

**FORCE PLATFORMS FOR ISOMETRIC  
HAMSTRING TESTING:  
RELIABILITY, VALIDITY AND PRACTICAL  
APPLICATIONS IN PROFESSIONAL SOCCER.**

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# ABSTRACT

Soccer is an intermittent sport, incorporating low and moderate intensity activity with high intensity actions such as sprinting and acceleration/deceleration (Spencer *et al.*, 2005; Russell *et al.*, 2014). These actions result in fatigue, which is a significant hamstring injury risk factor in soccer (Woods *et al.*, 2004). Hamstring injuries are one of the most common occurring injuries in soccer and typically occur during the latter stages of a match at both 1<sup>st</sup> team and academy levels (Price *et al.*, 2004; Ekstrand *et al.*, 2011). These injuries are often non-contact in nature, with 80% of these occurring in the bicep femoris (Verral *et al.*, 2003). Injury rates may be reduced by managing training running loads, match minutes and allowing sufficient time for recovery. Measurements of hamstring strength may allow recovery status to be assessed based on running loads.

Isokinetic dynamometry (IKD) is the gold standard hamstring strength test (Toonstra & Mattacola, 2013). However, its cost, lack of portability and time taken to test deem it impractical for elite team sports. An isometric test using a handheld dynamometer or sphygmomanometer has been proposed, although these tools do not demonstrate the reliability of IKD (Toonstra & Mattacola, 2013). Alternatively, an isometric test using a portable force platform (FP) has been proposed as an alternative to IKD, demonstrating high reliability in both dominant (CV = 4.3%) and non-dominant (CV = 5.4%) limbs and the ability to detect changes in strength in pre- vs. post exercise tests (McCall *et al.*, 2015). McCall's group did not assess the validity of force platforms however and suggested further study may be beneficial to assess post-match recovery kinetics in professional soccer. Therefore, the aims of this study aimed to 1) confirm the reliability and validity of FP for hamstring strength testing; and 2) assess hamstring specific recovery via strength testing and examine the relationship between running loads and changes in post-match hamstring strength.

In study 1, participants performed 5 isometric knee flexor contractions with both limbs at 90° knee and hip flexion using an FP and IKD. A re-test was performed at the same time of day 1 week later. Force platform reliability was high in the dominant (ICC = 0.95) and non-dominant (ICC = 0.93) limbs. There was moderate correlation between IKD and FP ( $r = 0.56$ , moderate) for the dominant limb and high correlation for the non-dominant limb

( $r = 0.72$ , strong). However, agreement between IKD and FP measures was generally poor. Despite this, FP's are still a suitable alternative for hamstring strength testing, provided data is not used interchangeably.

In study 2, seven players from an U21 English Premier League (EPL) team were assessed over 3-7 matches (33 observations). Hamstring strength was measured at baseline, +24H and +48H post-match, with GPS used to quantify running loads. Hamstring strength significantly decreased from baseline at +24H and +48H ( $p \leq 0.05$ ) in both limbs. At +24H, hamstring strength decreased by 13.6% and 12.5% in the dominant and non-dominant limbs, respectively. At +48H, hamstring strength was still reduced by 9.7% and 10.5% from baseline in both dominant and non-dominant limbs. A significant negative correlation ( $p \leq 0.05$ ) was observed between sprint distance and changes in dominant limb hamstring strength. Changes from baseline to +24H demonstrated a moderate negative correlation ( $r = -0.41$ ), whilst changes from baseline to +48H demonstrated a weak negative correlation ( $r = -0.39$ ). A relationship between sprint distance and post-match hamstring strength is suggested. Further work is required to identify the causal factors of this reduction in strength. Increases in sprint running loads could further reduce hamstring strength and prolong recovery. Such information may help inform the practitioner's decisions to individualise training programmes to maximise player availability.

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**CHAPTER 1**  
**GENERAL INTRODUCTION**

## 1.1 Research Background

Professional soccer is an intermittent sport, where high-intensity anaerobic activities (acceleration, deceleration, sprinting) are interspersed by prolonged aerobic activity (walking, jogging) (Bangsbo, 1994). Teams often play up to 50 games per season, during which they may often be required to play games within 72 hours of one another. The physical requirements of a professional player during these games is well researched, with total distances of ( ), high-speed distances of ( ) and sprint distances of ( ) identified. The high speed and sprint distance running loads demonstrated by professional soccer players during match-play appear to be increasing annually (+30-35%) (Barnes *et al.*, 2014). Given the physical exertion required during match-play and often short turnaround between games, it is highly unlikely that players are afforded the time to completely recover between these games. Even on one game per week schedules, players typically return to training within 48-72 hours of match-play. It is possible that players return to training whilst still in a fatigued state.

Fatigue is one of the most significant risk factors for hamstring strain injury (HSI). This has been observed in both professional (Ekstrand *et al.*, 2011) and academy (Price *et al.*, 2004) soccer. Hamstring injuries are one of the most commonly occurring injuries in professional soccer, accounting for 12% of injuries at the elite level (Ekstrand *et al.*, 2011). The hamstrings are at elevated risk of injury when sprinting where there is a rapid crossover from eccentric to concentric activity (Arnason *et al.*, 2008; Askling *et al.*, 2012). Given the susceptibility of the hamstrings to injury, particularly when fatigued, it would appear useful to measure their recovery status during the post-match period.

When implementing a fatigue monitoring tool in professional sport, the tool needs to be simple, efficient and exert no additional load on the player. Most importantly, the tool must be reliable. McCall *et al.* (2015) proposes an isometric test using a portable force platform to assess hamstring strength. The tool demonstrates excellent reliability and being an isometric test, doesn't incur muscle damage ( ), ensuring it is a suitable tool to be used during the post-match period. Several studies have assessed post-match fatigue in professional soccer, with tests utilising countermovement jump (CMJ) peak power output as a marker of fatigue (Magalhaes *et al.* 2010; Nedelec *et al.* 2012; Russell *et al.* 2016).

Whilst this provides an assessment of global fatigue and associations with the stretch shorten cycle, a hamstring specific test would enable practitioners to measure hamstring specific recovery, given the frequency of hamstring injury in professional soccer.

## **1.2 Rationale for the Proposed Research**

The rationale for this research comes off the back of recommendations by McCall *et al.* (2015). Although the authors assessed the reliability of portable force platforms as a tool to measure isometric hamstring strength, their validity was not measured. It was decided that as force platforms are a gold standard tool for isometric testing, the assessment of validity was not required. However, it has been recognised that isokinetic dynamometers are the gold standard tool for isometric testing (Martin *et al.*, 2006). Therefore, it would appear useful to assess the validity of force platforms for this test to observe the performance of this test vs. true performance (Currell & Jeukendrup, 2008) of an IKD.

McCall *et al.* (2015) measured player hamstring strength pre- vs. post-match, with reductions in force between time points indicating fatigue. Whilst this study was only inclusive of 1 soccer match, the authors acknowledged longitudinal assessment of players recovery kinetics through strength measures to identify post-match recovery time courses would be beneficial to practical applications. In consideration of Barnes *et al.* (2014), where high-speed and sprint distances during matches are continuously increasing, there appears a greater need to be assessing player recovery status, with specific focus on the hamstrings. Providing coaching staff with this information may help inform their decision on training session design and which players will participate in that session.

## **1.4 Aims and Objectives**

The thesis contains 2 different aims, each comprised of 2 objectives. The first aim of this thesis is to measure the reliability and validity of force platforms as a tool for measuring isometric hamstring strength. This aim will be investigated through the following objectives:

- 1) To measure the reliability of force platforms for isometric hamstring strength testing, closely following the protocol used by McCall *et al.* (2015), albeit testing with a different force platform and software
- 2) To determine the criterion validity of force platforms for isometric hamstring strength testing by comparison vs. isokinetic dynamometry

The second aim of this thesis is to propose the use force platforms as a hamstring specific recovery monitoring tool in professional soccer. This aim will be investigated through the following objectives.

- 3) To measure hamstring specific recovery during the +48hours post-match period
- 4) To determine the relationship between match-play running loads and changes in hamstring strength from baseline to post-match

# **CHAPTER 2**

## **RESEARCH METHODOLOGY**

## 2.1 Chapter 4 Methodology

Ten university students (age  $21.3 \pm 3$  years, height  $176.8\text{cm} \pm 6.7\text{cm}$  and mass  $81.1\text{kg} \pm 7.6\text{kg}$ ) volunteered for this study. The criteria for inclusion in this study included being male, aged 18-35. This age limit was set to reflect the age of all potential participants in chapter 5 (professional soccer players from an U21 soccer team). Although players involved are to fall  $\leq 21$  years, senior 1<sup>st</sup> team players may often drop down to the U21 squad for multiple reasons. Participants also had to be free of any musculo-skeletal injury whilst testing and have had no form of lower limb injury in the previous two months which had prevented the individual from engaging in physical activity. University students were selected as it allowed for greater control of scheduling of testing sessions and pre-test participant activity. Tests were performed one week apart at the same time of day and participants were encouraged to adopt similar sleep and diet patterns during the 2 days prior to each testing session.

With the assessment of test-retest reliability of a portable force platform the 1<sup>st</sup> objective of this chapter, 2 isometric hamstring strength tests were performed using a portable force platform, 1 week apart. The 2<sup>nd</sup> objective of this chapter was to confirm the criterion validity of a portable force platform (PA Sport PS-2141, Pasco, Roseville, USA) for isometric hamstring strength testing, which required comparison against gold standard isokinetic dynamometry (Biodex System 3, Biodex Medical Systems, Inc, New York).

To perform the isometric hamstring strength test, participants lay supine, facing a box on which the force platform was rested. The testing leg was positioned at  $90^\circ$  knee flexion with the heel rested on the force platform and the non-working leg extended alongside the box. To ensure the same knee angle for all participants, the height of the box was adjusted accordingly. On the call of “3,2,1, drive”, participants performed a 3s maximal voluntary contraction (MVC) by driving their heel down into the platform. A 30s rest was permitted between reps for participants to reassume the starting position and prevent acute fatigue, with participants performing 5 reps per limb. A 2-minute rest period was permitted between switching limbs. Participants were instructed to keep their arms across the chest, with the practitioner applying pressure to the contralateral hip to ensure the



buttocks remained fixed to the ground. To standardise the test, all participants performed the test without shoes.

To assess test-retest reliability, a paired *t*-test was performed. T-test values were supported by Cohen’s *d* effect size (ES), interclass correlations ( $ICC_{2,1}$ ), typical measurement error (TE) and coefficient of variation (CV%), with definitions below (Table 1.). Confidence intervals (95%) were calculated for both  $ICC_{2,1}$  and ES. Bland-Altman plots were also created to assess the agreement between the test and re-test. To assess criterion validity between force platform and IKD, Pearson’s correlation was used, with Bland-Altman plots produced to assess agreement between the two tools.

**Table 1. Measures of reliability and validity used to determine test-retest reliability of portable force platforms for isometric hamstring strength testing**

Measure	Abbreviation	Definition
<b>Cohen’s d Effect Size</b>	<i>ES</i>	Effect size used to indicate standardised difference between 2 means
<b>Intraclass Correlation</b> <sub>(2,1)</sub>	$ICC_{2,1}$	Describes how strongly units in the same group resemble one another
<b>Typical Measurement Error</b>	<i>TE</i>	Variation in value from measurement to measurement
<b>Coefficient of Variation</b>	<i>CV (%)</i>	Typical error expressed as a % of mean value
<b>Pearson’s Correlation</b>	<i>r</i>	Measure of the strength of linear correlation between two variables
<b>Bland Altman</b>	<i>BA</i>	Quantifies agreement between 2 quantitative measurements

## 2.2 Chapter 5 Methodology

Seven outfield professional soccer players from the Under-21 squad of an English Premier League team (age  $18.0 \pm 0.8$  years; height  $181.2\text{cm} \pm 4.6\text{cm}$ ; mass  $77.7\text{kg} \pm 6.9\text{kg}$ ) participated in this study. Performed across the 2014-2015 and 2015-2016 Premier League seasons, this study only included data for players who had completed 90 minutes during match-play. As a result, with no attempts to influence team selection were made, players completed a different number of matches (mean  $\pm$  SD =  $4.7 \pm 1.7$  games), with 33 observations made in total.

To measure hamstring specific recovery, a hamstring strength test using a portable force platform was performed, following the procedures in chapter 4. Prior to the testing period, participants performed three familiarisation tests of the isometric hamstring strength test. Baseline measures were obtained in-season during weeks where no game was scheduled. Players were tested pre-training following 2 days off, with multiple baseline tests performed throughout the season to account for changes in strength. During the experimental period, strength tests were performed at +24H and +48H post-match by the same practitioner, with all tests performed at a standardised time (10:00 – 11:00) at the start of the players' post-match recovery (MD+1)/pre-training prep sessions (MD+2). All tests were performed during 1 game week schedules. Players performed each test after a 10-minute standardised warm-up comprising of dynamic stretching of the lower posterior chain and 5-minutes of cycling at 90W, followed by a 5-minute rest period. Players performed 2 reps on each limb, with a 30s rest permitted between reps before switching limbs.

To determine the relationship between hamstring recovery and match-play running loads, running loads were quantified using Statsports Viper GPS (Viper 2 pod, Statsports, Newry, Co. Down, Northern Ireland). Device were posteriorly positioned on the upper trunk, fitted into a custom vest. Units were activated 20 minutes prior to the pre-match warm-up to allow a satellite signal to be attained. Players were assigned their own unit which was used for each match to minimise inter-unit variability (Jennings *et al.*, 2010). After each match, data was downloaded via Statsports Viper software, with the following metrics analysed: total distance, high-speed running (HSR) distance (distance covered between  $5.5\text{m}\cdot\text{s}^{-2}$  and  $6.9\text{m}\cdot\text{s}^{-2}$ ), sprint distance (distance  $\geq 7\text{m}\cdot\text{s}^{-2}$ ) and total number of

accelerations and decelerations. Information regarding data quality was not available, as the units did not provide the number of connected satellites or the quality of satellite connection (horizontal dilution of precision – HDOP).

To measure changes in hamstring strength over time, a one-way repeated measures ANOVA was used, with Mauchly's test of sphericity adopted alongside this. An ANOVA test with repeated measures is used when comparing three or more groups and the same participants are in each group, often occurring in interventions where participants are measured at different time points. In this chapter, the three groups are different time points (baseline, +24H and +48H), with the same group of participants (professional soccer players) tested on the same test at each of these time points. Additionally, Pearson's correlation ( $r$ ) was used to assess the relationship between changes in hamstring strength and match running loads.

**CHAPTER 3**  
**LITERATURE REVIEW**

### 3.1 Physical Demands of Professional Soccer

Soccer is an intermittent sport, incorporating periods of low and moderate intensity activities (standing, walking and jogging) with short high intensity actions such as sprinting, rapid acceleration/deceleration and repeated high intensity running manoeuvres (Spencer *et al.*, 2005; Gabbett *et al.*, 2013; Russell *et al.*, 2014). These fundamental movements are interspersed with highly variable and individual sport-specific activities (Drust *et al.*, 2007).

Being an intermittent sport, soccer highly taxes both aerobic and anaerobic energy systems. Although the aerobic component dominates energy delivery during a match (>90% of a match), match actions which lead to positive outcomes are typically anaerobic in nature (Stølen *et al.*, 2005; Wragg *et al.*, 2000). The activity performed by aerobic metabolism means a player is constantly performing just below their anaerobic threshold (80-90% max HR). Increased aerobic capacity, based off  $VO_2\text{Max}$ , has identified relationships with greater distances covered during match-play (Bangsbo, 1994) and league position in both Norwegian and Hungarian leagues (Apor, 1988; Wisløff *et al.*, 1998). Additionally, with players performing up to 250 intense actions during a game requiring anaerobic metabolism (Mohr *et al.*, 2003), average blood lactate concentrations range between 2-10mmol.l<sup>-1</sup>, although peaks of over 12mmol.l<sup>-1</sup> have been identified (Bangsbo, 1994; Krstrup *et al.*, 2006).

The physical demands of elite soccer have been analysed over decades (Reilly & Thomas, 1976), although analysis methods have improved with technological advancements. The physical demands, or 'load', experienced by a player, can be split into two components; the 'internal' load, that being the physiological response to an exercise stimulus, and the 'external' load, the exercise stimulus itself, typically quantified as distances covered at different velocities (Akubat, Barrett & Abt, 2013). Practitioners were initially limited to subjective data in the form of rating-of-perceived-exertion scales (RPE) (Borg, 1970) and the use of heart rate (HR) measuring devices to analyse the internal demands of soccer. Over the last 10-15 years, however, the ability to analyse the external load by tracking physical parameters of match-play and training has been made possible through the use of semi-automated camera systems (Di Salvo *et al.*, 2010;

Barnes *et al.*, 2014) and global positioning systems (GPS) or ‘wearables’ (Malone *et al.*, 2015, Russell *et al.*, 2016).

These devices have allowed for the quantification of running loads in professional soccer. Players cover 9-12km per game, dependent on their position (Rienzi *et al.*, 2000; Dellal *et al.*, 2011) (Table 2.). Central midfielders cover the greatest total distance and central defenders the lowest. Central midfielders regularly sprint with and without the ball, repeatedly accelerate and decelerate to press opposition players and engage in high-speed runs when attacking and defending. Alternatively, the role of a centre back means less high-speed running and sprint distance is required (Table 2.), typically accelerating and decelerating over short distances.

**Table 2. Match running loads of professional soccer players across 5 different positions (centre half, full back, centre midfield, wide midfield and forward) (Di Salvo *et al.*, 2009; Bradley *et al.*, 2009; Dellal *et al.*, 2011)**

PLAYER POSITION	TOTAL DISTANCE (KM)	HIGH-SPEED RUNNING DISTANCE (M)	SPRINT DISTANCE (M)
<b>CENTRE HALF</b>	9.8 – 10.6	451 - 514	152 - 201
<b>FULL BACK</b>	10.6 – 11.2	673 - 697	256 - 287
<b>CENTRE MIDFIELD</b>	11.2 – 11.9	711 - 723	204 - 235
<b>WIDE MIDFIELD</b>	10.9 – 11.7	789 - 868	255 - 346
<b>FORWARD</b>	10.3 – 10.8	691 - 706	264 - 269

Between 2006 and 2013, the average total distance covered in an English Premier League increased by 2% (Barnes *et al.*, 2014). On the other hand, high-intensity (HI)

distance (distance covered  $\geq 19.8 \text{ km} \cdot \text{h}^{-1}$ ) and sprint distance (distance covered  $\geq 25.1 \text{ km} \cdot \text{h}^{-1}$ ) increased by 30% and 35%, respectively, illustrating the evolution of the English Premier League with a reliance on players able to cover distances at a greater intensity. Distances covered in these 'high-end' speed zones are a better indicator of the physical demands of soccer due to the high energy cost involved. Players are often required to perform repeated sprint efforts and must be able to endure prolonged high intensity running activity, both of which are deemed critical components of successful match-play (Gabbett *et al.*, 2013). It is the ability to repeatedly perform sprint efforts and cover greater distances at high intensity which may discriminate between different player quality in both male and female domains (Mohr *et al.*, 2003; Gabbett & Mulvey, 2008).

However, HID may be misinterpreted as a marker of fitness during match-play (Drust *et al.*, 2007; Gregson *et al.*, 2010). If a player covers 1100m of HID in one match, but only covers 900m HID in the following match, it does not mean that the player is unfit, or their physical capacity has decreased. Given that soccer is dictated by a variety of contextual variables, HID may vary by 16% game-to-game (Di Salvo *et al.*, 2009; Gregson *et al.*, 2010). As well as position (Krustrup & Bangsbo, 2001; Di Salvo *et al.*, 2007), running loads are influenced by team and opposition tactics and formations, team quality (Mohr *et al.*, 2003) and current game dynamics/situation. Although player running loads are influenced by field position, players playing in the same position will also demonstrate large variability. Mohr *et al.* (2003) identified one central midfielder to cover 12.3km total distance during a game, 3.5km of which was at high-intensity, whilst a different central midfielder covered 10.8km, 2.0km of which was at high-intensity. Although both players played in the same position, the physical capacity of the players and the tactical role given to them by the coach are likely to have contributed to a variation in total and high-intensity distances, respectively.

### **3.2 Methods of Quantifying External Workload**

Unlike total distance, which remains relatively stable between games, HI distance demonstrates high variability (Barnes *et al.*, 2014). This variability may significantly increase when measuring tools are mixed, given that GPS devices and semi-automated camera systems often produce different HI distance values. Professional soccer teams

typically utilise semi-automated camera systems to measure the external load during match-play. Prior to the 2015-2016 English Premier League season, teams were not permitted to use GPS or 'wearables' during competitive match play, in accordance with FIFA ruling. A ruling change now allows teams to utilise GPS technology in matches to analyse player performance, although live data usage is forbidden. Despite the change in ruling, player and coach compliance has meant that many teams continue to use semi-automated camera systems during games, with GPS devices primarily used for training. Due to the between-system variability when measuring HI activity, it has been recommended that data from different systems should not be used interchangeably (Coutts & Duffield, 2010). However, Taberner *et al.* (2020) identified strong correlations ( $r^2 = 0.96$ ) between GPS and semi-automated camera systems (TRACAB) when measuring total distance, HSR and sprint distance.

The majority of research on the physical demands of soccer focuses on distances covered at different velocities. The effects of acceleration and deceleration efforts are rarely investigated, which is surprising considering the high metabolic and neuromuscular demands involved. The high eccentric forces exerted on the lower limbs during deceleration, where the hamstrings counteract torque generated by the quadriceps to decelerate the limb results in muscle damage and fatigue (Bennell *et al.*, 1998; Osgnach *et al.*, 2010; Akenhead *et al.*, 2013). Russell *et al.* (2016) found the number of decelerations performed during match-play correlated with increased blood creatine kinase levels 24 hours post-match, whereas acceleration activity correlated with reductions in countermovement jump (CMJ) peak power output (PPO) 48 hours post-match. If the physical demands of soccer are estimated by distances covered at different velocities alone, then the load exerted on a player is likely to be significantly underestimated. Where sprinting may account for 1-4% of the total game exertion, distance covered accelerating and decelerating may account for 8% of a player's 'workload' (Russell *et al.*, 2014). Acceleration and deceleration activity in specific speed zones has also been investigated, which may provide greater insight into the movement and fatigue related characteristics of professional soccer (Akenhead *et al.*, 2013).

### **3.3 Quantifying the Physical Demands of Professional Soccer**



Limited research in acceleration and deceleration activity may be down to inadequate measuring tools. Early 1Hz GPS devices were identified to be accurate for measuring total distance, although moderate variance was evident when measuring distances at higher velocities, particularly when non-linear in nature (Coutts & Duffield, 2010). With the unpredictable and non-linear nature of soccer, where players repeatedly change direction and maximally accelerate and decelerate over short sprint efforts lasting  $\leq 1s$ , 1Hz devices are not acceptable. Increasing the sampling rate to 5Hz shows no significant difference compared against 1Hz for total distance (Jennings *et al.*, 2010). Over short linear distances up to 20m, both 1Hz and 5Hz devices demonstrate poor reliability (CV = 10% $\leq$ ).

It would appear GPS devices recording at 10Hz are the most valid and reliable devices to be used in professional sport (Scott *et al.*, 2016), for linear (Castellano *et al.*, 2011) and simulated sport running protocols (Vickery *et al.*, 2014) when measured against timing gate and VICON motion analysis systems. Currently, professional sports teams utilise 10Hz GPS devices (Russell *et al.*, 2016) where the accuracy and reliability of data are significantly improved against lower frequency devices (Varley *et al.*, 2011). Devices measuring at higher frequencies are available, although research surrounding these is limited due to their short availability time. Rawstorn *et al.* (2014) identified good reliability for 15Hz GPS during linear and curved running drills, whilst Bucheitt *et al.* (2014) found these devices to demonstrate good reliability for total distances and distances  $\geq 14km/h$  and  $\geq 25km/h$ . However, when comparing 15Hz vs. 10Hz GPS, Johnston *et al.* (2014) found 10Hz to demonstrate greater validity and reliability. The devices analysed in the previous studies are not in fact sampling at 15Hz, instead boosting a 5Hz GPS signal. Increasing the sampling rate of GPS devices alone does not increase reliability of data (Malone *et al.*, 2017), with factors such as processor chips used and the number of available connected satellites key components.

GPS devices are valid and reliable during linear runs and circuit drills, but they must also demonstrate validity and reliability when measuring acceleration and deceleration efforts. Akenhead *et al.* (2014) found unit reliability to decrease at 10Hz with increased acceleration velocity, ranging from  $0-1m.s^{-2}$  (CV = 0.7%) to  $4m.s^{-2}$  (CV = 9.1%). Similar findings were reported by Varley *et al.* (2011), with unit validity greatest at lower changes

in speed ( $1-2\text{m}\cdot\text{s}^{-2}$ ). Although acceleration reliability is compromised beyond  $4\text{m}\cdot\text{s}^{-2}$ , professional soccer players do not regularly reach this acceleration threshold during match play. Across 76 individual match observations, Russell *et al.* (2016) identified high intensity accelerations ( $\geq 3\text{m}\cdot\text{s}^{-2}$ ) to account for just 4% of the total volume of accelerations during a match when measured by Statsports 10Hz GPS. Statsports devices show excellent reliability when measuring distances in a 20m linear run, 400m lap and specific team-sports based circuit, as well measuring peak speed over the 20m run (Beato *et al.*, 2018). Additionally, although limited in design, a case study by Marathon (2014) identified Statsports 10Hz GPS devices to show greater validity and reliability when compared against other GPS devices during linear, acceleration and soccer-specific tests.

Performance monitoring systems provide us with an objective measure of the external load during training and match play (Aughey, 2011; Malone *et al.*, 2015). With the association between increased running loads and soft-tissue injury occurrence, monitoring both training and match-play should allow for the management of player running loads to help reduce injury risk (Gabbett & Ullah, 2012; Ehrmann *et al.*, 2016). There is limited research in elite soccer investigating training 'load', with recent work from the English Premier League providing evidence of the quantification of training 'load' via GPS (Gaudino *et al.*, 2013; Malone *et al.*, 2015; Anderson *et al.*, 2016).

### **3.4 Relationships Between Running Loads and Injury Risk**

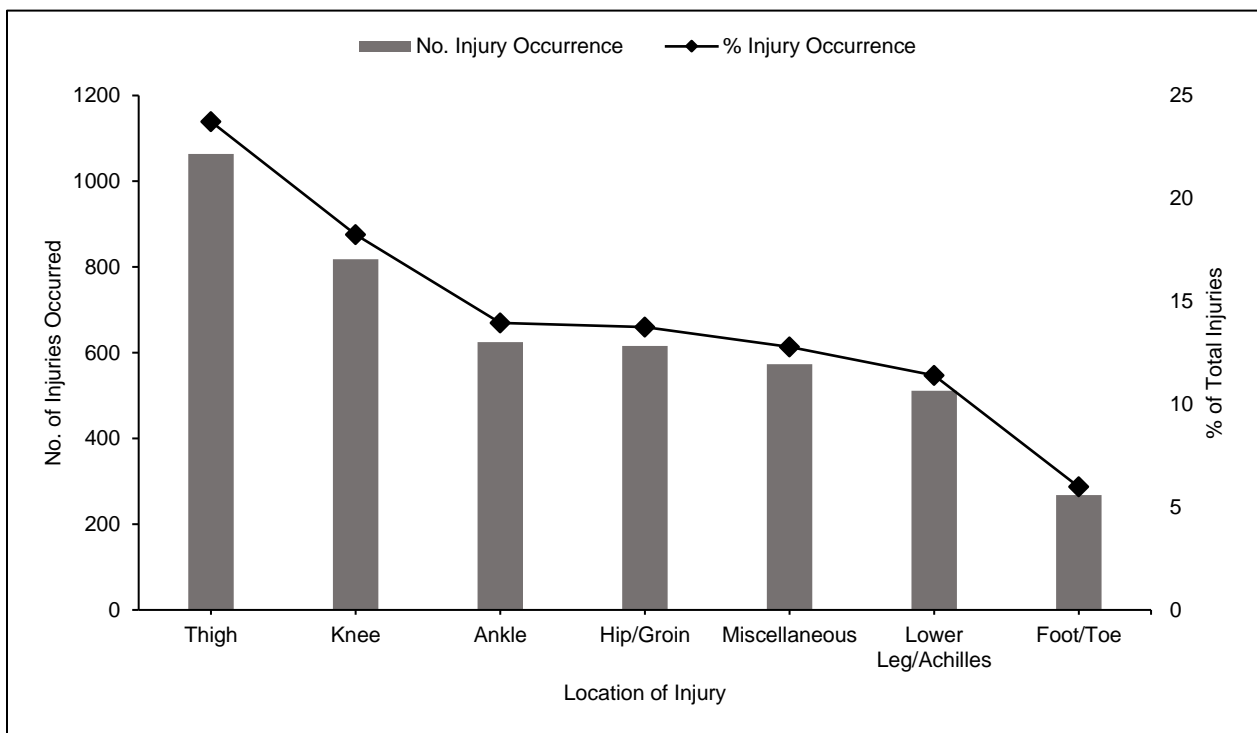
Research from professional soccer shows an increased risk of injury when high-speed running (distance  $\geq 5.5\text{m}\cdot\text{s}^{-2}$ ) was higher than normal acute loads and when chronic loads were higher than normal over consecutive weeks (Jaspers *et al.*, 2018). A similar trend was identified by Bowen *et al.* (2017), with high acute and high chronic high-speed running (distance  $\geq 5.5\text{m}\cdot\text{s}^{-2}$ ) both significantly increasing non-contract injury risk in elite youth soccer players. There is still limited research showing direct links between running loads and injury risk in professional soccer, with most research coming from other team sports such as Gaelic football (Malone *et al.*, 2017), Australian Football (Colby *et al.*, 2014) and Rugby Union (Gabbett & Ullah, 2012). More recently, an increasing number of studies have identified the training loads and practices of professional soccer teams. Using the same high-speed running distance threshold as Bowen *et al.*, (2017) and

Jaspers *et al.* (2018), Anderson *et al.* (2016) reported a mean of 41m of HSR covered per training session, on a one-game per week schedule. Little variation for two-game or three-game-week schedules was observed when based off training session loads alone. This is significantly lower than the value reported by Gaudino *et al.* (2013), where the mean HSR per session was 119m. These figures come from two different Premier League clubs and highlight how the coach's training methodology may affect training running loads.

There may be a 'fear' of injury when performing HSR in training leading into a game. However, there could be an equally high risk by restricting players from performing HSR during training, where players are under-prepared to run at these speeds during match-play (Gabbett *et al.*, 2016). On a one-game week schedule, teams will typically complete 4 training sessions during the week ahead of that game. During this training week, teams have been identified to average 41m (Anderson *et al.*, 2016) and 119m (Gaudino *et al.*, 2013) of HSR per session. Based off these figures, during a one-game week (minus the game itself), players may perform 164m (4 sessions x 41m HSR per session) or 476m (4 sessions x 119m HSR per session) of HSR. Which of these loads is best to prescribe; is there a right or wrong training methodology? To decide the required training exposure, the two components to consider are, 1) How much is enough or too much? This will vary between positions. Fullbacks and wide midfielders may need greater exposure during training to prepare them for match-play; they can cover 600m-1200m of HI distance per game, whereas a centre half performs significantly less high-intensity running (300-600m) during match-play, so exposure in training may not need to be as high (Bradley *et al.*, 2009; Lago-Peñas *et al.*, 2009). Additionally, 2) When is the right time to expose players to HI running in a training week? Running at high velocities involves large eccentric forces, hence adequate recovery time is required. Teams will often have their most difficult training session of the week 3 (MD-3) or 4 (MD-4) days before a match (Akenhead, Harley & Tweddle, 2016). Higher HSR loads are typically seen on these training days, with sessions incorporating larger pitch sizes focusing on extensive tactical and physical aspects of 11v11 match play (Kelly *et al.*, 2019). This may be the most appropriate time for greater exposure to HSR running loads, before a reduction each day (MD-2/MD-1) leading into the match to allow both adaptation and recovery (Martin-Garcia *et al.*, 2018).

### 3.5 Injuries in Soccer

The influence of injuries in professional soccer is significant, with relationships between reduced injury rates and improved team performance, evident by increased average points per game and higher league ranking (Hägglund *et al.*, 2013). There is also a large financial cost to clubs when injuries occur (Hickey *et al.*, 2014). Lower limb injuries account for 87% of all injuries in professional soccer (Figure 1.), with hamstring strains accounting for 12% of these (Ekstrand *et al.*, 2011). The majority of injuries occur during match-play, particularly hamstring injuries, 65% of which occur during matches (Ekstrand, Waldén & Hägglund, 2016). For injuries that occur during training, these are often seen as preventable (Gabbett, 2016). Training is viewed as a balance between fitness and fatigue (Banister *et al.*, 1975), with one aspect having the athlete ready to perform maximally during competition after being exposed to a sufficient training stimulus, or alternatively providing 'too high' a training load resulting overtraining and fatigue. Fatigue is a significant risk factor for hamstring injury in professional soccer, particularly during the latter stages of match-play and training (Woods *et al.*, 2004; Mohr *et al.*, 2005).



**Figure 1. The location of injuries suffered by European professional soccer players from the 2001/2002 to the 2007/2008 seasons (Ekstrand *et al.*, 2011)**

### 3.6 Hamstring Injuries in Soccer

Hamstring injuries are one of the most prevalent non-contact soft tissue injuries in professional soccer, characterised by pain and discomfort in the posterior thigh. Up to 80% of hamstring injuries occur in the biceps femoris (Verral *et al.*, 2003). Using the traditional grading system, injuries range in severity from grade I (partial function/mobility loss and no muscle fibre disruption) to grade III (complete tear of the muscle and immobility) (Reurink *et al.*, 2014; Wangensteen *et al.*, 2017). Using the British Olympic Association (BOA) classification (Table 3.) for HSI, injuries range from grade 1 (small tear/s to the muscle) to grade 4 (full tear of the muscle) with each grade broken down further depending on muscle/tendon involvement. Susceptibility of the hamstring, particularly the biceps femoris, to injury, is hypothesised to be related to its bi-articular structure, with the muscle stretched both proximally at the hip and distally at the knee. This increases injury risk during HSR and explosive actions, where there is a rapid crossover from eccentric to concentric activity (Arnason *et al.*, 2008; Askling *et al.*, 2012). Hamstring strain injuries are multifactorial in nature, predisposed by non-modifiable factors; previous injury history (Hallen *et al.*, 2014) age (Henderson *et al.*, 2010), muscle fibre type and distribution (Garret *et al.*, 1984) and ethnicity (Woods *et al.*, 2004), and modifiable risk factors; H/Q ratio strength imbalances (Croisier *et al.*, 2008), bilateral strength imbalances (Croisier *et al.*, 2008; Schache *et al.*, 2011), inadequate eccentric strength (Schache *et al.*, 2011), flexibility (Arnason *et al.*, 2004; Bradley & Portas, 2007) and fatigue (Pinniger *et al.*, 2000; Woods *et al.*, 2004).

**Table 3. The British Olympics Classification grading system for hamstring injuries (Pollock et al., 2014)**

GRADE	DESCRIPTION	A (PERIPHERY)	B (MUSCLE BELLY/MTJ)	C (TENDON)
I	<ul style="list-style-type: none"> <li>- Small muscle tear</li> <li>- Pain during &amp; post exercise</li> <li>- Normalised ROM at +24H</li> </ul>	<ul style="list-style-type: none"> <li>- Injury extends from fascia</li> <li>- High signal change at periphery of muscle</li> <li>- Extends &lt;10% into muscle / longitudinal length &lt;5cm</li> <li>- Fibre disruption &lt;1cm</li> </ul>	<ul style="list-style-type: none"> <li>- High signal change &lt;5cm in length / &lt;10% muscle cross sectional area</li> <li>- Fibre disruption &lt;1cm</li> </ul>	NA
II	<ul style="list-style-type: none"> <li>- Moderate muscle tear</li> <li>- Pain during exercise</li> <li>- Usually requires exercise to cease</li> <li>- Reduced range of movement and strength at +24H</li> </ul>	<ul style="list-style-type: none"> <li>- Injury extends from peripheral fascia into muscle</li> <li>- High signal change 5-15cm in length / 10-50% muscle cross sectional area</li> <li>- Fibre disruption &lt;5cm</li> </ul>	<ul style="list-style-type: none"> <li>- High signal change 5-15cm in length / 10-50% muscle cross sectional area</li> <li>- Fibre disruption &lt;5cm</li> </ul>	<ul style="list-style-type: none"> <li>- Injury extends into tendon</li> <li>- Injury within the tendon – longitudinal length &lt;5cm or 50% tendon diameter</li> </ul>
III	<ul style="list-style-type: none"> <li>- Extensive muscle tear</li> <li>- Sudden onset of pain</li> <li>- Exercise ceased</li> <li>- Pain walking and significantly reduced ROM at +24H</li> </ul>	<ul style="list-style-type: none"> <li>- Myofascial</li> <li>- MRI high signal change &gt;15cm in length / &gt;50% of cross-sectional area</li> <li>- Fibre disruption &gt;5cm</li> </ul>	<ul style="list-style-type: none"> <li>- Muscular / musculotendinous</li> <li>- MRI high signal change &gt;15cm in length / &gt;50% of cross-sectional area</li> <li>- Fibre disruption &gt;5cm</li> </ul>	<ul style="list-style-type: none"> <li>- Intrantendinous</li> <li>- Injury to tendon – longitudinal length &gt;5cm / &gt;50% of cross-sectional area</li> </ul>
IV	<ul style="list-style-type: none"> <li>- Complete muscle/tendon tear</li> <li>- Sudden onset of pain</li> <li>- Exercise immediately ceased</li> <li>- Often less pain than grade III due to full vs. partial tear</li> </ul>	<ul style="list-style-type: none"> <li>- Complete muscle tear</li> </ul>	<ul style="list-style-type: none"> <li>- Complete muscle tear</li> </ul>	<ul style="list-style-type: none"> <li>- Complete tendon tear</li> </ul>

### 3.6.1 Non-Modifiable Risk Factors

*Previous Injury History* – Players who have suffered previous HSI's are at a significantly increased risk of future HSI occurrence, particularly when there is bicep femoris involvement (Hägglund, Waldén & Ekstrand, 2006; Hallen *et al.*, 2014). Recent evidence suggests that hamstring injuries result in reduced eccentric strength, even after the player has returned to play, which may be a factor in future HSI recurrence (Lee *et al.*, 2009). Other HSI related defects have also been attributed to injury recurrence; muscle atrophy (Silder *et al.*, 2008), reduced flexibility, changes in lower-limb running mechanics and alterations in the angle of peak knee-flexor torque (Brockett, Morgan & Proske, 2004). Although it is accepted that modifications will occur as a result of HSI, whether these are a cause or result of the original injury are to be questioned. However, given that these are 'modifications', these factors should be returned to at least pre-injury levels before the player returns to training and competition. Additionally, the formation of scar tissue following tendon related HSI has been related to injury recurrence, where the lengthening capabilities of the muscle are reduced, resulting in greater strain placed on the muscle fibres during eccentric contractions (Lieber *et al.*, 1993; Silder *et al.*, 2010).

*Age* – Increasing age has been identified as a significant risk factor for hamstring injury in elite sports, with the odds of sustaining a hamstring injury in the dominant limb increasing by 1.78 per 1-year increase in age in EPL soccer (Henderson *et al.*, 2010). This contradicts findings by Hägglund *et al.* (2013), where increasing age related to calf injury risk only. The mean age of participants in Henderson *et al.* (2010) ( $22.6 \pm 5.2$  years) was lower than the participants in Hägglund *et al.* (2013) ( $25.8 \pm 4.5$  years), which brings the question of, at what age is there an increased risk of hamstring injury? Woods *et al.* (2004) appears to fall in line with Henderson *et al.* (2010), where players aged 17-22 (29%) sustained fewer hamstring injuries than those aged 23-28 (41%). Surprisingly, players aged 29-34 suffered the lowest amount of hamstring injuries (25%). This reduction in injuries from aged 29 onwards may be a result of match involvement during the later years of a player's career. Kalén *et al.* (2019) studied player involvement in the UEFA Champions League over 26 consecutive seasons, where the average of was  $25.8 \pm 4.1$  years. Eighty percent of the players involved during this period were aged 21-29

and from aged 29 onwards, a yearly decrease in player involvement was identified. The likelihood of older athletes suffering a hamstring injury could reasonably be assumed to be greater than for younger athletes through multiple years of training and game exposure alone (Henderson *et al.*, 2010). Given the physical demands of professional soccer, it is highly unlikely that a player will finish a 10-15-year career without suffering a hamstring injury. However, it is also likely that additional factors which occur alongside increasing age play a role in increasing injury risk. In Australian Footballers who had suffered no previous hamstring injuries, body weight and hip flexibility were significant predictors of hamstring injury in those aged >25 (Gabbe *et al.*, 2006; Best & Tietze, 2013). Maintaining hamstring strength, optimal body composition and flexibility during the latter years of a professional player's career may be beneficial to reduce the risk of hamstring injury (Wing & Bishop, 2020).

*Muscle Fibre Type and Distribution* – The hamstrings must cope with large eccentric and concentric forces during high speed running and sprinting, repeated throughout training or match-play and often whilst fatigued. Garrett *et al.* (1984) identified the hamstrings to have a relatively higher proportion of type II fibres. In a breakdown of the bicep femoris structure, the proximal bicep femoris long head (55.2%), distal bicep femoris long head (53.8%) and the bicep femoris short head (59.2%) all possess greater type II fibre distribution. Similarly, both the proximal and distal segments of the semitendinosus and semimembranosus contain a greater proportion of type II fibres. However, the distribution of type I and type II fibres in the semimembranosus is closer to a 50/50 split. All measurements were taken from cadavers, so whilst they provide a basic estimation of the composition of the hamstrings, the effects of their composition on injury risk is unclear. Additionally, it would be expected that the composition of a professional soccer players' hamstrings would differ from the general population due to their increased muscle mass and strength.

*Ethnicity* – English Premier League players of black origin are at greater risk of hamstring injury than Caucasian players, which may correlate with a higher proportion of type II muscle fibres (Woods *et al.*, 2004). Increased anterior pelvic tilt may increase the likelihood of hamstring injury in black players by altering the lengthening properties of the



hamstrings (Hennessey *et al.*, 1993; Brockett *et al.*, 2001). Hamstrings may appear shortened, causing 'tightness', which although will allow the athlete to generate more power when sprinting, it will also make them more susceptible to injury as the hamstring is unable to reach longer lengths during the eccentric phase.

### **3.6.2 Modifiable Risk Factors**

*Fatigue* – Fatigue is a significant risk factor for hamstring injury, with 47% of hamstring strain injuries occurring during the final 15 minutes of both halves (Woods *et al.*, 2004), a trend which is observed in both professional (Ekstrand *et al.*, 2011) and academy soccer (Price *et al.*, 2004). As stride length decreases, the hamstrings operate at much shortened muscle lengths. Combined with reduced eccentric strength under fatigued conditions, the hamstrings may not have the required strength to control knee extension, increasing risk of injury during the latter stages of match-play (Small *et al.*, 2009).

*Flexibility* – Findings regarding the relationship between flexibility and injury risk are inconsistent. In the EPL, players who performed significantly worse ( $p = <0.05$ ) in pre-season ROM tests demonstrated greater muscle strain injury risk (Bradley & Portas, 2007). Furthermore, although non-significant, non-injured EPL players demonstrated greater hip flexor ROM in the straight leg raise test (Henderson *et al.*, 2010). Gabbe *et al.* (2006) also found reduced flexibility to be associated with hamstring injury occurrence, but only in players >25 years old, suggesting that flexibility is directly related to age. However, some literature suggests that there is no relationship between hamstring flexibility and hamstring injury risk (Gabbe *et al.*, 2005; Engebretsen *et al.*, 2010). To determine if flexibility does or does not increase HSI risk is difficult due to reliability and validity of tests used which vary between studies. However, it does appear that if flexibility is associated with hamstring injuries, then it is likely to affect the proximal hamstrings at the hip more than the distal attachment.

*Hamstring/Quadricep Imbalances* – In professional soccer, players with a lower hamstring:quadricep (H:Q) ratio during pre-season were over 4 times more likely to sustain a hamstring strain injury during that subsequent season, compared to players with no strength imbalances (Croisier *et al.*, 2008). A lower H:Q ratio occurs when the mechanical limits of the hamstring are exceeded by that of the quadriceps during maximal

contraction (Aagard *et al.*, 1998). Hamstring:quadricep ratios were originally measured via concentric activity of the two muscle groups. However, a 'functional' H:Q ratio is currently used, measuring eccentric hamstring and concentric quadriceps activity in a test which better replicates the agonist/antagonist co-activation of the hamstring and quadriceps muscles during the gait cycle (Croisier *et al.*, 2008). During the latter stage of the swing phase, the hamstrings work eccentrically to counteract torque generated by the quadriceps to decelerate the limb and control extension at the knee (Bennell *et al.*, 1998; Chumanov *et al.*, 2011). Despite the clear relationship between H:Q ratios and hamstring injury risk, the ratio which dictates injury risk is unclear due to variation in dynamometers and protocols adopted in the literature.

*Bilateral Strength Imbalances* – It is suggested that asymmetrical hamstring strength significantly reduces hamstring injury risk. Injury rates of players without asymmetries were significantly lower (4.1% vs. 16.5%) than those who demonstrated asymmetrical differences >15% which were left untreated during pre-season isokinetic testing (Croisier *et al.*, 2008). Additionally, large changes in bilateral strength asymmetry via isometric MVC tests were linked to HSI in Australian Football (Schache *et al.*, 2011). During a four-week period of no injury, bilateral hamstring asymmetry remained within  $\pm 1.2\%$ . However, the following week, right hamstring MVC was 10.9% lower than that of the left, with the player straining the right hamstring during match-play five days later. Additionally, in-house data from two English Premier League (EPL) clubs (including the one involved in this study) identifies a mean bilateral asymmetry of 13.3% in a hamstring injury group, whereas a non-injured group demonstrated a 6.9% bilateral asymmetry (Cohen *et al.*, 2015). Further recommendations from professional soccer identify an aim for bilateral hamstring strength to be <10%, although it is acknowledged there may be some players who naturally assume larger asymmetries on a regular basis and do not suffer from HSI (Buckthorpe *et al.*, 2019). However, recent research from Australian soccer found bilateral eccentric and isometric strength imbalances between 10% and 20% did not increase HSI injury risk (Timmins *et al.*, 2016). Whether muscular imbalances truly affect HSI risk remain inconclusive, a large part of which may be down to the wide variety of testing tools to assess hamstring strength. Given the varied results in the research, perhaps the aim

of practitioners should be to maximise the strength of both hamstrings and reduce potential bilateral strength asymmetries in the process.

*Eccentric Strength* – The hamstrings attain their maximal length during the terminal swing of the gait cycle (Wood, 1987), where they are stretched both proximally and distally. The high eccentric forces involved are likely causes of HSI when sprinting due to the force exceeding the mechanical limits of the muscle tissue as the hamstring works eccentrically to control knee extension (Chumanov *et al.*, 2011). Low eccentric strength may reduce the hamstrings' capability to cope with these forces. Timmins *et al.* (2016) identified soccer players with eccentric strength <337N peak power (<4.35N.kg) on an eccentric knee flexor test on a Nordic Hamstring Exercise device (Nordbord, Vald Performance, Brisbane, Australia) suffered significantly more hamstring injuries than those scoring  $\geq 337\text{N}$  ( $\geq 4.35\text{N.kg}$ ). Those with higher eccentric strength suffered 1 injury per 17.5 players, and those with weaker eccentric strength suffered 1 injury per 4 players.

The performance of eccentric strength training as an injury prevention tool is therefore recommended. Fascicle lengthening ( $\text{BF}_{\text{LH}}$ ) results from eccentric strength training and those with short fascicle lengths are up to 4x more likely to suffer a hamstring injury than those with longer fascicles (Timmins *et al.*, 2015; Bourne *et al.*, 2017). It would be hypothesised that short fascicle lengths would be more susceptible to HSI as they cannot be stretched to longer lengths and are unable to handle the large eccentric forces performed when sprinting. Interventions in professional soccer have demonstrated reduced hamstring injury rates of 65%, with reduced injury rates during both training and match-play for players who completed eccentric training (Arnason *et al.*, 2008). Studying a larger sample size, Petersen *et al.* (2011) identified injury rates of 1 injury per 30.7 players and 1 injury per 9.25 players for intervention and control groups, respectively. Interventions typically implement the Nordic hamstring exercise, although the sliding leg curl (SLC) exercise has been proposed as an alternative, with a variety of variations and loading strategies (Taberner, O'keefe & Cohen, 2016). Both exercises are typically knee > hip dominant, although it is important to consider both knee (i.e. Nordic hamstring exercise/Sliding leg curl) and hip (i.e. Romanian deadlift) dominant exercises to improve

eccentric strength and increase fascicle length through the whole muscle (Buckthorpe *et al.*, 2018).

Given the number of potential risk factors associated with hamstring injuries, it is unlikely that they act independently and single-handedly result in injury. Instead, multiple risk factors likely combine, each of which further increases the risk of injury.

### **3.7 Relationships Between Running Loads and Hamstring Injury**

Despite practitioners implementing interventions to try and reduce HSI occurrence in professional soccer, over the last decade, hamstring injury rates have increased annually by 4% (Ekstrand, Waldén & Hägglund, 2016). Although most hamstring injuries occur during match play (65%), the rate of increased injury rate was not significant (1.5% per year). However, the rate of hamstring injury occurring during training significantly increased by 5% annually over this period. Although high intensity and sprint distance have significantly increased over recent years in match-play, the rate of hamstring injury occurrence has not mirrored this. It is difficult to explain why the rate of HSI has not increased more given the increased rate of running loads, however, there are 2 potential reasons: 1) players have simply adapted and become accustomed to higher running loads during match-play, or 2) progressive increased exposure to high-speed running and sprinting during match-play has had a preventative effect. Ekstrand, Waldén and Hägglund (2016) studied a variety of leagues from different countries, whereas these increases in HI and sprint distance are exclusive to the English Premier League, which is considered to be more physically demanding than others across Europe (Barnes *et al.*, 2014). One explanation for a significant increase in training-related injuries may be an increase in the training load to replicate an increase in high-intensity activity during match-play.

### **3.8 Assessment of Hamstring Strength**

As hamstring injuries are often fatigue related, injury rates may be reduced by efficiently managing training running loads, match minutes and recovery. Frequent assessments of hamstring strength may allow practitioners to quantify the effects of high-intensity workloads on post-match recovery. Following a simulated soccer-specific protocol,

hamstring strength was found to decrease by 16% against pre-test scores using isokinetic dynamometry (IKD) (Rahnama *et al.*, 2003). Small *et al.* (2010) also identified a 16% reduction in eccentric hamstring peak torque (pre-test vs. post-test) following a 90-minute soccer-specific aerobic field test (SAFT<sup>90</sup>) incorporating multi-directional movements and frequent acceleration and deceleration to replicate soccer match-play movements. Isokinetic dynamometry is a reliable and valid tool for hamstring strength testing and is considered the gold standard which other devices and methods are compared against (Anderson *et al.*, 1991; Stark *et al.*, 2011; Toonstra & Mattacola, 2013). Despite this, the time cost and lack of portability involved with dynamometry deem it unpractical for professional soccer environments, especially when testing a full squad of 25-30 players. Hence, isokinetic dynamometers are generally restricted to rehabilitation or individual athlete environments, with alternative testing tools required for professional soccer.

Alternative tests have been suggested to measure hamstring strength, although performing them in the days after a match may be unsuitable due to the eccentric nature of the exercises, either producing maximal outputs or performing repetitions until failure (Opar *et al.*, 2013; Freckleton *et al.*, 2014). When testing with professional soccer players, the device used needs to be quick and simple to use, portable, and have little to no physical effect on the player to attain player and coach buy-in. An isometric strength test using a sphygmomanometer or hand-held dynamometer has been suggested as an alternative to IKD as a means of frequently testing athlete hamstring strength to individualise post-match recovery (Schache *et al.*, 2011). Furthermore, McCall *et al.* (2015) proposed the use of a portable force platform to measure peak hamstring force, demonstrating good to high reliability at 90° knee flexion (maximal semi-membranosus and semi-tendinosus activation) in the dominant limb (CV = 4.3%) and the non-dominant limb (CV = 5.4%). Reliability was also good at 30° knee flexion (maximal bicep femoris activation) in the dominant limb (CV = 6.3%) and the non-dominant limb (CV = 4.8%). Performed unilaterally, the test can detect bilateral strength asymmetries and allows both localised acute and chronic fatigue to be monitored. Following a competitive soccer match, the force platform detected significant reductions in peak hamstring force vs pre-match values at 90° in the dominant (-16%) and non-dominant (-13%) legs and at 30° in the dominant (-15%) and non-dominant (-11%) legs (McCall *et al.*, 2015)

Pre- vs. post-match isometric hamstring MVC was also observed by Nédélec *et al.* (2014) using a sphygmomanometer cuff. Larger effect sizes were identified across a 72-hour period at 150° knee extension (0.72 – 1.08) compared to 90° knee extension (0.53 – 0.96). At 72 hours post-match, MVC values failed to return to baseline in both legs at 90° and 150°, respectively. The non-dominant leg appeared to recover quicker than the dominant leg, which may be due to the greater frequency of actions performed with the dominant leg, such as passing, shooting and tackling. Indeed, only values from the dominant leg at 90° knee extension 24 hours post-match correlated with the number of playing actions performed in a match. Measuring only the number of playing actions performed during match-play would appear less effective than measuring distances covered in different speed zones and acceleration and deceleration activity.. Pilot work from our group observed match workloads across three games against hamstring strength 24- and 48-hours post-match. Player 1's hamstring strength reduced by 10-21% at +24H, with no improvements after +48H following high exposure to distances covered accelerating and decelerating, with the hamstrings placed under large eccentric forces under braking. Player 2's hamstring strength reduced by 12-19% at +24H, and was still impaired by 8-15% at +48H when exposed to large high-speed running distances and when performing a large number of decelerations during match-play. Player 3 experienced reduced hamstring strength at +24H (6-19%) when exposed to high-speed running. At +48H, strength increased but did still not reach baseline values (5-10% reduction). The dominant leg experienced greater muscle damage, as seen by a reduction in peak hamstring MVC, and recovered slower than the non-dominant leg in each case, all in agreement with previous research conducted by Nédélec *et al.* (2014) and McCall *et al.* (2015).

Where an eccentric test may elevate muscle damage and increase HSI risk, maximal isometric contractions develop approximately half the force of eccentric activity, incurring minimal muscle damage in the process (Faulkner *et al.*, 1993). Not only is it unrealistic to perform high eccentric loads with professional soccer players following a match, greater exposure to high eccentric workloads may exaggerate muscle damage and prolong the recovery process (Clarkson *et al.*, 1992; Warren *et al.*, 1999). At present, only one research paper exists in the literature (McCall *et al.*, 2015) demonstrating the reliability

and sensitivity of the use of a force platform to measure hamstring strength. Although force platforms are deemed the gold standard tool for isometric testing (Verdara *et al.*, 1999), their use for hamstring testing is scarce in the literature, typically confined to professional sports where their quick and easy approach is preferred to other lower limb posterior strength measuring devices.

Further investigation is required regarding force platforms as a tool to measure hamstring strength. Force platforms are primarily used as an easier, cheaper and portable alternative tool to an IKD. Although valid as a tool to measure isometric strength, whether they can be used specifically for hamstring strength measures is yet to confirmed. It is reasonable to propose a validity test is required prior to their use in a professional environment. Moreover, research has shown hamstring strength to reduce following match-play and fail to return to baseline values even after 48 and 72 hours (Nédélec *et al.*, 2014; McCall *et al.*, 2015). Neither study attributes a reduction in hamstring strength to a specific component of match-play (i.e. high-speed running distance, sprint distance, acceleration and deceleration activity) and how these may affect each individual player's recovery kinetics.

Therefore, the overall aim of this study was to evaluate the use of force platforms for isometric hamstring testing in professional soccer as a method of monitoring post-match recovery in professional soccer. This aim would be achieved through 2 studies. The aim of study 1 was to establish the reliability and validity of force platforms for isometric hamstring testing. The aim of study 2 was to assess hamstring recovery during the +48hours post-match period and determine the relationship between hamstring recovery and match-derived running loads.

**CHAPTER 4**

**RELIABILITY AND VALIDITY OF AN ISOMETRIC  
HAMSTRING STRENGTH TEST USING A  
PORTABLE FORCE PLATFORM**



## 4.1 Introduction

Hamstring strain injuries are one of the most common lower limb injuries in professional soccer (Ekstrand *et al.*, 2011a), with the muscle typically at risk of injury during high-speed running and explosive actions, (Arnason *et al.*, 2008). Hamstring injuries are multifactorial in nature, although the main risk factors include fatigue (Woods *et al.*, 2004) and strength imbalances/deficits (Croisier *et al.*, 2008). It appears that those with bilateral imbalances are 4 times more likely to suffer a hamstring injury (Croisier *et al.*, 2008), which is further increased when no eccentric strength training protocol is provided to attenuate injury risk. Bilateral hamstring strength measures may therefore be a useful indicator of injury risk.

Regular hamstring strength testing can provide measures of bilateral asymmetries and changes in strength from baseline when assessed over sustained periods of time. Post-match assessments of hamstring strength may provide objective information on the muscle specific responses to soccer match-play. Nédélec *et al.* (2014) showed peak isometric hamstring strength measures fail to reach pre-match levels at 72 hours post-match in professional soccer players. Players' non-dominant leg recovered quicker than the dominant leg, which could be attributed to the number of actions performed with the dominant leg (i.e. passing, shooting & tackling). This delayed recovery may explain the increased amount (>13%) and severity of hamstring injury occurrence in the dominant leg of soccer players (Hawkins *et al.*, 2001).

Additional research using isokinetic dynamometry (IKD) found hamstring strength to decrease by 16% following a treadmill soccer-specific protocol (Rahnama *et al.*, 2003; Small *et al.*, 2010). Despite IKD being the gold standard measure for hamstring strength (Anderson *et al.*, 1991; Croisier *et al.*, 2008), it is unpractical to assess every player in an elite sports team, due to its timely process and lack of portability. Hence, dynamometers are typically restricted to laboratory-based studies, or if they are used in elite sports, they are typically limited to individual athlete or rehabilitation environments. Other tests have been suggested to measure hamstring strength, although performing them in the days following a match may be unsuitable due to their eccentric nature (Opar *et al.*, 2013; Freckleton *et al.*, 2014).

Recently, McCall *et al.* (2015) proposed the use of a portable force platform to measure hamstring strength. Other hamstring studies have typically used IKD, or alternatives such as handheld dynamometers or sphygmomanometer cuffs. However, force platforms automatically detect bilateral asymmetries and as tests are performed isometrically, produce less strain than eccentric contractions as the load is more evenly distributed across the muscle, reducing muscle damage (Faulkner *et al.*, 1993; McHugh *et al.*, 2000). At present, McCall *et al.* 2015 is the only existing research paper in the literature demonstrating the reliability of force platforms for measuring hamstring strength. Other hamstring studies have typically used IKD, or alternatives such as handheld dynamometers or sphygmomanometer cuffs. Performing two strength tests, one week apart, McCall's protocol followed that used in these studies (Landes *et al.*, 2010; Schache *et al.*, 2011); the participant lying supine with the testing leg positioned at 90° knee and hip flexion, driving the heel down into a force platform whilst keeping the body fixed to the ground. Performing tests one-week apart, the test demonstrated excellent reliability at 90° in both limbs, although reliability was marginally better in the dominant limb (ICC = 0.95, CV = 4.34%, TE = 9.4N) than the non-dominant limb (ICC = 0.95, CV = 5.48%, TE = 11.5N). Despite identifying excellent reliability, McCall's group did not assess the validity of the force platform. The authors judged that as force platforms are recognised to be a gold standard tool for isometric testing (Verdara *et al.*, 1999), they could be deemed appropriate for the proposed purpose. Therefore, to progress previous work, the aim of this study was to measure the reliability and validity of force platforms for isometric hamstring strength testing. This would be achieved through 1) measuring the test-retest reliability of force platforms when measuring isometric hamstring strength, and 2) measuring the criterion validity of force platforms for measuring isometric hamstring strength vs. gold standard measures.

## **4.2 Methods**

### **4.2.1 Participants**

Ten healthy and injury-free university students (age  $21.3 \pm 3$  years, height  $176.8\text{cm} \pm 6.7\text{cm}$  and mass  $81.1\text{kg} \pm 7.6\text{kg}$ ) volunteered for this study. To partake in the study, participants were required to meet the following inclusion criteria; a) male aged 18-35, b)

free of musculo-skeletal injury whilst testing, and c) have had no form of lower limb injury in the previous two months which had prevented the individual from engaging in physical activity (as these were not professional athletes, previous injuries prior to this 2 month cut off were not assessed). Participants were informed of the purpose, risks and benefits of the study prior to providing written consent to participate. This study was approved by the ethics board of Liverpool John Moores University (ethics number 15/SPS/037) and developed in accordance with the standards set by the Declaration of Helsinki.

#### **4.2.2 Procedure**

In the week prior to testing, participants completed a familiarisation session where hamstring strength was measured using a portable force platform and an IKD. Participants were required to have not performed strenuous physical activity in the 2 days prior to testing, with any session to be rated  $\geq 4$  on a subjective rating of perceived exertion (RPE) scale ranging from 1-10 (Borg, 1982).

To assess the reliability and validity of a force platform compared to IKD, a test-retest was performed on both devices. Tests were performed one week apart at the same time of day (set time for both testing days, with times set 9am-3pm). Participants were encouraged to adopt similar sleep/diet patterns during the 2 days prior to each session.

At the start of each testing session, participants performed a 10-minute standardised warm up comprising of dynamic stretching of the lower posterior chain and 5 minutes of cycling at 90W. For the testing protocol, participants performed 5 maximal unilateral isometric force tests on each leg using a portable force platform (PA Sport PS-2141, Pasco, Roseville, USA) integrated with an analogue-to-digital converter using Forcedecks software (Forcedecks, Vald Performance, Queensland, Australia). The force platform collected data at 1000Hz, measuring peak vertical force in Newtons (N). Legs were classified as dominant and non-dominant, with the dominant leg described as the preferred kicking leg (van Melick *et al.*, 2017) (10 participants = 8x right, 2x left).

*Portable force platform test.* Participants lay supine, facing a box on which the force platform was rested (Figure 1.). The testing leg was positioned at 90° knee and hip flexion using a goniometer (SAEHAN Corporation, Masan, South Korea), with the heel rested on

the force platform and the non-working leg extended alongside the box. To ensure this position for all participants, the height of the box was adjusted accordingly, with a standardised box height of 12" with 3" additional increments provided if required. On the call of "3,2,1, drive", participants performed a 3s maximal voluntary contraction (MVC) by driving their heel down into the platform. Participants were instructed to keep their arms across the chest, with the practitioner applying pressure to the contralateral hip to ensure the buttocks remained fixed to the ground (Figure 2 and Figure 3.) (Schache *et al.*, 2011; McCall *et al.*, 2015). The same practitioner applied pressure to the hips for each participant. As a strength-based protocol, it was important for participant posture to be completely controlled to reduce mechanical variation (Coldwells *et al.*, 1994). To standardise, all participants performed the test without shoes. A 30s rest was permitted between reps for participants to reassume the starting position and prevent acute fatigue, with a 2-minute rest between sets.



**Figure 2. Set up of isometric hamstring strength test**



**Figure 3. Testing position of isometric hamstring strength test**

*Isokinetic dynamometer test.* To determine the criterion validity of the force platform, participants performed an isometric test on each leg at 90° knee and hip flexion using an isokinetic dynamometer (Biodex System 3, Biodex Medical Systems, Inc, New York). Participants sat upright, ensuring the glutes and lumbar spine were flat back against the chair, with straps positioned across the trunk and hips to reduce movement. The lever of the IKD was secured 2cm above the lateral malleolus. On the practitioners call of “3,2,1, drive”, participants performed a 3 second MVC by attempting to drive the heel backwards. A 30-second rest was given between reps and 2-minute rest between sets. For individual FP and IKD tests, participants performed 1x5 reps on each limb. To ensure ease of data analysis, IKD torque measured in N.m was divided by the length of the participant’s lower limb measured from the lateral knee epicondyle to the lateral ankle malleolus, to provide a force measure in N to match that provided by the force platform.

Participants were tested on both limbs at 90° knee and hip flexion, respectively. At 90°, the hamstrings are isolated from the other hip extensor muscles, providing a truer representation of hamstring strength (Schache *et al.*, 2011). When testing at hip angles greater than 70°, there is resemblance to the hip angle observed during the swing phase when sprinting (Guex *et al.*, 2012). Testing at 90° is more reliable when assessing peak force (McCall *et al.*, 2015) and demonstrated slightly greater reliability in EMG activity of individual hamstring muscles (Read *et al.*, 2019).

#### **4.2.3 Statistical Analysis**

Comparisons of peak (highest force across all 5 reps) and average peak (average of peak force from each of the 5 reps) isometric hamstring strength were quantified for both dominant and non-dominant limbs. Descriptive data are presented as mean  $\pm$  standard deviation (SD). Test-retest reliability was examined via a paired *t*-test, supported by Cohen’s *d* effect size (ES), interclass correlations (ICC<sub>2,1</sub>), typical measurement error (TE) and coefficient of variation (CV%). Confidence intervals (95%) were calculated for both ICC<sub>2,1</sub> and ES. Using an interpretation of Cohen’s magnitude of effect sizes, an effect size of <0.1 = unsubstantial, 0.1 – 0.3 = small, 0.3 – 0.5 = moderate and  $\geq 0.5$  deemed large. Given this is a reliability study, effect sizes were expected to be unsubstantial (<0.1), where minimal differences between test and re-test means would be identified.

Interclass correlations were expected to be >0.90. It is acknowledged that ICC values <0.5 demonstrate poor reliability, ICC between 0.5 and 0.75 show moderate reliability and ICC values between 0.75 and 0.90 demonstrate high reliability (Portney & Watkins, 2000). Bland-Altman plots were also created to assess to agreement between test and retest.

Force platform-IKD measures were log-transformed due to a non-normalised distribution of data. Pearson's correlation was used to assess validity, measuring peak and average forces to assess the relationship between force platforms and IKD. Pearson's (r) correlation is used to assess association, with correlations classed as moderate (r = 0.40 – 0.59), strong (r = 0.60 – 0.79) and very strong (r = 0.80 – 1.00). Bland-Altman plots were produced to identify the agreement between IKD and FP, with 95% confidence intervals (CI) set at mean of differences  $\pm 1.96 * SD$  of the differences and upper and lower limits of agreement calculated for each CI.

### **4.3 Results**

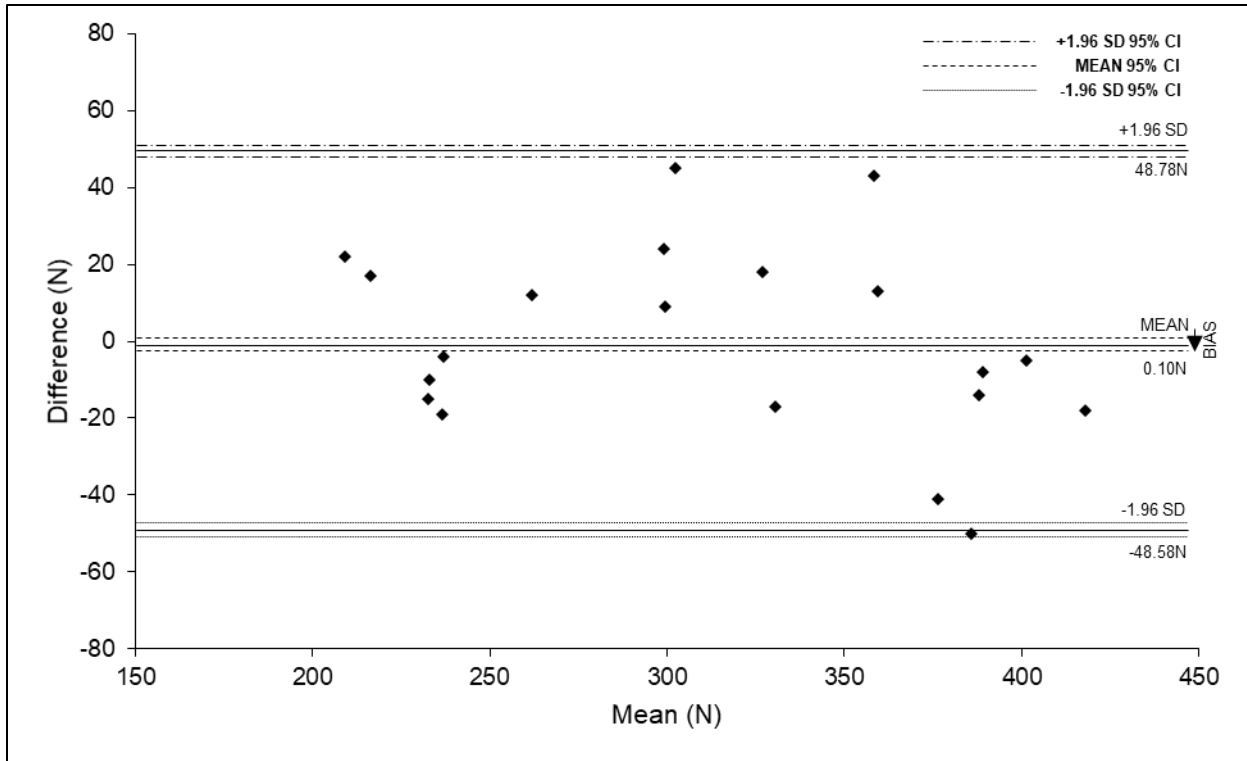
Descriptive statistics and test-retest reliability results for the force platform are shown in Table 4. Results for peak and average peak force for both dominant and non-dominant limbs are presented. Force platform reliability for peak force was high,  $ICC_{2,1} = 0.94$  (P = 0.986). Test-retest reliability for both dominant,  $ICC_{2,1} = 0.95$  (P = 0.441) and non-dominant limb peak force,  $ICC = 0.93$  (P = 0.493) was high. Reliability was also high for combined,  $ICC_{2,1} = 0.94$  (P = 0.865) dominant,  $ICC_{2,1} = 0.93$  (P = 0.807) and non-dominant,  $ICC_{2,1} = 0.95$  (P = 0.978) average peak force. When measuring peak force, typical error and CV% were lower in the dominant vs. the non-dominant leg. There were no differences in CV% in limbs for average peak force (Table 4.). Bland-Altman plots for all test types demonstrated good agreement between test and retest, with a very small bias present and narrow limits of agreement (Figures 4-9).

Correlations between FP and IKD are presented as Pearson's correlation (r) (Table 5). With limbs measured together, correlations were moderate (r = 0.5 – 0.7). When assessed separately, correlation was greater in the non-dominant limb for both peak and average forces. Analysis of Bland-Altman (BA) plots (Bland & Altman, 1986) identified  $\geq 95\%$  of IKD-FP mean differences falling within the limits of agreement (LOA). However, the width of the LOA was extremely wide, with a bias towards FP overestimating IKD

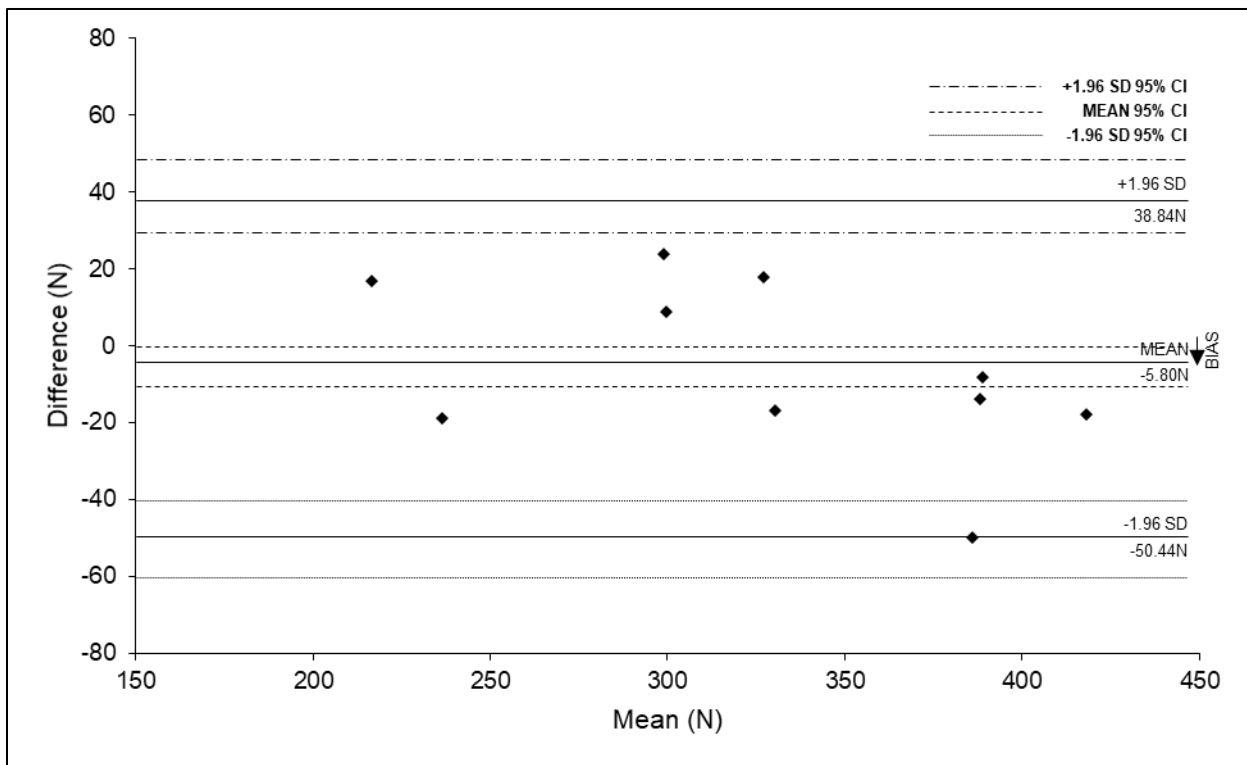
(Figures 10-15.). For all test types, the upper limit for the mean of differences averaged 52N. Lower limits ranged from -145N to -177N, with further analysis of BA plots suggesting a weak trend towards a larger difference when force outputs were increased, with an average value for  $r = 0.197$ . Force platform measures were identified to regularly overestimate those produced via IKD.

**Table 4. Test-retest reliability of force platforms for an isometric hamstring strength test at 90° knee and hip flexion**

	FP TEST 1 (MEAN ± SD)	FP TEST 2 (MEAN ± SD)	COHENS d EFFECT SIZE (LB, UB)	ICC <sub>2,1</sub> (LB, UB)	TE (N)	CV (%)
<b>PEAK FORCE</b>						
<b>COMBINED</b>	313 ± 67	313 ± 74	-0.01 (-0.88, 0.88)	0.94 (0.85, 0.98)	17.6	5.6%
<b>DOMINANT</b>	326 ± 63	332 ± 74	0.08 (-0.79, 0.96)	0.95 (0.80, 0.99)	16.1	4.9%
<b>NON-DOMINANT</b>	300 ± 72	294 ± 73	-0.08 (-0.96, 0.79)	0.93 (0.76, 0.98)	18.8	6.3%
<b>AVERAGE PEAK FORCE</b>						
<b>COMBINED</b>	291 ± 65	292 ± 72	0.01 (-0.61, 0.63)	0.94 (0.86, 0.98)	16.5	5.7%
<b>DOMINANT</b>	304 ± 61	306 ± 71	0.03 (-0.85, 0.91)	0.93 (0.74, 0.98)	17.8	5.8%
<b>NON-DOMINANT</b>	277 ± 70	277 ± 73	0.00 (-0.88, 0.87)	0.95 (0.81, 0.99)	16.0	5.8%



**Figure 4. Bland-Altman plot for peak force reliability**



**Figure 5. Bland-Altman plot for dominant limb peak force reliability**



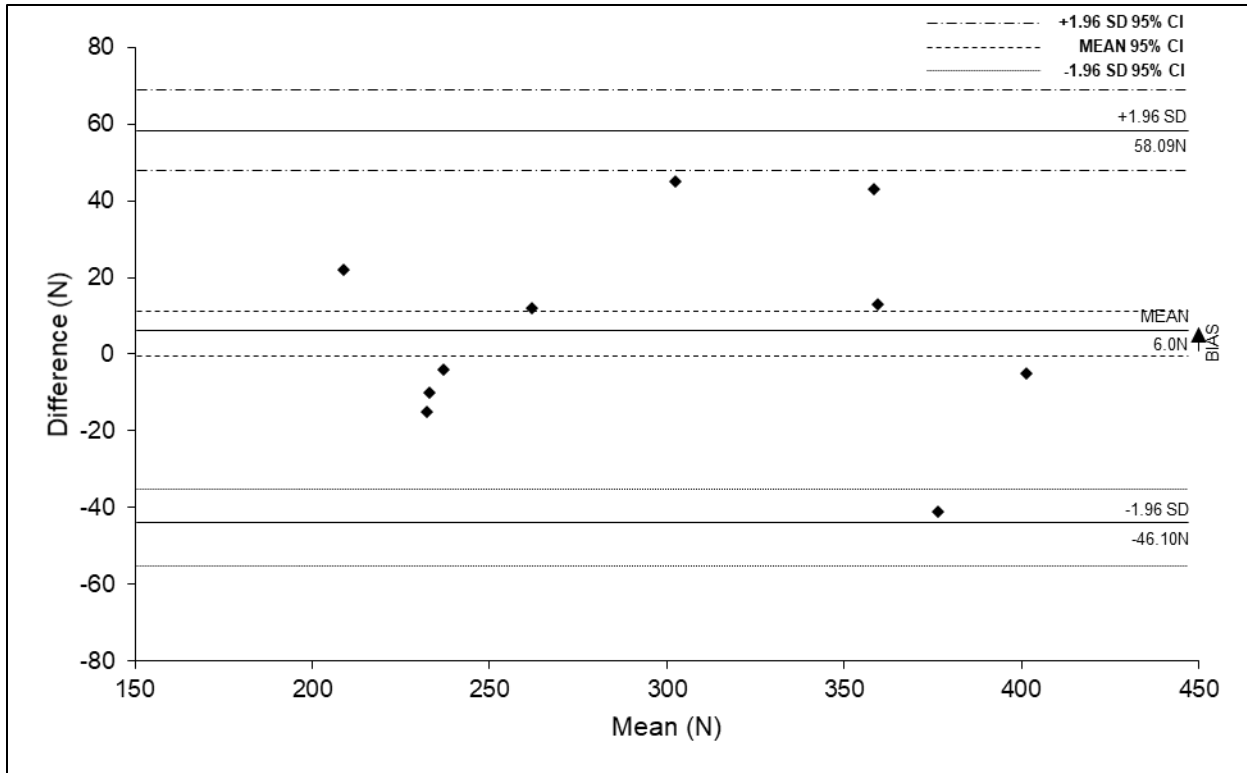


Figure 6. Bland-Altman plot for non-dominant limb peak force reliability

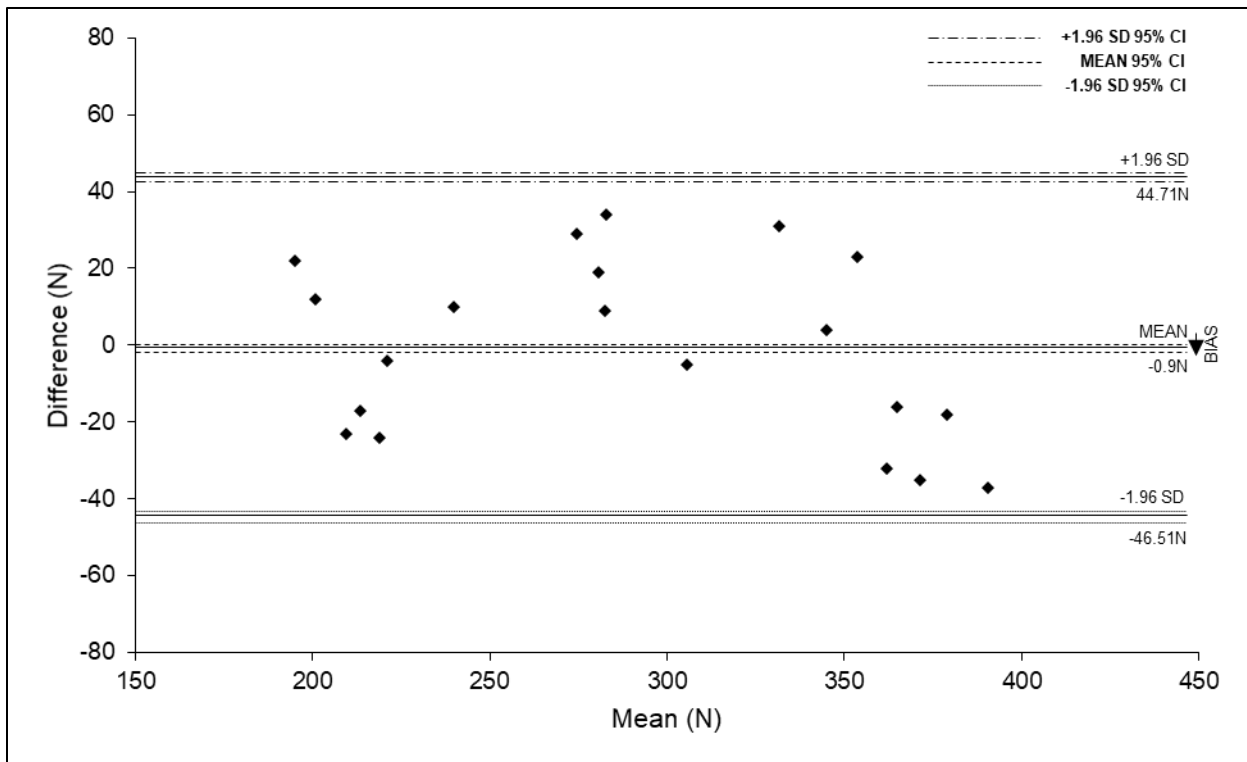
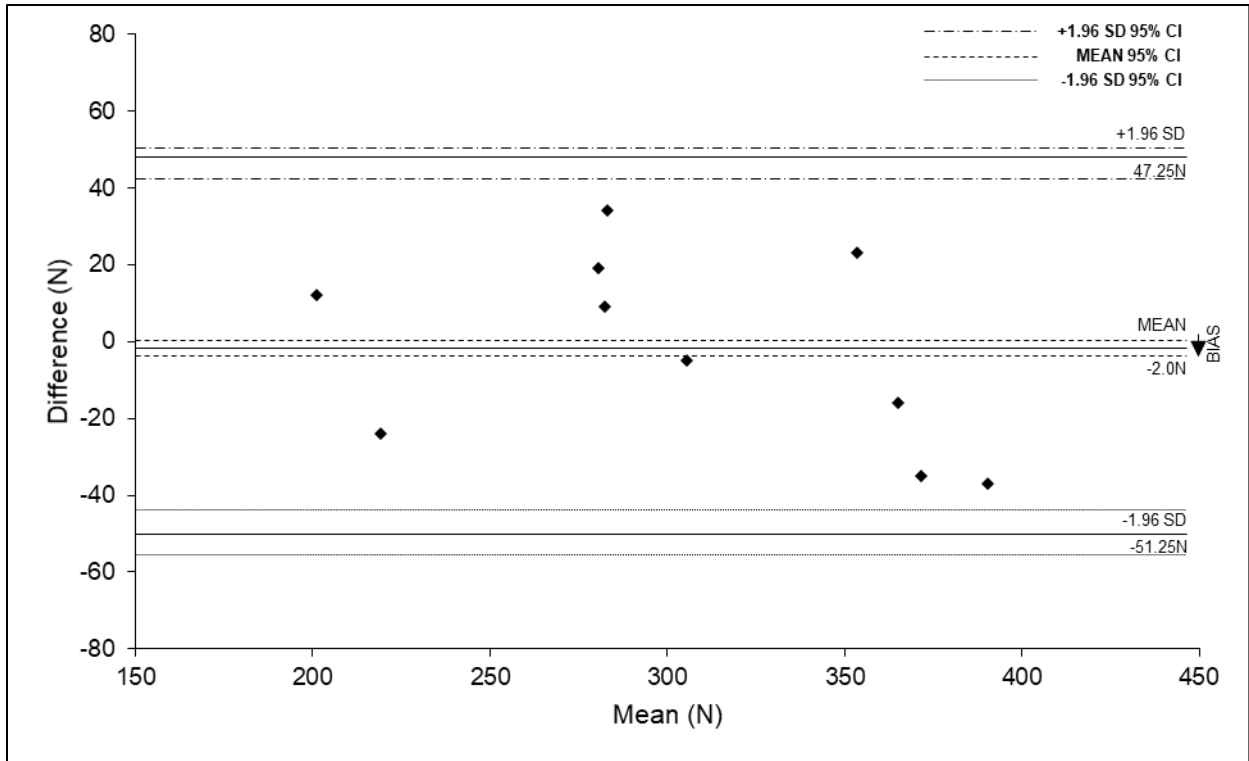
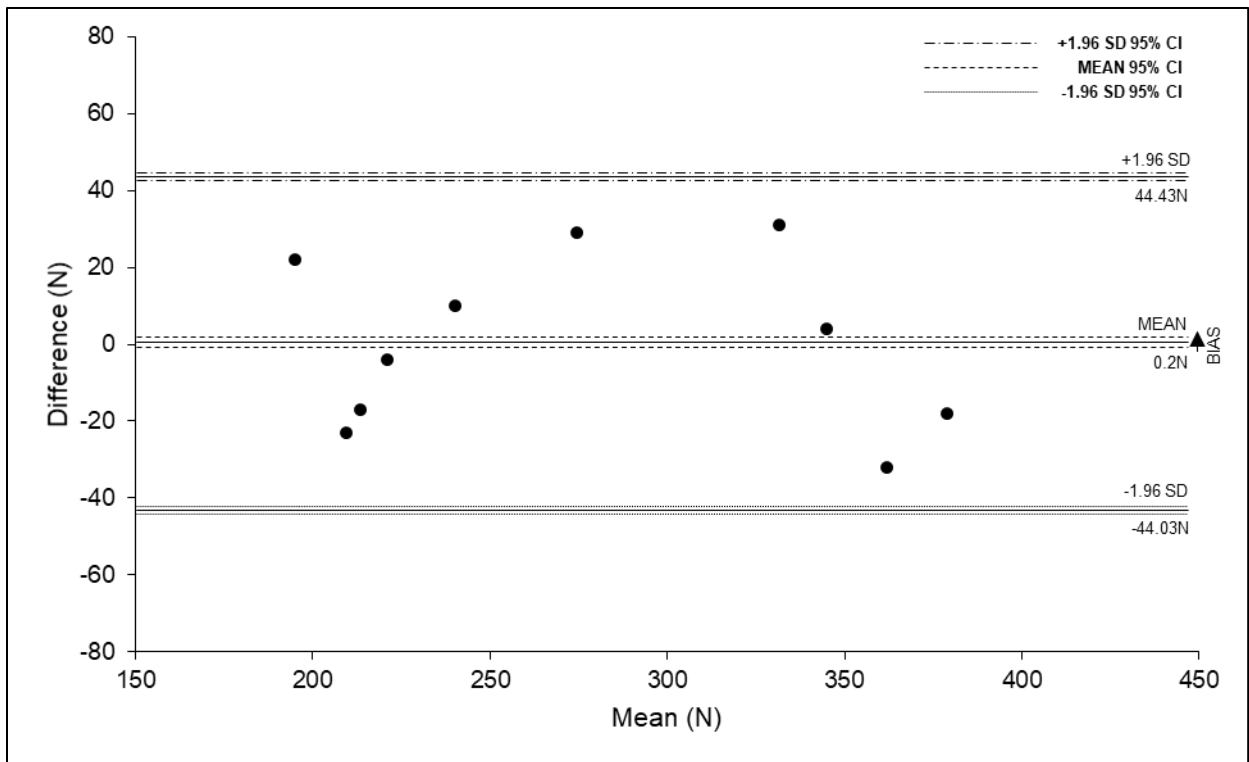


Figure 7. Bland-Altman plot for average peak force reliability



**Figure 8. Bland-Altman plot for dominant limb average peak force reliability**



**Figure 9. Bland-Altman plot for non-dominant limb average peak force reliability**

**Table 5. Validity of force platforms for an isometric hamstring strength test compared against isokinetic dynamometry at 90° knee and hip flexion**

	<b>IKD (MEAN ± SD)</b>	<b>FP (MEAN ± SD)</b>	<b>PEARSON (r) (LB, UB)</b>	<b>CONSTANT BIAS (N) (LB, UB)</b>	<b>PROP' BIAS (LB, UB)</b>	<b>SE (N) + %</b>
<b>PEAK FORCE</b>						
<b>COMBINED</b>	257 ± 46	313 ± 70	0.67 (Strong) (0.46, 0.81)	60.98 (-37.40, 159.37)	0.98 (0.60, 1.36)	53.8 (17.2%)
<b>DOMINANT</b>	266 ± 43	329 ± 67	0.56 (Mod) (0.16, 0.80)	158.63 (70.68, 246.58)	0.33 (0.06, 0.59)	36.4 (11.1%)
<b>NON- DOMINANT</b>	248 ± 50	297 ± 71	0.72 (Strong) (0.41, 0.88)	96.77 (23.0, 170.54)	0.51 (0.27, 0.75)	36.5 (12.3%)
<b>AVERAGE PEAK FORCE</b>						
<b>COMBINED</b>	235 ± 47	291 ± 68	0.55 (Mod) (0.29, 0.74)	123.64 (66.27, 181.01)	0.38 (0.19, 0.57)	40.0 (13.7%)
<b>DOMINANT</b>	244 ± 42	305 ± 64	0.45 (Mod) (0.01, 0.74)	157.72 (67.21, 248.24)	0.28 (-0.01, 0.57)	38.6 (12.7%)
<b>NON- DOMINANT</b>	225 ± 51	277 ± 70	0.58 (Mod) (0.18, 0.81)	104.04 (20.45, 187.64)	0.44 (0.14, 0.73)	42.4 (15.3%)

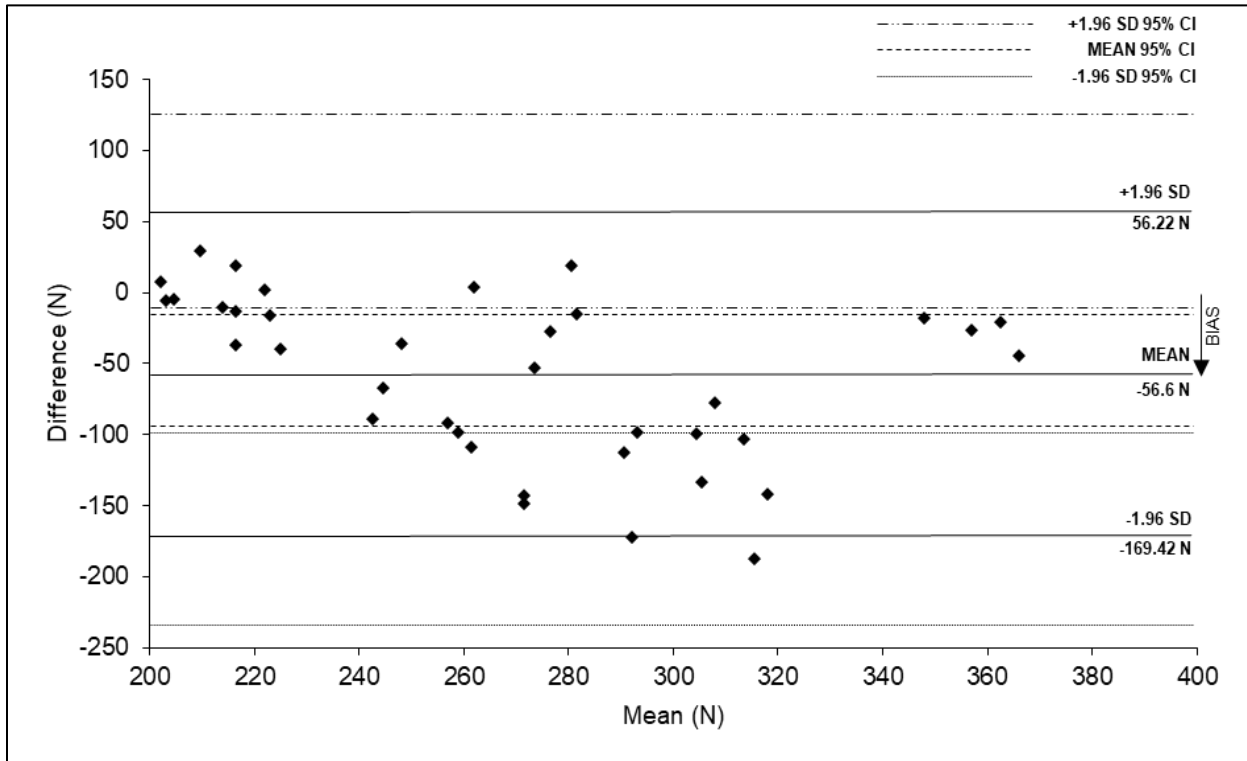


Figure 10. Bland-Altman plot for IKD vs. FP peak force

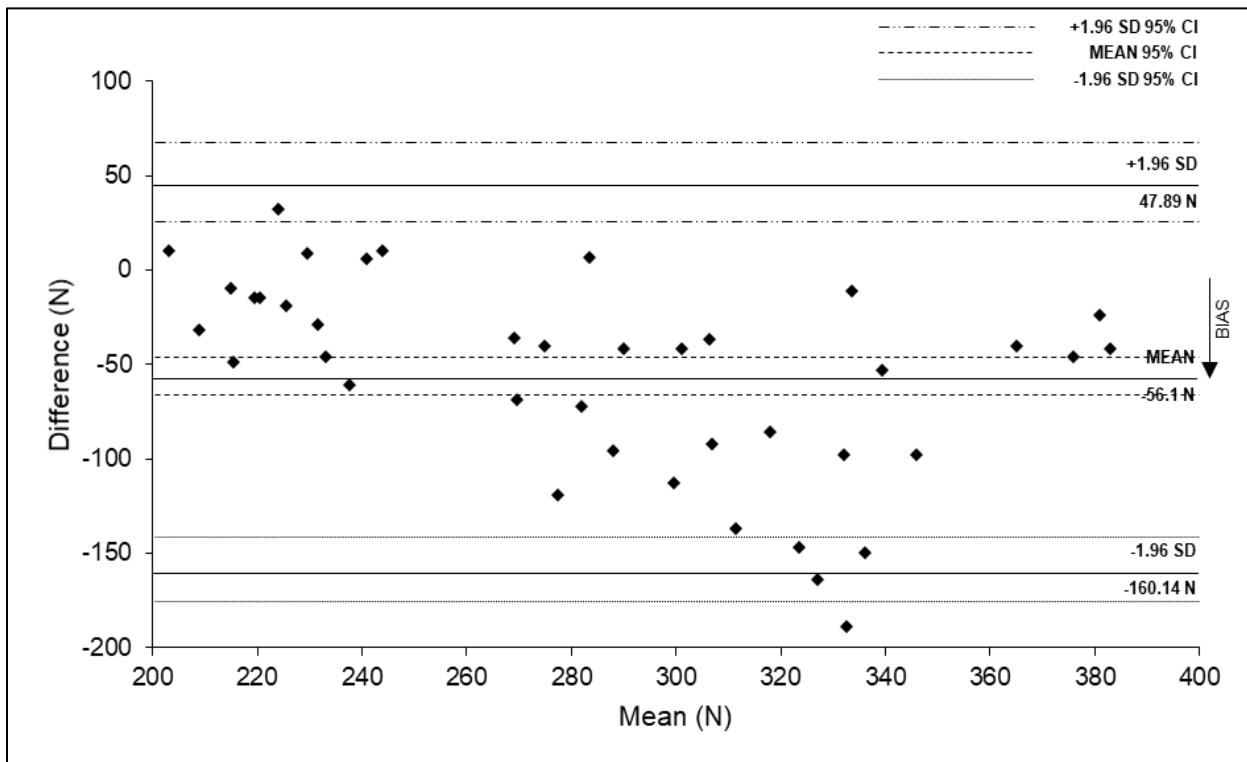


Figure 11. Bland-Altman plot for IKD vs. FP average peak force

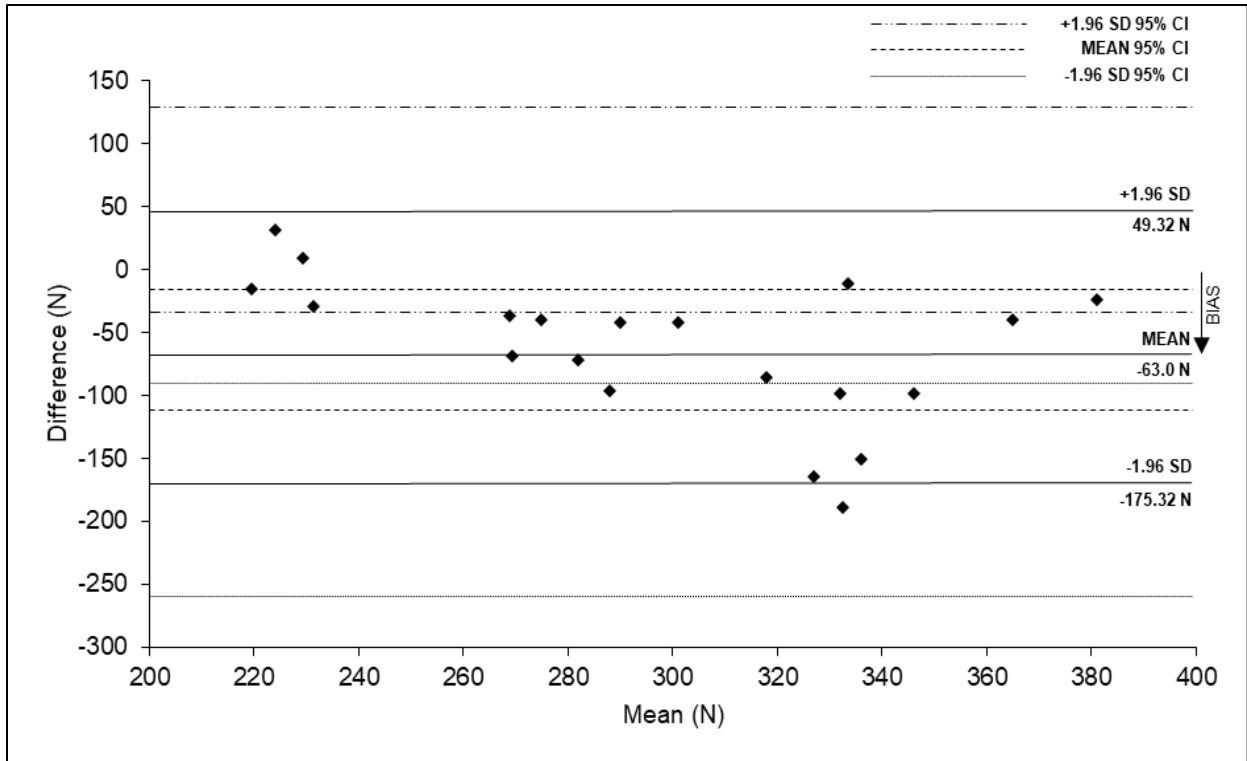


Figure 12. Bland-Altman plot for IKD vs. FP dominant limb peak force

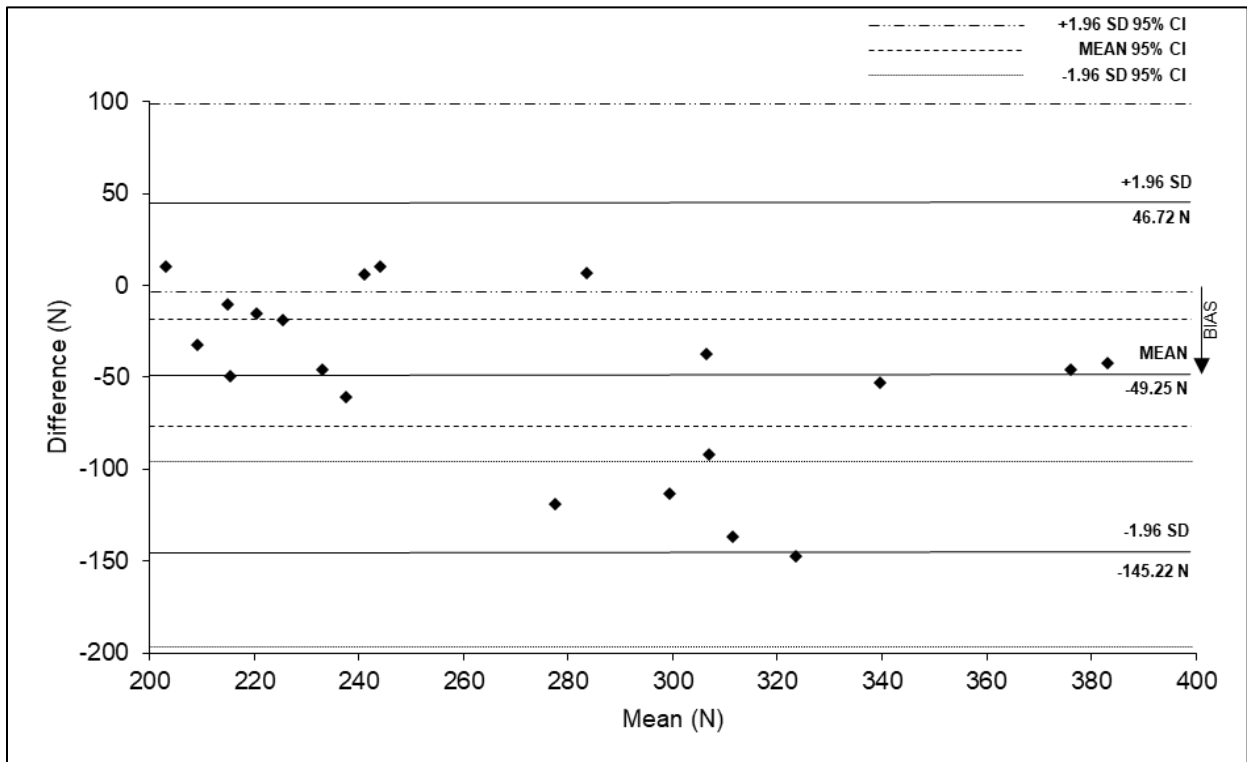
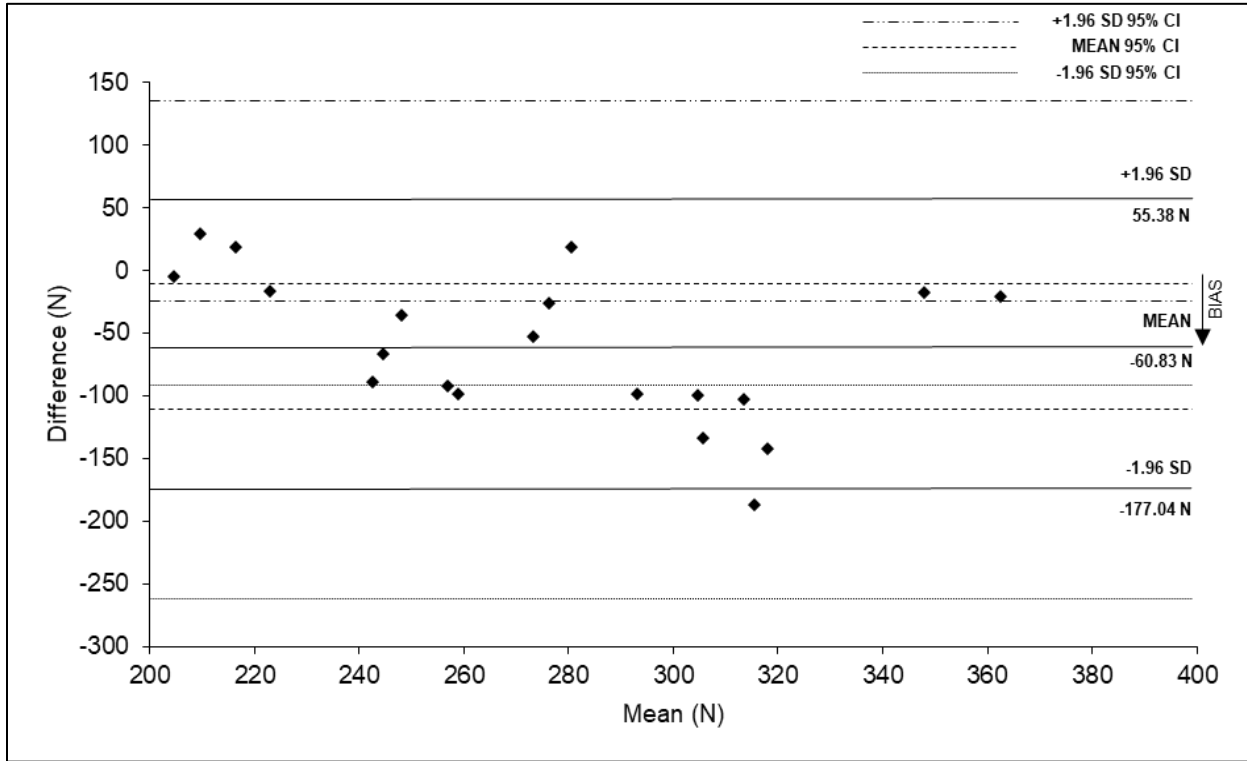
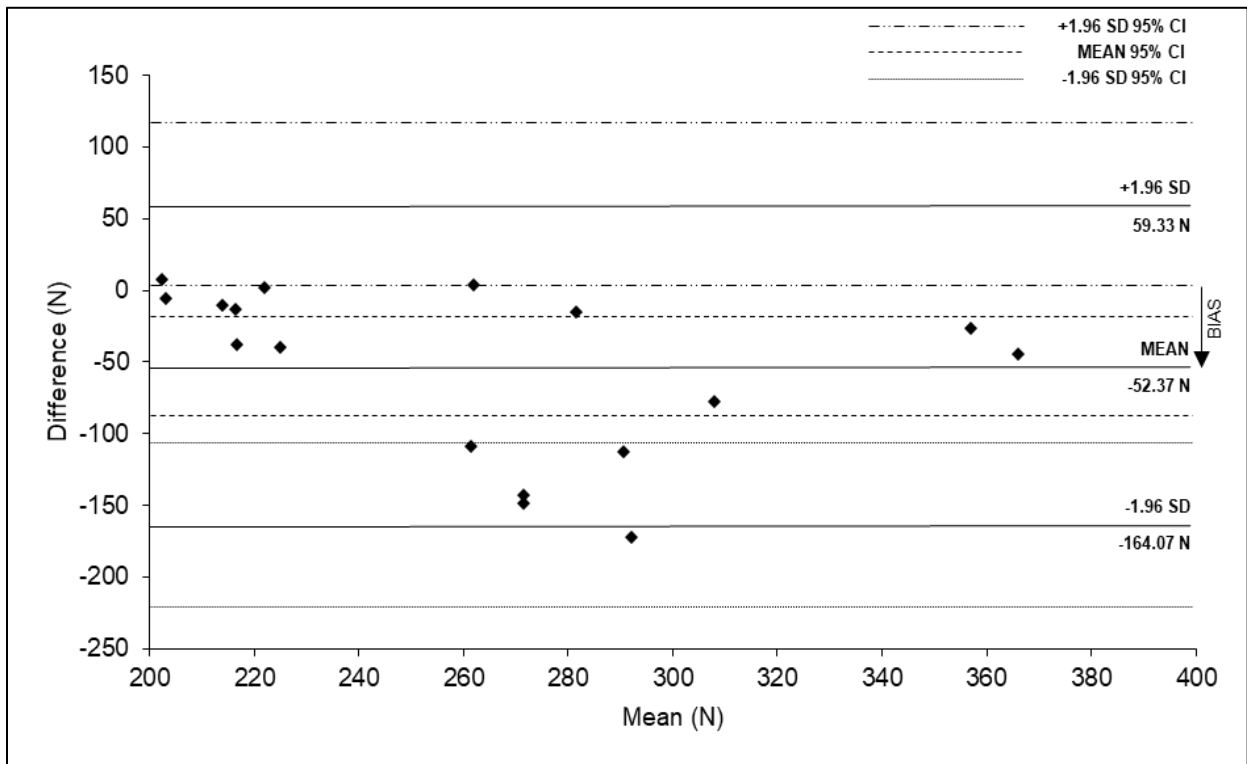


Figure 13. Bland-Altman plot for IKD vs. FP for non-dominant limb peak force



**Figure 14. Bland-Altman Plot for IKD vs. FP dominant limb average peak force**



**Figure 15. Bland-Altman plot for IKD vs. FP non-dominant limb average peak force**

#### 4.4 Discussion

In the current study, force platforms demonstrated high test-retest reliability when measuring hamstring strength. Trivial effect sizes (Cohen, 1988; Hopkins, 2002) were identified between test and retest for all test types (total, dominant and non-dominant for both peak and average forces). A trivial effect size meant no differences between test and retest values for the force platform. For all test types, interclass correlations were  $>0.90$ , demonstrating excellent reliability.

Associations between FP and IKD ranged from moderate to strong. With the dominant ( $r = 0.56$ ) and non-dominant ( $r = 0.72$ ) limbs separated, there was an unexpected greater correlation between the force platform and IKD in the non-dominant leg. A similar between-limb trend was also identified for average peak force, although correlations were reduced. A higher correlation may have been expected between IKD and FP for the dominant leg than the non-dominant. In the current study, the dominant leg was selected by the participants as their preferred kicking leg. However, it is suggested that limb dominance is task and movement specific which may need to be considered in a test environment (Promsri, Haid, & Federolf, 2018; Velotta *et al.*, 2011). Leg dominance may differ from self-reported leg dominance in unilateral tasks which require greater stabilisation (van Melick *et al.*, 2017). Although associations between FP and IKD are evident, bland-altman plots demonstrate a poor agreement between measures. For peak force, force platforms measured greater values for both dominant (+63N) and non-dominant (+49N) limbs, likewise for average peak force in both dominant (+61N) and non-dominant (+52N) limbs. Although an isokinetic test measuring knee flexor torque in N.m, force outputs for the IKD were multiplied by leg length (lateral condyle of the knee to lateral malleolus) to match force outputs of the force platform (N), the difference in testing position is likely to affect force production.

Other portable devices have been proposed as alternatives to IKD (Landes *et al.*, 2010; Schache *et al.*, 2011). However, these do not demonstrate the reliability shown by force platforms in the current study and lack the ability of force platforms and their accompanying software to automatically detect inter-limb asymmetries. Whilst IKD's can perform the latter, FP's have much greater scope for further analysis. Whilst also

measuring peak force, FP's can measure force at different time points, specifically the first 200ms of muscle contraction. Measuring the rate of force development (RFD) may be better suited to professional soccer than peak force due to its relationship with athletic performance. Rate of force development has been directly linked to jump (McLellan, Lovell & Gass, 2011) and sprint (Slawinski *et al.*, 2010) performance, both of which are regular components of match-play. Therefore, where IKD is not available or realistic to use, force platforms should be the primary measuring tool considered for isometric hamstring strength testing.

One key consideration for this study was deciding which knee and hip angles would be used for the testing protocol. McCall *et al.*, (2015) tested at both 30° and 90° knee flexion, with the 90° test demonstrating greater reliability, which could be due to greater isolation of the hamstring muscles and reduced glute involvement (Schache *et al.*, 2011). At the time the testing procedures in this study were performed, it was identified that 30° flexion increased bicep femoris activation and 90° flexion increased semimembranosus (SM) and semitendinosus (ST) activation. However, recent research using EMG has shown whilst bicep femoris activation significantly increased at 30°, altering the angle to 90° does not increase SM or ST activation (Read *et al.*, 2019). Instead, there appears to be slightly increased SM/ST and gluteus maximum activation at 30° flexion.

Unlike the IKD test, for the FP test there was no 'complete' postural control, as some participants may be strong enough to push the practitioner away, even with pressure applied to the contralateral hip. Isometric tests using a handheld dynamometer have shown reductions in reliability due to practitioner strength (Toonstra & Mattacola, 2013). The test could be improved by securing the participants position with a strap or fixed weight, which will reduce any potential input from the glutes. Finally, as noted by McCall's group, the use of EMG to measure hamstring activity and determine glute involvement would be beneficial for further study. It may be beneficial for further study to use force platforms to observe individual post-match recovery kinetics in professional footballers, examining posterior lower limb strength measures in relation to game running loads.

Although correlations between FP and IKD were moderate to strong, agreement between the two appears poor upon analysis of Bland-Altman plots. Force platform measures



appeared to consistently overestimate those of the IKD. Force output may be affected by testing position (supine vs. seated), the degree of support during contraction (practitioner support vs. straps) or the unit of measurement (N vs. Nm), although the conversion of Nm to N by calculating IKD torque by lower leg length to calculate a force value should account for this.

#### **4.5 Conclusion**

The findings from this study show that portable force platforms are a very reliable tool for measuring isometric hamstring strength. When compared against IKD, the validity of force platforms appears compromised. This test has been suggested as an alternative to isokinetic dynamometry, providing a quicker, easier and portable solution for strength testing. Moderate to high correlations were observed between FP and IKD, however, there was limited agreement between the two measure, based on the large width of the limits of agreement identified in the Bland-Altman plots. This may be due to the differences in body position when performing the test or due to differences in measuring units (N.m vs. N) and the conversion required from IKD to FP and vice versa. Nevertheless, the reliability of this test has been confirmed. Despite the limited agreement with IKD when assessing FP validity, force platforms are still a suitable alternative for hamstring strength testing, provided that the two tests are not used interchangeably. Force platforms are a practical alternative to IKD and could be used in elite sporting environments to monitor between-limb asymmetries, force outputs at different times and be used as a monitoring tool for recovery and rehabilitation purposes.

**CHAPTER 5**

**THE RELATIONSHIP BETWEEN MATCH  
RUNNING LOADS AND PHYSICAL MARKERS OF  
HAMSTRING RECOVERY IN PROFESSIONAL  
SOCCER**

## 5.1 Introduction

Hamstring injuries in professional soccer account for 12% of all injuries and can result in a team playing 15 matches a season with players missing through injury (Woods *et al.*, 2004). Soccer incorporates low and moderate intensity activity with high intensity actions such as high-speed running, sprinting and accelerations/decelerations (Gabbett *et al.*, 2013; Russell *et al.*, 2014). These high-intensity actions are fundamental components of match outcomes in soccer (Bradley *et al.*, 2010).

Increases in both high-speed running (HSR) and sprint distances have been identified in the EPL in recent years (Barnes *et al.*, 2014). Distances in these speed zones are affected by playing position at both 1<sup>st</sup> team (Bradley *et al.*, 2009) and U23 English Premier League levels (Abbott *et al.*, 2018), with fullbacks and wide midfielders covering the greatest distances. Increasing match demands may significantly increase injury risk if players are not accustomed to these higher loads. Training may require progressive exposure to increased running loads to improve the physical qualities of players in order to cope with the demands of match loads and reduce injury risk as a result of this (Bowen *et al.*, 2017).

Hamstring strain injury (HSI) occurrence in soccer is increasing annually (Ekstrand, Waldén & Hägglund, 2016) and is predisposed by both modifiable and non-modifiable factors (Woods *et al.*, 2004). Of those modifiable factors, fatigue and bilateral muscular imbalances  $\geq 15\%$  are believed to be largest contributors to HSI risk (Schache *et al.*, 2011; McCall *et al.*, 2015). Bilateral hamstring strength measures may therefore be a useful indicator of individual responses to running load exposure and HSI risk.

Isometric strength tests provide a quick and easy measure of hamstring strength. Compared to eccentric tests, isometrics produce less strain and incur minimal muscle damage due to a greater number of motor units recruited to distribute the force across the muscle (Faulkner *et al.*, 1993; McHugh *et al.*, 2000). Isometric strength test using a force platform have been proposed as an alternative tool to IKD for strength testing. The time taken to test with a force platform is considerably shorter than IKD due to the set up and calibration required. Force platforms are cheaper to purchase and importantly for team sports, are portable, so testing can be performed wherever the practitioner requires. The reliability of force platforms for hamstring strength was confirmed by both McCall *et*

*al.* (2015) and the authors of the current study. Reliability was high for both dominant (CV = 4.3% - 4.9%) and non-dominant (CV = 5.4% - 6.3%) limbs. The authors of the current study found force platforms to present acceptable validity for measuring hamstring strength, provided data from the two tests was not used interchangeably. Furthermore, McCall *et al.* (2015) confirmed force platforms were sensitive enough to detect changes in hamstring strength from baseline to post-match tests.

Upon cessation of a soccer-specific treadmill protocol, in two separate investigations, hamstring strength measured by IKD decreased by 16% from pre-exercise values (Rahnama *et al.*, 2003; Small *et al.*, 2010). By assessing post-match strength measures individual recovery kinetics can be assessed and analysed accordingly. Nédélec *et al.* (2014) performed post-match isometric tests using a sphygmomanometer cuff, with both limbs returning to 94% of baseline MVC at 72-hours post-match. Strength measures during this 72-hour period were compared against number of technical and physical actions, with no reference to distances covered in speed zones. To the authors knowledge, no study has yet investigated the relationships between physical match metrics and post-match hamstring recovery.

With the rapid crossover from concentric to eccentric activity, the hamstrings are at larger risk of injury during high speed running and explosive actions such as accelerating and decelerating (Arnason *et al.*, 2008; Askling *et al.*, 2012). To reduce hamstring injury risk, training loads must be balanced with adequate time for recovery and adaptation. If players return to training or match-play too quickly, their risk of injury may increase further (Dupont *et al.*, 2010). Training and match running loads are measured by Global Positioning Systems (GPS) and quantify player movements such as total distance, distances covered in different speed zones and acceleration and deceleration activity (Coutts *et al.*, 2010; Aughey, 2011). By using GPS to monitor training and match running loads, players could be prescribed appropriate individualised training loads to minimise injury risk.

When training/match running loads and recovery are efficiently managed, injury risk is significantly decreased (Dupont *et al.*, 2010). During periods of match congestion (i.e. 2-3 matches per week), the time between successive matches is 2-3 days. Even on a single game week schedule, players are expected to return to training within 48-72 hours post-

match. However, physical performance measures fail to meet pre-match values 48-72 hours post-match (Thorpe & Sunderland, 2012; Russell *et al.*, 2016). It is likely that some players are not afforded sufficient time between games and training to allow complete recovery (Nédélec *et al.*, 2012). It is proposed that quantifying training and match running loads and analysing the succeeding physical responses will aid the decision-making process when planning training to help reduce injury risk. Therefore, the aim of this study was to propose the use of force platforms for isometric hamstring strength testing as a means to assessing hamstring specific recovery in professional soccer.

## **5.2 Methods**

### **5.2.1 Design**

This study was conducted over a 12-month period, covering fixtures from the 2014-2015 and 2015-2016 U21 Premier League seasons. Physical performance tests were performed at +24hours (+24H) and +48hours (+48H) post-match to measure isometric hamstring strength as a recovery marker.

### **5.2.2 Participants**

Match and testing data were only presented for those who completed 90 minutes during match-play, with those involved remaining injury-free throughout the study. As a result, seven outfield professional soccer players from the Under-21 squad of an English Premier League team (age  $18.0 \pm 0.8$  years; height  $181.2\text{cm} \pm 4.6\text{cm}$ ; mass  $77.7\text{kg} \pm 6.9\text{kg}$ ) participated in this study. As an observational study, no attempts to influence team selection were made, hence players completed a different number of matches (mean  $\pm$  SD =  $4.7 \pm 1.7$  games), with 33 observations made in total. Throughout this time, all involved players performed individual strength training programmes on a weekly basis. With testing procedures in place prior to the study commencing, consent was provided by the club's sport science department in agreement with the ethical board of Liverpool John Moores University (ethics number 15/SPS/037).

### **5.2.3 Procedure**

During pre-season of the 2014-2015 U21 Premier League season, participants performed three familiarisation tests using a force platform to measure peak hamstring strength at 90° hip and knee flexion. Baseline measures were obtained in-season during weeks where no game was scheduled. Players were tested pre-training following 2 days off, with multiple baseline tests performed throughout the season to account for changes in strength. During the experimental period, strength tests were performed at +24H and +48H post-match by the same practitioner, with all tests performed at a standardised time (10:00 – 11:00) at the start of the players' post-match recovery (MD+1)/pre-training prep sessions (MD+2). A further test performed at +72H would have been preferred to fall in line with previous research (Nedelec *et al.*, 2014). This would have allowed the practitioners to assess if a 'complete' recovery was achieved. However, the practical restrictions involved of controlling team schedules meant this was not possible. All tests were performed during 1 game week schedules. Players performed each test after a 10-minute standardised warm-up comprising of dynamic stretching of the lower posterior chain and 5-minutes of cycling at 90W, followed by a 5-minute rest period.

*Isometric Hamstring Strength Testing.* Hamstring strength was measured using a portable force platform (PA Sport PS-2141, Pasco, Roseville, USA) with an integrated analogue-to-digital converter using Forcedecks software (Forcedecks, Vald Performance, Queensland, Australia). Data was collected at a sampling frequency of 1000Hz and peak vertical force (N) was extracted. Lower limbs were classified as dominant and non-dominant, with the dominant limb described as the preferred kicking leg (in this study, all participants were right leg dominant).

Both dominant and non-dominant limbs were tested at 90° knee and hip flexion, positioned using a goniometer (SAEHAN Corporation, Masan, South Korea). At 90° hip/knee flexion, the hamstrings are most isolated from the glutes, where glute activation drops to 64% MVC (Worrel *et al.*, 2001; Schache *et al.*, 2011). In the current study, the test was performed supine, with a force platform placed atop an adjustable plinth. This ensured the knee remained at 90° flexion, irrespective of limb length. The calcaneus was placed on the centre of the force platform and the non-working leg extended alongside the plinth. The reliability of this testing protocol in the dominant (ICC = 0.95, CV% = 4.9%)

and non-dominant limbs (ICC = 0.93, CV% = 6.3%) has been confirmed by the authors of this study. The force platform was zeroed, the testing limb weighed, and when instructed, players performed a 3s maximal voluntary contraction (MVC) by driving their heel down into the platform. Players performed 2 reps on a randomly selected limb, with a 30s rest between reps before switching limbs. The same practitioner was present to apply pressure to the contralateral hip to control participant posture, reducing mechanical variation (Coldwells *et al.*, 1994). For standardisation purposes, the test was performed without shoes for all players.

*GPS Analysis – Player Running Loads.* During match-play, player running loads were monitored using a 10Hz GPS accelerometer device (Viper 2 Pod, Statsports, Newry, Co. Down, Northern Ireland). Statsports devices show excellent reliability for total distance and peak speeds, although these were only linear in nature, with the limitation being soccer is a multidirectional sport (Beato *et al.*, 2018). Although peer-reviewed studies have not assessed the reliability and validity of acceleration and deceleration efforts measured by Statsports Viper units, an independent case study (Marathon, 2014) identified this device to present a lower error margin for acceleration-based activities during small sided games compared against other GPS devices. The GPS device was posteriorly positioned on the upper trunk, fitted into a custom designed vest. Units were activated 20 minutes prior to the pre-match warm-up to allow a satellite signal to be attained, in accordance with the manufacturer's guidelines. Players were assigned their own unit which was used for each match to minimise inter-unit variability (Jennings *et al.*, 2010). After each match, data was downloaded via Statsports Viper software, with the following metrics analysed: total distance, high-speed running (HSR) distance (distance covered between  $5.5\text{m}\cdot\text{s}^{-2}$  and  $6.9\text{m}\cdot\text{s}^{-2}$ ), sprint distance (distance  $\geq 7\text{m}\cdot\text{s}^{-2}$ ) and number of accelerations and decelerations. Information regarding data quality was not available, as the units did not provide the number of connected satellites or the quality of satellite connection (horizontal dilution of precision – HDOP). However, GPS velocity traces were assessed following each game to check for errors or 'spikes' in the trace where player velocity may appear excessively high, or for signal dropout where no velocity was recorded. Player's average game loads for these metrics are shown in Table 6.

**Table 6. Average match running loads of 7 professional soccer players during 33 match observations (mean  $\pm$  SD)**

TOTAL DISTANCE (KM)	HIGH-SPEED RUNNING (M)	SPRINT DISTANCE (M)	ACCELERATIONS (NO. OF)	DECELERATIONS (NO. OF)
10.1 $\pm$ 0.8	722 $\pm$ 320	177 $\pm$ 131	201 $\pm$ 26	193 $\pm$ 22

### 5.2.4 Statistical Analysis

Descriptive data is presented as mean  $\pm$  standard deviation. All GPS metrics were rounded to the nearest whole number, with peak force (N) rounded to 1 decimal place. Using SPSS 24.0 (IBM, Armonk, NY, USA), differences in hamstring strength between baseline, +24H and +48H were assessed using a one-way repeated measures ANOVA, with Mauchly's test used where sphericity was assumed. Relationships between match workload and changes in hamstring strength (% difference from baseline) were analysed using Pearson's product-moment correlation ( $r$ ). Alpha was set at 0.05.

## 5.3 Results

### 5.3.1 Changes in Hamstring Strength

Player's individual mean hamstring strength at baseline, +24H and +48H are shown in figures 16-22. Group mean hamstring strength at baseline, +24H and +48H is shown in figure 23. Significant reductions in hamstring strength ( $P \leq 0.05$ ) were identified from baseline to +24H for both the dominant (-13.6%) and non-dominant (-12.5%) limbs. Significant differences remained at +48H, with peak force failing to return to baseline values in both the dominant (-9.7%) and non-dominant (-10.5%) limbs. There was significant difference between dominant and non-dominant limbs at baseline ( $P = 0.009$ ), although peak force at +24H ( $P = 0.186$ ) and +48H ( $P = 0.701$ ) showed no significant difference between dominant and non-dominant limbs.



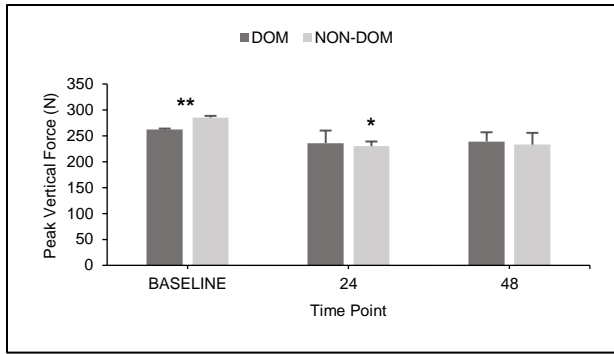


Figure 16. P1 mean ± SD hamstring strength at baseline, +24H & +48H

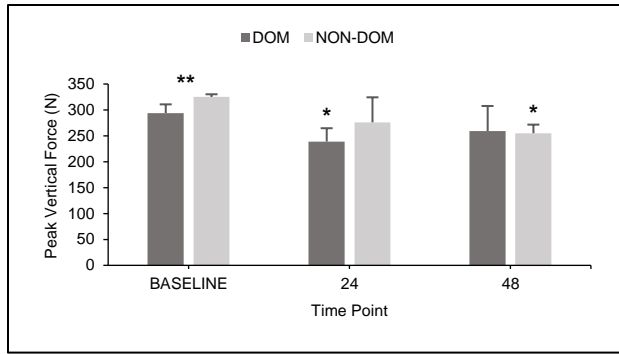


Figure 17. P2 mean ± SD hamstring strength at baseline, +24H & +48H

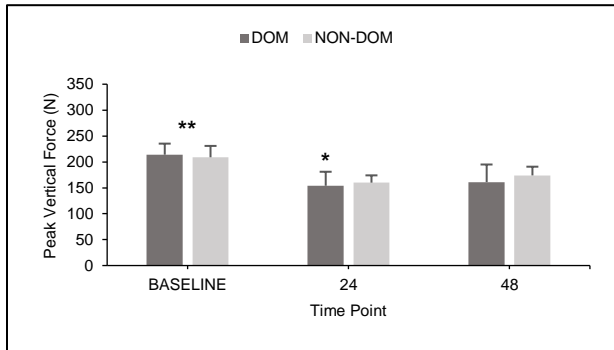


Figure 18. P3 ± mean SD hamstring strength at baseline, +24H & +48H

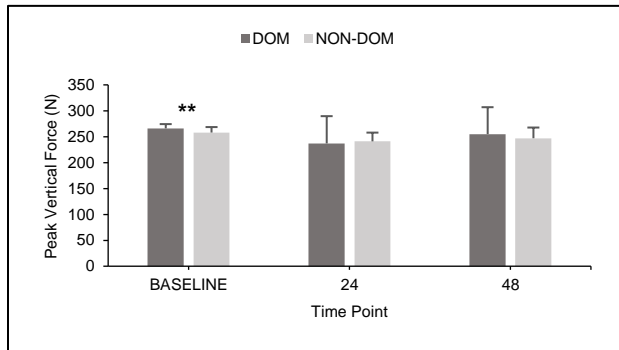


Figure 19. P4 mean ± SD hamstring strength at baseline, +24H & +48H

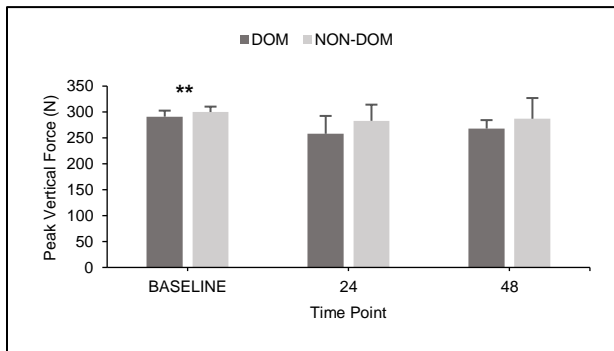


Figure 20. P5 mean ± SD hamstring strength at baseline, +24H & +48H

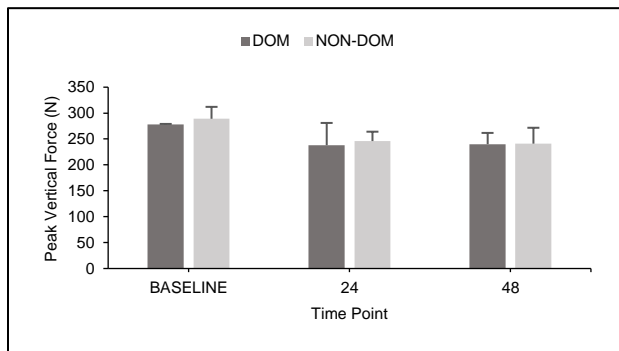


Figure 21. P6 mean ± SD hamstring strength at baseline, +24H & +48H

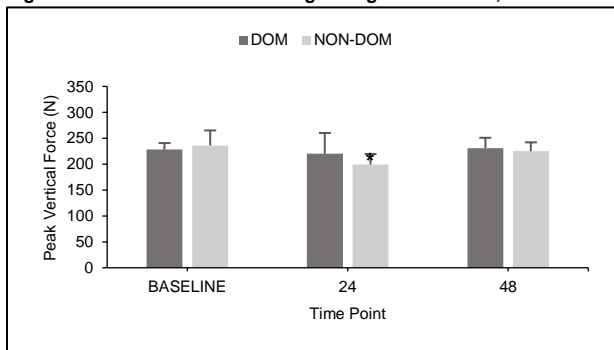
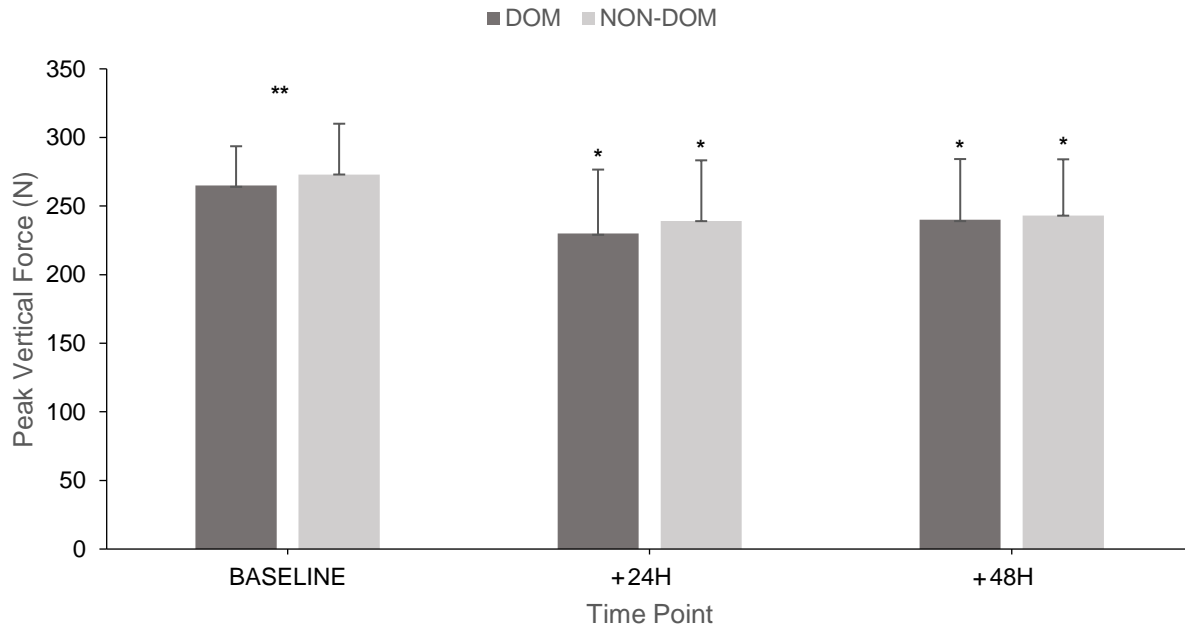


Figure 22. P7 mean ± SD hamstring strength at baseline, +24H & +48H

\* = Statistical significant difference from baseline ( $p < 0.05$ )

\*\* = Statistical significant difference between limbs ( $p < 0.05$ )



\* = Statistical significant difference from baseline ( $p < 0.05$ )

\*\* = Statistical significant difference between limbs ( $p < 0.05$ )

**Figure 23. Group mean  $\pm$  SD of hamstring strength at baseline, +24H and +48H**

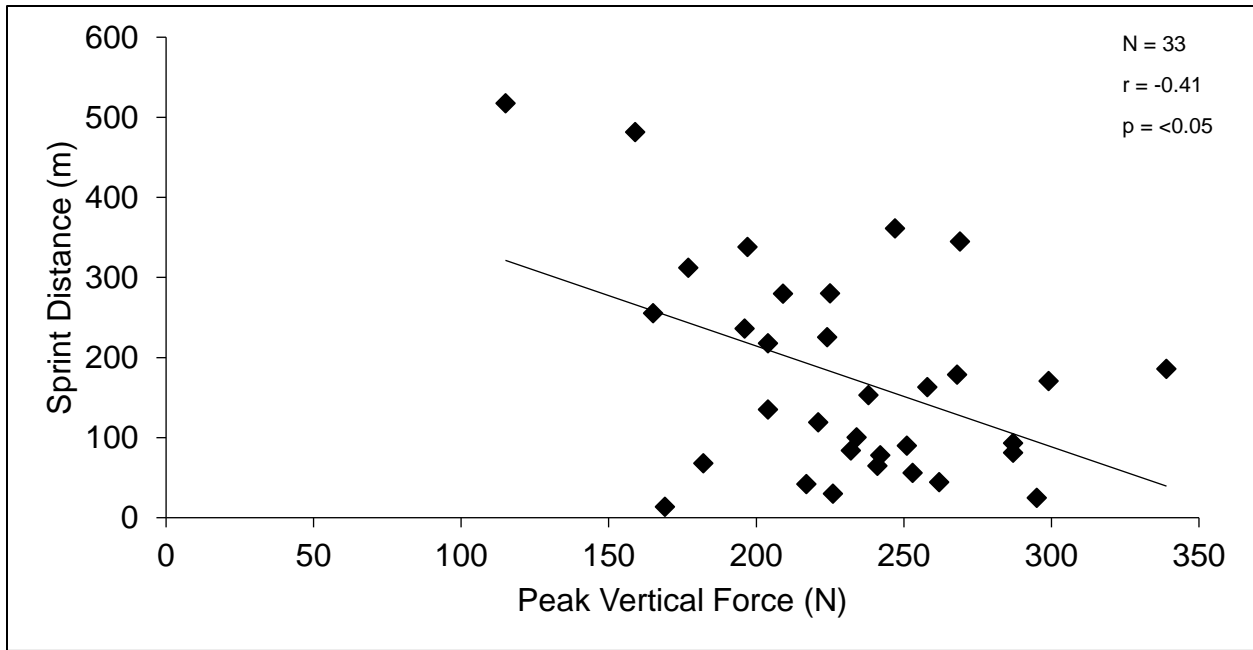
### 5.3.2 Correlations Between Match Running Loads and Changes in Hamstring Strength (%)

Relationships between player workload and percentage (%) changes from baseline hamstring strength (N) are shown in table 7. Increases in sprint distance during match-play significantly reduced ( $p \leq 0.05$ ) hamstring strength from baseline values at +24H ( $r = -0.41$ , CI = -0.66 to -0.08) (figure 24.) and +48H ( $r = -0.39$ , CI = -0.65 to -0.05) (figure 25.) in the dominant limb. Based off Evans (1996) classification, correlations are termed very weak ( $<0.20$ ), weak (0.20 – 0.39), moderate (0.40 – 0.59), strong (0.60 – 0.79) and very strong ( $\geq 0.80$ ) In the current study, correlations ranged from very weak (number of accelerations) to weak (total distance, high-speed running and number of decelerations) at +24H in the dominant limb. At +48H, correlations decreased by a much smaller amount or not at all. For the non-dominant limb, correlations were very weak (high-speed running and sprint distance) or weak (total distance, number of accelerations and number of decelerations) at +24H. At +48H, correlations decreased further for all metrics apart from number of decelerations. Correlations ranged from very weak (number of accelerations)

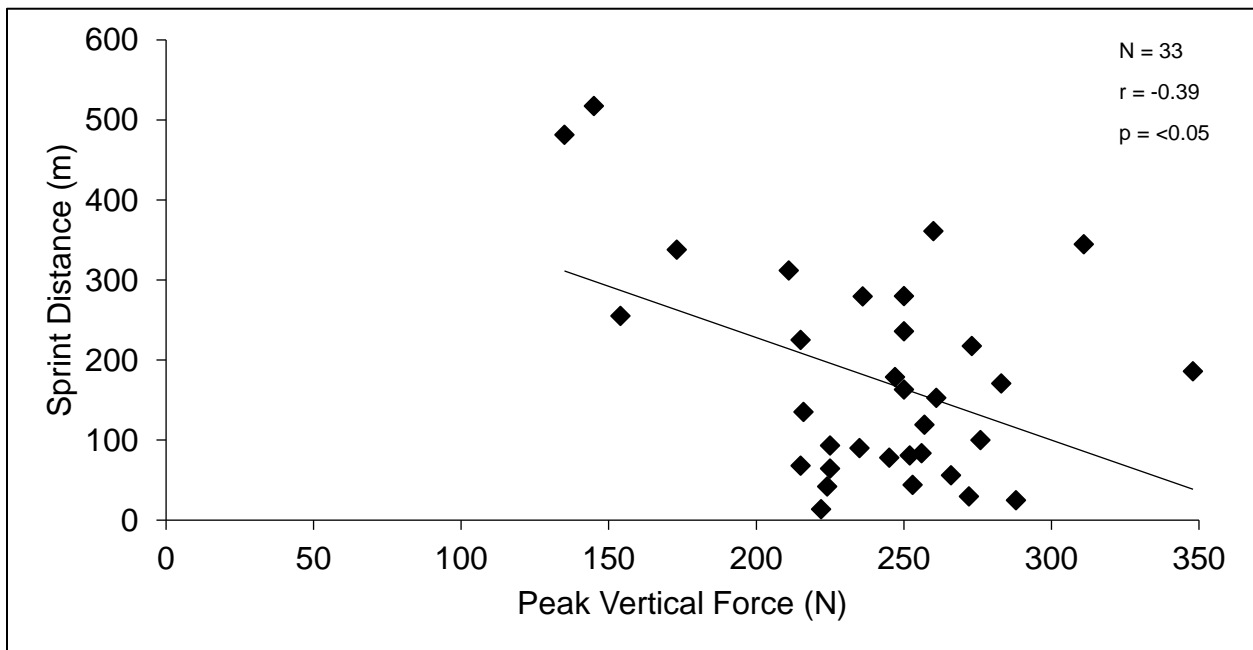
to weak (total distance, high-speed running and number of decelerations) at +24H in the dominant limb. At +48H, correlations decreased by a much smaller amount or not at all.

**Table 7. Pearson’s product-moment correlation (*r*) between % change from baseline in hamstring strength and GPS derived player workload metrics (\*\* = statistically significant at  $p \leq 0.05$ )**

	COMBINED		DOMINANT		NON-DOMINANT	
	+24H	+48H	+24H	+48H	+24H	+48H
<b>TOTAL DISTANCE (KM)</b>	-0.23	-0.13	-0.20	-0.17	-0.26	-0.10
<b>HIGH-SPEED RUNNING (M)</b>	-0.23	-0.14	-0.31	-0.24	-0.13	-0.05
<b>SPRINT DISTANCE (M)</b>	-0.28**	-0.23	-0.41**	-0.39**	-0.13	-0.09
<b>ACCELERATIONS (NO. OF)</b>	-0.21	-0.15	-0.21	-0.29	-0.20	-0.01
<b>DECELERATIONS (NO. OF)</b>	-0.03	-0.06	-0.03	-0.06	0.20	0.26



**Figure 24. Relationship between sprint distance and % change in hamstring strength at +24H for 7 professional soccer players across 33 match observations**



**Figure 25. Relationship between sprint distance and % change in hamstring strength at +48H for 7 professional soccer players across 33 match observations**

## 5.4 Discussion

The aims of the current study were to assess hamstring recovery during the +48H post-match period in professional soccer and to determine the relationship between match running loads and changes in hamstring strength. This study found hamstring strength fail to reach baseline measures at +24H and +48H post-match. This study also identified correlations between increased sprint distance and prolonged reductions in hamstring strength in the dominant limb. No significant correlations were identified between total distance, sprint distance, high-speed running, accelerations or decelerations and decreases in hamstring strength in the non-dominant limb during the +48H post-match period. The hypothesis of sprint distance, high-speed running and decelerations effecting post-match hamstring strength was rejected.

The findings from the current study are similar from those reported by Nédélec *et al.* (2014), who identified professional soccer players of a similar age to still present impaired hamstring strength at +72H in both dominant and non-dominant limbs. After +48H, neither limb had recovered to baseline values, with reductions of 6.7% (vs. 9.7% in the current study) in the dominant limb and 8.8% (vs. 10.5% in the current study) in the non-dominant limb observed. Further research from French professional soccer identified reduced hamstring strength from baseline at 5-15mins post-match (McCall *et al.*, 2015). Similar findings have been identified in Portuguese League 2 & 3 soccer players (Magalhaes *et al.*, 2010), with further analysis indicating that hamstring strength at +24H, +48H and +72H had not returned to baseline measures. The baseline measures in these studies were performed pre-match, compared to the current study, with baseline measures performed at various points throughout the season on single game week schedules. Although pre-match baseline measures may provide a truer representation of the players current state, this was not possible in the current study due to coach buy-in and pre-match scheduling. Furthermore, varying measuring tools between studies makes comparisons difficult to ascertain. Many studies use a sphygmomanometer cuff to measure peak isometric force, although these are not sensitive enough to measure bilateral strength asymmetries when compared against an IKD (Mondin *et al.*, 2018). Portable force platforms have been proposed as an alternative tool, demonstrating high reliability and

the ability to detect bilateral strength asymmetries and changes in hamstring strength following soccer match-play (McCall *et al.*, 2015).

High-speed running and sprint distances were hypothesised to correlate with reductions in hamstring strength, given the eccentric forces involved. When sprinting, the hamstrings are stretched to greater lengths at high velocity to decelerate the body, placing great strain on the muscles and increasing muscle damage (Thompson, Nicholas & Williams, 1999; Byrne & Eston, 2002). Similar correlations between sprinting and post-match testing in U21 Premier League soccer players have been identified, where countermovement jump (CMJ) peak power failed to reach baseline values at +24H and +48H (Russell *et al.*, 2016). At +24H, significant correlations were found between a reduction in peak power and increases in high-speed running, sprint distance and number of accelerations. However, at +48H, there were no significant differences between any GPS metric and reductions in CMJ peak power. In soccer, at the end of a sprint, there is usually a rapid deceleration to either stop or change direction. This braking force places even greater strain on the hamstrings as they work eccentrically to quickly slow down, a force which may incur further muscle damage (Howatson & Milak, 2009). In the current study, total number of decelerations did not correlate with changes in hamstring strength. However, the magnitude of these decelerations was not recorded. It could be argued that high magnitude deceleration following a sprint may effect changes in post-match hamstring strength, with a rapid reduction in velocity performed with limited time and space required (Harper & Kiely, 2018). The activity profiles of national league soccer players identified midfielders to perform the greatest distances at high speed ( $\geq 19.7 \text{ km} \cdot \text{h}^{-1}$ ) and also the greatest number of high-intensity decelerations ( $\geq 4.0 \text{ ms}^{-2}$ ) (Wehbe *et al.*, 2014). These rapid decelerations require high eccentric forces, resulting in fatigue and increased mechanical load exerted on the player (Harper & Kiely, 2018). Compared against other match play metrics, high-intensity decelerations produce the highest magnitude of mechanical load per metre by up to 65% (Dalen *et al.*, 2016).

Reductions in hamstring strength were correlated against the number of match actions performed in professional soccer by Nédélec *et al.* (2014). However, limitations of this work are evident, with match actions analysed through time-motion analysis, which for

running loads, is not gold standard. Observed match actions included number of sprints and high intensity runs, although the study provides no information on the intensity/distances of these runs. Players performed  $25.1 \pm 9.6$  high intensity runs. However, these 25 runs could have been 40m or 15m each, with significant differences expected if this was considered. Had GPS been used, distances in these speed zones could have been identified which would have provided greater detail into the relationship between running loads and hamstring strength. This was an observational study, with no efforts to affect team selection made and no alterations made to training schedules to accommodate testing. For future study, time taken for hamstring strength to return to baseline values could be assessed, as this is likely to take longer than the +48H observed in the current study. This would have allowed greater comparison to other studies, with many observing over +72H post-exercise. Additionally, although assessment of muscular force is the most reliable marker of muscle damage, this study could have been aided by assessing perceived delayed onset of muscle soreness (DOMS), as this typically peaks at +24H - +48H (Damas *et al.*, 2016), to determine players' subjective assessments of post-match recovery.

## **5.5 Conclusion**

This study found hamstring strength fail to recover to baseline values during the +48H post-match period. During a one game per week schedule, players may be provided with enough time for recovery before returning to training (in the form of day/s off or present at the training ground but not involved in pitch-based training). On a one game week schedule, selected players could be afforded 72 hours recovery and still have 3 days of training for and tactical work. If this is not possible and all players are required to train +72H post-match, scheduling the training session for later in the day may suit both the players, in allowing them extra recovery time, and the manager, by still having all their players available to train. However, during congested match schedules of 2-3 games in a week, it is highly unlikely there is sufficient time for complete recovery between games. During this period, players will typically spend the following a game engaging in recovery modalities to try and speed up the recovery process. The focus during this period will be adopting good sleep and nutritional strategies. Additional recovery modalities may be

utilised to aid the recovery process (Nédélec *et al.*, 2013), each with varying results. Modalities may include cold-water immersion (Pooley *et al.*, 2019; Vromans *et al.*, 2019), whole body cryotherapy (Rose *et al.*, 2017; Russell *et al.*, 2017), contrast water therapy (Bieuzen *et al.*, 2013), massage (Zainuddin *et al.*, 2005), active recovery (Sairyo *et al.*, 2003), compression (Brown *et al.*, 2017) or foam rolling (Rey *et al.*, 2019).

This study also found increases in sprint distance to significantly reduce hamstring strength in the dominant limb during the +48H post-match period. After 48-hours, hamstring strength still failed to reach baseline values. However, what was surprising was that this correlation was only observed in one limb, not both, given both dominant and non-dominant limbs are identified to fatigue at similar rates, with no alterations in running biomechanics observed during fatigued conditions (Brown *et al.*, 2014). Current findings suggest it is key to consider when is best for a player to return to training following a match, and when they do, what that training programme will consist of.



# **CHAPTER 6**

# **SYNTHESIS**

## 6.1 Synthesis

This chapter summarises the results from studies 1 and 2 and discusses the practical applications of these findings. The aims of these findings were to help inform the practices of practitioners and coaches. Influencing decision making processes may result in the efficient management of player running loads and recovery based on post-match strength testing in order to reduce injury risk.

Force platforms demonstrated high reliability when measuring peak hamstring force in both dominant and non-dominant limbs. The force platform test was performed in study 2 on players in a non-fatigued state for baseline measures. Additionally, it was also performed in a fatigued state at +24H and +48H. However, force platform reliability was only assessed when participants were in a non-fatigued state. When implementing a fatigue monitoring tool, the value of the test is identifying the change in values from non-fatigued to fatigued states, hence most tests will be performed under fatigue. It would be beneficial to know how reliable the test is under both fatigued and non-fatigued conditions. Other physical performance tests have demonstrated reliability in both non-fatigued (ICC = 0.98) and fatigued following 80% 1RM states (ICC = 0.91) (Augustsson *et al.*, 2006).

When measured against IKD, force platforms consistently measured greater values than IKD. Although IKD is the gold standard measure for hamstring strength, its time cost and lack of portability make it unpractical for elite team sport environments. Alternatives to IKD were proposed before force platforms were found to be reliable for isometric hamstring testing by McCall *et al.* (2015). Handheld dynamometers (HHD) and sphygmomanometer cuffs (Landes *et al.*, 2010; Schache *et al.*, 2011) have both been proposed. Handheld dynamometry reliability is dependent on tester strength and is less reliable than IKD (Toonstra & Mattacola, 2013). Sphygmomanometers demonstrate better reliability than HHD (Souza *et al.*, 2014), but lack the ability of force platforms and their accompanying software to automatically detect inter-limb asymmetries and forces at different time points. Therefore, in professional soccer, force platforms should be the primary measuring tool for hamstring strength testing, allowing for a quick and simple assessment of hamstring strength in isometric conditions, thereby incurring minimal to no muscle damage in the process, which is key if testing post-match.

Despite the varied agreement between IKD and FP measures, force platforms are valid tools for isometric testing. Of course, testing in isometric conditions may appear limited as hamstring injuries typically occur during eccentric actions when sprinting at high velocity. Being aware of this, the club adopts 2 hamstring strength tests; an isometric test at 90° knee flexion using a force platform, and an eccentric test using a novel knee flexor strength testing device (Opar *et al.*, 2013). For the current study and the clubs testing protocol, the test was performed at 90°. Despite recent findings by Read's group, the authors are happy with the selected test position. Testing at 90° is more reliable with regards to peak force test-retest variability (McCall *et al.*, 2015) and demonstrated slightly greater reliability in EMG activity of individual hamstring muscles (Read *et al.*, 2019). Furthermore, anecdotally, the protocol appears easier to perform for both the player and practitioner at 90°. For the practitioner, positioning players at 90° knee and hip flexion is easier to execute and importantly, maintain with pressure on the hips. For the player, when testing at 30°, they appear to apply pressure into the force platform by trying to lift the glutes more as opposed to driving the heel into the platform via isometric knee flexion. Hence, it is more difficult for the practitioner to maintain player posture and reduce the mechanical variation in the test.

Both isometric and eccentric tests have been implemented into the clubs testing battery. The isometric test allows for more frequent testing, whilst the eccentric test provides greater specificity to sprinting. Both tests are performed during pre-season, which allows for baseline measures so that they can be compared to tests performed later in the season. During pre-season, the isometric test is performed prior to the eccentric test, given that the eccentric test is more likely to incur muscle damage, which could reduce peak force on the isometric test if performed beforehand. Strong players are expected to reach >300N during the isometric test and >350N on the eccentric test.

Both tests are also used during hamstring injury rehabilitation. The isometric test is predominantly used during the early stages of rehab. The % of peak force achieved vs. baseline and bilateral peak force asymmetry are both used to guide exercise selection, where asymmetries  $\leq 10\%$  allow progression from isometric to eccentric exercises. It is typical of peak force to return to baseline values relatively quickly, depending on the

severity of the injury. Rate of force development across the 1<sup>st</sup> 200ms of contraction is assessed and tracked and used as guidance for when return to running is permitted, dependent on injury severity. Only when the player has reached baseline values of peak force and rate of development on an isometric test, progressed through isometric and eccentric exercises with sufficient load and began a return to running programme, is the eccentric test then implemented (Taberner & Cohen 2018). This test allows the clubs practitioners to guide max speed % targets during outdoor rehabilitation to the point where the player is able to repeatedly perform high-speed runs and sprint at maximum velocity. Given that both isometric and eccentric hamstring strength tests are utilised by the club, only the isometric test was utilised in these studies as a method to assess recovery. As noted by Carling *et al.* (2018) it is understood that both coach buy-in and player compliance can indeed be problematic when measuring post-match fatigue. In reply Lewis & O'Driscoll (2019) note a need to educate coaches about what is being done and why. From personal experiences in professional soccer, coaches typically want to know how their players feel in the post-match period, ahead of returning to training. Taking coach buy-in and player compliance into account, when deciding on a fatigue monitoring tool/test, the following factors must be considered: 1) Efficiency – Is the test fast and easy to perform? In the 'real world', practitioners are likely to get 30 minutes to test a whole squad and the potential logistical issues of testing every player during this time pre-training/recovery should be minimised; 2) Simplicity – The test is efficient to perform, but how quickly can testing results be relayed to the appropriate coaching/medical/sports science staff and can these results be relayed in a simplistic manner. Realistically, are coaches going to want to know the rate of force development across time points or what a player's landing forces were, or will they just want to know has their player recovered or not; and 3) Exert no additional load. Many fatigue monitoring tests require maximal efforts. These tests provide valuable information regarding fatigue status, although if they are exhaustive or incur further fatigue, then they are unsuitable for professional sports (Thorpe *et al.*, 2017). Both the isometric and eccentric tests performed at the football club are suitable for points 1 and 2. Both tests allow a player to be tested within 60s, ensuring a full squad can be tested in a 30min pre-training window. Additionally, the results derived from both tests can be easily interpreted to ensure they are relayed to the relevant staff

in a simplistic manner. Point 3 is where the isometric is chosen ahead an eccentric test, where an isometric contraction is neither exhaustive or causes any further muscle damage, unlike a maximal eccentric test which is likely to exaggerate muscle damage and muscle soreness (Warren *et al.*, 1999).

At the time of testing, the isometric test was used to inform player training availability at 1<sup>st</sup> team level. On a 1 game per week schedule, the 1<sup>st</sup> team were off at +24H post-match. At +48H post-match, the team returned to training, but those involved in match-play participated in a recovery session. The following day (+72H), all players were to return to full training. To aid the decision-making process of who trained and what training comprised of, both on team and individual bases, isometric hamstring strength tests were performed on this day as the players arrived at the training ground. Sports science staff reported to coaching staff on players who may be at risk of injury or may require a reduced training load based on reductions in peak force from baseline or bilateral strength asymmetries  $\geq 10\%$ . This 10% cut off was partially based off pilot work from the football club involved in the current study and 1 other English Premier League football club. In 31 players tested at 90°, 8 had previously suffered a hamstring injury. Mean hamstring asymmetry in the injured group was 13.3% vs. 6.9% in the non-injured group. This guideline was also supported by Schache *et al.* (2011), where bilateral asymmetry remained  $< 1.2\%$  over 4 weeks, before increasing to 10.9% and returning to training, where injury then occurred. It is important to note that this 10% asymmetry was a guide for this football club. There is no one-size-fits-all cut-off, with asymmetry guides specific to each club, although others have also been identified to use this as a guide (Buckthorpe *et al.*, 2019). Given that there is no one-size-fits-all, on reflection, a 10% asymmetry cut-off for every player may not be substantial or practical. Meaningful changes for individuals' peak force asymmetry could have been determined by calculating smallest worthwhile change. This would have allowed for greater confidence in results demonstrating a real change in performance as opposed to typical test error/variation. However, if SWC's were adopted, they would have to be greater than the CV% observed during the test to be of use, otherwise any observed change is likely to be a result of error. In this case, changes greater than the observed CV% can be used as a sign of meaningful change.

As SWC's were not calculated during this period, when interpreting testing results ahead of reporting back to coaching staff, it was important to acknowledge the error observed in the test and how this could affect variation in testing results. In an attempt to limit testing variation from external factors, tests were performed in the 1<sup>st</sup> team changing room immediately as players arrived at the training ground, prior to having breakfast and consuming caffeine. Additionally, although signal:noise ratios were not calculated for tests, force-time curves were assessed to check the starting point of each MVC was zeroed to 0N and the curve itself was smooth with no drop-offs in force output during each rep.

This information collected during these post-match tests could suggest an extended recovery for players after match-play. The extent to which this information is used will depend on the coach and their training principles. At the time of testing, the club's 1<sup>st</sup> team manager was more receptive to this information. Upon provision of this information, the manager and head of performance would decide on training interventions as they saw fit, with that decision based mainly off the player as individual, taking onto account the following:

- The importance of the player – is the player regularly in the starting eleven?
- If the player is not a regular starter, are they 'fit enough'? Can they afford to miss training, or do they need extra training?
- The players previous injury history – does the player have a history of previous hamstring injuries. Does the player training mean unnecessary risks are taken?
- The age of the player – would risks be taken on a senior player when a young player could fill that position for a training session?

Throughout this period at the club, training interventions were more regularly put in place for senior players in and around the starting eleven. These players had also suffered several minor hamstrings during their careers, which may have influenced the decision-making process. Unless they had a history of hamstring injuries, younger players were often not afforded an extended recovery. Although the reason to this was unknown, perhaps the coach believed younger players required the training sessions to improve their physical and technical qualities.

It is recognised that extended recoveries or reduced training loads are not always possible due to fixture congestion, squad availability and the coach's decisions on training schedules. During periods of fixture congestion, there may only be 48H-72H between games. Although there will be an emphasis on recovery between games, there comes a point when the coach requires those players to train to work on tactics ahead of the next game, particularly if they are likely to be involved in the starting 11. Likewise, with squad availability, there are always injuries and suspensions to deal with in professional soccer, where certain players may be required to train ahead of being selected as there are no other players available to replace them in the team, regardless of their physical condition. Finally, the coach makes the final call. Practitioners can try to offer their opinions, but if those opinions are coming off the back of a defeat or a poor individual or team performance, it is possible players will train regardless of the provided information. It is also important to note that for some players, a bilateral asymmetry  $\geq 10\%$  may be normative. However, the way in which the practitioner interprets and presents this information to the coaching staff is key to try and inform their decision-making processes if it is in the best of interests of their planning and the players welfare.

Despite the numerous methods of testing available at the club's disposal, the isometric test is the preferred option as it allows for more frequent monitoring due to the lack of muscle damage caused in performing the test, particularly when game schedules vary so differently on a weekly basis. Even on a one game week schedule, the U23 squad are exposed to sufficient eccentric stimuli via sprint distances achieved in the game and through the 4/5 potential training sessions leading into that game. Additional eccentric loading is attained via both knee flexor (sliding leg curl/Nordic) and hip extensor (Romanian deadlift) focused eccentric hamstring exercises during lower body strength sessions which are performed once per week. When the U23 squad are required to play 2/3 games in one week, the eccentric load experienced by players comes solely from sprinting in games. Sprint loads in training are reduced to help account for the rise in game-derived sprint loads, whilst any potential lower body strength work focuses on isometric as opposed to eccentric loading. Eccentric testing in-season can be difficult if it is only for testing purposes, unless in a rehabilitation setting. Testing procedures must fit around training methodologies, and as a result, training and match running loads. If tests

potentially leave players suffering from DOMS, coach and player buy-in is likely to be poor. If eccentric tests were performed post-match, it is possible muscle damage could be exaggerated through sarcomere disruption from forced muscle lengthening (Clarkson *et al.*, 1992).

The results from this work demonstrate the reductions in hamstring strength from baseline and their associations with sprint distance during match-play. However, it is evident not all players respond the same to a given stimulus. Given the positional differences in running loads in professional soccer, perhaps post-match responses will differ between positions too. Wide midfielders and fullbacks cover greater sprint distances in games compared to other positions. It would be expected that players in these positions may be more accustomed to high sprint loads. Increases in sprint loads may therefore cause greater reductions in hamstring strength in players not accustomed to these loads (central defenders, central midfielders & attackers).

## **6.2 Limitations and Challenges**

The limitations and challenges of the thesis relate mainly to the observational nature of chapter 4. In this study, schedules were not able to be controlled, where testing dates could often be weeks or months apart. Scheduling during the post-match period was often result dependent, or dependent on the 1<sup>st</sup> team schedule. This meant players were often off on +24H and +48H, or only in for one of these days. Other studies have assessed recovery status over 72 hours post-match, with strength/performance values still not returning to baseline. In an ideal situation, this study would have assessed players over 72 hours for greater comparison to other studies and to identify if players did fully recover by this point. However, it would not have been feasible in the current study to assess recovery over this time frame, given the challenges already present when testing over 48 hours.

## **6.3 Recommendations for Future Research**

In the process of summarising the findings of this thesis, several further research questions were identified, with recommendations for chapters 4 and 5 outlined below.

### **Chapter 4**



1 - It is recommended that for future study, sample size should be increased. With the limited sample size, limits of agreement and 95% CI's were wide, suggesting a potential sample error. By increasing sample size, this error would be reduced by narrowing of the 95% CI's (Giavarina, 2015). Charter (1999) suggested 400 participants are required for reliability studies and potentially more for validity. Whilst this typically relates to clinical based research and may appear unrealistic for elite sports environments, advice can be taken from this with regards to maximising the number of participants for reliability and validity research. Regardless of the monitoring tool, it is recommended elite sports teams carry out their own due diligence and perform in-house reliability and validity work before committing to purchasing and implementing.

2 - It is recommended that when used in the elite sports, then values derived from force platforms should not be interchanged from values from other tools (i.e. IKD, handheld dynamometers, sphygmomanometer cuffs). The results from the current thesis show a systematic bias between force platforms and IKD, where force platforms overestimate values identified by IKD. The mean bias shown between devices is shown in BA plots. If data has to be compared then these bias values can be used as a guide when trying to interpret data, however this is not advised.

## **Chapter 5**

1 - It is recommended that professional soccer clubs conduct their own research to assess responses to match play. Not only will responses be individualised by player, but trends may also be identified for different clubs based on their training and match running loads and as a result of the manager/coach's philosophy.

2 - It is recommended that future research explores further higher-intensity external load metrics, particularly acceleration and deceleration efforts performed at different velocities, as opposed to the total number of efforts. Given the constant improvements in GPS devices since this study was carried out, the reliability of these high intensity metrics will also have improved.

3 - It is recommended that future research utilises individualised speed thresholds as opposed the absolute speed thresholds, particularly if assessing younger athletes. The

athletes used in this study had maximum speeds which easily exceeded the absolute sprint speed threshold of  $7\text{m}\cdot\text{s}^{-1}$ . Younger athletes' maximum speeds may not reach this value.

4 - It is recommended further research performs post-match testing over an extended period (72 hours +). The current study only performed testing up until +48H, at which point players not recover to baseline values.

5 - It is recommended further research measures changes in rate of force development as a recovery marker given its relationship with sprint performance (Slawinski *et al.*, 2010).

6 - It is recommended for longitudinal work to be performed to assess relationships between isometric hamstring strength and hamstring injury risk.

**CHAPTER 7**  
**CONCLUSION**

## **7.1 Conclusion**

These studies identified force platforms to be reliable and demonstrate acceptable criterion validity when measuring isometric hamstring strength. Findings also demonstrated reductions from baseline in hamstring strength across a +48H post-match period, of which sprint distance during soccer match-play was associated. Professional soccer is an intense game and during periods of match congestion, players are often unable to completely recover between games. This test allows for a practical assessment of post-match strength to quantify the rate of hamstring specific recovery. Previously, this may have been done via IKD. However, IKD is unpractical for elite team sports due to its time cost and lack of portability. Given the time demands of professional soccer, contact time with players is extremely limited. A player's time at the training ground extends much further than training in the modern game, incorporating; breakfast, pre-training activation work, physiotherapy/masseur treatments both pre-and post-training, gym strength sessions, lunch, media duties and player/coach meetings. Therefore, testing procedures which practitioners may want to implement, such as this isometric hamstring strength test, must be quick and easy to perform whilst also demonstrating good reliability and validity.

## 7.2 Practical Applications

# FORCE PLATFORMS FOR ISOMETRIC HAMSTRING TESTING PRACTICAL APPLICATIONS

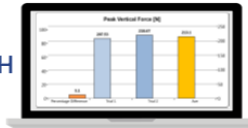
JASON O'KEEFE

1

### PLAYER FATIGUE MONITORING

- MONITOR PLAYER FATIGUE DURING POST-MATCH PERIOD

- ASSESS THE CHANGE IN STRENGTH FROM BASELINE/PRE-MATCH VALUES



- ASSESS THE CHANGE IN ASYMMETRY FROM BASELINE/PRE-MATCH VALUES - IS IT MUCH HIGHER THAN THE PLAYER'S NORMAL VALUES?

- ADAPTABILITY - IF OFF ON +24H, TEST ON +48/72H (WHEN WILL THE TEAM NEXT TRAIN)

- COMMUNICATION TO RELEVANT STAFF IS KEY - MAKE IT SIMPLE!



2

### STRENGTH/POWER PROFILING

- HAMSTRING STRENGTH A KEY RISK FACTOR FOR HAMSTRING INJURY

- DURING HSR, BELIEVED TO BE AN ISOMETRIC COMPONENT (VAN HOOREN & BOSCH, 2018)

- ISOMETRIC STRENGTH MUST BE INCREASED (+ TENDON TENSILE STRENGTH) - TRACK STRENGTH BY TESTING REGULARLY

- POWER ASSESSED THROUGH RATE OF FORCE DEVELOPMENT (RFD)

- RFD LINKED TO SPRINT PERFORMANCE (SLAWINSKI *ET AL.*, 2010)

3

### REHABILITATION/RETURN TO PLAY CRITERIA/PROGRESSION

- USED DURING EARLY STAGE REHABILITATION (TABERNER & COHEN, 2018) AS A METHOD FOR ASSESSING STRENGTH WHEN ECCENTRIC STRENGTH MEASURES ARE NOT SUITABLE AT THIS STAGE (THESE CAN BE INTRODUCED LATER ON DURING REHABILITATION)

- ISOMETRIC STRENGTH ASYMMETRY <10% ALLOWED FOR PROGRESSION OF INDOOR S&C - INTRODUCTION OF PLYOMETRIC WORK TO TARGET FAST STRETCH SHORTENING CYCLE (SSC) ACTIVITIES TO PREPARE FOR OUTDOOR CONDITIONING (<250ms)

- WITH INCREASES IN RELATIVE (BASED OFF % OF MATCH RUNNING LOAD) HSR (DISTANCE >5.5m.s<sup>-2</sup>) LOADS FOLLOWING PROGRESSIVE EXPOSURE, RFD <100ms ASYMMETRY <10% - RELATES TO RUNNING AT HIGHER VELOCITIES, AS SPRINTING IS A FAST SSC ACTIVITY LASTING APPROX 80-90ms

- PROGRESSIVE INCREASE IN STRENGTH AT PEAK FORCE & RFD AT <100ms DRIVE A REDUCTION IN INTERLIMB ASYMMETRY IN BOTH VARIABLES



### SUMMARY/RECOMMENDATIONS



WHEN REPORTING INFORMATION TO COACHES AND/OR PLAYERS, IT IS IMPORTANT TO CONSIDER WHAT ROLE POTENTIAL ERROR MAY PLAY IN RESULTS. THIS THESIS HAS SHOWN FORCE PLATFORMS TO BE RELIABLE, BUT PRACTITIONERS SHOULD ALWAYS UNDERSTAKE THEIR OWN RELIABILITY WORK. DATA FROM FORCE PLATFORMS SHOULD NOT BE INTERCHANGED WITH THAT FROM OTHER TOOLS/DEVICES.

Figure 26. Practical applications of isometric hamstring strength test

# **CHAPTER 8**

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