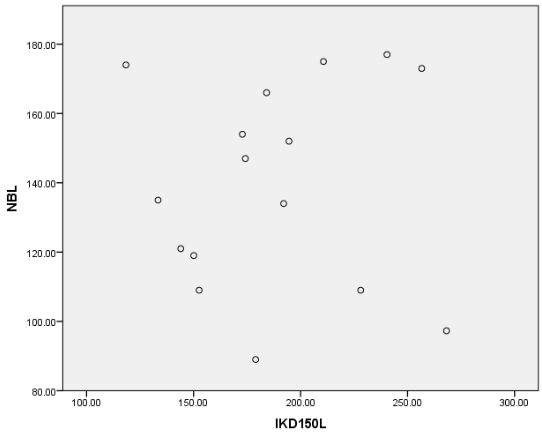
Correlation NBL/IKD60L

		NBL	IKD60L
NBL	Pearson Correlation	1	-.006
	Sig. (2-tailed)		.982
	N	16	16
IKD60L	Pearson Correlation	-.006	1
	Sig. (2-tailed)	.982	
	N	16	16



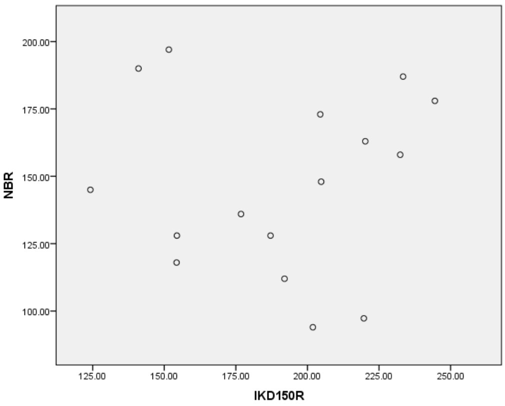
Correlation NBL/IKD150L

		NBL	IKD150L
NBL	Pearson Correlation	1	$.898^{**}$
	Sig. (2-tailed)		.000
	N	16	16
IKD150L	Pearson Correlation	$.898^{**}$	1
	Sig. (2-tailed)	.000	
	N	16	16



Correlation NBR/IKDR150

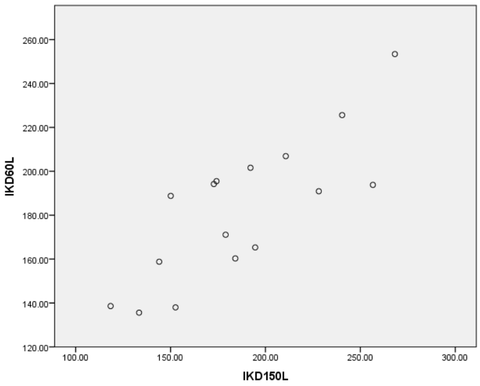
		NBR	IKDR150
NBR	Pearson Correlation	1	.034
	Sig. (2-tailed)		.901
	N	16	16
IKDR150	Pearson Correlation	.034	1
	Sig. (2-tailed)	.901	
	N	16	16



Correlation IKDL60/IKDL150

		IKDL60	IKDL150
IKDL60	Pearson Correlation	1	.808**
	Sig. (2-tailed)		.000
	N	16	16
IKDL150	Pearson Correlation	.808**	1
	Sig. (2-tailed)	.000	
	N	16	16

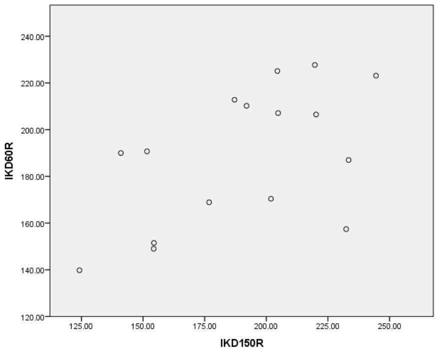
**. Correlation is significant at the 0.01 level (2-tailed).



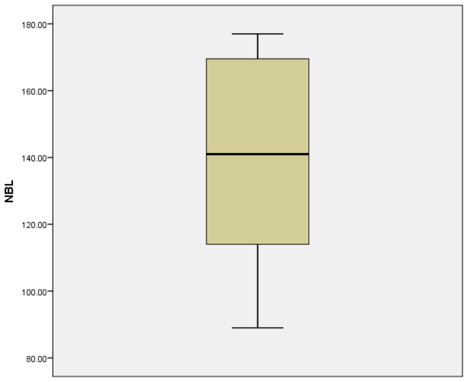
Correlation IKDR60/IKDR150

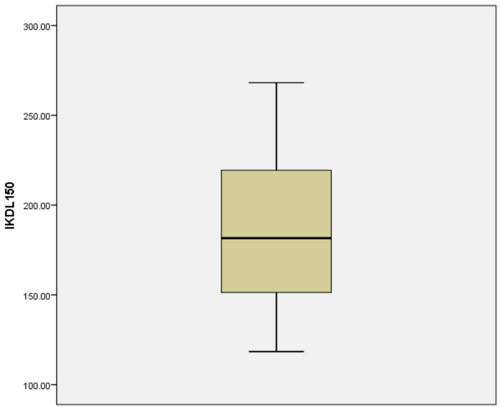
		IKDR60	IKDR150
IKDR60	Pearson Correlation	1	.551*
	Sig. (2-tailed)		.027
	N	16	16
IKDR150	Pearson Correlation	.551*	1
	Sig. (2-tailed)	.027	
	N	16	16

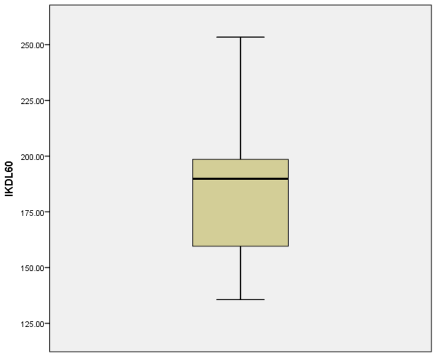
*. Correlation is significant at the 0.05 level (2-tailed).

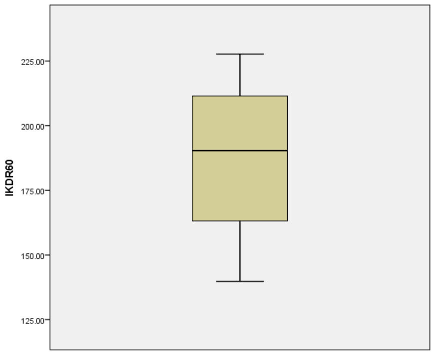


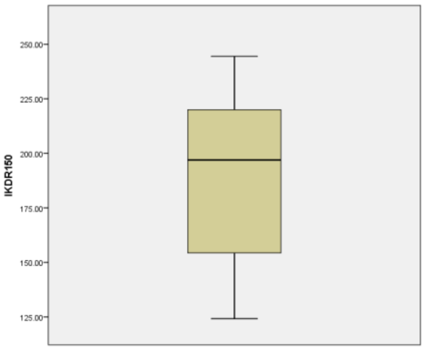
BOX PLOTS

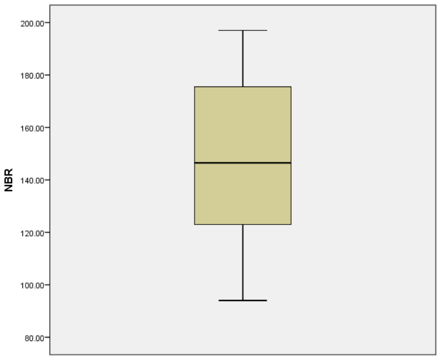

NBL
180.00
160.00
140.00
120.00
100.00
80.00


IKDL150
300.00
250.00
200.00
150.00
100.00


IKDL60
250.00
225.00
200.00
175.00
150.00
125.00


IKDR60
225.00
200.00
175.00
150.00
125.00


IKDR150
250.00
225.00
200.00
175.00
150.00
125.00


NBR
200.00
180.00
160.00
140.00
120.00
100.00
80.00

T-Tests

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	NBR - IKD60R	-41.55625	40.69470	10.17368	-63.24093	-19.87157	-4.085	15	.001
Pair 2	NBL - IKD60L	-42.94375	44.16908	11.04227	-66.47979	-19.40771	-3.889	15	.001

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	NBR	147.0187	16	32.81878	8.20469
	IKD60R	188.5750	16	29.20487	7.30122
Pair 2	NBL	139.4562	16	29.56187	7.39047
	IKD60L	182.4000	16	32.63501	8.15875

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	NBR & IKD60R	16	.143	.598
Pair 2	NBL & IKD60L	16	-.006	.982

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	NBR - IKD150R	-43.15625	48.23040	12.05760	-68.85642	-17.45608	-3.579	15	.003
Pair 2	NBL - IKD150L	-48.00000	51.64816	12.91204	-75.52136	-20.47864	-3.717	15	.002

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	NBR & IKD150R	16	.034	.901
Pair 2	NBL & IKD150L	16	.055	.841

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	NBR	147.0187	16	32.81878	8.20469
	IKD150R	190.1750	16	36.46899	9.11725
Pair 2	NBL	139.4562	16	29.56187	7.39047
	IKD150L	187.4562	16	43.99339	10.99835

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	IKD60L - IKD150L	-5.05625	26.08085	6.52021	-18.95375	8.84125	-.775	15	.450
Pair 2	IKD60R - IKD150R	-1.60000	31.76199	7.94050	-18.52477	15.32477	-.201	15	.843

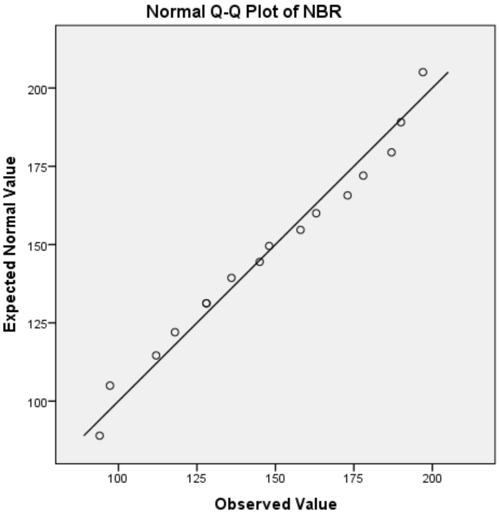
Paired Samples Statistics

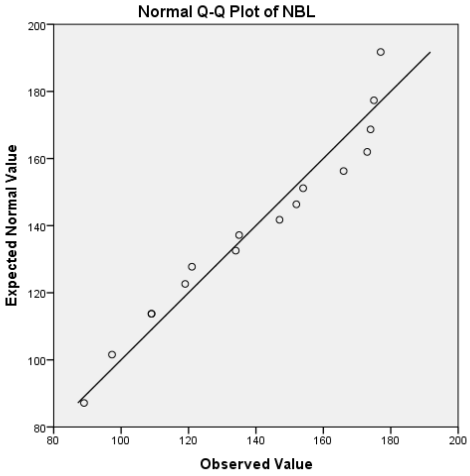
		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	IKD60L	182.4000	16	32.63501	8.15875
	IKD150L	187.4562	16	43.99339	10.99835
Pair 2	IKD60R	188.5750	16	29.20487	7.30122
	IKD150R	190.1750	16	36.46899	9.11725

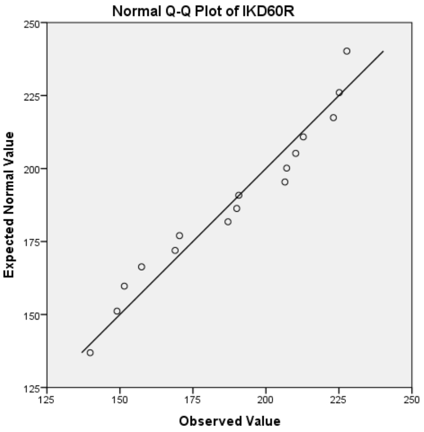
Paired Samples Correlations

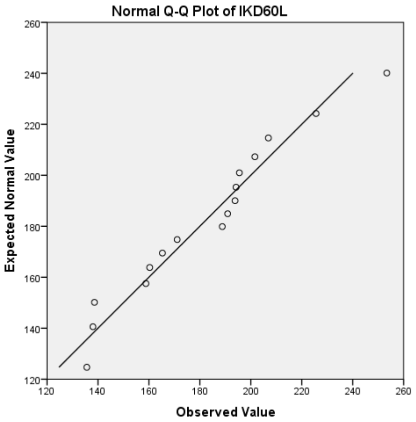
		N	Correlation	Sig.
Pair 1	IKD60L & IKD150L	16	.808	.000
Pair 2	IKD60R & IKD150R	16	.551	.027

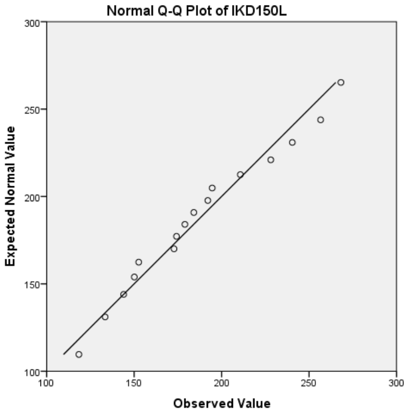
Q-Q Plot

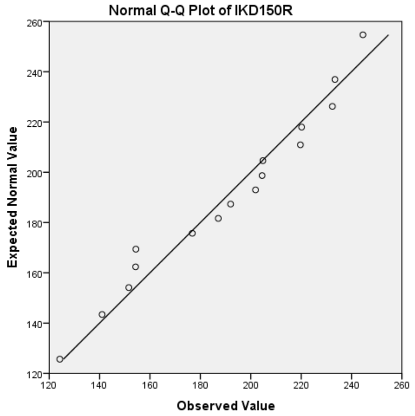





Normal Q-Q Plot of IKD60R


Normal Q-Q Plot of IKD60L


Normal Q-Q Plot of IKD150L


Normal Q-Q Plot of IKD150R