THE EFFECT OF FULL RANGE NORDIC HAMSTRING CURLS DURING PRE-ACTIVATION WARM-UP SESSIONS ON HAMSTRING ECCENTRIC STRENGTH, NEURAL ACTIVATION AND ATHLETIC PERFORMANCE IN ENGLISH ACADEMY SOCCER

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1.0 Abstract

Background: It has been widely reported in the scientific literature that hamstring injuries are an issue in professional soccer. These injuries generally occur at long muscle lengths and joint angles similar to those observed during sprinting. Factors affecting the incidence of hamstring injuries are numerous but one highly researched modifiable factor is eccentric hamstring strength. The Nordic Hamstring Exercise (NHE) is a commonly researched and implemented exercise to improve eccentric hamstring strength because of its ease to administer using no equipment. NHE programmes have been shown to be effective at improving strength and reducing hamstring injuries but commonly have high workloads which produce high levels of muscle soreness, resulting in low compliance and thus are not practical in professional soccer.

Aims: The aim of the study was to assess the assisted NHE when used as part of a pre-activation warm up on hamstring muscle strength and neuromuscular activation, and in turn, the effect on soccer-specific performance. The theory behind the use of the assisted NHE was that anecdotally the full range of movement of the NHE is not commonly completed (i.e., chest to the floor). Thus, the traditional NHE does not train the hamstring muscles at long lengths specific to those in sprinting.

Method: Sixteen full time academy footballers (aged 17 ± 2 years, height 183 ± 7 cm, mass 72.3 ± 9.0 kg) undertook a crossover design study in which firstly the players completed a six-week control period during which the players undertook a soccer-specific training programme. Testing was undertaken before and after the control period to establish any changes in eccentric strength, muscle contractile properties, and sprint and jump performance. Players subsequently undertook a six-week intervention period where players continued to take part in a soccer-specific training programme with the addition of the assisted NHE during the pre-activation warm up. The testing battery was repeated pre- and post-intervention to establish any changes due to the intervention.

Results and conclusions: A significant change was observed from the intervention in eccentric strength in the right limb but not in the left limb (+34N, $p = 0.034$; ES: 0.66 & +15N, $p = 0.471$). These changes were smaller in magnitude than previously seen in the literature, likely due to differences in volume. Muscle contractile properties showed no significant changes; however, significant changes were observed in 10m sprint (-0.02 secs, $p=0.005$; ES: -0.16), 30m sprint (-0.09 secs, $p \leq 0.001$; ES: -0.61), SJ (+3.5cm, $p=0.008$; ES: -0.12) and CMJ performance (+3.3cm, $p=0.006$; ES: 0.00) after the intervention. Therefore, the assisted NHE intervention may not have been provided enough stimulation to promote similar changes hamstring muscle contractile and strength improvements in both limbs. However, there may have been more significant changes that occurred at longer muscle lengths, in turn changing the tension length relationship of the hamstring muscles and thus resulting in the significant improvements in sprint and jump performance.

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Dedications and Acknowledgements

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List of abbreviations

NHE – Nordic hamstring exercise

DOMS – Delayed onset of muscle soreness

PAP – Post activation potentiation

FIFA - Fédération Internationale de Football Association

sEMG – Surface electromyography

fMRI - Functional magnetic resonance imaging

EMG – Electromyography

N.m – Newton meters

N – Newtons

CMJ – Counter movement jump

SJ – Squat jump

COD – Change of direction

AKE – Active knee extension

TMG – Tensiomyography

Td – Delay time

Tc – Contraction time

Ts – Sustain time

Tr – Relaxation time

Dm – Maximal displacement

Vc – Contraction velocity

ICC - Intraclass correlation coefficient

GPS – Global positioning system

Hz – Hertz

2.0 Literature Review

2.1 Introduction

Soccer is a high intensity intermittent team sport consisting of low intensity periods of walking and jogging and frequent high intensity actions including sprinting, jumping, changing direction, accelerating and decelerating. In match play, elite male soccer players can cover 9000-12000 meters including approximately 7-61 sprints, 52-100 accelerations, 300 changes of direction and 10-15 jumps (Taylor, Wright, Dischiavi, Townsend, & Marmon, 2017). Over recent years it has been reported in the English Premier League that high intensity actions such as high speed running have increased by as much as 37% with the number of sprints increasing by 107% and sprint distance increasing by 70% (Bradley et al., 2016).

Injuries are commonplace in professional soccer, with eight injuries per 1000 hours of total exposure (matches and training). Match injury incidence is 10 times higher than training incidence with 3.7 injuries per 100 hours of training and 36 injuries per 1000 match hours (López-Valenciano et al., 2019). Unsurprisingly, due to fatigue, injury rates have been shown to increase towards the end of each half (López-Valenciano et al., 2019). On average, a professional football player suffers two injuries per season meaning that an average squad of 25 players suffers fifty injuries per season (Ekstrand, Hagglund, & Walden, 2011; López-Valenciano et al., 2019). Youth academy soccer players are still at a high risk of injury, although they are less at risk than their adult counterparts. It has been estimated that academy players are injured for 6% of their development time, thus missing 21.9 days of training 0.4 times per season on average (Price, Hawkins, Hulse, & Hodson, 2004).

A third of all time lost due to injury is because of muscle injuries (Ekstrand, Walden, & Hagglund, 2016). Posterior thigh (hamstring) injuries are the most frequent injury in soccer (López-Valenciano et al., 2019) and are classified in grades from 1-4 (grade 1 being small muscle tears and grade 4 being full ruptures; (Pollock, James, Lee, & Chakraverty, 2014). Hamstring strains account for 12% of all injuries, with an average of five hamstring strains per club per season, thus hamstring injuries in English soccer clubs across two seasons accounted for 13116 days of training missed and 2029 matches (Woods et al., 2004). Time missed due a hamstring injury can be up to 395 days in extreme cases but the average hamstring injury equates to an average 17 days with a standard deviation of 21 (Ekstrand et al., 2016). However, this is likely to be higher since hamstring injury rates have reported to have risen by 4% each year since 2001 (Ekstrand et al., 2016). An average squad misses players for 90 days of training and 15 matches per season due to hamstring injuries (Woods et al., 2004). For a top European professional soccer club the estimated cost of a player being injured for a month is around 500,000 Euros (Ekstrand, 2013). Therefore, hamstring injuries come at large financial cost for professional soccer clubs. Despite this problem being identified, hamstring injury rates have been increasing year on year.

The majority (91%) of all hamstring injuries in soccer are non-contact and 57% of these occur during running (Woods et al., 2004). Of these hamstring muscle injuries, the most common site is the bicep femoris long head (Ekstrand et al., 2011; Woods et al., 2004).Hamstring muscles, and specifically the bicep femoris, cross both the knee and hip joints. Typically hamstring injuries occur late in the swing phase of sprinting when the knee is extended and hip flexed and the hamstring muscles are long in length and having to apply large amounts of force eccentrically to control both knee and hip extension before ground contact (Chumanov, Schache, Heiderscheit, & Thelen, 2012). The causal factors of hamstring injuries are numerous and varied, including factors such as age, previous injury, muscle strength, fascicle length, fatigue, flexibility, neural tension, insufficient warm up procedures and load management. These risk factors associated with hamstring injuries have generally been classified as either non-modifiable or modifiable risk factors. Non-modifiable risk factors are factors such as age and previous hamstring injury (Arnason et al., 2004), whereas modifiable risk factors are factors which can be changed such as fascicle length and eccentric strength (Opar et al., 2015; Timmins et al., 2016). Low eccentric hamstring muscle strength has been identified as a key risk factor for hamstring muscle injury in soccer players. This risk increased further when combined with a short bicep fascicle length (Opar et al., 2015; Timmins et al., 2016). Improving eccentric hamstring muscle strength has even been suggested to reduce the risk from some non-modifiable risk factors (Opar et al., 2015; Timmins et al., 2016).

Thus, a regularly used method in the prevention of hamstring injuries is improving eccentric strength, which has been demonstrated to help reduce the incidence of this type of injury in soccer players (Arnason, Andersen, Holme, Engebretsen, & Bahr, 2008; Askling, Karlsson, & Thorstensson, 2003; Iga, Fruer, Deighan, Croix, & James, 2012; Petersen, Thorborg, Nielsen, Budtz-Jorgensen, & Holmich, 2011; van der Horst, Smits, Petersen, Goedhart, & Backx, 2015). An eccentric contraction is the contraction of a muscle while lengthening whereas a concentric action is the contraction of muscle while shortening. The most notably used exercise in eccentric hamstring strength programmes is the Nordic hamstring curl/exercise (NHE). The NHE and its effect on hamstring injury has been extensively researched. A recent meta-analysis concluded that soccer players can reduce their chance of hamstring injury by as much as 51% by implementing the NHE either alone or as part of a wider injury prevention training programme (Al Attar, Soomro, Sinclair, Pappas, & Sanders, 2017). Despite this, the NHE programmes are not commonplace in professional soccer clubs with only 16% of clubs implementing NHE programmes (Ekstrand et al., 2016). Reasons for this low implementation of NHE programmes are a lack to time due to busy fixture schedules and negative opinions regarding the exercise from players (Ekstrand et al., 2016). Anecdotally, these negative opinions from soccer players regarding the NHE are due to muscle soreness produced by NHE due to its eccentric nature.

The NHE produces large forces and neural activity at similar levels and angles to that of sprinting (Iga et al., 2012; van den Tillaar, Solheim, & Bencke, 2017).Therefore, it is rational to suggest the NHE could be used as part of a warm up for sprinting activity. Pre-activation is common practice in soccer as a gym based warm up before beginning the on field warm up. Pre-activation, or post activation potentiation (PAP), is the increasing of muscle function by creating high levels of neural activity (Maloney, Turner, & Fletcher, 2014). It may be advantageous to incorporate the NHE during a pre-activation warm up to elicit post activation potentiation. Using the NHE in way could increase the uptake of this exercise by soccer clubs, improve eccentric strength, safely prepare the hamstring muscles for upcoming sprinting activity while also improving the performance of the hamstring muscles during sprinting which is likely to occur in soccer specific training.

However, a common issue with the NHE is the participant's inability to complete the full range of movement as it requires high levels of strength (Buchheit, Simpson, Hader, & Lacome). Not completing the full range of movement of the NHE will only train the muscles at short muscle lengths and not train the muscles at long muscle lengths as these are only achieved at the end range of the NHE. A full range NHE allows the hamstring muscles to be trained at longer length positions, which are more specific to the length at which hamstring injuries occur during running (Matthews, Jones, Cohen, & Matthews, 2015). Thus, due to continually increasing hamstring injury rates and the significant time lost due to these injuries, preventing hamstring injuries should be high priority for soccer clubs. Therefore, the aim of this study is to assess the effectiveness of the full range NHE as a form of pre-activation or PAP on hamstring eccentric strength, neural activation and soccer-specific performance.

This chapter will go on to review the literature on hamstring performance enhancement and injury prevention strategies specifically those of the NHE and PAP. This will result in a comprehensive literature review of the NHE regarding its current prescription, volume, timing, range of motion and its effect on muscle strength, architecture, activation, performance and injury.

2.2 Nordic Hamstring Exercise (NHE)

The Nordic hamstring exercise (NHE) or Nordic hamstring curl is a commonly used exercise to strengthen the hamstring muscles which requires little or no equipment (see Figure 1). The NHE requires an athlete to start in a kneeling position with their ankles anchored, normally by a partner and resist the forward falling of the trunk towards the ground against gravity using their hamstring muscles. This action causes an eccentric contraction of the hamstring muscles. The NHE has predominately been implemented for the purpose of injury prevention by improving hamstring eccentric strength; a risk factor for hamstring injury (Al Attar, Soomro, Sinclair, Pappas, & Sanders, 2017). Commonly the NHE is prescribed in repetitions ranging from three to fifteen depending on how accustomed to this type of exercise the athlete is. This recommendation is from the FIFA 11+ (Bizzini & Dvorak, 2015). The FIFA 11+ is an injury prevention programme designed specifically for soccer players, particularly those of amateur level.

The NHE is an eccentric knee flexor exercise. This is important as it requires the hamstrings to contract eccentrically which is similar to that during sprinting (van den Tillaar et al., 2017). This exercise has been shown to create high levels of hamstring muscle activation and a higher eccentric hamstring activation than most other commonly used hamstring exercises (Bourne, Opar, Williams, Al Najjar, & Shield, 2016; Bourne et al., 2017; Iga et al., 2012). Hamstring activation is normally measured either via surface electromyography (sEMG) or functional magnetic resonance imaging (fMRI). Both methods provide activation measurements as percentage changes compared to a baseline measure but these methods have not always had consistent findings with each other (Bourne et al., 2017). This is most likely due to sEMG measuring electrical activity from the muscle whereas fMRI measures metabolic changes (Bourne et al., 2017). This means sEMG can provide valuable information on the timing of the activation but cannot differentiate between different activated sections of muscle; whereas fMRI can identify these differences (Bourne et al., 2017). Using these methods, it has been shown that hip extension exercises tend to recruit the lateral hamstrings (bicep femoris long and short head) whereas knee flexor exercises such as the NHE tend to recruit the medial hamstrings (semitendinosus and semimembranosus; Bourne et al., 2017). Using fMRI and compared to the semitendinosus, the bicep femoris long head was four times more active in hip extension than in the NHE (Bourne et al., 2017). Despite this, the NHE has been found to produce higher levels of bicep femoris hamstring activation in eccentric activity via EMG than a variety of commonly used hamstring exercises including those classed as hip extension exercises (Bourne et al., 2017).

Figure 1 Nordic hamstring exercise performed on the Nordbord

2.3 Eccentric Strength

Eccentric strength training programmes have been shown to be a more effective method of improving eccentric strength compared to traditional concentric methods (Kaminski, Wabbersen, & Murphy, 1998; Roig et al., 2009), demonstrating that the specificity of strength training is important. Not only has eccentric strength training been shown to be an effective method of increasing eccentric strength but research has shown eccentric strength training is particularly effective for improving hamstring strength even in athletic populations such as in elite soccer players adhering to a normal soccer-specific training regime (Askling et al., 2003).

One of the most common eccentric strength exercises used to improve eccentric hamstring strength is the NHE. The NHE has been consistently shown in the literature to increase eccentric hamstring strength and usually measured via one of two methods, isokinetic dynamometry or a NHE field testing device (Opar, Piatkowski, Williams, & Shield, 2013). The NHE is widely used and common across a variety of sports such as rugby union (Severo-Silveira et al., 2018), amateur team sports (Siddle et al., 2018) and soccer (Iga et al., 2012; Mjolsnes, Arnason, Osthagen, Raastad, & Bahr, 2004). The NHE is an equipment-less exercise and so is easy to administer to all levels or athletes and has been shown to effective to all athlete levels from amateur (Siddle et al., 2018) to professional (Severo-Silveira et al., 2018).

Through extensive research, the NHE has consistently been shown to improve eccentric hamstring strength, with peak torque changes reported as +14N·m (Severo-Silveira et al., 2018), +20N·m (Iga et al., 2012), +28N·m (Askling et al., 2003), +27N·m (Mjolsnes et al., 2004) and +31N·m (Siddle et al., 2018). Only one of these studies used professional athletes in a full-time sports specific training programme (Iga et al., 2012) whereas the rest used participants who were not categorised as professional athletes. These non-trained participants are more likely see larger positive improvements in strength after an NHE programme because they are less likely to previously participated in a structured strength training programme, and have a lower baseline strength than athletes. Further studies with professional athletes are required to further assess the effectiveness of an NHE programme on hamstring strength. Additionally, all of the peak torque measurements in the previously mentioned studies were detected via isokinetic dynamometry. Isokinetic dynamometry has often been seen as the gold standard for strength assessment however there is a growing amount of literature measuring hamstring eccentric strength using a portable NHE field testing device which can assess maximal hamstring strength and between limb differences (Opar et al., 2013). This device has been shown to be shown to high to moderate levels of reliability (Opar et al., 2013), and can be used easily in the field and is considerably cheaper than the laboratory based isokinetic dynamometry.

NHE intervention studies using this NHE field testing device have reported consistent increases in hamstring eccentric strength with max force changes publicised in the literature of +31N (Bourne et al., 2017), +62N (Ishoi et al., 2018), +68N (Pollard, Opar, Williams, Bourne, & Timmins, 2019) and +93N (Presland, Timmins, Bourne, Williams, & Opar, 2018). Although it appears that studies using the NHE field testing device identified larger improvements in eccentric hamstring strength, a poor correlation between isokinetic and NHE field testing has been demonstrated, suggesting that these devices actually measure different strength characteristics (van Dyk, Witvrouw, & Bahr, 2018). This is supported by the difference in measurement units of hamstring strength with the NHE testing device reporting maximal hamstring force in newtons (N) whereas the laboratory testing reporting maximal torque via isokinetic dynamometry is measured in newton meters (N·m). Additionally, poor correlation between the tests could also be explained by differences in test protocol, position, and movement. Isokinetic dynamometry utilises a unilateral test and requires the participant to sit down causing hip flexion, whereas the NHE testing device is a bilateral test in which the participants have their hips extended while kneeling (van Dyk et al., 2018).

Studies specifically looking at soccer players who have undertaken an NHE training programme have been consistent with other sports and demonstrated increased hamstring eccentric strength.(Iga et al., 2012; Ishoi et al., 2018; Mjolsnes et al., 2004). Notably, participant levels ranged in ability in these studies with them being described as amateur, (Ishoi et al., 2018) well trained (Mjolsnes et al., 2004) or professional soccer players (Iga et al., 2012). Therefore, findings should be taken with caution as there is limited research into NHE programmes using professional soccer players partaking in a concurrent training programme.

Improving hamstring eccentric strength is one of the modifiable factors relating to hamstring injury. Low hamstring eccentric strength has been associated with increased risk of hamstring injury (Opar et al., 2015; Timmins et al., 2016). These findings were found in elite athletes from soccer and Australian football (AFL). For soccer players it has been suggested that having an average eccentric hamstring force below 337N means the chances of subsequent hamstring injury are increased by as much as 4.4 times (Timmins et al., 2016). Therefore, improving hamstring eccentric strength should be considered an important part of preventing hamstring injuries.

In summary, low hamstring strength has been identified as a risk factor which can be altered and the NHE has been consistently demonstrated to increase eccentric hamstring strength in a variety of populations (see Table 1), including that of professional athletes, in particular elite soccer players (Bourne et al., 2017; Iga et al., 2012; Ishoi et al., 2018; Mjolsnes et al., 2004; Pollard et al., 2019; Presland et al., 2018; Siddle et al., 2018). These findings are extremely important as reducing the incidence of hamstring injuries in soccer is a priority for coaches, practitioners and researchers.

2.4 Volume (workload)

A large proportion of the NHE intervention studies within the literature have focused on ten-week interventions which culminate in a high workload regarding sets and repetitions. These interventions totalled repetitions ranging from 646–736 in which some week's participants were doing up to 100 repetitions a week (Bourne et al., 2016; Ishoi et al., 2018; Krommes et al., 2017; Mjolsnes et al., 2004). Three of the studies measured eccentric hamstring strength and found improvements; however, the participant numbers were small and training levels were not that of professional athletes, so improvement in hamstring strength would be expected (Bourne et al., 2016; Ishoi et al., 2018; Mjolsnes et al., 2004). Another study did use professional soccer players from the Danish league but did not measure hamstring strength. However, they did find improvements in performance measures including sprinting and jumping performance (Krommes et al., 2017). The very high workloads in these studies are not very practical to implement into a professional full time training schedule hence the majority of these studies occurring in non-professional athletes. The one study that did use professional athletes implemented this high workload NHE programme during the mid-season winter break which occurs in the Danish league therefore the players weren't actively in a concurrent training programme at the time of the intervention.

Due to difficulties in implementing this volume of intervention three studies have investigated much shorter interventions lasting four–six weeks. These interventions had much lower workloads, totalling considerably less repetitions than the ten week intervention studies with one study totalling 520 repetitions (Siddle et al., 2018) and the other two studies totalling 160 repetitions (Iga et al., 2012) and 128 repetitions (Pollard et al., 2019) respectively. Despite all of these interventions having significantly lower workloads, all three of these studies showed improvements in eccentric hamstring strength (Iga et al., 2012; Pollard et al., 2019; Siddle et al., 2018). Again, it should be noted that only one of the studies used professional soccer players (Iga et al., 2012). It could be suggested that these studies show that shorter interventions with small workloads can be just as effective at improving eccentric hamstring strength as longer interventions with higher workloads. There does not appear to be a dose-response relationship regarding total workload and the magnitude of hamstring strength improvements as some of the shorter interventions elicit similar strength improvements, even more in some cases compared to higher workload NHE programmes (see Figure 2).

Although not specific to soccer, other noteworthy research from elite Rugby Union players undertaking either a constant or progressive workload over an eight-week NHE training programme found that eccentric strength was only improved in the progressive workload group, whereas bicep femoris fascicle length was improved in both training groups. This is significant as a short bicep femoris fascicle length is a known risk factor for hamstring injury (Bourne et al., 2018). The progressive workload group had their training programme workload increased by an increase in volume across the 8 weeks. This progressive workload group totalled up 456-488 repetitions across the 8 weeks compared to the constant workload group who completed 276 repetitions. Since total volume is different between the two training groups it cannot be certain that differences in eccentric strength are down to progression of workload or simple differences in workload (Severo-Silveira et al., 2018).

There is one thought-provoking study done by Presland et al. (2018) who compared the effects of Low vs High volume NHE training programme over a six-week timescale. The low group completed 128 repetitions whereas the high group completed 440. Despite this difference in volume they found that both groups improved both eccentric hamstring strength and bicep femoris fascicle length and interestingly there was no significant differences in eccentric strength or bicep femoris fascicle length found between the different groups. These results were observed in recreationally active males and so may not translate to elite soccer players (Presland et al., 2018).

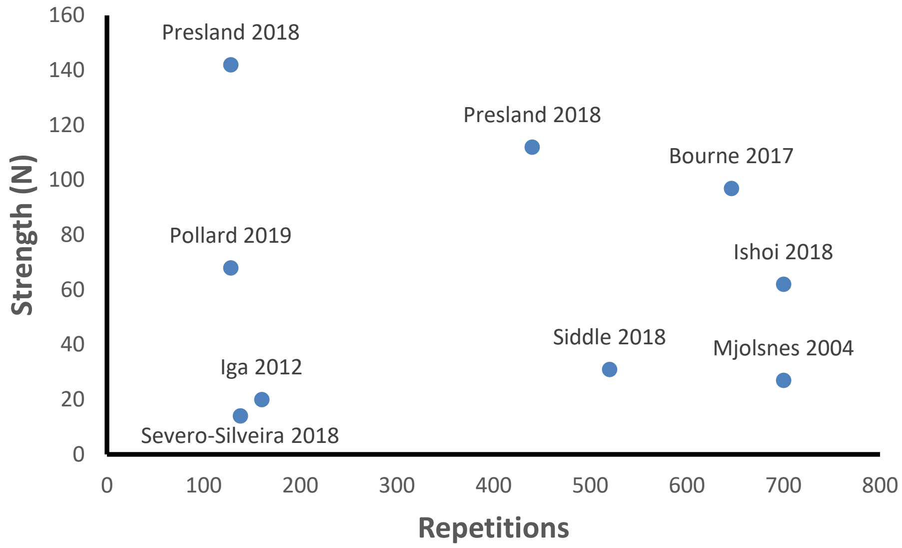

Figure 2 NHE interventions total repetitions (volume) and strength results

All these findings suggest that high volume NHE programmes are not necessary to have a significant positive effect on hamstring muscle strength. This is supported by a recent systematic review on the effect of NHE intervention volume which concluded with the same findings (Cuthbert et al., 2019). This review theorises the reasons for these findings are that the high volume workloads require large amounts of effort and cause severe Delayed Onset of Muscle Soreness (DOMS); this in turn causes the compliance to these programmes to be very poor. Not only is the compliance poor but due to the high perceived exertion and fatigue accumulated in these programmes the Nordic breaking point or range of motion of the NHE reduces, causing a plateau in the exercise progression and even a possible decrease in actual work done (Cuthbert et al., 2019). Therefore, reducing the volume of this exercise can actually increase the intensity and progression due to the athletes completing a larger or fuller range of motion during the exercise and in turn getting stronger especially at longer muscle lengths (Cuthbert et al., 2019). This theory is consistent with findings from (Pollard et al., 2019) who observed benefits of increasing the intensity of NHE albeit through the slightly different method of adding external weight.

In summary, the literature suggests that lower NHE workloads are just as effect as higher NHE workloads for several reasons including intensity, progression, compliance and perceived exertion. This finding is vital for real world professional sports settings as compliance in professional sport is normally extremely low due to DOMS and high training and match workloads. All these conclusions still pose questions on what is the minimal effective dose for the NHE as there is no currently established dose within the literature.

2.5 Timing

There are two trains of thought regarding the rational of when is the optimal time to perform the NHE. One rational is to programme the NHE before activity as part of a warm up to activate the hamstring muscles.

Whereas the other rationale is to programme the exercise after activity when the hamstring muscles are already fatigued and therefore not to cause unnecessary fatigue before activity.

Implementing the NHE before exercise has grown in popularity in recent years due to its inclusion in the FIFA 11+ protocol (Bizzini & Dvorak, 2015). Thus, the NHE is becoming more common in amateur soccer as part of a strength training programme or a warm up. The FIFA 11+ promotes beginners undertaking 3-5 repetitions, intermediates 7-10 repetitions and advanced 12-15 repetitions before football specific practice (Bizzini & Dvorak, 2015). A number studies that involve an NHE intervention have the intervention performed first before training as the main aim is normally to assess hamstring eccentric strength and therefore it best to perform the exercise in a non-fatigued state (Iga et al., 2012; Severo-Silveira et al., 2018; Siddle et al., 2018). All these studies found positive effects of the intervention showing improvements in hamstring eccentric strength but this cannot be attributed to the timing of the intervention because performing the intervention after exercise has shown to be equally effective at improving eccentric hamstring strength (Ishoi et al., 2018; Lovell et al., 2018). It should be noted that studies performing the NHE before training only reported one injury in the study periods related to the NHE therefore providing evidence the NHE appears to be safe to perform prior to training (Iga et al., 2012; Severo-Silveira et al., 2018; Siddle et al., 2018).

There has been concern and caution about performing the NHE before exercise due the high fatiguing effect of the exercise. Hamstring fatigue is widely known as a risk factor for injury (Lovell et al., 2018). Just one set of five NHE has been shown to cause fatigue in the hamstring muscle group via a reduction in strength, as measured on an isokinetic dynamometer (Marshall, Lovell, Knox, Brennan, & Siegler, 2015) These findings were reinforced further by another study which found similar results and concluded that performing the NHE before training was deemed to increase the risk of subsequent hamstring injury due to reduced hamstring muscle strength in the form of reduced peak torque and angle specific torque forces (Lovell, Siegler, Knox, Brennan, & Marshall, 2016). Again, these strength decrements were detected via isokinetic dynamometry. Interestingly this study also noted that performing the NHE prior to training prevented a decline in sprint speed by 2.0-3.2% (Lovell et al., 2016). It should be noted that this study did not state an exact amount of time between performing soccer simulated exercise and performing the NHE. The authors only state that the NHE occurred after a soccer-specific warm up and before the first battery of testing which occurs before performing the soccer simulated exercise. Authors from both of these papers conclude that performing the NHE before training is risking hamstring injury and that the NHE should be performed after field based training. In both of these studies the participants were amateur athletes (Lovell et al., 2016; Marshall et al., 2015; Small, McNaughton, Greig, & Lovell, 2009). Findings in elite athletes may be different because in theory, professional or elite athletes should have higher baseline levels of hamstring eccentric strength and be suitably conditioned to regular intense training and therefore more resistant to fatigue caused by NHE.

Additionally, one interesting study actually examined the effect of timing of the NHE. It investigated NHE before vs NHE after vs a control. The study measured hamstring activation, maximal eccentric strength and a variety of muscle architecture measures including fascicle length, pennation angle and muscle thickness. Interestingly the results of this study showed that performing the NHE exercise both before or after training increased eccentric strength similarly compared to control group but the architectural changes linked to these strength gains were different depending on the timing if the NHE. The NHE before group had increases in bicep femoris fascicle length compared to the after group and control whereas the NHE after group had increases in muscle thickness and pennation angle compared the NHE before and control group (Lovell et al., 2018). Findings from this study suggest that timing of the NHE may be relevant depending on the target outcome of the exercise whether that be injury prevention or hypertrophy. It is important to note that this study used a small number of amateur soccer players who trained twice a week and noted that compliance to NHE programme was modest with only 41% of the prescribed volume being completed. Therefore, repeatability of these results needs to be investigated further.

Pre-activation in soccer is common practice. Pre-activation is term used for a gym based pre-warm up to activate essential muscles prior to an on field warm up. It effectively becomes the R (raise), A (activate), M (mobilise) of a RAMP based warm up protocol. Therefore, the field based warm up can get to the field specific potentiate (P) section of the warm up more effectively and efficiently (Jeffreys, 2007). Soccer specific warm ups including pre-activation have the common goal of achieving what is scientifically referred to as PAP or post activation potentiation. PAP is the occurrence of increase muscle performance after exercise (Robbins 2005). The theory behind how PAP works is that the exercise increases muscular performance by enhancing neural activation or exciting the nervous system. Thus, in theory the NHE can be used as the activate (A) section of a pre-activation session before the PAP section of the soccer specific warm up which usually occur on field, commonly in the form sprinting.

In summary, there is still conflicting ideas around the NHE used before soccer specific training however there is growing evidence that the NHE is safe to use before soccer specific training. Eccentric hamstring strength improves regardless of the timing of the NHE however the mechanisms behind these improvements appear to differ. Therefore it could be suggested that the NHE can be implemented as part of a pre-activation session to effectively activate the hamstring muscle group to safely prepare the hamstrings for subsequent sprinting activities and maybe even provide an increase in performance by reducing a decline in subsequent sprint speed (Lovell et al., 2016).

2.6 Post Activation Potentiation

Post activation potentiation (PAP) is the occurrence of increase muscle performance after exercise (Robbins, 2005). Another definition of PAP is phenomena in which muscle characteristics are acutely enhanced by as a result of their contractile history (Tillin & Bishop, 2009). Common ways have inducing

PAP is by performing a voluntary contraction normally at as close to maximal intensity as possible (Tillin & Bishop, 2009).

The mechanisms around PAP are not fully understood and conclusive however there are a few main mechanisms suggested for this phenomenon. The first mechanism is the recruitment of more motor units within the muscle (Tillin & Bishop, 2009), secondly there is the idea of an increased pennation angle (Tillin & Bishop, 2009), another proposed mechanism is the phosphorylation of myosin light chains (Tillin & Bishop, 2009) and the final suggested mechanism is at spinal level through the improved synaptic efficacy (Tillin & Bishop, 2009).

Contraction type is likely to have an effect on the mechanism and the PAP response. Contraction types have been classified as dynamic (concentric and eccentric) and isometric. Isometric contractions may induce greater central fatigue and excite the peripheral mechanisms of PAP whereas dynamic contractions produce central PAP mechanisms but cause peripheral fatigue (Tillin & Bishop, 2009). Eccentric contractions are suggested to improved synaptic efficacy at spinal level (central) which in turn recruits more motor units but would cause some muscular fatigue (peripheral). Therefore, it could be theorised that the NHE would cause a PAP effect by improving synaptic efficacy at spinal level which in turn would recruit more motor units within the hamstring muscles but also cause some fatigue.

The purpose of PAP is to improve subsequent athletic performance. The effects of PAP on athletic performance have been investigated with improvements in performance ranging from two to five percent (Maloney et al., 2014). It should be noted that the athletic performance measures in the majority of studies is a countermovement jump and the improvements were induced via ballistic exercise and not the NHE. Despite this, not all studies have found consistent improvements in performance from PAP. One study investigating three different PAP protocols on professional soccer players found no significant improvements in jump or sprint performance from any of the PAP protocols compared to a control (Till & Cooke, 2009). However, it should be noted that large individual responses were seen in this study with some participants seeing improvements of eight percent. The three PAP protocols in this study were isometric, plyometric and weighted and did not include the NHE or any form of eccentric exercise. Eccentric exercise induced PAP has been investigated on amateur soccer players and was found to have improvement in performance in the form of change of direction (Beato, Madruga-Parera, Piqueras-Sanchiz, Moreno-Pérez, & Romero-Rodriguez, 2019). It should be noted that the eccentric exercise in this study was in form of flywheel exercises and the NHE. However, this study show that eccentric exercise can be used as an effective method of inducing PAP.

A recent systematic review on warm up strategies including PAP, investigated the effects of PAP on performance in soccer players. This review found PAP to have a small positive effect (+3.73%) on jump performance and a larger positive effect on sprint performance (4.7%) (Hammami, Zois, Slimani, Russel, & Bouhlel, 2018). This review concluded that warm ups inducing PAP caused an acute improvement in soccer performance or at least did not have any negative effects on soccer performance. Again, it should be noted that the NHE was not used to induce any of the performance improvements from PAP.

2.7 Athletic Performance

Eccentric strength training has been commonly used across sports mainly in injury prevention programmes. Eccentric training has been regularly shown to increase training availability and reduce the days lost which arguably is a performance benefit. This is vital when you consider that hamstring injuries are the most common injury in professional soccer players (López-Valenciano et al., 2019).

In soccer, the NHE has commonly been used to prevent hamstring injury but is has also been shown to improve hamstring strength, sprint speed, jump height and change of direction (Clark, Bryant, Culgan, & Hartley, 2005; Ishoi et al., 2018; Krommes et al., 2017; Siddle et al., 2018). Speed has been shown to improve in a number of studies; however, all these studies used different distances and testing protocols (Ishoi et al., 2018; Krommes et al., 2017; Siddle et al., 2018). Ten-meter sprint speed has repeatedly been shown to improve from a NHE intervention with -0.047s (Ishoi et al., 2018), -0.06s (Siddle et al., 2018) and -0.09s (Krommes et al., 2017) improvements published in the literature. It should be noted that all these studies had small sample sizes and only one study used professional soccer players (Krommes et al., 2017). However, at the point the intervention occurred the players were on a mid-season break therefore the players were not undertaking regular concurrent soccer training. This study with Danish professional soccer players (Krommes et al., 2017) also looked at other performance measures such as counter movement jump height (CMJ), 5m sprint speed and 30m sprint speed. CMJ height was used a measure of explosive characteristics and they found that NHE improved CMJ height by two centimetres compared to a control group (Krommes et al., 2017). Similar jump improvements were found in amateur Australian rules footballers (Clark et al., 2005). The jump improvements found in the Danish professional soccer players correlated with improvements in 5m (-0.08 seconds) and 10m (-0.09 seconds) sprint times (Krommes et al., 2017). These sprint improvements should be seen as meaningful as they are larger than the measurement error of 0.001 seconds stated by the manufactures of the photocells used (Enoksen, Tønnessen, & Shalfawi, 2009). Interestingly, 30m sprint did not improve with the improvements occurring in the more explosive power based performance measures.

Other performance measures which have been investigated in the NHE intervention studies are change of direction (CoD) speed, hamstring capacity, repeated sprint ability and hamstring flexibility. Change of direction (Siddle et al., 2018), repeated sprint ability and hamstring capacity (Ishoi et al., 2018) were shown to improve following a NHE intervention compared to a control group. Change of direction improved by -0.12 seconds (Siddle et al., 2018) after NHE intervention. Both hamstring capacity and repeated sprint ability also improved. Hamstring capacity was measured as the rate of decline on eccentric force and repeated sprint ability using a 10m repeated sprint test. They found that the participants last 10m sprint was faster after the NHE intervention however it should be noted that the first or fastest 10m sprint was also improved (Ishoi et al., 2018). In this same study hamstring flexibility was measured in the form of activate knee extension (AKE) however no improvement was detected compared to the control group (Ishoi et al., 2018). All of these performance measures are important to soccer players as they are all specific to the demands of soccer and improving these performance measures should allow soccer players to not only reduce the likelihood of injury but also improve their physical performance.

Sprint speed is a critical aspect of soccer performance and the literature around the relationship of eccentric hamstring strength and its effect on sprint speed is growing (Ishoi et al., 2018; Krommes et al., 2017; Markovic et al., 2018; Siddle et al., 2018). In youth soccer players (U12-U18) 20 meter sprint speed correlated highly with Nordic hamstring strength (Markovic et al., 2018) .This paper also found that Nordic hamstring strength increased with age. Additionally, when the Nordic hamstring strength was normalised to body mass they found that this relative Nordic hamstring strength accounted for 27% of the variance of 20m sprint speed (Markovic et al., 2018). Furthermore, low eccentric strength has been associated with a poor sprint performance and that faster athletes were able produce high eccentric forces in their hamstring muscles just before ground contact (Morin et al., 2015). Evidence suggests that high eccentric hamstring strength is important for sprint performance (Markovic et al., 2018; Morin et al., 2015) and eccentric hamstring strength training has important benefits for athletic performance.

In summary, the body of evidence is growing in support of performance benefits (see Table 1) from eccentric hamstring training with a specific focus on the NHE and athletic performance.

2.8 Range of motion

Traditionally, one of the limitations with the NHE is that most athletes do not complete the full range of movement. The full range of movement is considered lowering the chest all the way to the floor and back up the original start position (see Figure 3) while resisting gravity.

Figure 3 NHE start position.

This is not commonly achieved because it requires very high levels of eccentric hamstring strength at all ranges of the NHE which most athletes do not possess to complete the movement (see Figure 4) or at least when beginning this type of training programme.

Figure 4 Common NHE break point

Most published literature does not note what range of NHE is completed. Due to the high strength requirement throughout the movement it is suspected that the full range of movement is not often performed. However, some papers such as Mjolsnes et al (2004), do note that load is increased as the participant can withstand the forward fall longer therefore increasing the range of the movement throughout the programme, this is due the athletes getting stronger (Mjolsnes et al., 2004). Other studies note that if sufficient strength and control were shown in the last 10-20 degrees of the movement then the NHE would be progressed. In these studies, the NHE was progressed by adding external weight (Pollard et al., 2019; Presland et al., 2018). It should be noted technique of the NHE is crucial to full range of movement of the NHE that if the athlete had 10-15 degrees hip flexion they did reach knee flexion angles of below 30 degrees (Alt, Nodler, Severin, Knicker, & Struder, 2018). Despite the full range of NHE movement not commonly being performed, hamstring muscle activation at the end ranges of the NHE remains elevated suggesting the importance of completing the NHE to full range to build eccentric strength and prevent hamstring injury (Iga et al., 2012).

One way of ensuring the full range of movement is completed in the NHE is by assisting the exercise to make it easier (see Figure 5). It can be assisted using strength bands or cable machines to allow athletes to complete the full range of movement.

Not completing the full range of movement will subsequently only train the hamstring muscles at a small range of muscle lengths, whereas full range Nordic hamstring curls allow the hamstring muscles to be trained at longer length positions; which are more specific to the length at which hamstring injuries occur during running (Matthews et al., 2015).

Figure 5 Full range assisted NHE

2.9 Muscle architecture

The effect of eccentric exercise and specifically the effect of the NHE on the hamstring muscle architecture is well researched. The literature shows two main effects which are changes in muscle fascicle length and the tension-length relationship of muscle. Eccentric exercise causes muscle damage, in turn this causes the muscle to adapt. Eccentric muscle damage typically occurs at longer muscle lengths and this would typically be the angle at which NHE breaks and the athletes falls. However, after this type of exercise the muscle recovers and adapts by getting stronger at those longer lengths. This is called the tension-length relationship or the muscle torque angle curve. The NHE has been shown to change the tension-length relationship of the hamstring muscles and therefore change the optimum length at which the hamstring muscles function (Brockett, Morgan, & Proske, 2001).

Fascicle lengths have been shown to increase after NHE training (Alonso-Fernandez, Docampo-Blanco, & Martinez-Fernandez, 2018; Bourne et al., 2017; Presland et al., 2018; Ribeiro-Alvares, Marques, Vaz, & Baroni, 2018). Having a short fascicle length of the bicep femoris has been shown to be risk factor for hamstring injury, this is multiplied if knee flexor eccentric strength is also low (Timmins et al., 2016). The NHE has been shown to increase the fascicle length of the bicep femoris long head (Bourne et al., 2017). However, there is some contradictory research and one study in 2017 found that an NHE intervention did not cause meaningful increases in fascicle length but did increase hamstring muscle mass (Seymore, Domire, DeVita, Rider, & Kulas, 2017). It should be noted that this study also found no changes in hamstring strength and is an outlier amongst the literature. Architectural changes of the hamstring muscles after NHE interventions have been shown to be effected by a variety of factors including timing, (Lovell et al., 2018) volume (Cuthbert et al., 2019) and intensity (Pollard et al., 2019). Knee flexor exercises such as the NHE has been shown to specifically increase the muscle mass of the bicep femoris short head and the semitendinosus compared to hip extension which promotes increases in bicep femoris long head and semimembranosus (Bourne et al., 2017).

Manipulating the timing of when the NHE is performed has been shown to have some very interesting effects on the muscle architecture adaptations. As previously mentioned, performing the NHE before training when to increase bicep femoris fascicle length whereas performing the NHE after training has been shown to increase muscle thickness and pennation angle. Both these intervention groups had similar eccentric strength gains; however, the mechanism behind these strength improvements appears to very different depending of the timing of the NHE (Lovell et al., 2018).

Volume of NHE programmes has been investigated regarding its effect on muscle architecture adaptations. It has been reported that small volume workloads are just as effective as higher volume workloads at improving strength and therefore altering muscle architecture. No effect has been observed on NHE volume on fascicle length or pennation angle with both small and high workloads improving fascicle length and decreasing pennation angle equally (Cuthbert et al., 2019). As previously mentioned one particular study investigated the effects of low volume vs high volume NHE intervention and concluded that the low volume actually had statistically significant decrease in pennation angle (Presland et al., 2018). It should be noted that a recent systematic review around NHE volume effects concluded that low volume NHE programmes are just as effective as high volume programmes not because of volume but because of compliance which makes the small volume workloads actually more intense (Cuthbert et al., 2019).

Intensity has been reported to have an effect on hamstring muscle architectural adaptations with weighted NHE programmes (more intense) having a greater effect than bodyweight NHE programme on fascicle length (Pollard et al., 2019). It should be noted that the participants in this study were untrained and therefore likely to have low base levels of strength, thus having greater changes. This may not be true for professional athletes whom are more accustomed to this type of training.

Table 1 Summary of NHE intervention studies

Study	Participants details	Intervention length & workload	Intervention Timing	Main findings	Additional findings
Pollard et al. 2019	30 Recreationally active males	6 weeks Total 128 reps	N/A	Eccentric strength improved +68N	Weighted NHE improved eccentric strength +81N
Siddle et al. 2018	14 Amateur intermittent team sports athletes	6 weeks Total 520 reps	Before training	Eccentric strength improved +31·81N.m 10m Speed improved -0.06s COD improved -0.12s	
Mjolsnes et al. 2004	21 Well trained soccer players (Norwegian university soccer players)	10 weeks Total 700-726 reps	Not stated	Eccentric strength improved +27N·m	
Krommes at al. 2017	19 Danish professional soccer players		Mid-season break	5m Speed improved -0.08s 10m Speed improved -0.09s 30m Speed no change CMJ improved +2cm	
Ishoi et al. 2018	35 Amateur soccer players		After training	Eccentric Strength improved +62.3N Hamstring Capacity Speed 10 improved -0.047s Repeated sprint improved	

				AKE no change	
Bourne et al. 2017	30 Recreationally active males	10 weeks Total 646-726 reps	N/A	Eccentric Strength improved +97.38N	No significant difference in strength between NHE vs Hip extension
Iga et al. 2012	18 English professional soccer players	4 weeks Total 160 reps	Before training	Eccentric Strength improved +20N·m	
Severo-Silveira et al. 2018	21 premier league rugby union players	8 weeks Total 138–244 reps	Before training	Eccentric strength improved +14N·m	Progressive workloads improved strength vs a constant workload which showed no changes strength. Fascicle length improved in both groups
Presland et al. 2018	20 recreationally active males	6 weeks Total 128–440 reps	N/A	Eccentric strength improved +142N	Low volume increased strength more than high volume

2.10 Tensiomyography (TMG)

Tensiomyography or TMG is used as a non-invasive method of assessing muscle mechanical and contractile properties (Macgregor, Hunter, Orizio, Fairweather, & Ditroilo, 2018). TMG works by evoking an involuntary contraction of the muscle belly and recording the radial displacement of the muscle using a probe. TMG has five main explored parameters which include Delay time (Td), Contraction time (Tc), Sustain time (Ts), Relaxation time (Tr), Maximal Displacement (Dm), and Contraction velocity (Vc). Vc is a calculated measure and is a combination of Dm and Tc (Macgregor et al., 2018). Dm has been suggested as measure of muscle stiffness (Pisot et al., 2008). Thus meaning that decrease in Dm would indicate an increase in muscle stiffness (Pisot et al., 2008). Muscle stiffness is a desired adaptation from strength training as stiffer muscles have been associated with increased athletic performance in activities such as sprinting. However, this should be used with caution as there is currently no studies validating Dm against muscle stiffness (Macgregor et al., 2018) Dm has also been suggested as a possible neuromuscular measure of excitability (de Paula Simola et al., 2015).

Tc is the time between 10% and 90% of Dm, therefore Tc can be considered a measure of contraction speed (Macgregor et al., 2018). Thus, meaning a longer contraction time equals a slower speed of contraction. Hence Tc can be used to assess fibre type composition of the muscle (Pisot et al., 2008). It should be noted that Tc can also be affected by changes in tendon stiffness (Pisot et al., 2008) and that a larger Dm will mean a longer Tc (Macgregor et al., 2018). The latter creating the need for the calculated measure of Vc to get a genuine measure of contraction speed. Vc has been calculated in several ways with no one accepted standard method yet established (Macgregor et al., 2018). Td is the time delay between the stimulus to the muscle and 10% of Dm. Td has been suggested as a measure of muscle responsiveness (Garcia-Manso et al., 2011).

Dm, Tc and Td have been shown to be very reliable measures (Macgregor et al., 2018; Martin-Rodriguez, Loturco, Hunter, Rodriguez-Ruiz, & Munguia-Izquierdo, 2017) with intra-class correlation coefficient (ICC) values for Dm reported as 0.82-0.99, Tc 0.70-0.99 and Td 0.60-0.98 (Martin-Rodriguez et al., 2017). It should be noted that the majority of these studies did not use the hamstring muscles however a study did measure the bicep femoris muscle (Rey, Lago-Penas, & Lago-Ballesteros, 2012). This study used professional soccer players and reported ICC values of 0.95 for Dm, 0.82 for Td and 0.86 for Tc (Rey et al., 2012).

Strength training protocols have been shown to affect some TMG parameters and therefore changes in muscle architecture. Specifically, Dm has been publicised to change after strength training protocols especially those involving eccentric contractions (de Paula Simola et al., 2015). Dm significantly decreased after strength training indicating an increase in muscle stiffness (de Paula Simola et al., 2015), a normal desired outcome of strength training. This same study also found decreases in Tc however this was attributed to decreases Dm rather than strength training (de Paula Simola et al., 2015). However, another study found eccentric exercises to affect both Tc and Td but this effect was an acute change rather than a chronic adaptation to type of exercise. Interestingly this suggests that eccentric exercise can acutely improve contraction speed and muscle responsiveness which would be considered a PAP response (Beato, Madruga-Parera, Piqueras-Sanchiz, Moreno-Pérez, & Romero-Rodriguez, 2019). It should be noted that none of these studies used the NHE and to date there have been no studies investigating the effect of NHE on TMG parameters.

The relationship between soccer specific training and TMG measures has been investigated over a ten-week training block. Tc, Td and Dm were all found to be sensitive to change suggesting muscle architecture and neuromuscular changes compared to a control group.(Garcia-Garcia, Serrano-Gomez, Hernandez-Mendo, & Tapia-Flores, 2016) Tc, Td and Dm were all found to decrease significantly (Garcia-Garcia et al., 2016). However, these changes were found in three knee extensor muscles and not the bicep femoris muscle. In the bicep femoris muscle Dm and Td were found to significantly increase after the soccer specific training. Tc also increased in the bicep femoris however this was not statistically significant (Garcia-Garcia et al., 2016). The unfavourable changes in the bicep femoris were concluded to be a result of neuromuscular fatigue induced by match-play. Additionally, there have been differences identified in TMG values of professional soccer players compared to general populations. With soccer players having smaller Dm, Tc, and Td values compared non-soccer players and generally having stiffer muscles. These would be expected adaptations from a full time training programme (Garcia-Garcia et al., 2016; Rey et al., 2012). Interestingly TMG differences between soccer players appears to be affected by playing position and appear to be product of the how the muscles are used (Rey et al., 2012).

To summarise, some (Dm, Tc and Td) TMG parameters are reliable but not conclusively validated measures of neuromuscular and contractile muscle properties. However, TMG is a non-invasive and portable method which has shown to be sensitive to strength training especially those involving eccentric contractions suggesting that eccentric training could create stiffer muscles which potentially contract and respond faster. Additionally, TMG has never been used to assess changes in muscle properties following an NHE training programme. Thus, this study will be novel regarding its use of TMG.

The aim of the study is to assess the full range NHE when used as part of a pre-activation warm up on hamstring muscle strength and neuromuscular activation, and in turn, the effect on soccer-specific performance. Full range NHE will be achieved by assisting the exercise. The rationale behind the use of the assisted NHE was that anecdotally the full range of movement of the NHE is not commonly completed (i.e., chest to the floor). Thus, the traditional NHE does not train the hamstring muscles at long lengths specific to those in sprinting.

3.0 Methods

3.1 Participants

Sixteen full time academy footballers (17 ± 2 years, 183 ± 7 cm, 72.3 ± 9.0 kg) participated in the study. All players were recruited from an English Premier League Football Club Academy. All players provided informed consent and parental consent forms for participation in the study and use of their data. Ethical approval was granted by the University of Huddersfield School of Human and Health Sciences Ethics Committee prior to the study commencing.

3.2 Research Design

The followed a crossover design, with the players undertaking a baseline testing battery followed by a six-week period plus one week for adaptation (15/10/18 – 3/12/18) where the players underwent concurrent training without intervention and retesting at the end of the seven-week period to establish a control. Another six-week period followed in which the players undertook the intervention and the same testing protocols before and after six-week period plus one for week for adaptation were no intervention was performed (21/1/19 – 11/3/19). The purpose of the adaptation week was to prevent any fatigue from the intervention affecting the testing results. All testing occurred after two days off training starting at 9am and finishing at 2pm. All players were tested in the same order with players first undertaking TMG followed by eccentric strength testing and then finally the performance testing in the order of SJ, CMJ and then the sprint testing. During the intervention period players underwent the same concurrent training along with the intervention. Between the two periods the players had some rest time (10 days Christmas break). Players returned to training on the 7/1/19 and trained for two weeks prior to intervention period beginning. Before the intervention period all players took part in a familiarisation session of the intervention exercise to negate any learning effects. Throughout both six-week periods players took part in a concurrent training and a weekly match programme. The concurrent training consisted of on field soccer specific training and off field strength and power training an example training week has can been seen in Figure 6 and a full schematic of the study can be seen in Figure 7. The strength and conditioning programmes were consistent throughout and gym attendance tracked. On field load (training volumes and intensities) across the two six-week blocks was recorded and matched as closely as possible. Load from training and games was recorded using STAT Sports APEX global positioning system (GPS) (STATSports, Belfast, UK). STAT Sport APEX GPS pods sample at 10Hz and have 100HZ triaxial accelerometers, 100HZ triaxial digital gyroscope and 10HZ magnetometer. STATSports APEX software version 3.0.3112 was used for download and analysis

Attendance was recorded during resistance exercise sessions in the gym. Load was monitored, this was self-recorded via Teambuidr (Maryland, USA) iPad application. Teambuildr is a cloud based online strength and conditioning software were players can record gym loads live within gym sessions. However due to technical issues and poor compliance this was not used. Players completed a wellness questionnaire via laptop consisting of eight questions on training days to monitor readiness to train and responses to load. These questions are soreness, fatigue, recovery, health, sleep quality, sleep duration, fatigue, body mass and travel time. All questions other than body mass and travel time were rated on a 1-5 scale. A copy of the questionnaire is provided in Appendix 3.

Mesocycle : Microcycle (week)							
Day	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Focus	Recovery	Intensive	Extensive	Tactical	Match Prep	Match	Rest
MD	MD+2	MD-4	MD-3	MD-2	MD-1	MD	MD+1
8:00							
8:30	Breakfast & subjectives	Breakfast & subjectives			Breakfast & subjectives	Report & Breakfast	
9:00	Education	Strength			Education		
9:30							
10:00			Report | Subjectives	Report | Subjectives			
10:30		Individual/Unit Training	Individual Training	Power		Warm Up	
11:00						Match	
11:30							
12:00	Lunch	Lunch	Lunch	Lunch	Lunch		
12:30							
13:00	Education						
13:30		Pre-Activation	Pre-Activation	Pre-Activation	Pre-Activation		
14:00		Training	Training	Training	Training		
14:30							
15:00							
15:30							
16:00							

Figure 6 Typical training week

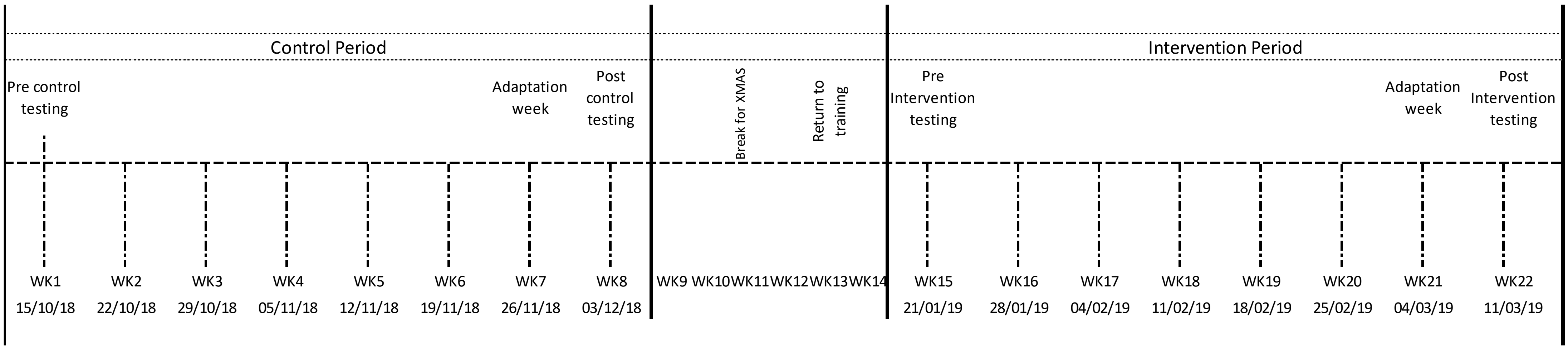

Figure 7 Overview of study timeline

3.3 Eccentric strength testing

Hamstring maximal eccentric strength was measured by performing three Nordic hamstring curls where a Nordbord (VALD Performance, Queensland, Australia). The Norbord is a NHE field testing device were the players kneel on a padded board, anchored down by braces attached to load cells aligned vertically at the medial malleolus. The kneecap position is recorded on the Scorebord application on the players profile. Players were all familiar with the testing due to a previous testing battery in pre season. Once in position players were instructed to cross their arms across their chest and try to lower their chest to the floor and back up if possible. Players were instructed not flex from the hip and if they did this was classed as a false trial and was instructed to complete another. Each player completed three repetitions. This was recorded via Scorebord iPad application and stored in the cloud to be accessed later via Dashbord website and downloaded as a csv file. This provided a maximum eccentric hamstring force and torque for both of the limbs individually measured in Newtons (N) and Newton meters (N·m). The players best score was taken for analysis. This method of assessing eccentric hamstring strength is non-invasive and been shown to be valid and reliable with reported typical error values of 21.7N-27.5N and ICC values of 0.83-0.90 (Opar et al., 2013).

3.4 Tensiomyography (TMG)

TMG was used to assess bicep femoris muscle neuromuscular and contractile properties (see Figure 8). Players were instructed to lay face down on a plinth. A trained TMG operator with expert knowledge of anatomical landmarks and muscle architecture first palpated the ischial tuberosity and the lateral condyle before measuring the distance and marking a horizontal line half way between the two points. Then the operator asked the player to flex at the knee while the operator resisted the flexion and palpated the bicep femoris to mark up the lateral and medial borders of this muscle. Halfway between these borders a vertical line was marked intersecting the previous horizontal line. This X is the marked-up muscle belly of the bicep femoris muscle. This was done both on both limbs. The TMG probe was positioned on the X and self-adhesive electrodes were placed at the proximal and distal ends of the bicep femoris and a series of increasing stimulation pulses interspersed by ten seconds (Jones, Hind, Wilson, Johnson, & Francis, 2016). This causes the muscle to contract and move the probe. TMG parameters were recorded from this. A full set up of this method can be seen Figure 8. Maximal displacement (Dm), contraction time (Tc) and time delay (Td) were recorded and used for analysis.

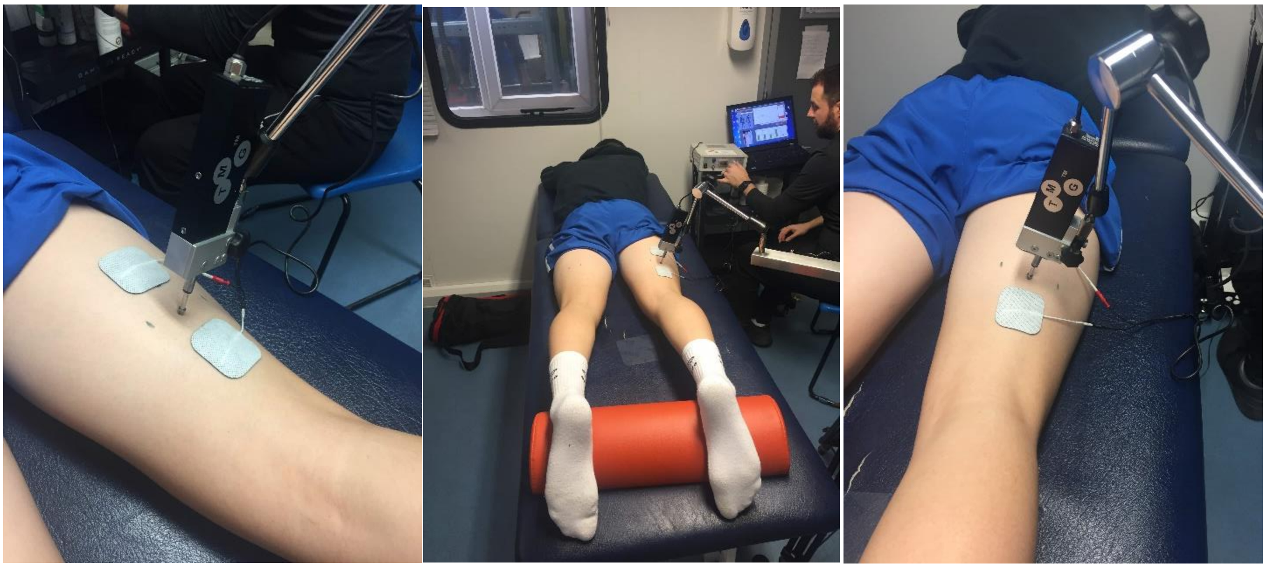

Figure 8 TMG testing set up

3.5 Performance testing

The performance testing battery included Squat Jump (SJ), Counter Movement Jump (CMJ), as well as 10 and 30 m sprint. Both the SJ and CMJ were performed using an OptoJump photocell system (Microgate, Bolzano, Italy) and the protocols for each are shown below and similar to those commonly researched (Van Hooren & Zolotarjova, 2017). The reliability of SJ and CMJ with the OptoJump have been previously examined, with an ICC of 0.989 for SJ and 0.994 for CMJ (Attia et al., 2017).

3.5.1 Squat Jump (SJ)

Players were required to step into the OptoJump system and place both their hands on their hips. The players were instructed to assume a squatting position, with their knees flexed at approximately 90º and then pause for 3 seconds before jumping. A standardised countdown of “2, 1, jump” was used and the players were instructed to jump as high as possible while landing in controlled fashion. Players were reminded to not to flick their heels as this may impair their jump performance. Each player had three jump attempts with a minimum of 2 minutes recovery between jumps to allow each jump to performed at maximal effort. Performance in the jumps was measured as vertical distance jumped (cm) and the highest measurement was used for analysis.

3.5.2 Countermovement Jump without Arms (CMJ)

Players were required to step into the OptoJump system and place both their hands on their hips. A standardised countdown of “2, 1, jump” was used and the players were instructed to jump as high as possible while landing in controlled fashion. Players were reminded to not to flick their heels as this may impair their jump performance. Each player had three jump attempts with a minimum of 2 minutes recovery between jumps to allow each jump to performed at maximal effort. Performance in the jumps was measured as vertical distance jumped (cm) and the highest measurement was used for analysis.

Both 10m and 30m sprint tests were performed using Brower timing gates (Brower Timing Systems, Draper, USA). The reliability of sprint tests with Brower timing gates have been previously examined with a reported ICC of 0.944 (Martin et al., 2019). The procedures for sprint speed testing are similar those previously used (Krommes et al., 2017) and specific instructions are indicated below:

The course for the sprint speed test should be set up as illustrated below in Figure 9. Once set up the players took part in a standardised warm up. When ready players were instructed to start the test with their dominant leg on the start cone. Players were reminded to run at maximal effort through all three sets of gates. Three sprints were performed from which peak acceleration (over 10 m) and speed (time over 30 m) can be determined. Any feedback was only given after all players had completed all tests.

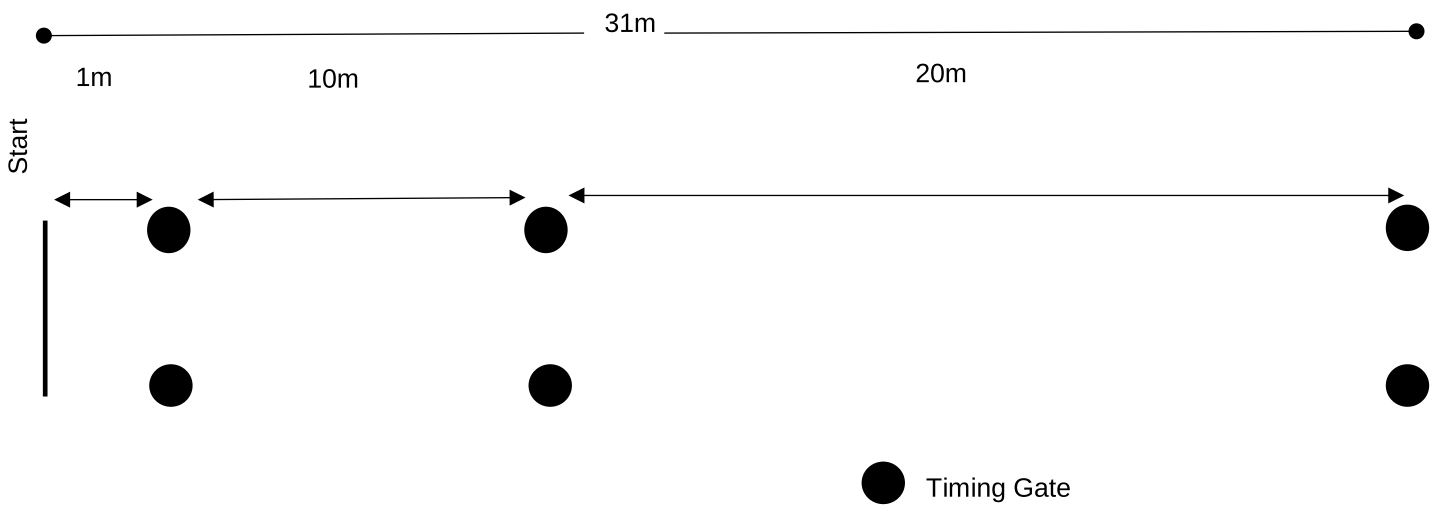

Figure 9 Speed testing set up

3.6 Intervention

The intervention period consisted of the addition of a band assisted NHE as seen in Figure 10. Players were instructed to perform the exercise with a partner. Five repetitions of this exercise were performed during pre-activation warm up sessions which took place before every training session. This pre-activation session also included five repetitions of the Copenhagen adductor groin exercise each side for groin activation, five single leg hops for calf activation and a 30 second wall sit for quadricep activation. All players were instructed to use the appropriate strength band to allow them to complete the assisted NHE with full range of movement in controlled manner, to the floor and back to the start position. All players started on the strongest band (green) and when 5 full range repetitions were completed players were instructed to progress to a lighter band. Therefore, people used different strength bands throughout the intervention (Green>Purple>Black>Red). Players were encouraged to progress to lighter strength bands throughout the intervention period as along as full range of movement was still achieved for all 5 repetitions. Acceptable compliance was set at 70%. One player did not meet acceptable compliance and therefore was removed from subsequent analysis.

Figure 10 Assisted NHE

3.7 Data Analysis

All statistical analysis was carried out using IBM SPSS Statistics 26 (Chicago, IL, USA). Significance was defined at $p<0.05$. Statistical tests included repeated measures ANOVA tests which were used for strength and TMG outcomes however one-way ANCOVA tests were run for all performance outcomes due to significant differences at baseline values identified via paired t test analysis of pre-control and pre-intervention measures. Paired t tests were used for GPS load comparison between control and intervention periods. All data is presented as means ± standard deviation. Effect sizes were calculated for any significant findings using Hedges G, with thresholds indicating <0.2 = trivial, ≥0.2 = small, ≥0.5 = moderate and ≥0.8 = large.

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4.0 Results

All sessions throughout the study period were recorded and tracked. All intervention sessions were supervised by a staff member with attendance recorded and tracked which can be seen in Table 2. Acceptable compliance was set at 70%. Player 12 was removed from all analysis due to unacceptable compliance. Gym attendance was recorded and can be seen in Table 3. GPS was worn for soccer specific field sessions with total time, total distance, accelerations, decelerations, high speed running and sprint distance recorded which is reported for the control period in Table 4 and intervention period in Table 5.

Table 2 Intervention Compliance

Player	Number of sessions	Compliance %
1	23	100.0
2	17	70.6
3	20	100.0
4	21	100.0
5	18	83.3
6	24	100.0
7	24	91.7
8	20	100.0
9	19	100.0
10	24	100.0
11	25	100.0
12	14	42.9
13	22	95.5
14	21	100.0
15	19	84.2
16	25	100.0
Average	21	91.8

Table 3 Gym session attendance

Player	Control period gym sessions	Intervention period gym sessions
1	9	11
2	9	10
3	7	8
4	10	9
5	5	7
6	7	11
7	9	12
8	7	7
9	6	7
10	9	11
11	10	11
12	9	8
13	9	11
14	9	9
15	4	8
16	10	11
Average	8	9

Table 4 GPS control totals

GPS Control Totals						
Player	Total Time (HH:MM:SS)	Total Distance (m)	Accelerations	Decelerations	High speed distance (m)	Sprint distance (m)
1	52:18:25	191930	2286	1678	8428	2067
2	51:36:36	183137	1704	1499	8506	2692
3	42:29:16	174773	1222	1418	6317	940
4	N/A					
5	59:04:34	221690	2089	1697	7763	1778
6	57:48:19	222164	2036	1701	6165	1069
7	53:52:41	208264	1865	2040	9937	1667
8	47:11:57	163682	1756	1230	5221	1318
9	56:28:47	224155	1833	1519	7089	1685
10	40:56:01	123363	1060	869	3653	1219
11	53:46:32	178015	1046	999	3465	223
12 (REMOVED)	39:18:50	135691	1200	940	6493	2255
13	43:07:16	177697	1396	1294	4756	1398
14	49:20:16	177289	1288	1386	4563	924
15	48:48:51	184344	1140	1016	4934	1127
16	40:48:55	174526	991	1113	3697	803
Average	49:07:49	182715	1527	1360	6066	1411
Standard Deviation	06:34:32	29076	431	337	1980	629

Table 5 GPS intervention totals

GPS Intervention Totals						
Player	Total Time (HH:MM:SS)	Total Distance (m)	Accelerations	Decelerations	High speed distance (m)	Sprint distance (m)
1	53:16:56	184629	2434	1732	11348	2464
2	48:31:18	161311	1603	1532	8519	2224
3	41:20:13	152588	1149	1315	6357	762
4	N/A					
5	51:41:23	204486	1959	1809	9001	2104
6	51:42:33	218578	1995	1905	8925	1416
7	54:11:35	193591	1667	1962	11508	2020
8	47:18:47	146321	1806	1209	3675	483
9	53:39:31	198335	1888	1604	6353	1233
10	52:44:58	176592	1915	1704	5748	1263
11	54:06:35	193880	1741	1788	8838	1692
12 (REMOVED)	45:32:16	160351	1240	1094	8019	2377
13	33:57:00	140622	1096	1042	4390	939
14	44:50:06	177306	1255	1323	5080	1029
15	56:01:44	212128	1600	1693	8019	1588
16	37:23:03	130069	857	883	2969	513
Average	48:25:12	176719	1614	1506	7250	1474
Standard Deviation	06:38:51	27225	421	339	2591	661

Player 4 did not wear GPS throughout both control and intervention periods as this was applicable to goalkeepers. Paired t tests were run for all metrics. There was 1184 meter difference between average high speed running distances in the intervention and control periods. This difference observed in high speed distance was statistically different (p=0.022). All other metrics were more closely matched and no significant differences were observed.

4.1 Strength Outcomes

One player was unable to perform strength testing due to pre-existing injury history. Fourteen players carried out the strength testing protocol and the results which can be seen in Table 6 and Figure 11. There was small negative change (-17N & -32N) in maximum hamstring force during the control period compared to a positive change (+15N & +34N) after the NHE control period. Statistical analysis found a significant interaction effect for right limb force output (p = 0.034) but not for the left limb (p = 0.471). Thus, the intervention improved right limb force output from pre (348±68N) to post (382±63N p=0.038; ES: 0.66; M*diff* = 26N, 95% CI_{diff} = 1 – 50), with no change during the control condition. Small changes in maximum hamstring torque were observed throughout the study.

Table 6 Strength results

Measure	Pre-Control (n=14)		Post Control (n=14)		Pre-Intervention (n=14)		Post Intervention (n=14)	
	Left	Right	Left	Right	Left	Right	Left	Right
Max Force (N)	347±90	363±72	330±90	331±85	350±87	348±68	365±71	382±63
Max Torque (Nm)	141±39	148±32	136±38	136±34	146±39	146±30	151±31	159±30

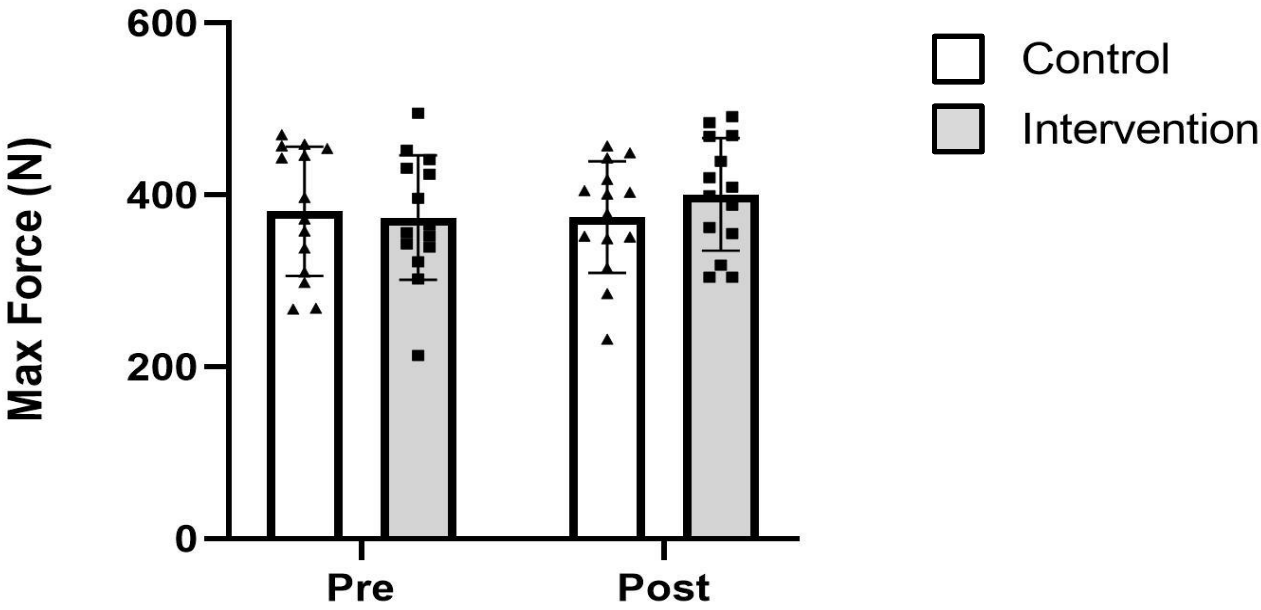

Figure 11 Maximal hamstring force. Squares and triangles are individuals in both control and intervention periods.

4.2 Activation Outcomes

Due to illness one player missed the post control TMG testing and therefore was removed from all TMG analysis (see Table 7). Changes in maximal displacement (Dm) were seen during the study, with larger changes during the NHE intervention period (-0.69mm & -0.52mm) compared to the control (+0.10mm & -0.11mm; see Figure 12). Repeated ANOVA tests found these changes were not statistically significant as no significant interaction effect was observed on Dm for both left (p = 0.407) and right limbs (p = 0.548). Similar findings were observed for delay time (Td) with a small change (+0.21ms & -0.35ms) during the control period versus a larger change (-0.63ms & -3.28ms) after the NHE intervention period (see Figure 13). Again, no significant interaction effect was found on Td in the left limb (p = 0.514) and right limb (p = 0.434). The final TMG parameter assessed was contraction time (Tc), which observed changes of -1.17ms & -2.31ms in the control period and +0.01ms & -3.76ms after the intervention period (see Figure 14). Once more no significant interaction effect was found for Tc in the left limb (p = 0.891) or right limb (p = 0.706).

Table 7 TMG outcomes

Measure	**Pre-Control (n=14)**		**Post Control (n=14)**		**Pre-Intervention (n=14)**		**Post Intervention (n=14)**	
	Left	**Right**	**Left**	**Right**	**Left**	**Right**	**Left**	**Right**
Dm (mm)	3.42 ±2.01	2.77 ±1.78	3.52 ±2.47	2.66 ±2.20	3.81 ±2.20	3.86 ±2.04	3.12 ±2.83	3.34 ±3.36
Td (ms)	21.11 ±2.77	20.18 ±2.11	21.32 ±2.39	19.83 ±2.68	22.14 ±2.70	25.53 ±9.90	21.51 ±2.81	21.71 ±3.30
Tc (ms)	30.16 ±13.64	24.78 ±11.12	28.99 ±12.02	22.47 ±10.54	32.32 ±16.74	31.49 ±10.74	32.33 ±16.19	27.73 ±14.56

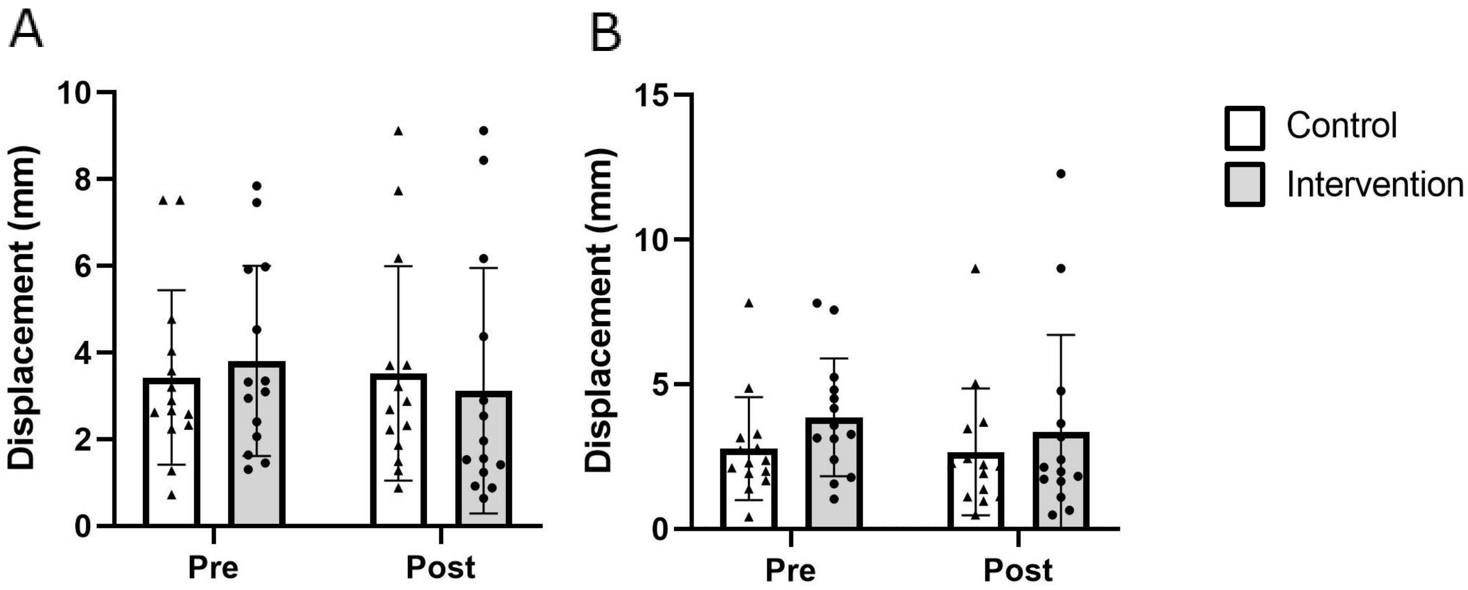

Figure 12 Maximal displacement (Dm) results. A = left limb. B = right limb. Squares and triangles are individuals in both control and intervention periods.

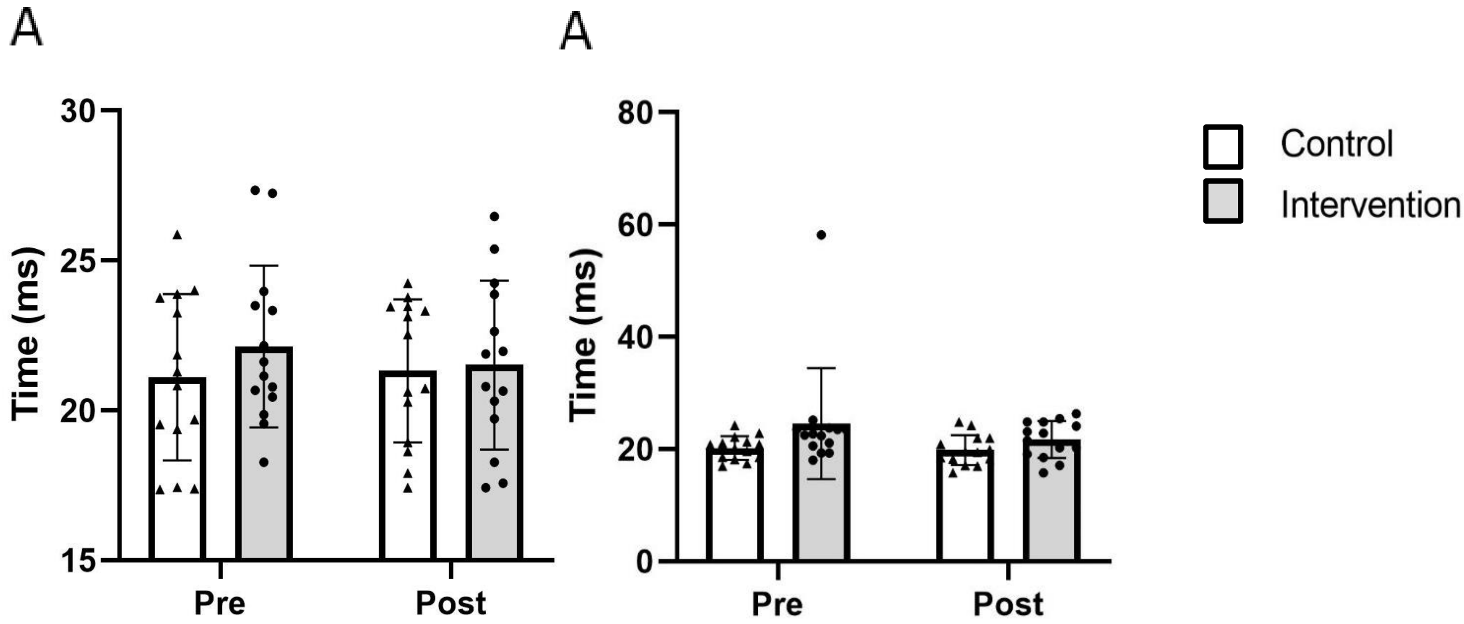

Figure 13 Delay time (Td) results. A = Left limb. B = Right limb. Squares and triangles are individuals in both control and intervention periods.

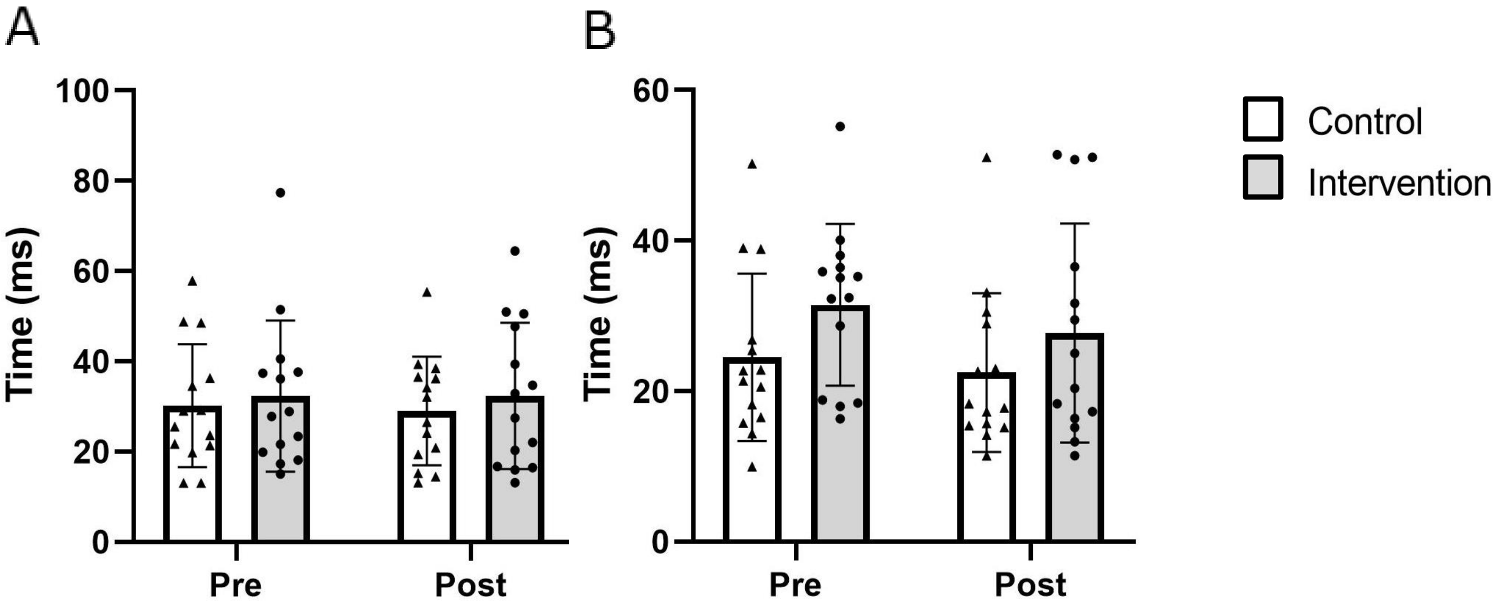

Figure 14 Contraction time (Tc) results. A = Left limb. B = Right limb. Squares and triangles are individuals in both control and intervention periods.

4.3 Performance Outcomes

All players completed jump testing (see Table 8) however two players were unable to complete speed testing (see Table 9) at all time points due to injury and have been removed from all analysis. Jump height changes were similar for both jump measures with positive changes observed in both squat jump (+3.5cm) and CMJ (+3.3cm) after the NHE intervention period compared to small negative changes after the control period (Figure 15). Also, both speed measures improved after NHE intervention albeit both improvements were very small with a -0.02 seconds change in 10m speed and -0.09 second change in 30m speed (Figure 16).

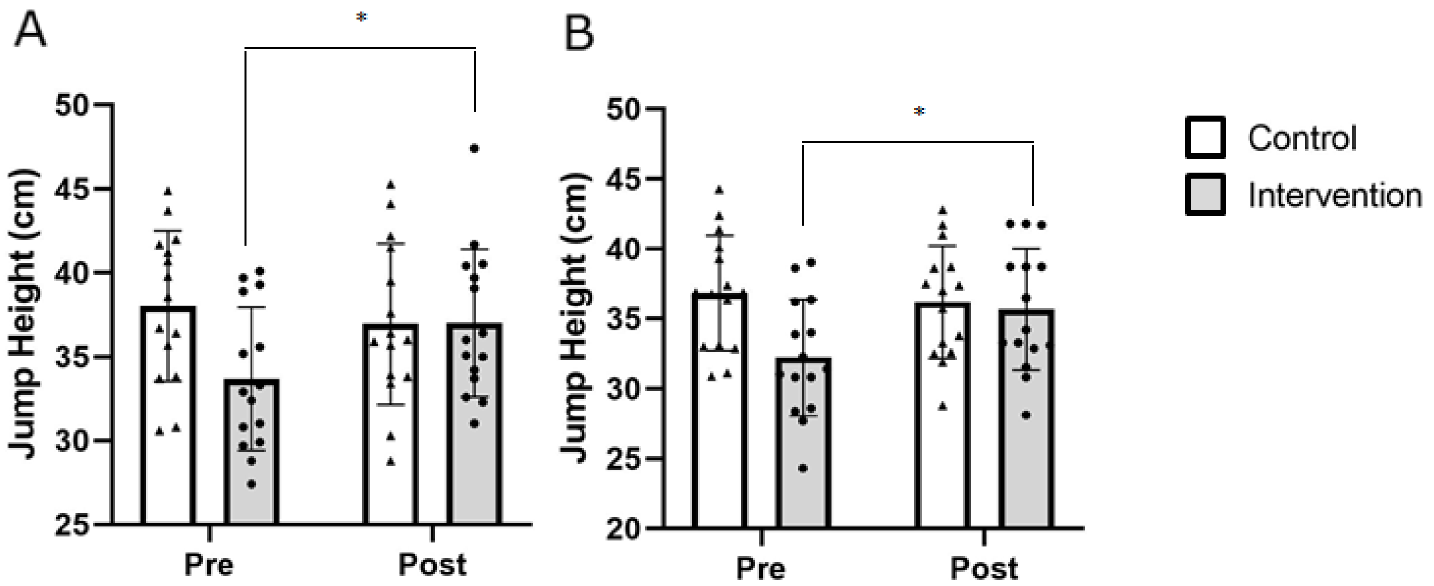

Figure 15 Jump testing results A = CMJ. B = SJ. * denotes significance (p<0.05). Squares and triangles are individuals in both control and intervention periods.

Table 8 Jump testing results

Measure	Pre-Control (n=15)	Post Control (n=15)	Pre-Intervention (n=15)	Post Intervention (n=15)
Squat Jump (cm)	36.9 ±4.1	36.2 ±4.0	32.2 ±4.2	35.7 ±4.4
CMJ (cm)	38.0 ±4.5	37.0 ±4.8	33.7 ±4.3	37.0 ±4.4

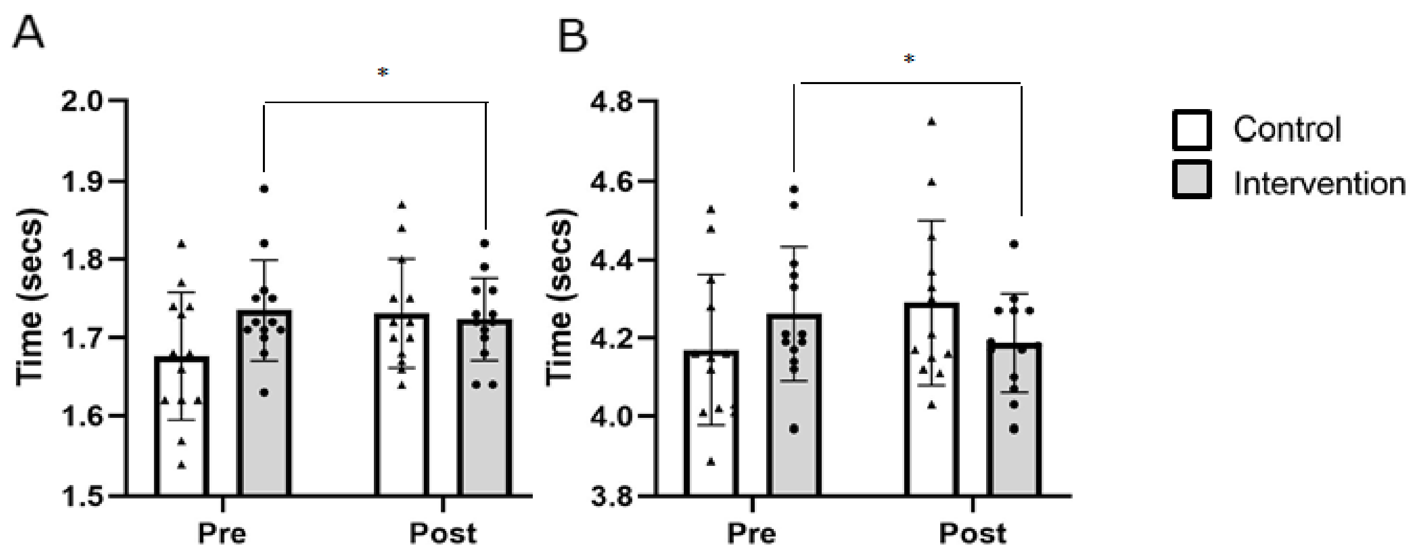

Figure 16 Sprint testing results. A = 10m sprint time. B = 30m sprint time. * denotes significance (p<0.05). Squares and triangles are individuals in both control and intervention periods.

Table 9 Speed testing results

Measure	Pre-Control (n=13)	Post Control (n=13)	Pre-Intervention (n=13)	Post Intervention (n=13)
10m Speed (secs)	1.68 ±0.08	1.73 ±0.07	1.74 ±0.07	1.72 ±0.05
30m Speed (secs)	4.17 ±0.19	4.30 ±0.21	4.28 ±0.17	4.19 ±0.13

All performance outcomes were found to be statistically significant differences at baseline (pre-control and pre-intervention) by paired -test analysis. Due to these differences all performance outcomes were analysed with one-way ANCOVA tests. All performance outcomes were found to be significantly affected by the intervention. The intervention was considered to improve squat jump by 3.2cm (p=0.008; ES: -0.12; M*diff* = -3.1cm, 95% CI_{diff} = -5.4- -0.9) and CMJ by 3.6cm (p=0.006; ES: 0.00; M*diff* = -3.6cm, 95% CI_{diff} = -6.0 - -1.5). Additionally, the intervention was estimated to improve 10m speed by 0.048s (p=0.005; ES: -0.16; M*diff* = 0.048s, 95% CI_{diff} = 0.015-0.08) and 30m speed by 0.18s (p≤0.001; ES: -0.61; M*diff* = 0.18s, 95% CI_{diff} = 0.12-0.24).

5.0 Discussion

The aim of the study was to the assess the effect of an assisted NHE when used as part of a pre-activation warm up on hamstring muscle strength and neuromuscular activation and in turn its effects on soccer-specific performance. The theory behind the use of the assisted NHE was that anecdotally the full range of movement of the NHE is not commonly completed, chest to the floor. Thus, the traditional NHE doesn't train the hamstring muscles at long lengths specific to those in sprinting. The absence of the full range of movement is due to lack of strength at long muscle lengths or muscle fatigue caused by the prescription of large numbers of repetitions as found in many common NHE programmes causing a high NHE breaking point. The rationale for using the NHE as part of a pre-activation warm up was that the NHE is a very intense exercise which activates the hamstring muscles and therefore should help prevent hamstring injury in the subsequent training session. Additionally, it was theorised that the assisted NHE would increase hamstring muscle strength as well as training the hamstring muscles at lengths specific those found in sprinting and therefore improve athletic performance and in turn soccer-specific performance.

As the intervention was specifically focussed on hamstring strength it would be expected that hamstring strength would improve significantly after the intervention, however this was not the case for both limbs. Despite there being small improvements in both limbs +15N in the left limb and +34N in the right limb, only the right limb improvement was deemed to be statistically significant. This is compared to small decreases in both limbs -17N and -32N after the control period. The change in left limb was not statistically significant and with reported typical error values of 21.7N-27.5N (Opar et al., 2015) it is difficult to attribute this small change to the NHE intervention. This finding is extremely surprising considering the right limb was observed to have a significant change and the assisted NHE is a bilateral exercise so changes in both limbs would be expected to be the same. This surprising finding is difficult to explain however one suggested idea maybe that 11 of the 14 players used in this study had were right limb dominant. However, a recent systematic review suggests that limb dominance doesn't effect strength between limbs (DeLang, Rouissi, Bragazzi, Chamari, & Salamh, 2019).

There is a plethora of literature showing improvements in hamstring strength after an NHE intervention; therefore, improvements in strength after the assisted NHE intervention would have been predicted (Bourne et al., 2017; Iga et al., 2012; Ishoi et al., 2018; Mjolsnes et al., 2004; Pollard et al., 2019; Presland et al., 2018; Severo-Silveira et al., 2018; Siddle et al., 2018). However, despite this +34N improvement in strength in the right limb being found to be statistically significant and above the typical measurement error of the NHE field testing device it is noticeably smaller in magnitude compared to other published literature using an NHE field testing device (Bourne et al., 2017; Ishoi et al., 2018; Pollard et al., 2019; Presland et al., 2018). Previous literature reported changes using the NHE field testing device of +20% (Ishoi et al., 2018), +15% (Pollard et al., 2019), +27% (Bourne et al., 2017) and +34% (Presland et al., 2018) after NHE intervention. All these changes are larger than the 4% and 10% improvements found the left and right limbs after the assisted NHE. It should be noted there are important differences between this study and other previously researched such as the participant population, intervention volume, timing, intensity and progression which may have been significant factors in producing these unexpected and surprising strength findings in both limbs.

At the current point of writing this thesis there are no NHE intervention studies investigating an assisted NHE intervention amongst elite athletes. Traditionally the NHE is a bodyweight exercise which is considered a maximal exercise. Whereas the assisted NHE is designed to help the athlete complete the full range of movement of the exercise and specifically help the athlete in the lower phases of the exercise where muscle lengths longer (Matthews et al., 2015). These muscle lengths are more specific to sprinting and the lengths at which hamstring injuries commonly occur (Chumanov, Schache, Heiderscheit, & Thelen, 2012). Full range of movement is not commonly achieved during the NHE as it requires very high levels of eccentric strength, hence the need for assistance. The assistance during this intervention was done via strength band (elastic band) (Matthews et al., 2015). Using a strength band allows the assistance of exercise to increase as the stretch in the band increases as the range of movement increases (chest gets closer to the floor). Despite advantages of the assisted NHE being clear, it of course has its trade-offs. The assisted NHE although allowing full range of movement actually decreases the exercise intensity and it is no longer a maximal exercise. The reduced intensity could be an important factor regarding the lack of strength improvements after the assisted NHE intervention. Increasing the intensity of the traditional NHE by adding external weight has been shown to improve hamstring strength compared to the traditional bodyweight NHE. This indicates that intensity is a notable factor effecting strength improvements after an NHE intervention (Pollard et al., 2019). However, due to the lack of research on the assisted NHE it is difficult to exactly distinguish whether assisting and in turn reducing the intensity of the NHE reduces the strength adaptations of this exercise.

Another important difference of the NHE intervention used in this study is the volume and workload of the intervention. Traditionally NHE interventions have had large volumes (sets and repetitions) with many totalling over 400 repetitions, with some managing to amass upwards of 700 repetitions (Bourne et al., 2017; Ishoi et al., 2018; Mjolsnes et al., 2004; Presland et al., 2018; Siddle et al., 2018). Despite these studies, there is a growing trend to use smaller workloads as they have been shown to be equally as effective at improving hamstring strength (Iga et al., 2012; Pollard et al., 2019; Presland et al., 2018). These studies all totalled less than 160 repetitions with the smallest intervention workload totalling only 128 repetitions. The NHE intervention in this study had total repetitions ranging from 85 to 125 repetitions depending on compliance, with the average number of repetitions equalling 105. Therefore, the volume in this study was lower than previous studies investigating NHE interventions. Despite the low volume in this study it is difficult to establish this as the main factor for the smaller magnitude of strength adaptations because no minimal effective dose has been established for low volume NHE interventions, even though low volumes have been shown to be effective at increasing eccentric hamstring strength (Cuthbert et al., 2019). It should be noted that only one low volume NHE intervention study used elite level soccer players similar to that used in this study (Iga et al., 2012). The overall volume totalled 160 repetitions which is larger than in this study. Along with the total volume being larger there is a key difference in the way the volume is delivered, as in the study by Iga et al 2012 the intervention length was only four weeks and thus equalling an average 40 repetitions per week whereas the average repetitions per week in this study is half of that used at 17.5 repetitions per week. Other study interventions have had similar volumes with 17.25 repetitions per week (Severo-Silveira et al., 2018) and 21.3 repetitions per week (Pollard et al., 2019; Presland et al., 2018). Both studies averaging 21.3 repetitions per week found improvements in eccentric hamstring strength however both improvements were not deemed to be statistically significant. Nonetheless, it should be noted that both studies used recreational athletes meaning they are likely to be novices regarding resistance training and rarely taken part in a structured strength and conditioning programme and therefore more likely to benefit from this intervention due to a possible lower starting point compared to elite athletes with a longer training history (Kraemer & Ratamess, 2004). The other study which had weekly volumes averaging 17.25 repetition used athletes but did not result in any hamstring strength improvements. These findings were similar to that found after assisted NHE but although this study used athletes, they were rugby union players playing in the Brazilian premier league and the authors do not state whether they were full time professional athletes (Severo-Silveira et al., 2018). To summarise, the assisted NHE intervention in this study can be considered less intense than previous NHE interventions due to the low total volume, low repetitions per week and the assistance of the NHE. This may have resulted in not providing enough stimulation to the hamstring muscles to promote strength adaptations similar to that reported in previously published studies. Another interesting difference in the way the intervention was structured in this study was that the frequency was very high with a constant minimal dose delivered daily rather than the traditional strength training prescription of two or three exposures a week with several sets of numerous repetitions which progresses throughout the programme to provide overload.

Due to the high frequency of the intervention in this study a constant one set of five repetitions was used with the only progression in workload being if the player could complete five full range repetitions meaning they could progress to a lighter strength band providing less assistance. Since the assisted NHE intervention was limited in its progression of workload it could be theorised that this intervention did not provide enough progressive overload of the hamstring muscles to stimulate strength adaptations in either limb as changes in the right limb were smaller in magnitude to that seen in other published NHE interventions and in the left limb no significant strength changes were observed. Progressive overload is an established principle of resistance training known to be very important for strength improvements and can be achieved by manipulating programme variables that culminate in total workload.(Kraemer & Ratamess, 2004). This is supported by Severo-Silveira et al. (2018) who investigated the effect of a constant vs progressive NHE workload. The findings from this paper confirmed that progression in workload is an important factor as they found no change in eccentric hamstring strength in the constant workload group compared to the progressive workload group which had an increase eccentric hamstring strength.(Severo-Silveira et al., 2018) On the other hand, these findings should be viewed with caution as there was a crucial flaw with the study design as the constant and progressive workload groups had different total workloads with progressive workload totalling more than 100 more repetitions across the study. This maybe a significant factor in the findings of the study rather than solely the progression of the workload. Despite the study limitations the authors concluded that progressive workload in NHE programmes is important for high level competitive athletes (Severo-Silveira et al., 2018). Interestingly, this paper also investigated muscle architecture changes and found an increase in bicep femoris fascicle length in both the constant and progressive workload groups (Severo-Silveira et al., 2018). This suggests that the NHE promotes positive hamstring muscle changes which may help prevent hamstring injury even when the workload is low and constant without progressive overload. Although no strength changes were detected after the assisted NHE intervention these findings by Severo-Silveira et al (2018) suggest there may still be some muscle architecture changes; however, this is impossible to decipher as there are was no muscle architecture assessment in this study.

Additionally, when interpreting the results from the assisted the NHE intervention the timing of the intervention should be considered. As the intervention was delivered as part of a pre-activation warm up, it was undertaken before soccer-specific field training and therefore when the hamstrings were in a non-fatigued state. This factor should have had no effect on the strength adaptations as the majority of NHE interventions occur before any sport specific training (Iga et al., 2012; Severo-Silveira et al., 2018; Siddle et al., 2018). Furthermore, it has been shown that the timing of the NHE whether that be before or after exercise has no effect on strength changes as both are equally as effective at improving strength (Lovell et al., 2018). Despite this it has been suggested that the timing of the NHE intervention does have an effect on the muscle architecture changes behind the subsequent strength adaptations (Lovell et al., 2018). Findings indicate that performing the NHE after exercise when the hamstrings are in an already fatigued state has more hypertrophic adaptations, including increased muscle thickness and pennation angle. Whereas performing the NHE before exercise when the hamstrings are not fatigued is suggested to stimulate an injury prevention adaptation of increased fascicle length (Lovell et al., 2018). Again, this suggests that although strength changes detected were small in magnitude after the assisted NHE intervention compared to other studies, there is the possibility some muscle architecture changes occurred such as increases in fascicle length; however, it cannot be said with any certainty as there was no muscle architecture assessment in this study.

Alternatively, the changes in eccentric strength although not statistically significant in both limbs, maybe in fact be meaningful because typical error values have been reported as 21.7N-27.5N.(Opar et al., 2013) Curiously both limbs did not have equal improvements with the right limb showing a significant change of +34N which is larger than the typical error and the left limb having a non-significant change by +15N which is less than the typical error. This suggests that the changes in the right limb are meaningful but caution should be taken when interpreting these results because the smaller magnitude of change and the results observed in the left limb, which are not significant and smaller than the typical error. Thus, would not be classed as meaningful. These findings are unexpected considering the assisted NHE is a bilateral exercise so should train both limbs equally and the eccentric strength testing was assessed using a bilateral NHE on the NHE field testing device which measures strength in both limbs simultaneously.

On the other hand, because the typical error is larger than left limb hamstring strength improvement after the assisted NHE intervention, it would suggest that this change is not meaningful and could be attributed to measurement error. It should be noted that these typical error values were calculated using 30 sub elite males (Opar et al., 2013) and error values may be different in professional soccer players who have a history of undertaking structured concurrent training programme. Therefore, it would be logical to assume that professional soccer players would have higher baseline strength levels due to exposure to formal strength training as well regular sprinting which has been associated with high levels of eccentric hamstring strength (Freeman et al., 2019). Surprisingly, normative data from the sub-elite males (344.7N ± 61 and 361.2N ± 65; (Opar et al., 2013) was similar to the baseline values of professional soccer players (347N ± 90 and 363N ± 72) used in this study. Despite baseline strength levels being similar, earlier quoted typical error values may not be applicable to elite level soccer players as exposure to regular structured concurrent training could cause meaningful changes to be smaller in professional soccer players.

When looking at the strength changes on an individual player basis after the assisted NHE intervention there were seven players who had strength changes smaller than the typical error and six who had positive changes above the typical error. Whereas after the control period twelve out of the thirteen players had strength changes below the typical error. This highlights the individual responses to strength training (Ahtiainen et al., 2016; Erskine, Jones, Williams, Stewart, & Degens, 2010). It should be noted that individual responses to strength training have not been researched in athletic populations (Ahtiainen et al., 2016; Erskine et al., 2010). Nevertheless, the findings after an assisted NHE intervention were similar to that by Seymore et al. (2017), who, after an NHE intervention, classified players into two groups, either a high responder or a low responder (Seymore et al., 2017). This may explain the variation in eccentric strength changes after an assisted NHE intervention; however, more research is required around individual responses to strength training especially in elite athletic populations involved in regular concurrent training. It should be noted that not all players used the same level of assistance throughout the intervention and this differing level of assistance could in fact be the reason behind the different magnitudes of response.

Finally, it could be possible that the method of testing used could not detect these changes. For instance, eccentric hamstring strength may have improved after the intervention but at longer muscle length as was the intervention design. This could be undetectable via the NHE hamstring field testing device if players still have the same NHE breaking point. The NHE breaking point is defined as the angle at which the free fall occurs without the eccentric action of the hamstrings in the NHE. The test for hamstring eccentric strength was an unassisted NHE on the NHE field testing device and if the NHE break point is high, the range of movement would be small and any strength changes at long muscle lengths and thus beyond the NHE break point maybe undetected by the NHE field testing device. This change in strength at long muscle lengths would be known as a change in the tension length relationship or the angle at which peak torque is produced in which the NHE has previously been shown to be effective at changing in the hamstring muscles. (Brockett, Morgan et al. 2001, Clark, Bryant et al. 2005) Meaning that after an NHE intervention the angle at which peak torque produced by the hamstring muscles is larger, more knee extension. (Brockett, Morgan et al. 2001, Clark, Bryant et al. 2005) Thus the hamstring muscles produce more force at longer muscle lengths and angles more specific to sprinting. This supported by the significant improvements in sprint speed found in this study. This effect maybe increased by the assisted NHE intervention which was specifically designed to train muscles at longer lengths.(Matthews et al., 2015) Therefore, it is rationale to suggest that the assisted NHE could elicit adaptations and strength improvements at longer muscle lengths which could have potential performance benefits. However, these changes could be undetectable using the unassisted NHE testing protocol on the NHE field testing device because if the players have a high NHE breaking point they would not enter the range of movement at which long muscle lengths occur hence any strength improvements at this range of movement would be undetectable.

Alternatively, the assisted NHE intervention used in this study may have had minimal or no effect on eccentric hamstring strength changes observed and these changes may actually be product of the high speed running differences between the control and intervention periods. The difference in high speed running between periods was an average of 1184 meters and this was found to be statistically significant. High speed running has been shown to be an effective method of improving hamstring eccentric strength and equally as effective as an NHE programme (Freeman et al., 2019). Thus, the changes in eccentric hamstring strength observed in this study could be attributed to the high speed running differences rather than the intervention or a combination of both.

TMG parameters after the intervention showed no significant changes compared to the control. This is not surprising as muscle contractile properties would most likely be linked to strength changes and these were small in magnitude in this study. It would have been anticipated that maximal displacement (Dm) would decrease as the bicep femoris would increase in stiffness.(Pisot et al., 2008) This has been shown to be case following resistance training protocols and specifically those inducing eccentric muscle contractions.(de Paula Simola et al., 2015) Hence an assisted NHE intervention would be expected to increase the stiffness of the bicep femoris and therefore decrease the Dm. The lack of significant change in Dm is most likely down to intervention design variables previously mentioned such as volume and intensity. This is supported in the literature as Dm has previously been shown to be more sensitive to resistance training programmes involving high repetitions, high intensity and eccentric contractions.(de Paula Simola et al., 2015) Therefore the low intensity and low volume of the assisted NHE intervention is likely to be reason for the lack change in muscle contractile properties observed in this study such as changes in Dm. Previously bicep femoris Dm values have been reported as 5.30 in Spanish professional soccer players.(Garcia-Garcia et al., 2016; Rey et al., 2012) This would suggest that the players used in this study had stiffer hamstrings at pre-control than those reported in the Spanish professional soccer players. Therefore, this could mean that improvements in Dm could be more difficult to observe due to the already high levels of stiffness at baseline.

As with Dm, Delay time (Td) and contraction time (Tc) would have been anticipated to decrease after intervention as the bicep femoris becomes more responsive (Garcia-Manso et al., 2011) and the speed of contraction increases (Macgregor et al., 2018; Pisot et al., 2008) due to an increase in muscle stiffness as well as possible muscle fibre composition changes towards more fast twitch fibres. However, this did not occur which is most likely as any changes would be associated with changes in strength. Previously reported Td values from Spanish professional soccer players are 21 - 24.7ms (Garcia-Garcia et al., 2016; Rey et al., 2012) which are similar to those reported in this study. Additionally, previously reported Tc values in the bicep femoris range from 26.6 - 29.8ms in Spanish professional soccer players (Garcia-Garcia et al., 2016; Rey et al., 2012) which are similar to those observed in this study. This indicates that the players in this study are well trained and already had stiff, responsive and fast contracting bicep femoris muscles which may have made any improvements more difficult to occur.

Overall TMG parameters have been shown to be sensitive to changes in muscle strength especially when strength training has included high repetition, high intensity and eccentric contractions (de Paula Simola et al., 2015). However, there was no significant changes in Dm, Td and Tc observed after the assisted NHE intervention. The reasoning behind this appears to be similar to that which resulted in the strength changes being smaller than expected in magnitude and only significant in the right limb. Which is most likely due to the NHE being assisted and the intervention having an overall low total repetitions, low volume and low intensity thus it is reasonable to suggest this combination didn't provide enough stimulation to provoke any substantial muscle contractile changes.

Other significant changes in this study were observed after the assisted NHE intervention compared to the control period. These came in all performance related outcome measures SJ, CMJ, 10m sprint and 30m sprint. The improvements in these performance measures are consistent with the literature (Clark et al., 2005; Ishoi et al., 2018; Krommes et al., 2017; Siddle et al., 2018).

Normally studies which have measured both hamstring strength and sprint speed found that both outcome measures improved after NHE intervention (Ishoi et al., 2018; Siddle et al., 2018). Ten-meter sprint speed improved after the assisted NHE intervention period by 0.02 seconds; this was consistent with the literature but a smaller change than previously reported improvements of 0.047 seconds (Ishoi et al., 2018), 0.09 seconds (Krommes et al., 2017) and 0.06 seconds (Siddle et al., 2018) It should be noted that even though ten meter sprint speed results showed significant improvements after the assisted NHE intervention compared to the control, the fastest results for the ten meter sprint speed were at the pre-control timepoint. This difference between pre-control and pre-intervention timepoints was found to be statistically significant and hence the improvements in ten-meter sprint speed should be viewed with caution. Despite this, the magnitude of change being different in previous studies compared to that found in this study maybe explained partly by total volumes of the NHE intervention, with much larger volumes used in the previously reported studies compared to the volume in this study. Previously reported total volumes were 520 repetitions (Siddle et al., 2018) and 726 repetitions (Ishoi et al., 2018; Krommes et al., 2017) whereas there was only 105 repetitions in the assisted NHE intervention. Furthermore, the participants used in these studies were amateur athletes (Ishoi et al., 2018; Siddle et al., 2018) therefore likely to be novices regarding strength training and unlikely to have regular exposure to concurrent training and thus more likely to have larger improvements due to a lower starting point compared to professional athletes who are more accustomed to this type of training (Kraemer & Ratamess, 2004).

One study did use professional soccer players from the second Danish division but even though these players were described as professional they were also described as part time by the authors and hence their exposure to regular concurrent training maybe more similar to amateur athletes than full time professional athletes. (Krommes et al., 2017). Furthermore, the authors delivered the intervention during the Danish league mid-season break when the players would not be undertaking a normal soccer specific training and games programme and most likely be less fatigued, making adaptation to the intervention more likely. Interestingly this study also assessed 30-meter sprint speed and did not find any improvements in same Danish professional soccer players whereas significant changes were seen after the assisted NHE intervention used in this study, with 30-meter sprint speed improving by 0.09 seconds. Despite this improvement in 30-meter sprint speed it should be interpreted with caution because once more the fastest results for the 30-meter sprint speed were at the pre-control timepoint. The 30-meter sprint speed difference between the timepoints of pre-control and pre-intervention was statistically significant and hence this finding should be interpreted with caution. However, a proposed theory for this change in 30-meter sprint speed could be due to change in the tension length relationship of hamstring muscles. As previously mentioned the NHE has previously been shown to be an effective method in changing the tension length relationship of the hamstring muscles (Brockett et al., 2001; Clark et al., 2005). Effectively, after an NHE intervention the angle at which peak torque produced by the hamstring muscles is larger, with more knee extension (Brockett et al., 2001; Clark et al., 2005). Thus, the hamstring muscles produce more force at angles more specific to sprinting especially those of maximum velocity. This effect could be enhanced as the assisted NHE is an exercise is designed to help train the hamstring muscles at specific lengths, similar to those used in sprinting. This could explain the differences in 30m sprint speed results from this study and that by Krommes et al. (2017).On the other hand, it should be noted that there were significant differences in high speed running volumes between control and intervention periods in this study with players completing on average an additional 1184 meters of high speed running during the intervention period; this may have had an effect on the sprint speed results especially the 30-meter sprint speed.

Squat jump (SJ) and countermovement jump (CMJ) improved after the assisted NHE intervention compared to the control with a significant effect shown by the intervention. Once more, this is consistent with the literature as previously reported CMJ changes have been reported to improve by 2cm (Krommes et al., 2017) and vertical jump height improved by 3cm (Clark et al., 2005). In this study after the assisted NHE intervention SJ improved by 3.5cm and CMJ improved by 3.3cm. Although this is similar to other studies it is difficult to directly compare these results as previous studies tested jump heights using varying protocols and with different equipment. The OptoJump photocell system was used in this study whereas a force plate was used with the Danish professional soccer players (Krommes et al., 2017) and the Vertec jump system was used with the 9 non athletes (Clark et al., 2005). Additionally, as previously mentioned these studies did not use full time professional soccer players and both had intervention volumes much larger than the assisted NHE intervention used in this study therefore it is slightly surprising that improvements in CMJ (Krommes et al., 2017) and vertical jump (Clark et al., 2005) were not larger because the participants would most likely be considered novices to strength training and therefore the intervention could have had a larger effect than on the athlete who are familiar with this type of training (Kraemer & Ratamess, 2004).

As previously mentioned regarding sprint speed findings in this study the pre-control SJ and CMJ results were the largest, meaning the players jumped highest at this timepoint. Regardless of the significant improvements after the intervention players did not jump higher than at the start of the control. This difference between pre-control and pre-intervention timepoints was found to be statistically significant through paired t-test analysis therefore repeated ANCOVA analysis was used instead of the repeated ANOVA analysis. Hence the improvements in SJ and CMJ should be viewed with caution as the intervention did not improve SJ and CMJ performance to that observed at the pre-control testing. A possible explanation for the performance outcomes in this study appearing to firstly get worse in the control period before improving after the assisted NHE intervention, could be the period of the season in which the study was undertaken. The control period occurred from mid-October till the beginning of December whereas the intervention period occurred from mid-January till mid-March. The control period occurred in mid-October and ended at the beginning of December resulting with the players having already undertaken 24 weeks of soccer specific training which could have resulted in some fatigue from the chronic workload accrued from training and matches. Whereas the intervention period occurred after two weeks of soccer specific training and importantly after a two-week Christmas break when players did not undertake a full-time soccer specific training programme. Thus, the players might have been less fatigued due to smaller workload while on two-week Christmas break. Therefore, despite the GPS tracking and gym attendances showing that on field training and gym workloads were similar throughout both the control and intervention periods, players may have been more fatigued during the control period and importantly the post-control testing due to the build-up of fatigue from the previous 24 weeks of the soccer season.

5.1 Limitations

Limitations of the study are numerous as normal with concurrent training programmes. Due to this concurrent training programme the study design was a crossover design that used same players in the control and intervention. Thus, these two periods had to occur at different timepoints in the football season. The timing of the study could have been an important factor as the control period took place after numerous weeks of soccer specific training in which fatigued could have already been accumulated whereas the intervention occurred after a two-week Christmas break. This of could have had an effect on the results due to baseline fatigue levels being different at the start of control and intervention periods.

Strength sessions are an important part of the concurrent training programme and occurred throughout the study with gym attendance being tracked but not the actual load lifted in the gym. This was not monitored due to poor compliance using a self-reporting cloud-based system. Although strength programmes were consistent throughout the study (see Appendix 1) it is very difficult to tell whether loads were significantly different and therefore if they had any effect on the study findings.

As with concurrent training programmes training was not exactly the same in both control and intervention periods due to a variety factors of which some include match scheduling, player availability, facilities availability and coaching themes however both periods were monitored using GPS and only one significant difference was identified between the two training blocks, this being high speed running. As with all sports, soccer involves matches in which only 11 players and 5 substitutes can participate therefore not all players can be involved in all games therefore players will not have the same exposure of match minutes in each training block however this was included in the GPS monitoring.

The number of players in the study was a small sample size so repetition of this study would be required to repeat the results to add more confidence in the findings from this study. Additionally, the profile of the players used in the sample was very homogenous with all players very similar in age and training experience. Thus, these findings may not be transferable to first-team football squads who have a wider range of ages and training experiences.

The intervention was designed to applicable in a real-world professional soccer setting however due to this design the intervention lacked structured progression which may have been required to provided progressive overload. There was some player progression during this study in the form of the strength of the powerband used for the assistance however this was very difficult to monitor. Additionally, the assistance method required a partner to hold the powerband, this involves the partner holding the band at different tensions to apply to correct assistance to the exercise. NHE testing method used a field-testing device in which the players were asked to perform a maximal NHE to assess eccentric hamstring strength however this appears to not be a suitable method in assessing hamstring muscle strength at longer muscle length as designed by the assisted NHE. The performance testing although testing athletic performance may not be transferable directly to soccer performance. As to say that soccer performance was improved because as all these athletic skills are contextual specific in soccer match play and therefore include tactical factors, soccer specific actions, reaction times and decision making. There was no muscle architecture assessment in the study so any changes of the muscle architecture are inferred from other research. Future studies should look to assess muscle architecture changes after an assisted NHE intervention. TMG assessment was performed on both limbs separately and only one of the hamstring muscles, the bicep femoris. Additionally, TMG is an isolated involuntary contraction of this muscle in prone position. Therefore, any transferable changes are unlikely as the intervention uses a voluntary eccentric contraction in a knee flexed exercise.

5.2 Practical Implications

Due its nature the assisted NHE is safe to use as part of daily football specific warm up and presents the opportunity to provide a minimal dose of eccentric hamstring stimulus. The assisted NHE is an easy to administer, minimal equipment exercise which has a high compliance compared to traditional NHE programmes. Therefore, maybe a practical alternative to the traditional NHE which are mostly not utilised by professional soccer clubs as it is difficult to maintain high compliance due to the exercise volume and intensity being very high normally inducing high levels of DOMS. However more research is required to assess whether the assisted NHE is a suitable alternative to improve eccentric strength compared to the traditional NHE.

Possible future research avenues should look to find an effective workload or minimal dose for the assisted NHE to stimulate more meaningful strength changes possibly over an extended time frame. Other avenues of research could focus on acute muscle activation with the potential use of EMG to directly look at muscle activation before, during and after the assisted NHE to assess its effectiveness as pre activation exercise at inducing a PAP response. Additionally, research could look to assess muscle architecture changes such as bicep femoris fascial length after an assisted NHE intervention to identify any injury prevention benefits of the intervention. All future research would be advantageous to occur with a different research design to that used in this study, by the use of matched independent groups used in a randomised control trial.

6.0 Conclusion

In summary after the assisted NHE intervention changes in strength albeit small and only significant in one limb (right) were observed along with significant improvements in SJ, CMJ, 10m sprint and 30m sprint. Despite this there was no observed effect on TMG parameters Dm, Td, Tc and thus change in muscle stiffness. Additionally, there was no detriment to performance so appears the assisted NHE still has a place within a soccer specific training programme.

The surprising changes in strength observed are multifactorial including factors such as individual responses and athlete level however most likely it is due to the assisted NHE intervention not provided enough stimulus to promote muscle strength changes similar to those previous reported. Most likely due to the low volume, low intensity, constant workload providing limited opportunity for progressive overload. On the other hand, it is rational to theorise that more significant strength changes may have occurred but at longer muscle length creating a change in the tension length relationship, which is undetectable via the protocol used on NHE field testing device. This could explain improvements in SJ, CMJ, 10m sprint and 30m sprint.

7.0 Appendices

Appendix 1

Gym sessions throughout study as seen on teambuildr.

- Trapbar Deadlift
  4 x 6
- BB RDL (Romanian Deadlift)
  3 x 8
- Reverse Nordics
  2 x 8
- Drop Jumps
  4 x 5
- BB Bench Press
  3 x 10
- DB OH Press
  4 x 6
- DeadBugs
  3 x 20 ea.

- Reverse Nordics
  2 x 8
- SL RDL
  3 x 8 ea.
- DB Bulgarian Split Squat
  3 x 6 ea.
- SL Box Jump
  3 x 4 ea.
- Plank
  4 x 30 secs
- Wide Grip Pull Ups
  3 x AMAP
- DB SA Row
  3 x 8 ea.

Appendix 2

Intervention Pre-activation programme

Pre Activation		
EXERCISE	**SETS**	**REPS**
Wall Sit	1	30 secs
Copenhagen Groin	1	5 e/s
Single Leg Hop	1	5 e/s
Banded Nordic	1	5

Control pre-activation programme

Pre Activation		
EXERCISE	**SETS**	**REPS**
Wall Sit	1	30 secs
Copenhagen Groin	1	5 e/s
Single Leg Hop	1	5 e/s
Glute Bridge	1	5

Appendix 3

Response to Load
Pre-Training Question Scale

Mass (kg)		Stand on the scales - what is your mass (without footwear)?
Travel Time (min)		In minutes, how long did it take you to get into the club?
Leg Soreness		How sore are your legs?
	1	In absolute agony, I can't move!
	2	Extremely sore!
	3	Quite sore.
	4	Not too bad.
	5	No soreness whatsoever.
Soreness Area		If you scored 1 or 2, tell us where you feel sore?
Fatigue		How tired do you feel?
	1	Absolutely shattered!
	2	Really tired and drained.
	3	Tired but OK.
	4	Quite fresh.
	5	Feel great!
Recovery		How well recovered do you feel?
	1	Dead. No energy. Not recovered at all.
	2	Don't feel great.
	3	Feel OK.
	4	Feeling good.
	5	Buzzing!
Health		How is your health (e.g. do you have a cold/hayfever?)
	1	Feel awful.
	2	Don't feel great.
	3	I have some symptoms, but nothing too bad.
	4	I feel something, but nothing drastic.
	5	No symptoms at all.
Sleep Quality		How well did you sleep last night?
	1	Up all night.
	2	Tossed and turned - pretty bad.
	3	Interrupted but not bad.
	4	Slept well.
	5	Slept like a log.
Sleep Duration		How long did you sleep for (e.g. 8.5 hours)?

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