Isometric Hip and Groin Strength in Elite Football Players: Preliminary investigations into the validity and reliability of testing, comparison to a normal population and in-season strength changes.

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Abstract

Hip and groin injuries account for 2-5% of all sporting injuries worldwide. Within elite football they account for 12-16% of all injuries in a season, making them the second most prevalent injury for the sport. Isometric measurement of hip and groin strength is common practice in football and is used in athlete monitoring, injury prevention and rehabilitation protocols. Despite its use, one area yet to be explored fully is the comparison of isometric hip and groin strength in elite-footballers using a new fixed frame dynamometry system. There is also no reference data to understand a 'normal' population as a control. Similarly, where this data is used in rehabilitation, there is current a lack of understanding of any variation in isometric strength across a season. The aim of this study is to establish (1) a reliable method to assess hip and groin strength, (2) compare hip and groin strength profiles (dominant and non-dominant maximum adduction and abduction scores, adductor ratios, abductor ratios and adductor:abductor ratios) between elite footballers and a normal population, and (3) explore the variability of isometric hip and groin strength across a season in elite footballers.

Study One - Thirty-three participants were recruited to determine the reliability between the KangaTech and HHD using intraclass correlation coefficients. Results showed excellent internal reliability for Kangatech (ICC= L: 0.929 [CI=0.887-0.956]; R: 0.929 [CI=0.886-0.956]) and the HHD (ICC= L: 0.951 [CI=0.920-0.970]; R: 0.931 [CI=0.890-0.957]).

Study Two - Twenty-five elite footballer players and sixteen 'normal' participants where used to explore differences between the groups' hip and groin strength profiles. Results showed there was no significant difference between elite football players and a normal population for dominant and non-dominant adduction maximum scores, adduction ratios or abduction ratios. There was a significant difference between elite football player's and the 'normal' population for dominant and non-dominant abduction maximum scores; dominant and non-dominant side adduction:abduction ratios.

Study Three - Seasonal variation (June-March) of the elite football player's hip strength profiles was analysed. This was conducted on a subgroup of seventeen elite football players who had continuous data throughout the season. The season was divided in to three separate time points (TP); TP1- Pre-Season (June), TP2- Mid Season (November), TP 3- Late Season (March). Results from repeated measures ANOVA's showed no significant time effects on any of elite football players hip strength profiles, except for dominant side adduction:abduction ratios that increased from TP1 to TP3. Although not statistically significant, clinically significant differences were seen in non-dominant adductor maximum scores which increased by 12.5% between timepoint (TP) 1 and TP2 compared to 3% between TP2 and TP3. Dominant maximum adduction scores increased by 18% and 0%, respectively.

This research project achieved its aims and established reliable methods of isometric hip strength data measurement in the Kangatech and HHD. Similarities and differences in isometric hip strength profiles between high level elite athletes and a normal population were identified (while obtaining normative values for a normal population) alongside an apparent weakness in the adductor strength of elite football players during pre-season. Therefore, it is recommended that both the KangaTech and HHD can be used to assess isometric hip strength. Considerations should be taken during elite football pre-season return to training protocols due to proposed reduced adductor strength at this time. The use of adductor and abductor ratios of approximately 1 throughout the season is appropriate for monitoring, injury prevention and rehabilitation protocols, however care should be taken when using ratios as variance is observed season throughout the season.

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1 Introduction

1.1 Introduction to the hip and groin region

The hip and groin region is an anatomically complex area, that contains a number of structures including, but not limited to, the hip joint - a ball and socket articulation between the femur and the pelvis; the pelvic girdle - made up from the ilium, the ischium and the pubic bones; the pubic symphysis - a fibrocartilaginous articulation between the two pubic bones; and the surrounding soft tissues (McMahon et al, 2010). The major musculature of the hip and groin region is comprised of the adductor longus, adductor brevis, adductor magnus, pectineus, gracilis, sartorius, rectus femoris, iliopsoas and the gluteus maximus, medius and minimus.
The ball and socket articulation of the hip joint allows a large range of motion, compared to other joints, in all planes of motion (sagittal, frontal and transverse). The primary movements at the hip joint are; flexion, extension, abduction, adduction, internal rotation and external rotation. During athletic movement, forces generated are transferred through the hip joint (Tammaredi et al, 2013) and up to eight times body weight has been reported to be transferred through the joint during jogging alone (Anderson et al, 2001). The structures within the hip and groin region are uniquely adapted to transfer these forces, and with the body’s centre of mass being located within the pelvis, this region is extremely important in athletic performance (Anderson et al, 2001).

Hip and groin injuries are a major issue for sports clinicians around the world, with between two and five percent of all sporting injuries occurring in the region (Morelli and Smith 2001). They are the fourth most common injury in Rugby Union, steadily increasing, having risen from 16th since 2002 (Ryan et al. 2014). A 2011 report of groin injuries in Gaelic football found that within youth level Gaelic footballers, there was a 24% incidence of chronic groin pain, and it was deemed to be the second most common problem within the sport after hamstring injury (Glasgow et al. 2011). In the Australian Football League, groin injuries account for 17% of all match play injuries (Orchard and Seward, 2002) whilst in elite professional football, hip and groin injuries contribute to 12-16% of all injuries reported within a season (Werner et al.2009).

Challenges in the management of these injuries arise from the wide variety of possible pathologies in many anatomical structures in the region, in addition to commonly found abnormalities presenting in asymptomatic athletes (Weir et al. 2015a). Historically there have been many different definitions related to hip and groin pain; osteitis pubis, athletic pubalgia, adductor tendinitis, adductor tendinopathy, adductor enthesiopathy and inguinal groin pain are some examples (Weir et al. 2015b). This range in definitions was reflected by the findings of the systematic review by Serner and colleagues (2015), which highlighted 33 different diagnostic terms used for ‘groin pain’ in athletes. This disparity in terminology can lead to obvious difficulties in recording, understanding and diagnosing hip and groin pain in athletes. There was a need identified in 2015, for an injury epidemiology consensus to address the range of terminology used, and to avoid specific hip and groin pain pathologies being reported merely as a ‘groin injury’ due to diagnostic uncertainty (Orchard 2015). A one-day consensus meeting (the Doha agreement meeting on terminology and definitions in groin pain in athletes) was convened in 2015 to provide consistency in guidance towards the management of these injuries (Weir et al. 2015a). During this consensus meeting, a single set of terms to define groin pain was agreed upon. “Groin pain in athletes” was the umbrella term, with a classification system using the newly agreed terminology also established. The classification system defined: Clinical entities for groin pain (Adductor-related groin pain, Iliopsoas-related groin pain, Inguinal-related groin pain, and Pubic-related groin pain); Hip–related groin pain; and other causes of groin pain in athletes (Werner et al. 2009). The agreement from this consensus statement has subsequently provided an internationally accepted guideline to be used, for both clinical practice and for research.

1.2 Hip and groin injuries in football

Despite the breadth of research associated with understanding the hip and groin area, the complex nature of the region means it is still not fully understood and gaps remain in the literature. Coupled with a high injury incidence (12-16%) in elite football (Werner et al. 2019) hip and groin injury remains a prevalent issue in the industry. In 2013, Ekstrand (2013) reported that a first-team player in a professional football team being injured for one month, was estimated to cost up to €500,000 to the club they play for. Alongside this, player availability to participate in matches has been strongly correlated with team success in the Qatari men’s professional football league (Ekstrand, 2013). In a 2013 study, Eirale et al (2013), found that lower injury incidence was correlated with team success. A lower injury incidence was found to strongly correlate with a higher team ranking (r=0.929, p=0.003), more games won (r=0.883, p=0.008) and goals scored (r=0.893, p=0.007), a better goal difference (r=0.821, p=0.003) and more points won (r=0.929, p=0.003). This study, however, was potentially limited by the smaller number of teams in the Qatari professional football league in comparison to European leagues (10 vs 20) and subsequently a lower number of games in a season. Similar findings though, can be seen in Hägglund and colleagues' (2013) 11-year follow-up study of UEFA Champions League teams, where injuries of the lower extremities were found to negatively affect team performance. This study reported lower injury burden ($p=0.011$) and higher match availability ($p=0.031$) were associated with a higher league table finish. Similarly, lower injury incidence ($p=0.035$), lower injury burden ($p<0.001$) and higher match availability ($p<0.001$) were associated with a higher number of points per match.

A key framework used in elite sports, designed to aid in the prevention of sports injuries, was proposed by Van Mechelen et al (1992). This framework outlined a Four-Step Approach to Injury Prevention:

Step One: Establish the extent of the problem within in the sport (e.g. incidence and severity).

Step Two: Identify the factors and mechanisms that play a role in the injury being explored.

Step Three: Introduce measures that are likely to reduce injury risk based on the two previous steps.

Step Four: Measure/evaluate the effect of any measures introduced in Step Three by repeating Step One.

1.3 Section summary and organisation of this thesis

It is known that hip and groin injuries are a common occurrence in elite football (Werner et al. 2019) and subsequently can affect global football clubs financially (Ekstrand, 2013) and competitively (Eirale et al., 2013). Therefore, the purpose of this study is to add to the understanding of the elite footballer's hip and groin region and contribute to the growing body of evidence regarding the monitoring, prevention and rehabilitation of such injuries in elite football.

In order to achieve this aim, this thesis is going to be presented in the following way. A literature review will follow this section and will examine the epidemiology of hip and groin injuries in football; the risk factors associated with hip and groin injuries; the methods used for screening and monitoring risk factors and how this data is used in elite football; the factors that can affect this data; and finally the limitations of the current evidence. The method and results of each of three studies undertaken for this current research are then presented individually, with an overall discussion and conclusion drawing together all findings and relating them to the project aim.

2 Literature Review

2.1 Epidemiology of hip and groin injuries in football

In elite football (association football/soccer), adductor related groin injuries are the most common hip and groin injury, making up two-thirds of diagnoses by medical staff, followed by iliopsoas related groin injuries. Hip related groin pain is the least common issue diagnosed by medical staff (Werner et al. 2009; Mosler et al. 2018).

A number of studies have explored and reported on the incidence of groin injury in elite football: Werner et al. (2009) reported between 19-22% of all players in an elite football team will sustain a groin injury; There was an ,18% incidence rate of groin injury during a 2-year prospective study in the Qatari men's professional football league (Mosler et al., 2018); Over a 7-season period from 2001-08, Ekstrand et al. (2011) surveyed 14 professional men's football teams who competed at the highest level in Europe over the last decade. During this study they found that hip and groin injuries were the second most common injury, behind thigh injuries. Mosler and colleagues (2018) found the overall incidence of groin injuries to be 1.0/1000 hours of play, with match play incidence being 3.7/1000 hours and training incidence being 0.7/1000 hours. This was consistent with the number reported by Werner et al. (2009) showing total groin injury incidence was 1.1/1000 hours with 3.5/1000 match hours and 0.6/1000 training hours. Hip and groin injuries result in an average time loss of 15 days (Werner et al. 2009) and a median of 10 days of absence from training and/or matchplay (Mosler et al. 2018). A time loss injury was defined as;

> "an injured player had to miss at least one future training session or match, the next training session or match, missed the next day, or was removed from

play or missed at least one future training session or match" (Walden et al, 2015, p10).

This use of a time-loss method for capturing groin injury incidence data may not be a true reflection of injury incidence however, as evidence suggests that many players continue to play with hip and groin symptoms (Harøy et al. 2019). A recent study of football leagues in Spain by Esteve and colleagues (2020a), recorded groin injuries from 17 teams over 39 consecutive weeks. The prevalence of hip and groin injury in this study was 11.7%, with only 1.3% of these injuries resulting in time loss and 10.4% of injuries not leading to any time lost. In this study groin injury time loss was combined with self-reported groin pain (Esteve et al. 2020a).

Groin injury incidence is higher in the pre-season compared to the competitive in-season component of a football season. Esteve et al (2020b) examined 386 players from 17 Spanish male amateur footballers and reported during pre-season (21%) the average weekly prevalence of groin problems was 1.8 times higher (95% CI 1.6 to 2.0) compared to in-season (12%).

2.2 Risk Factors for hip and groin injuries

As presented in section 1.2, in order to prevent a sports injury, the extent of the injury problem needs to first be established (Van Mechelen et al. 1992). Section 2.1 has reported on the epidemiology of hip and groin injury and therefore this stage of the literature review will now address Step Two of Van Mechelen et al's (1992) strategy: the establishment of the mechanisms and risk factors for the injury being explored.

2.2.1 Non- Modifiable

There are many non-modifiable risk factors associated with hip and groin injury reported in the literature: A 2014 systematic review by Ryan et al. (2014) (Table 1) found previous injury, older age, early maturation and femur diameter to be the most common non-modifiable risk factors for injuries within the region. An updated 2015 systematic review by Whittaker et al. (2015) agreed with these findings and reported previous injury and higher level of play as the most common risk factors.

Table 1 - Non-Modifiable Risk Factors

Study	***Previous Injury***	***Older Age***	***Early Maturation***	***Femur Diameter***	***Level of Play***
Arnason et al. 2004	*X*	*X*			
O'Connor, 2004		*X*		*X*	
Maffey and Emery, 2007	*X*				
Le Gall et al. 2007			*X*		
Werner et al. 2009	*X*				
Whittaker et al. 2015					*X*

Previous injury to the area has been identified by several studies (Arnason et al. 2004; Maffery and Emery, 2007; Werner et al. 2009) as the most prominent non-modifiable risk factor throughout the literature. Arnason et al. (2004) found that players who had previously injured their groin were seven times more likely to get injured, than the players who had never sustained a groin injury. However, it should be noted that this study was conducted on sub-elite athletes in Iceland, where medical care was not consistently available. Older age has also been established as a risk factor (Arnason et al. 2004; O'Connor, 2004) as has early maturing football players (due to their increased biological and skeletal age) (Le Gall et al. 2007).

2.2.2 Modifiable

Modifiable risk factors for hip and groin injuries are of more interest to clinicians as, as the name suggests, they can be modified in an attempt to reduce injury risk. There are many modifiable risk factors in relation to hip and groin related injuries reported in current literature: Deficits in hip adduction range of motion and total hip rotation range of motion have both been identified (Arnason et al. 2004; Verrall et al. 2007); Verrall and colleagues 2007 study, found that restricted hip range of motion is associated with the development of chronic groin injuries; A systematic review from Tak et al. (2017) reported that total rotation of both hips below 85°, as measured during pre-season screening, was a risk factor for groin pain development in athletes. Internal rotation, abduction and extension were not associated with the presence of groin pain or the risk of groin injury. However, this systematic review included some low-quality evidence case control studies with the overall quality ranging from 29%-92% (Tak et al. 2017).

Patient Reported Outcome Measure (PROM) scores can also be used to identify risk of injury with the systematic review by Mosler et al. (2015) identifying PROM scores as a strong indicator for athletes with groin pain. A PROM designed for young to middle aged physically active individuals with long standing hip and/or groin pain is the Hip and Groin Outcome Score questionnaire (HAGOS) (Thorborg et al. 2011a). The HAGOS has been developed and validated in accordance with the consensus-based standards for the selection of health Measurement Instruments (COSMIN) recommendations. It has six subscales, each employing five-item likert scales. The subscales measured include: symptoms; pain; function in daily living (ADL); function in sport and recreation (sports/rec); participation in physical activities (PA) and hip and groin-related quality of life (QOL). A subsequent prospective study by Delahunt et al. (2017) in Gaelic football found that a pre-season score of below 87.5 on the Hip And Groin Outcome Score questionnaire (HAGOS) had an odds ratio of 8.94 for sustaining a groin injury, compared to those above this score.

Systematic reviews conducted by Ryan et al. (2014) and Whittaker et al. (2015) indicate strength as the most prominent modifiable risk factor in hip and groin related injuries. Weak hip adductors have been found to increase the likelihood of sustaining a hip and groin related injury (Ryan et al. 2014; Engebretsen et al. 2010). The 2010 study by Engebretsen et al. (2010) reported that soccer players with weak adductor muscles were four times more likely to sustain a groin injury. This finding was further supported by the study of O'Connor et al. (2004), where uninjured rugby league players were found to have higher peak torque in hip adduction compared to their injured counterparts.

Another modifiable risk factor identified by the systematic review of Ryan et al. (2014) were hip strength ratios. This is in keeping with the findings from O'Connor et al. (2004) which found differences in peak torque in non-dominant limb adduction and abduction between injured and non-injured rugby league players. Merrifield and Cowan (1973) also found that hip strength ratio differences increased risk of injury in ice hockey. The authors found that adduction strength was 95% of abduction strength in uninjured players, whereas in athletes who had suffered groin injuries adduction strength was only 78% of abduction strength. This study concluded that a strength imbalance of greater than 25% between legs was identified in players prone to adductor strain (Merrifield and Cowan 1973). However, this testing was conducted on a small number (n=54) of high school amateur athletes at a single pre-season time point, with only 8 groin injuries sustained over the season.

2.2.3 Strength as a risk factor for hip and groin injuries in football

In football, isometric hip and groin strength can be analysed in many ways, but most commonly through maximum strength scores (usually given in Newtons or Kg) or through ratios. A 'hip and groin strength profile' can be produced by analysing and reporting these findings together, to give a broad insight in to overall hip and groin health. Throughout the literature, both maximum strength scores and ratios have been identified as risk factors for injuries (Ryan et al. 2014; Whittaker et al. 2015; Engebretsen et al. 2010; O'Connor et al. 2004).

Maximum Strength Scores

Alongside generally being considered a risk factor for hip and groin injury in field-based sports, reduced isometric hip adduction strength has been specifically identified as a key risk factor for hip and groin injury in elite football (Ryan et al. 2014; Moreno-Perez et al. 2019; Engebretsen et al. 2010; Esteve et al. 2018). Moreno-Perez's (2019) prospective study conducted on Portuguese First Division and u19 players, found that maximum isometric hip adductor strength was lower in players who suffered a groin injury, compared to their uninjured counterparts. Markovic et al. (2020) reported that a lower level of isometric adductor strength significantly increased the risk of future groin injuries in professional football players in the Croatian League. Within their study, ten groin injuries occurred during the 2017/18 season in 45 healthy outfield players, and when comparing injured players to uninjured players, those who sustained a groin injury had significantly lower isometric adductor strength ($p = 0.002$). A 2010 study examining risk factors for groin injuries in football players, by Engebretsen et al. (2010) found reduced isometric hip adduction strength to be a risk factor when using univariate analysis. Similar results are seen in Esteve et al. (2018) a cross-sectional study conducted on 17 amateur Spanish football teams. This study showed that athletes who had previous groin pain lasting longer than 6 weeks had significantly weaker (13%) hip adduction strength scores.

Ratios

There are three primary ratios used in elite football when assessing isometric hip and groin strength and strength symmetry. The adduction ratio is the maximum strength of the dominant side adductor vs the maximum strength of the non-dominant side adductor; and the abduction ratio is the maximum strength of the dominant side abductor vs the maximum strength of the non-dominant side abductor. Finally, the adduction:abduction ratio is the maximum strength of the adductor vs the maximum strength of the abductor on the ipsilateral side, computed for both dominant and non-dominant sides (Thorborg et al. 2011b). The study from Thorborg et al. (2011b) examining 100 elite male soccer players found no clinically relevant differences between dominant and non-dominant adductors with an adduction ratio of 1.03. This study also reported an adduction:abduction ratio of 1.04 and 1.06 for dominant and non-dominant sides respectively. A prospective study conducted in the Croatian league over one season on 45 healthy male football players found that injured players had a significantly greater between limb adductor strength asymmetry than uninjured players (16.92%±10.61% vs 2.65%±1.06%, respectively) (Markovic et al. 2020).

Establishing Normative Values

A study by O'Brien et al. (2019) established normative isometric hip and groin strength values for healthy elite football players (Table 2). This study was conducted on one Australian A-League football team, with 31 male players using a fixed frame isometric strength testing device, the GroinBar, described in section 2.3.3. This testing period took place in June at the end of the 2016-17 Australian A-League season. This study reported similar ratios to Thorborg et al. (2011b). To the author's knowledge these are the only two papers reporting ratios for isometric strength testing in elite athletes. Moreover, there are no published normative values of isometric hip strength on a fixed frame isometric strength testing device for a normal population.

Table 2 – Elite football players normative hip and groin strength values

	Side	Mean
Adduction	Dominant	361.2N (SD=109.9)
	Non-Dominant	370.3N (SD=110.4)
Abduction	Dominant	385.9N (SD=78.3)
	Non-Dominant	327.9N (SD=23.6)
Adduction:abduction Ratio	Dominant	0.94
	Non-Dominant	1.12
Adduction Ratio	-	0.97
Abduction Ratio	-	1.17

2.3 Methods of measuring hip and groin strength in elite football

There are many methods in which hip and groin strength data is collected in an elite football environment.

2.3.1 Isokinetic Dynamometer

Isokinetic dynamometry (IKD) is considered the "gold standard" for strength testing throughout research and in clinical practice (Kambič et al. 2020). IKD uses computerized passive devices which resist forces applied to them and control the speed of exercise at a predetermined rate (Osternig,1986). Practically, muscle assessment using IKD is considered reliable and reproducible, with correlation coefficients between 0.93 and 0.99 for peak force values and between 0.91 and 0.96 for total workload value (Ben Moussa Zouita et al., 2020). IKD is capable of measuring multiple elements of strength including peak force, power, endurance and angle of maximal force production (Stark et al., 2011). These parameters are important to evaluate muscular performance and post-injury recovery (Estradiote et al. 2017). This form of testing has been used in clinical settings for 45 years (Stark et al. 2011). Although IKD is considered the gold standard, they are neither affordable nor easily transportable.

2.3.2 Hand-Held Dynamometry

Hand-held dynamometry (HHD) provides a more accessible method of measurement of isometric strength as they are more affordable and portable. However, there is conflicting literature regarding its reliability. Fulcher et al. (2009) reported good to excellent inter-reliability (ICC=0.66-0.87) and intra-reliability (ICC=0.70-0.89) when assessing hip strength in athletes. This study examined the maximum strength of hip flexion, abduction and adduction in 30 healthy male semi-professional athletes. Kemp et al. (2013) have also identified HHD as a reliable source of measuring isometric hip strength in healthy adults. Conversely, Thorborg et al. (2013) showed that handheld dynamometers are susceptible to between-tester bias, with tester experience and strength both influencing scores. This study suggested to improve inter reliability the dynamometer likely needs external fixation.

2.3.3 *Fixed Frame Isometric Strength Testing*

In recent years, fixed- frame dynamometry systems to measure strength have become available to clinicians. These devices can replicate the use of the hand-held dynamometer, without the influence of tester bias. The KangaTech system is a whole-body, portable fixed frame dynamometry system capable of measuring force/torque at any joint in each cardinal plane (Saunders, 2019). The KangaTech 360 model has been described as a testing platform consisting of a portable, adaptable, fixed frame dynamometry system that allows accurate measurement of isolated neuromuscular strength, endurance and control. In addition to being used as a testing device, the KangaTech possesses the capabilities to be used as a strength training device. It's system houses eccentric and isometric strength training programmes based off an individual's testing scores. Repetitions, sets, percentage of maximum voluntary contraction and time under tension can all be modified and individualised for desired results. However, at the time of writing, there is little research regarding the reliability of fixed frame dynamometry systems. Ransom et al (2020) established the KangaTech to have very high test-retest reliability for left hip adduction (ICC 0.958), right hip adduction (ICC 0.955), left hip abduction (ICC 0.957), right hip abduction (ICC 0.945), left knee flexion (ICC 0.927) and right knee flexion (ICC 0.923). A similar fixed frame system known as the Groinbar has shown excellent test-retest reliability (ICC=0.94), (Ryan et al. 2018). The Kangatech and the GroinBar are very similar fixed frame devices. However the KangaTech 360 model possesses the ability for the sensor pads to be rotated on two axes giving it the ability to test in all planes of motion, something that initial versions of the Groinbar (Ryan et al. 2018) and the KangaTech (Ransom et al. 2020) are unable to do. Therefore, it is essential that the reliability of this device is established for use in an elite clinical environment.

2.4 How the data is used in elite football

Once risk factors have been established and data has been collected using the discussed methods, step three of Van Mechelen's (Van Mechelen et al. 1992) framework begins. Interventions are introduced to attempt to reduce injury risk.

2.4.1 Screening and Monitoring

Many elite football clubs worldwide employ injury risk factor screening techniques in an attempt to decrease the likelihood of injuries (Bahr, 2016). These screening tests are usually conducted at the beginning of the season and thought to identify any athlete who is showing signs of a pre-determined risk factor and therefore risk of subsequent injury. This data can then be used to shape individualised injury prevention strategies and strengthening programmes during the season. Although the efficacy of this method is questioned by Bahr (2016).

Paul et al. (2014, p 1) suggested an alternative method for the use of this data "to examine the athlete more frequently and check for variation in these physical measures thereby potentially identifying deterioration in physical condition rather than relying on arbitrary cut-points" . This monitoring technique would regularly examine changes in an individual athlete's scores and give insights regarding their response to training loads and match play. This allows training methods to be balanced between enough to elicit a response in an individual and the maximum load tolerable before injury occurs (Paul et al. 2014). Crow et al. (2010) found that a decrease in adductor strength preceded the onset of groin pain in elite junior Australian footballers, suggesting frequent monitoring would be beneficial in preventing hip and groin injuries. Both screening and monitoring techniques are commonly used in elite football to attempt to reduce injury risk of injury.

2.4.2 Injury Prevention Strategies

As discussed in section 2.4.1, isometric hip and groin strength data can be used to establish strength deficits, allowing the subsequent addressing of these deficits through the prescription of strength training-based injury prevention programmes. Whilst many different definitions for the phrase ‘strength’ or ‘resistance’ training are used in research,” repetitive, monotonic, and effortful voluntary muscle contractions” (Hortobágyi et al, 2021, p 1) is the definition used in this literature review. This definition was chosen as it best describes the capacity in which strength/resistance training will be used throughout the following research. Strength training is used to address muscle imbalance and strength ratio deficits, with the number of sets and repetitions being individualised and manipulated to give desired outcomes (Śliwowski et al. 2015). Unilateral, adapted strength programmes may be adopted to address individual issues. An 8-week isokinetic strengthening programme was shown by Gioftsidou et al. (2008) to restore imbalances in knee muscle strength in footballers who initially presented with deficits, suggesting that isokinetic programmes are efficient at addressing muscle imbalances.

A randomised controlled trial (RCT) from Jensen et al. (2014) found that a progressive adductor strengthening programme using a combination of isometric, concentric and eccentric muscle actions resulted in a statistically significant increase in maximal eccentric adductor strength. However, this study had a small sample size (n=34) and a poor compliance rate. This RCT was also completed during a mid-season break (Nov-March), with the intervention beginning in January (coinciding when the players return to training). It could be speculated that these strength gains were partly induced by the return to training following a period of detraining, as Hortobágyi et al (1993) observed a 12% decrease in eccentric force after 14 days of training cessation in power athletes. Komi et al. (1978) undertook an RCT and identified that a 12-week maximal isometric knee extension programme resulted in a 20% increase is isometric knee strength, suggesting isometric strength programmes have positive effects on maximum isometric strength output.

Within football, the FIFA 11+ was introduced to reduce the risk of overall injury in soccer players (Bizzini and Dvorak 2015) (with FIFA being the Federation Internationale de Football Association). It is a 20-minute equipment free warm up programme designed to be completed twice per week. Components of the FIFA 11+ include strength, plyometric and balance exercises. Research from Sadigursky et al. (2017) concluded that the FIFA 11+ reduced the risk of injury in soccer players of both sexes over 13 years of age and of amateur and professional playing status, by up to 30%. However, this systematic review found large discrepancies in the frequency (1-3 times/week) the programme was completed, the duration it was completed for (4.5-9 months) and the athletes' adherence to the programme, all which may have affected the results (Sadigursky et al. 2017). At the time of writing, no study has analysed the effect of the FIFA 11+ related to hip and groin injuries. A groin-specific injury prevention protocol (5 exercises including concentric and eccentric strengthening of the groin, co-ordination and core stability exercises) was examined by Holmich et al (2010). This intervention group was compared to a control group who completed their normal warm up. Although, there was no significant effect in the intervention group (P=0.18), the risk of groin injury in the intervention group was reduced by 31% (Hölmich et al. 2010).

The most recent hip and groin injury prevention intervention established is the "Adductor Strengthening Programme" (Harøy et al. 2019). The Adductor Strengthening Programme is based on the Copenhagen adduction exercise which has been shown to have high activation of the adductor longus and to cause significant increases in eccentric adduction strength (Harøy et al. 2019; Ishøi et al. 2016). It has varying levels of difficulty, with level 1 being the easiest and level 3 being the most difficult. This injury prevention strategy was tested on 35 semi-professional male Norwegian football teams. The average prevalence of groin injuries during the season was 13.5% in the intervention group and 21.3% in the control group meaning the intervention reduced the prevalence and risk of groin injury by 41%, across the season (Harøy et al. 2019).

2.4.3 Return to Play Protocols

Alongside being used to prevent hip and groin injuries from occurring, hip and groin isometric strength data can also be used in the rehabilitation of athletes who have already sustained a hip and groin injury. Criteria based return to play protocols are increasingly popular among clinicians today. These return to play protocols use specific tests to aid in the decision-making process of when an athlete is ready to progress to the next stage of their rehabilitation. An example of such tests can be simple, such as range of motion, or more complex functional movements such as reactive change of direction (Clover and Wall, 2010). Given that isometric hip and groin strength data is widely collected as part of the screening and monitoring process, it is often used as one of these criteria in return to play after injury. Traditionally, a lower extremity strength deficit of less than 10% between injured side and uninjured has been considered as a clinical milestone before return to sport (Augustsson et al. 2004; Orchard et al. 2005). Specifically, in relation to hip and groin injuries, an adduction:abduction ratio of >90% and equal bilateral adductor strength have been suggested as clinical milestones before return to play after injury (Nicholas and Tyler, 2002). In some sub-elite programmes, where regular testing is not readily available, criteria-based return to play protocols refer to return to baseline strength as an objective marker of readiness. Similarly, a maximum strength score of within 10% of baseline strength has been an indication of an athlete's readiness to return to play.

2.5 Factors that may affect isometric hip and groin strength data

The hip and groin region has been widely researched in recent years and the understanding of the region among clinicians and researchers has moved forward considerably. Great strides have been made in establishing the extent of the problem within many field-based sports, identifying risk factors and mechanisms of injury and improving injury prevention and rehabilitation methods. The data commonly captured in elite football provides a detailed insight into the hip and groin health of an athlete. However, there remains some uncertainty within the literature as to how certain factors can affect this data.

2.5.1 Limb Dominance

Thorborg et al (2011b) assessed the isometric hip and groin strength, using a HHD and unilateral testing approach, of 100 elite male football players. This study found a 3% difference in isometric hip adduction and a 4% difference in isometric hip abduction between dominant and non-dominant sides. However, these differences fall within the measurement difference of the procedure and do not imply a clinical meaningful change. Conversely, a study conducted on nine elite football players and nine matched controls assessing eccentric hip adduction and abduction strength found up to a 14% difference in adduction strength and up to 31% difference in abduction strength between dominant and non-dominant sides in elite football players but no side-to-side differences were found in controls (Thorborg et al. 2011c).

A possible explanation for this, suggested by Thorborg et al. (2011b), is that increased eccentric strength in the dominant side stems from improved co-ordination of the motor system from repetitive kicking, as there is high EMG activity of the adductors during the early swing phase of kicking in football (Brophy et al. 2007; Charnock et al. 2009). The lack of difference between dominant and non-dominant sides, when tested isometrically, may be explained by the use of the non-dominant adductor as a stabiliser during the kicking phase (Thorborg et al. 2011b). However, the effect of limb dominance remains largely undetermined.

2.5.2 Stage of the Season

A typical season for an elite football club consists of a six-week pre-season training period, followed by a ~40-week competition period (Julian et al. 2021). It is well established that within the English Premier League, the lack of a winter break leads to a period of increased fixture congestion (Jones et al. 2019). As part of the UEFA Champions League study, Bengtsson et al. (2013) found that fixture congestion was associated with increased muscle injury incidence. Therefore, it is plausible to suggest that different stages of the seasons, with varying match play schedules, may have an effect on strength measures.

However, a 2021 study by Klij et al. (2021) investigated the variation in eccentric adductor and abductor strength throughout an elite football season. This study assessed 188 players from 9 teams at 3 time points (pre-season, mid-Season, end of season) throughout the Dutch professional football season. The results showed no statistically significant change in eccentric adductor strength (Nm/Kg) (3.40 ± 0.72, 3.30 ± 0.65 and 3.39 ± 0.74, $p = 0.186$), while abduction strength significantly decreased during the season from 3.45 ± 0.67 to 3.28 ± 0.61 Nm/Kg ($p < 0.001$). However, at the time of writing this thesis, there is no published research on the seasonal variation of isometric hip strength, leaving us largely in the dark in considering how this affects the widely used data.

2.6 Limitations of current evidence

At the time of writing there have been no reliability or validity studies published regarding the KangaTech system. A similar fixed frame dynamometry system, the GroinBar has been proven to have excellent reliability (ICC=0.94) by O'Brien et al. (2019). Although the O'Brien et al. (2019) study suggested normative isometric hip and groin strength values for elite soccer and AFL players, there is a lack of any normative values for a normal population using a fixed frame dynamometry system. Subsequently, a comparison between an elite football player and the normal population is unknown.

At the beginning of this research project, there had been no published studies examining the effect of an elite football season on hip and groin strength. Recently, a study by Klig et al. (2021) found no significant time effect on adduction strength, while abduction strength significantly decreased throughout the season. However, this study was completed using an HHD and examined eccentric strength. As discussed in section 2.5.1, previous research from Thorborg et al. (2011b) has shown the same properties cannot be assumed for eccentric and isometric strength.

2.7 The need for this study

From examining the current body of evidence, we know that the HHD and fixed frame dynamometry systems are becoming increasingly popular for data collection in elite sporting populations. However, there is a need to establish the reliability and validity of both systems for measuring the hip and groin strength of an elite football population. Despite the growing body of high-quality research in this area, and although there are published normative values for elite populations, there remains a lack of evidence regarding normative values of a normal population's hip and groin strength used a fixed frame dynamometry system. This data would allow us to compare the hip and groin strength profiles of elite athletes and a normal population, giving an insight into the specific mechanisms and components of an athlete's training programme and the adaptations they potentially elicit. It would also be beneficial for clinicians who specialise in the rehabilitation of hip and groin injuries in a normal population. Despite this data being widely used in elite football settings, we still do not understand how isometric hip and groin strength normally fluctuates throughout an elite football season. Any variations in data throughout a season could potentially have vital effects on screening and monitoring methods, injury prevention interventions and rehabilitation protocols.

Therefore, the aims of this project are confirmed through the exploration of previous literature, as:

(i) to establish the reliability and validity of KangaTech and HHD systems, and to report normative values of isometric hip and groin strength using this fixed frame dynamometry system (KangaTech) for a normal population;

(ii) to compare the hip and groin strength profiles of an elite football population to the values established for a normal population and examine for any effect of limb dominance;

(iii) to examine the variation in isometric hip and groin strength throughout an elite football season.

The research questions this project aims to answer are:

Study One:

- Is the KangaTech a reliable source of measurement for isometric hip and groin strength?
- Is the HHD a reliable source of measurement for isometric hip and groin strength?
- Are the KangaTech and HHD valid sources of measurement for isometric hip and groin strength?
- What are the normative values of isometric hip and groin strength for a normal population?

Study Two:

- Will elite football players demonstrate a significantly stronger isometric hip and groin strength profile than a normal population?
- Will elite football players demonstrate adductor and abductor ratios of approximately 1?
- Will a normal population demonstrate adductor and abductor ratios of approximately 1?

- Will elite footballers demonstrate an adductor:abductor ratio of approximately 1 for both dominant and non-dominant legs?

- Will the normal population demonstrate an adductor:abductor ratio of approximately 1 for both dominant and non-dominant legs?

- Will elite footballers have significantly different dominant and non-dominant adductor:abductor ratio?

- Will the normal population have significantly different dominant and non-dominant adductor:abductor ratio?

Study Three:

- Will the stage of the season have a significant effect on elite footballer players isometric hip and groin strength profiles?

3 Study One – A study to establish the validity, reliability and normative data for KangaTech and Hand-Held Dynamometer, in measuring isometric hip and groin strength.

3.1 Introduction

Currently there is a lack of published research regarding the reliability and validity of newly established fixed frame isometric dynamometry system (KangaTech 360), alongside conflicting literature regarding the reliability of handheld dynamometers (Fulcher et al. 2009; Thorborg et al. 2013). Recent research from Ryan et al. (2018) and Ransom et al (2020) have shown fixed frame dynamometry systems, similar to the one used in this research, to have excellent reliability. In addition to this, although normative values using these frames have been established for elite athletes (O'Brien et al. 2019), none have been identified for a normal population. Therefore, the aims of this current study are to establish the reliability and validity of the HHD and the KangaTech in assessing isometric hip and groin strength, alongside identifying normative values for a normal population using these instruments.

3.2 Method

3.2.1 Study Design

This is a repeated-measures, reliability and concurrent validity study design, conducted at the Vitality Stadium, Bournemouth over a one-month period (24/01/20-28/02/20). A repeated measures design was the chosen study design for this project as one in which "multiple, or repeated, measurements are made on each experimental unit" (Sullivan, 2008, p 1) best fit the aims. Similar study designs have been observed in previous reliability studies (Fulcher et al. 2009; Ryan et al. 2018) and validity (Arnold et al. 2010).

Ethical approval for this study was granted by Bournemouth University Ethics Committee (29269) (see section 9.2.1). The key ethical issues identified, were associated with a risk of muscle soreness and injury as a result of maximal strength testing on unaccustomed participants. As a result, all participants were given an appropriate education session and thorough warm up prior to beginning the testing session.

3.2.2 Participants

The study was conducted with volunteering participants from Bournemouth University (BU). All participants were students at that institution. Study size was calculated using the method described in Walter et al. (1998) with a desired r value range of 0.7-0.9 and two repeated tests giving a sample size of at least 18.4 (Walter, Eliasziw and Donner, 1998). Participants were recruited through advertisements and word of mouth at Bournemouth University. This group of University students represented a sample of the 'normal population' for the purpose of this research project. Thirty-five participants expressed an interest in this study, all 35 were invited to attend to account for potential dropouts. In total 33 male (n=26) and female (n=7) University students aged between 18-25, provided written informed consent to participate in the study. Participants were recruited through advertisements and word of mouth at Bournemouth University.

Inclusion Criteria for the research were: recreationally active university students who expressed interest in the invitation to participate.

Exclusion Criteria for the research were: Participants under the age of 18 at the time of the study; participants with any significant lower limb injury or surgeries in the previous 12 months; participants with any significant medical illnesses or diseases; participants with any heart instability or disorders, screened using a health questionnaire.

3.2.3 Data Collection

Data were collected using two systems of isometric strength testing, the KangaTech and the HHD. The KangaTech is a whole-body, portable fixed frame dynamometry system capable of measuring force/torque at any joint in each cardinal plane (Saunders, 2019). The HHD used was MicroFET 2 Wireless. All data were recorded anonymously with results recorded in Newtons and stored on a password protected computer.

3.2.4 Procedure

Participants were divided in subgroups of six to ten participants, each given a specific testing date (based on individual participant availability), time and instructed to wear comfortable sporting clothes. Each testing day consisted of orientation, education and warm up at Station 1, and then participants were randomly assigned to start with either Station 2) KangaTech isometric strength testing, or Station 3) HHD isometric strength testing. Testing at both stations occurred simultaneously and participants swapped stations once testing had been completed at the initial station to achieve randomisation. Testing staff included one Bournemouth University MRes student, one Bournemouth University lecturer and one AFC Bournemouth Physiotherapy intern. All testing staff received training prior to use of equipment.

Validity

To assess for validity, manual scores were taken by one tester applying pressure directly on to the force transducer of the KangaTech using the HHD transducer. The same HHD positioning was maintained for this test. The peak force in Newtons was recorded for each instrument in each test. 50 tests were performed across a range of resistance from 15N to 600N.

Reliability

Participants entered the testing room in groups of two and were given orientation and education at Station 1 as a pair (Table 3). Participants then proceeded to either station 2 or 3 individually as instructed by the tester. Participants swapped stations once testing was completed at their initial station. Testing at both stations occurred simultaneously, therefore randomisation occurred naturally accounting for any fatigue and learning effects on the equipment.

The testing position for all tests was supine lying with 90-degree knee flexion and 45-degree hip flexion in bare feet or socks. Previous research has shown this position as optimal in eliciting adductor muscle activity and is a position commonly used in clinical practice (Delahunt et al. 2011; Lovell, Blanch and Barnes, 2012; O'Brien et al. 2019). This short lever position has also previously been used in isometric abductor strength testing (O'Brien et al. 2019). During unilateral testing on the HHD, the untested leg was at zero degrees hip and knee flexion. The force transducers of the KangaTech and HHD were placed at the lateral epicondyle of the femur for abduction and medial epicondyle of the femur for adduction (O'Brien et al. 2019). Peak force was taken from each of the two attempts, left and right.

Each test was performed three times; a familiarisation test at 50% effort, followed by two maximal efforts in line with previous research by Jeon et al (2019), who recommend these parameters. Each repetition was held for 5s and separated by 30s rest to minimize the effects of fatigue (Keep et al. 2016).

For HHD, the tester adopted a ‘make’ test positioning (Keep et al. 2016) with bilateral elbow extension and wrist extension for abduction and bilateral elbow extension and wrist flexion for adduction. Peak force was taken from each of the two attempts, left and right.

Table 3 – Study One Testing Protocol

Station	**1**	**2**	**3**
Test	***Education/Warm Up***	***KangaTech Testing***	***HHD Testing***
	Participants given a 5-minute education session including; their warm-up instructions, the sequence of tests they were to follow, the positions they would be in for testing and they also had their landmarks (lateral and medial femoral condoyles) marked with a bio friendly marker. Participants completed a 5-minute submaximal self-regulated static bike warm-up (Watt Bike) at a resistance of 3.	**Participants conducted:** One bilateral adduction warm up effort at 50% for a duration of 5s, followed by 30s rest. 1st bilateral maximal adduction effort for a duration of 5s, followed by 30s rest. 2nd bilateral maximal adduction effort for a duration of 5s, followed by 30s rest. This was repeated for abduction. This participant then moved to station 3 or left the testing room if finished. Randomisation occurred by alternating which test (abduction or adduction) was conducted first.	**Participants conducted:** One right sided unilateral adduction warm up effort of 50% for a duration of 5s, followed by 30s rest. 1st right sided unilateral maximal adduction effort for a duration of 5s, followed by 30s rest. 2nd right sided unilateral maximal adduction effort for a duration of 5s, followed by 30s rest. One right sided unilateral abduction warm up effort of 50% for a duration of 5s, followed by 30s rest. 1st right sided unilateral maximal abduction effort for a duration of 5s, followed by 30s rest. 2nd right sided unilateral maximal abduction effort for a duration of 5s, followed by 30s rest. This was repeated for left side. This participant then moved to station 2 or left the testing room if finished. Randomisation occurred by alternating which leg was tested first each time.

3.2.5 Statistical Analyses

Statistical analyses were conducted using SPSS version 26 (SPSS Inc, Chicago, IL). Data were analysed for normality using the Shapiro-Wilk method. All reliability data captured on KangaTech and HHD were normally distributed except for the validity data, which were not normally distributed.

A Spearman Correlation and a Wilcoxon Signed Rank test was computed between the variables HHD scores and Kangatech scores for validity. Correlation coefficients of $\rho < 0.25$ were considered as small; 0.25–0.50 as moderate; 0.50–0.75 as good; and > 0.75 as excellent (Portney et al. 2009).

Internal reliability analysis was performed on the 33 samples, assessed at two different time points, separated by 30s rest, tested by one rater. For both pieces of equipment Left test 1 vs Left test 2, and Right test 1 vs Right test 2 were analysed. The Intraclass Correlation Coefficient (ICC) was used for this analysis. Type A (Koo and Li, 2016) intraclass correlation coefficients using an absolute agreement definition was used. Mean estimations along with 95% confidence intervals (CI) were reported for each ICC. Interpretation was as follows: <0.50, poor; between 0.50 and 0.75, fair, between 0.75 and 0.90 good; above 0.90, excellent (Koo et al. 2016).

3.3 Results

3.3.1 Validity

The Spearman Correlation coefficient demonstrated a strong positive correlation between score achieved with the HHD and those achieved with the KangaTech. r=0.996, n=50, p=<0.001.

A Wilcoxon Signed Rank test was conducted to compare KangaTech readings to HHD readings. There was no significant difference observed between the scores t=681, z=-.681, p=0.496.

3.3.2 *Reliability*

Mean and SD scores for each method and limb are presented in Table 4.

Table 4 - Mean and SD of KangaTech and HHD

Equipment	**Side**	**Test 1 Avg (N±SD)**	**Test 2 Avg (N ±SD)**
KangaTech	L	342.8N (±97.9)	341.3N (±97.3)
KangaTech	R	346.9N (±98.7)	346.4N (±100.3)
HHD	L	177.9N (±45.8)	174.2N (±43.0)
HHD	R	173.8N (±43.4)	175.3N (±44.8)

Notes. HHD; hand-held dynamometry, L; left, R; right, N; newtons, (±SD); Standard Deviation

The internal reliability for both instruments of equipment were excellent with ICC values, confidence intervals and p values reported in Table 5.

Table 5 - ICC's

Equipment	**Side**	**ICC (CI)**
KangaTech	L	0.929 (0.887-0.956)
KangaTech	R	0.929 (0.886-0.956)
HHD	L	0.951 (0.920-0.970)
HHD	R	0.931 (0.890-0.957)

Notes. HHD; hand-held dynamometry, L; left, R; right, ICC; Intraclass Correlation Coefficient, CI; 95% Confidence Intervals

3.3.3 Normative Data

Normative values have been established for a normal population using a fixed frame dynamometry system (Table 6).

Table 6 - Normal Population Normative Data

Equipment	Side	Adduction	Abduction
KangaTech	L	336N(±96.0)	348N(±97.5)
KangaTech	R	337.2N(±98.5)	358.3(±97.1)

Notes. L; left, R; right, N; newtons, (±SD); Standard Deviation

3.4 Study One – Summary

In line with previous research (Arnold et al., 2010; Fulcher et al., 2009; Hirano et al., 2020; Kemp et al., 2013) this study has established the HHD as reliable and valid measurement of isometric hip and groin strength. Additionally, this project established the KangaTech 360 as a reliable and valid fixed frame dynamometry system, for measuring isometric hip and groin strength, something that had been previously undetermined. Slight differences in the most commonly used clinical testing procedures and position, potentially elicits different maximal values between the KangaTech and HHD, meaning results cannot be interpreted interchangeably between the two devices. However, individually, both have shown excellent internal reliability. Previously unknown normative values have been established for a normal population using a fixed frame dynamometry system (Table 6). However, what remains unknown is how these figures compare to that of an elite football player. Understanding the differences and similarities between these two cohorts may give us an indication of how the specific mechanisms of elite football and the training regimes followed effect hip and groin health.

4 Study Two – A comparison of the isometric hip and groin strength profiles of an elite football player to the normal population

4.1 Introduction

The aim of this study is to compare the previously established normative values of the normal population's hip and groin strength, to those of elite football players, using the isometric fixed frame dynamometry system, the KangaTech. To the author's knowledge this has not been investigated before in previous research and by doing so it will identify the differences and similarities between the hip and groin strength profiles of the two populations. This information will lead to potential insights as to how the specific mechanisms of the sport and training protocols elite football players are subjected to, can affect hip and groin health. Allowing clinicians to better understand how elite footballer's hip and groin health is affected by the mechanisms of the sport, will potentially lead to a more in-depth and athlete specific approach to injury prevention and rehabilitation protocols.

4.2 Method

4.2.1 Study Design

This was a cross sectional study design. A cross sectional study can analyse data between populations at a specific point in time (Setia, 2016). This study design perfectly fits the aims of this research project and has been used in similar studies previously (von Rosen et al. 2019; Fett et al. 2017). STROBE Guidelines (Von Elm et al, 2007) were used to guide the study's methods. Ethical approval for this study was granted by the BU Ethics Committee (36096) (see section 9.2.2)

4.2.2 Participants

The study was conducted on 25 members of the First Team playing squad at AFC Bournemouth during already timetabled, testing sessions. This session of pre-season testing was chosen for comparison as it had the highest number of participants (n=25), of all testing sessions done during pre-season. Due to Covid-19 restrictions a new ‘normal’ population could not be recruited, therefore limb dominance data was requested of the participants from Study 1. A convenience sample of those who replied (n=16) from those volunteering university students in Study One was used for comparison, representing a ‘normal population’. Table 7 shows the breakdown by gender and foot dominance of this recreationally active population aged between 18 to 25 years. (M=21.2, SD= ±1.79).

Table 7 - Participants

	Male	Female
Right Dominant	11	4
Left Dominant	1	0

Inclusion Criteria – AFC Bournemouth First Team squad members who completed pre-season testing; Over the age of 18 at the time of the study.

Exclusion Criteria – Under the age of 18 at the time of the study; Any significant injuries causing inability to train or play at the time of the study.

4.2.3 Data Collection

The data were collected by AFC Bournemouth during one pre-season testing session (29/07/19) prior to the 19/20 Premier League season. These data were collected by a member of the first team medical staff. All members of medical staff received extensive training in the use of all screening equipment. These data were collected as part of a weekly screening protocol. Data were collected using the KangaTech isometric strength testing system, as described in Study One.

4.2.4 Procedure

Elite football players

Testing was conducted as part of a 'carousel' of screening tests. This battery of tests is conducted weekly, typically Monday morning before training begins. The order in which players complete the tests varies player by player, therefore randomisation occurred naturally. This weekly carousel of screening is a method commonly used in elite sports to monitor the condition of the athlete and subsequent injury risk (Bahr, 2016; Paul et al. 2014).

The testing position for both adduction and abduction tests was supine lying with 90-degree knee flexion and 45-degree hip flexion as described in detail above (section 3.2.4). The order of the tests were alternated for each player. Each contraction was held for 5s (Keep et al. 2016). Due to time constraints and familiarity to the testing, only one maximal contraction was performed for each test.

Results from this test, that occurred during pre-season (29/07/19), was used for comparison.

Normal Population

Data collected from 'Study One' conducted on a normal population, who had documented their dominant limb (n=16) were used for comparison in this study. As only one test effort was recorded for the elite football players, a paired samples t-test was conducted, comparing the normal population's first and second test scores. The second test score was used as there was no significant difference detected between test 1 or test 2 (see section 4.3.1 Results).

4.2.5 Statistical Analyses

Statistical analyses were conducted using SPSS version 26 (SPSS Inc, Chicago, IL). Data were analysed for normality using the Shapiro-Wilk method. All data were normally distributed. A paired samples t-test was conducted on the normal population Test 1 vs Test 2 results for adduction and abduction, to determine which test score to use.

Independent Sample t tests were conducted on adductor and abductor strength scores to assess for differences between groups.

Ratios were also calculated for each participant as described in Table 7.

Independent samples T test were conducted for each ratio, to assess for differences between groups. Paired sample t tests were conducted within group, between dominant and non-dominant adductor:abductor ratios to assess for between limb difference.

Table 8 – Ratio Definitions

Ratios	
Adductor	Dominant Adductor:Non Dominant Adductor
Abductor	Dominant Abductor:Non Dominant Abductor
Dominant Side Adductor:Abductor	Dominant Adductor:Dominant Abductor
Non-Dominant Side Adductor:Abductor	Non Dominant Adductor:Non Dominant Abductor

4.3 Results

4.3.1 Selecting a single test from the normal population

Due to a difference in testing procedure with elite footballers where a single maximal test was taken, testing was carried out to identify which of the two tests conducted in a normal population should be used. There was no significant difference in adduction scores between Left Test 1 (M=336, SD=79.5) and Left Test 2 (M=331.7, SD=81.2) conditions; t (15) = 0.478, p=0.640. There was no significant difference in adduction scores between Right Test 1 (M=338.9, SD=76.8) and Right Test 2 (M=334.8, SD=72.7) conditions; t (15) = 0.365, p=0.72.

There was no significant difference in abduction scores between Left Test 1 (M=343.4, SD=77.6) and Left Test 2 (M=332.9, SD=71.4) conditions; t (15) = 1.856, p=0.083. There was no significant difference in abduction scores between Right Test 1 (M=347.6, SD=81.6) and Right Test 2 (M=339.8, SD=71.9) conditions; t(15) = 1.018, p=0.33. This suggests no learning effect or fatigue enabling the use of either score in normal population to allow for comparison to the elite football players. Therefore, to allow for as much of a fair test as possible, the second test effort was used, to account for the elite football player's familiarity with the test- despite no familiarisation effect evident.

4.3.2 Elite football players vs normal population

There was no significant difference in non-dominant adduction scores between elite football players (M= 298.9N, SD= 94.9) and the normal population (M=331.2N, SD= 81.2) conditions; t(39)= -1.125, p=0.268. There was no significant difference in dominant adduction scores between elite football players (M= 295N, SD= 103.5) and the normal population (M= 334.7N, SD= 72.7) conditions; t(39)= -1.336, p=0.189.

There was a significant difference in non-dominant abduction scores between elite football players (M= 422.1N, SD= 96.1) and the normal population (M=333N, SD= 71.4); t(39)= 3.185, p=0.003. There was a significant difference in dominant abduction scores between elite football players (M= 422.3, SD= 100.4) and the normal population (M= 339.8, SD= 71.9); t(39)= 3.536, p=0.001.

4.3.3 Ratios

Ratios of each test for each population are presented in Table 8.

Table 9- Ratios Mean and Standard Deviation of Populations

	Elite football players		***Normal population***	
	Mean	*SD*	*Mean*	*SD*
Adduction	.969	.12	1.01	.08
Abduction	1.05	.09	1.02	.04
Dominant Side	.657	.15	1.00	.19
Non-Dominant Side	.72	.17	1.01	.21

Notes. SD= Standard Deviation

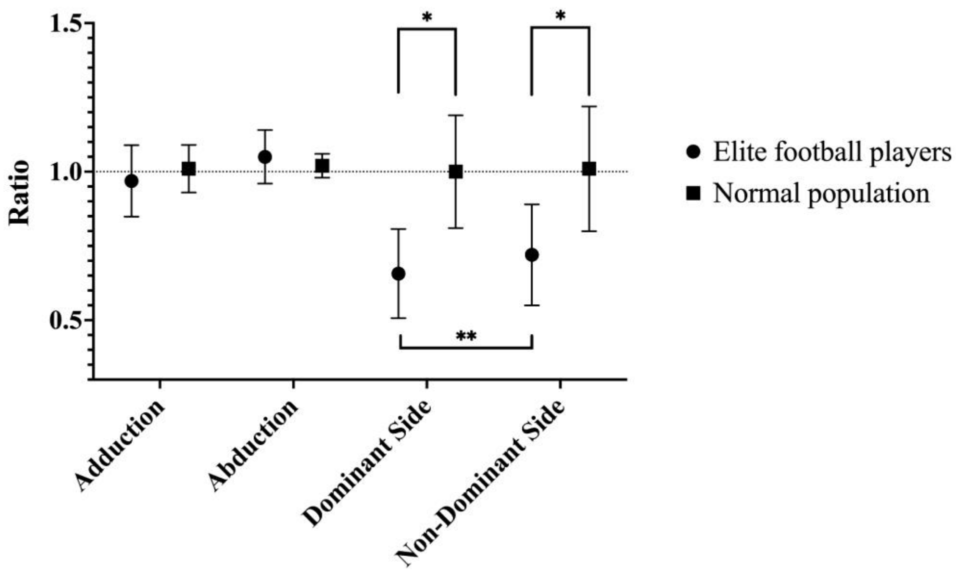


Figure 1. Comparison of conditions between and within groups.

** denotes significant difference between groups. ** denotes a significant difference within a group.*

As presented in Figure 1, between the groups, there was no significant differences in adduction ratios between elite football players (M=0.969, SD= 0.12) and the normal population (M=1.01, SD= 0.08) conditions; t (39) = -1.47, p= 0.150.

There was no significant difference in abduction ratios between elite football players (M=1.05, SD= 0.09) and the normal population (M=1.02, SD= 0.04) conditions; t (39) = 1.34, p= 0.188. There was a significant difference in dominant side adduction:abduction ratios between elite football players (M=0.657, SD= 0.15) and the normal population (M=1.00, SD= 0.19) conditions; t(39)= -6.442, p=<0.001.

There was a significant difference in non-dominant side adduction:abduction ratios between elite football players (M=0.72, SD= 0.17) and the normal population (M=1.01, SD= 0.21) conditions; t(39)= -4.817, p=<0.001.

Figure 1 also shows, within each group, there was no significant difference between dominant side (M=1.00, SD= 0.19) and non-dominant side (M=1.01, SD= 0.21) ratios in the normal population, conditions; t (15)= -.492, p=0.674. There was a significant difference between dominant side adductor:abductor (M=0.657, SD= 0.15) and non-dominant side adductor:abductor (M=0.72, SD= 0.17) ratios in elite football players, conditions; t (24)= -.313, p=0.003.

4.4 Study Two - Summary

Initial findings from this study suggest that at the pre-season time point, elite football players have significantly stronger abductors than a normal population, however, surprisingly there was no difference in adduction strength. Adduction and abduction ratios remained at approximately 1 for both groups, while adduction:abduction ratios were significantly different. These results identify some unprecedented similarities and differences between the normal population and elite football players.

Increased abductor strength in the elite cohort and adductor and abductor ratios of approximately one, agrees with current published research (O'Brien et al., 2019;

Thorborg et al,.2011b). However, perhaps the most interesting and unexpected finding of this study was the similarity in adductor strength between the elite and normal populations. This apparent reduced adductor strength of the elite football players subsequently effected their adductor:abductor ratios leading to a disagreement with current findings (O'Brien et al., 2019; Thorborg et al,.2011b). It is proposed that, similar to the effects observed by Hortobágyi et al. (1993) in power athletes, the elite football players may have experienced a detraining effect of the adductors over the course of the off-season period due to lack of high intensity sports specific activity or a potential lack of adherence to maximal testing protocols by the athletes effected their scores (Neupert et al., 2018). It is unknown the exact factors responsible for this finding, however, to examine these proposed theories, it must be understood how the isometric hip and groin strength profile of elite football players behave and fluctuates throughout a whole season. It is important to examine this behaviour of hip and groin strength profiles throughout the season before these values can be confidently used for injury prevention and rehabilitation methods (Nicholas and Tyler, 2002). However, given a recreationally active member of the normal population would have a less intense and more consistent schedule of activity throughout the year, it is proposed that these findings can be used in the rehabilitation of a normal recreationally active person.

5 Study Three – A longitudinal analysis of elite football player's isometric hip and groin strength profiles

5.1 Introduction

Findings from Study One and Study Two have established the KangaTech as a valid and reliable method of isometric hip strength measurement and identified some novel findings in the comparison of elite football players and the normal population. We now know from Study Two, that, at pre-season elite football players show greater abductor strength but no difference in adductor strength when compared to the normal population. Both cohorts (footballers and 'normals') display an adductor and abductor ratio of approximately 1, which remains true for the normal population's adductor:abductor ratios also. However, we see a significant difference when it comes to elite football players adductor:abductor ratios.

It is common practice in elite sporting environments to use contralateral limb strength (Nicholas and Tyler, 2002) or return to preseason baseline strength as criteria-based return to play markers. Dragijsky (2017) examined seasonal variation in elite youth athletes and Klij et al (2021) examined eccentric hip strength in elite Dutch footballers using a seasonal breakdown to account for the 'start, middle and end' of the competitive period. Dragijsky (2017) examined on pitch physical outcome measures such as change of direction and linear running speed, while Klig et al (2021) found no significant change in eccentric hip strength throughout the season. However, there is no evidence to suggest that longitudinal isometric hip strength data will follow similar trends. It is essential to identify how these isometric hip and groin strength values and ratios behave throughout an elite football season to confidently evaluate and develop future strategies in injury prevention and rehabilitation. Therefore, the aim of this study is to identify any significant differences in hip and groin strength profiles, for elite football players, between three seasonal time points.

5.2 Method

5.2.1 Study Design

A longitudinal study design was chosen for this research project. A study which employs continuous and repeated measures to follow individuals over prolonged periods of time with quantitative data being collected and without any external influence being applied (Caruana et al. 2015) was optimal to answer the research question posed. STROBE Guidelines (Von Elm et al, 2007) were used to guide the study's methods. Ethical approval for this study was granted by BU Ethics Committee (36096) (see section 9.2.2).

5.2.2 Participants

The study was conducted on members of the first team playing squad at AFC Bournemouth.

Inclusion Criteria – AFC Bournemouth First Team squad members; Over the age of 18 at the time of the study; Players who had completed a weekly screening session within 7 days of specified dates and who had data at all three time points.

Exclusion Criteria – Players who did not have data at all three time points; Players who had missed >50% of testing sessions for any reason.

According to this criteria, 17 members of the first team playing squad were eligible to participate in this study. Due to uncontrollable circumstances such as transfers, injuries or international duty, which in turn caused them miss over 50% of testing sessions or to not have data at all three time points, 8 members of the first team squad were excluded.

5.2.3 Data Collection

The data were collected by AFC Bournemouth during the 19/20 Premier League season. Data was collected over a nine-month period (July-March) until the season was paused due to the COVID 19 pandemic. These data were collected by a member of the first team medical staff during weekly screening, typically completed on a Monday. All members of medical staff received extensive training in the use of all screening equipment. Data were collected using the KangaTech isometric strength testing system as describe above (Section 4.2.4)

5.2.4 Procedure

Testing was conducted as part of a ‘carousel’ of musculoskeletal screening tests that were already scheduled by the football club to be conducted weekly prior to training. The order in which players complete the tests is randomised and is a commonly used method in elite sports environments, to monitor the condition of the athlete and subsequent injury risk (Bahr, 2016; Paul et al. 2014).

The testing position for both adduction and abduction tests was supine lying with 90-degree knee flexion and 45-degree hip flexion. Previous research has shown this position as optimal in eliciting adductor muscle activity and is a position commonly used in clinical practice (Delahunt et al. 2011; Lovell, Blanch and Barnes, 2012; O’Brien et al. 2019). This short lever position has also previously been used in isometric abductor strength testing (O'Brien et al. 2019). The force transducers of the KangaTech were placed at the lateral epicondyle of the femur for abduction and medial epicondyle of the femur for adduction (O'Brien et al, 2019). The order of the tests alternated for each player. Each contraction was held for 5s (Keep et al. 2016). Due to time constraints only one maximal contraction was performed for each test with all test results being recorded via software connecting to the testing unit on a password protected computer.

For the purpose of analysis, the season was divided into 3 separate time points.

Time point 1 – Pre-season (29/07)
Time point 2 – Mid-Season (04/11)
Time point 3 – Late Season (02/03)

These dates were selected as Timepoint (TP) 1 indicates the beginning of the season. TP 3 was the final testing session of the season (before it was paused due to the COVID-19 pandemic) and TP 2 occurs approximately at the midway point of this season, prior to the Christmas period where a condensed period of fixtures may have affected testing availability. Similar seasonal breakdown can be seen in Dragijisky (2017) examining seasonal variation in elite youth athletes, and in Klij et al (2021) examining eccentric hip strength in elite Dutch footballers.

Data was taken from one testing session during each of the following periods. If a player had missed one of these pre-selected testing sessions but had attended a testing session within 7 days, their data was also analysed. Although football is a team sport, each player is an individual and would be treated as such in an injury and rehabilitation setting, therefore, we explored the cumulative average, 4-week cumulative average and raw scores of each of these squad members individually.

5.2.5 Statistical Analyses

Statistical Analyses were conducted using SPSS version 26 (SPSS Inc, Chicago, IL). Data were analysed for normality using the Shapiro-Wilk method. All data were normally distributed.

Repeated Measures ANOVA with post-hoc Bonferroni were conducted to establish any differences in hip and groin strength scores and ratios between the three time points. The cumulative average, 4-week cumulative average and raw scores over the course of the season (July-March) are displayed on a graph for each player’s;

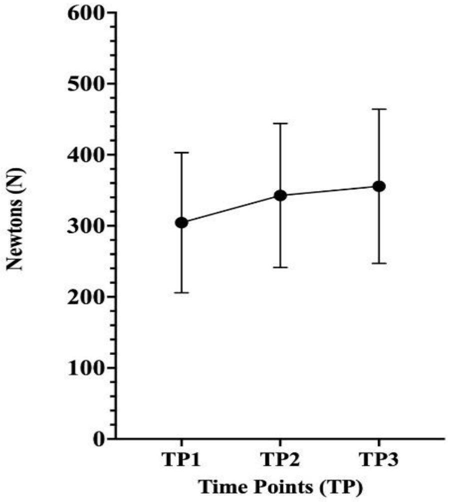
- Dominant and non-dominant adductor scores
- Dominant and non-dominant abductor scores
- Adductor and abductor ratios
- Dominant and non-dominant adductor:abductor Ratios

5.3 Results

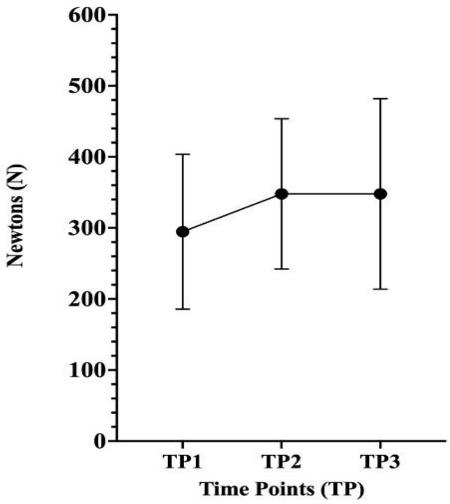
5.3.1 Repeated Measures ANOVA’s

Results from the Repeated Measures ANOVA indicated a non-significant time effect on non-dominant adduction scores; Wilks Lamda = .781, F (2,15) = 2.106, p = 0.156. Although this effect was not significant, Figure 2 shows a 12.5% increase in non-dominant adduction scores from TP1 (M=304.4, SD=98.60) to TP2 (M=342.7, SD= 101.32), and a 3% increase from TP2 (M=342.7, SD= 101.32) to TP3 (M=355.6, SD=108.47). A non-significant time effect was also seen on dominant adduction scores; Wilks Lamda = .694, F (2,15) = 3.304, p = 0.65. Similarly, although this effect was not significant, Figure 2 shows an 18% increase in dominant adduction scores from TP1 (M=294.7, SD=108.96) to TP2 (M=347.9, SD= 105.75), and a 0% increase from TP2 (M=347.9, SD= 105.75) to TP3 (M=347.9, SD= 134.00).

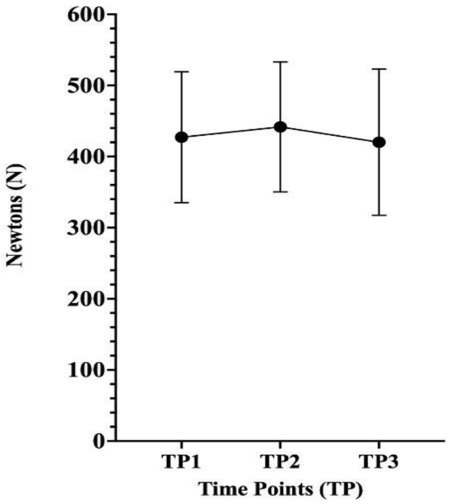
Findings also showed a non-significant time effect on non-dominant abduction scores; Wilks Lamda = .867, F (2,15) = 1.147, p = 0.344; Post Hoc analysis showed a 3.3% increase from TP1 (427.10 ±91.95) to TP2 (441.71 ±91.40) and a 4.9% decrease from TP2 (441.71 ±91.40) to TP3 (420.2 ±102.74). A similar non-significant time effect was observed in dominant abduction scores; Wilks Lamda = .792, F (2,15) = 1.971, p = 0.174. Figure 2 shows a 3.2% increase from TP1 (455.80 ±85.64) to TP2 (470.80 ±90.20) and a 5.2% decrease from TP2 (470.80 ±90.20) to TP3 (446.50 ±107.77).



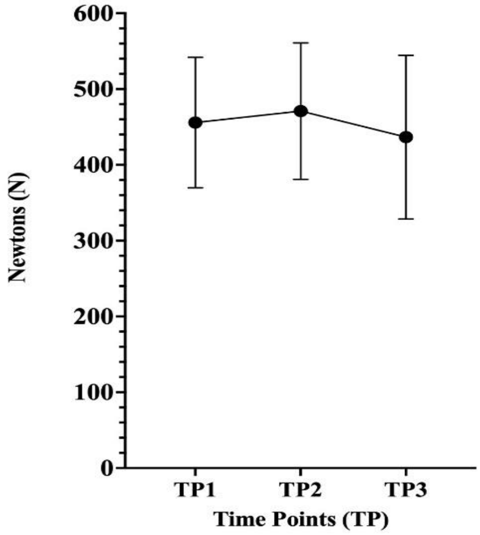
(a) Non-Dominant Adduction



(b) Dominant Adduction



(c) Non-Dominant Abduction



(d) Dominant Abduction

Figure 2 – Max Score(N) comparison between Time Points (TP)

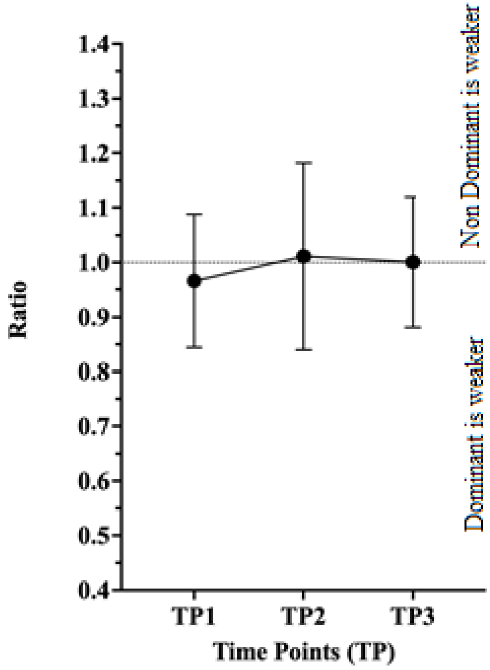
(a)Non-Dominant Adduction, (b)Dominant Adduction, (c) Non-Dominant Abduction, (d) Dominant Abduction

Figure 3 shows results from the ANOVA indicating a non-significant time effect on; (a) adduction ratios;Wilks Lamda = .936, F (2,15) = .509, p = 0.611 and, (b) abduction ratios;Wilks Lamda = .909, F (2,15) = .752, p = 0.488. Further statistical analyses indicated a non-significant time effect on (c) non-dominant adductor:abductor ratios; Wilks Lamda = .834, F (2,15) = 1.497, p = 0.255.

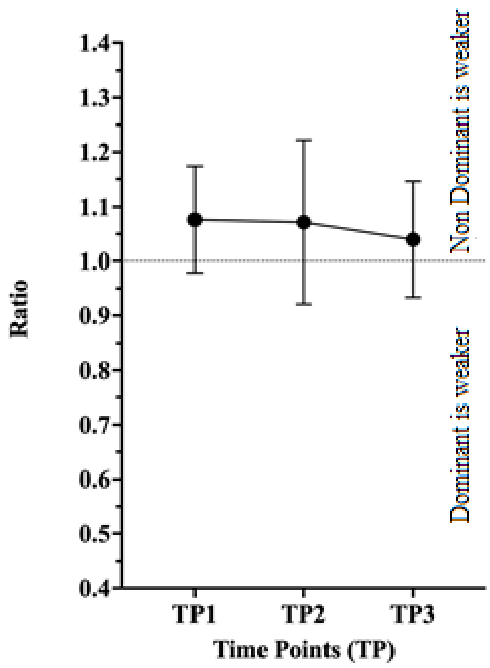
A significant time effect was discovered on (d) dominant adductor:abductor ratios; Wilks Lamda = .936, F (2,15) = 4.155, p = .037. Post-Hoc analysis showed a significant difference between TP1 (0.64 ±0.17) and TP3 (0.80 ±0.21) conditions; t (16) = -2.891, p = .011. Mean and standard deviations are presented in Table 9.

Table 10 - Ratios across Timepoints

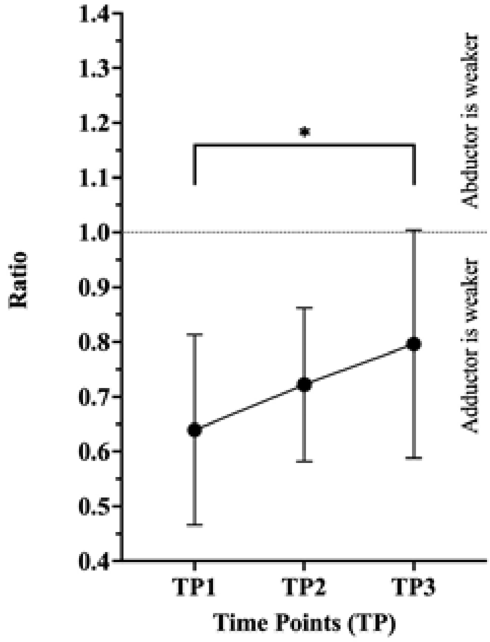
	TP1	TP2	TP3
Adduction Ratios	M=0.96 (± .12)	M=1.01 (± .17)	M=1.00 (± .11)
Abduction Ratios	M=1.07 (± .09)	M=1.07 (± .15)	M=1.03 (± .10)
Non-dominant Ratios	M=0.74 (± .15)	M=0.74 (± .16)	M=0.82 (± .23)
Dominant Ratios	M=0.64 (± .17)	M=0.72 (± .13)	M=0.79 (± .20)



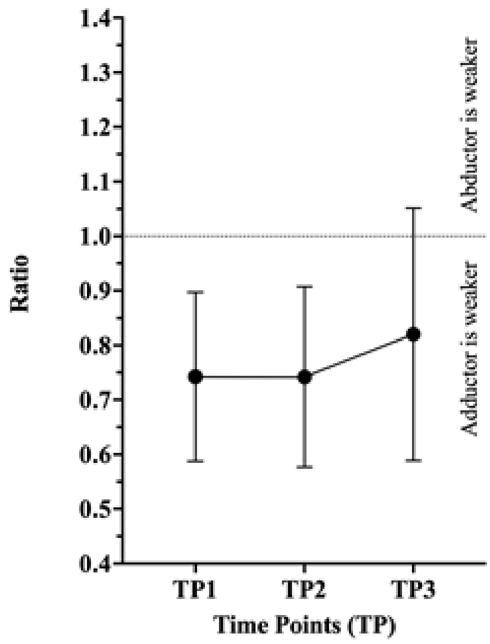
(a) Adduction Ratios



(b) Abduction Ratios



(c) Dominant Ratios



(d) Non-Dominant Ratios

Figure 3- Ratio comparisons between Time Points (TP)

(a) Adduction Ratios, (b) Abduction Ratios, (c) Non-Dominant Ratios, (d) Dominant Ratios

A paired sample t-test showed no significant difference between dominant side adduction:abduction ratios (0.74±0.16) and non-dominant side adduction:abduction ratios (0.78 ±0.14) at TP2, p=0.158. Similar results were seen at TP3, dominant side adduction:abduction ratios (0.8 ±0.19), non-dominant adduction:abduction ratios (0.83 ±0.21), p=0.239.

5.3.2 Seasonal Trends

Players' cumulative average, 4 week average and maximum score graph for non-dominant adduction (Figure 4), dominant adduction (Figure 5), non-dominant abduction (Figure 6), dominant abduction (Figure 7) and ratios (Figure 8 and Figure 9) were produced. An illustrated representation of a single player is displayed in Figure four to nine, portraying a profile that shows: A great seasonal increase in maximum adductor strength (> three SD's); an increase in abductor maximum strength score to a lesser extent (one – three SD's); fluctuating but relatively consistent adductor and abductor ratios (one – three SD's); and adductor:abductor ratios (> three SD's) climbing to reach one as the season progressed. Note that week one to four are pre-season, the green line represents maximum score, the blue represents cumulative average, the orange 4-week cumulative average and the dotted lines are standard deviations. See appendix 9.1 for graphs for each player.

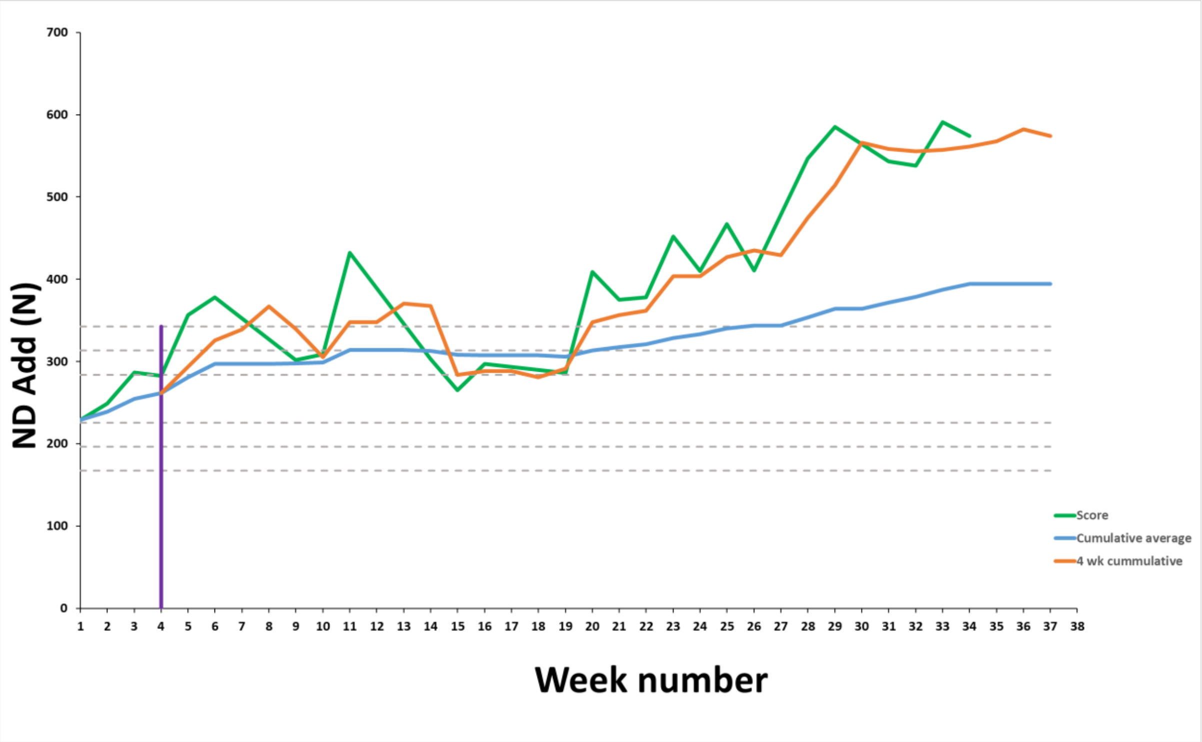


Figure 4 - Example Player Non-Dominant Adduction

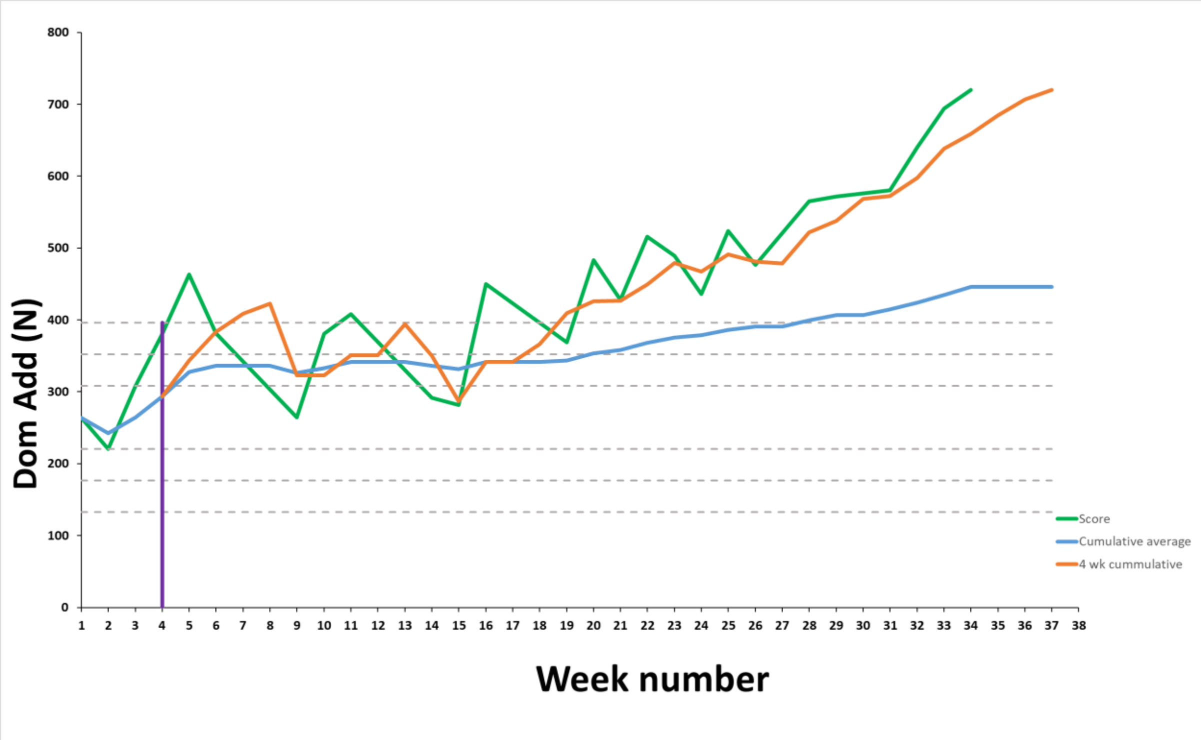


Figure 5 – Example Player Dominant Adduction

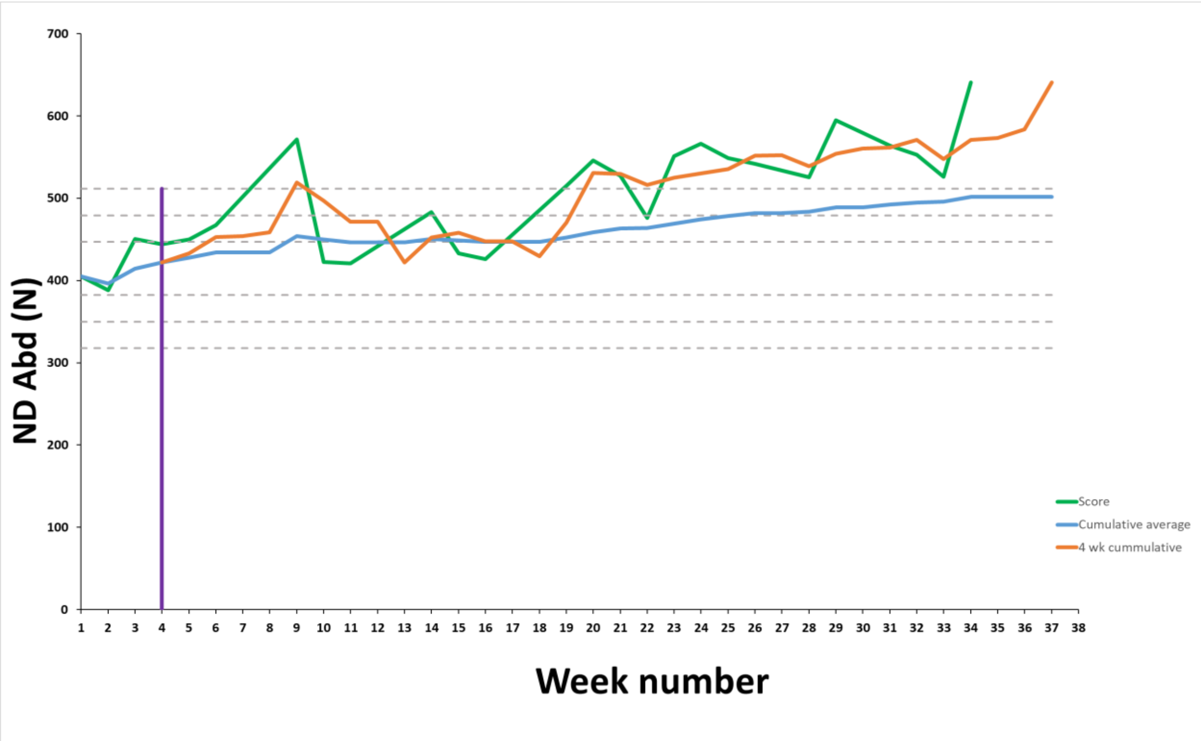


Figure 6 - Example Player Non-Dominant Abduction

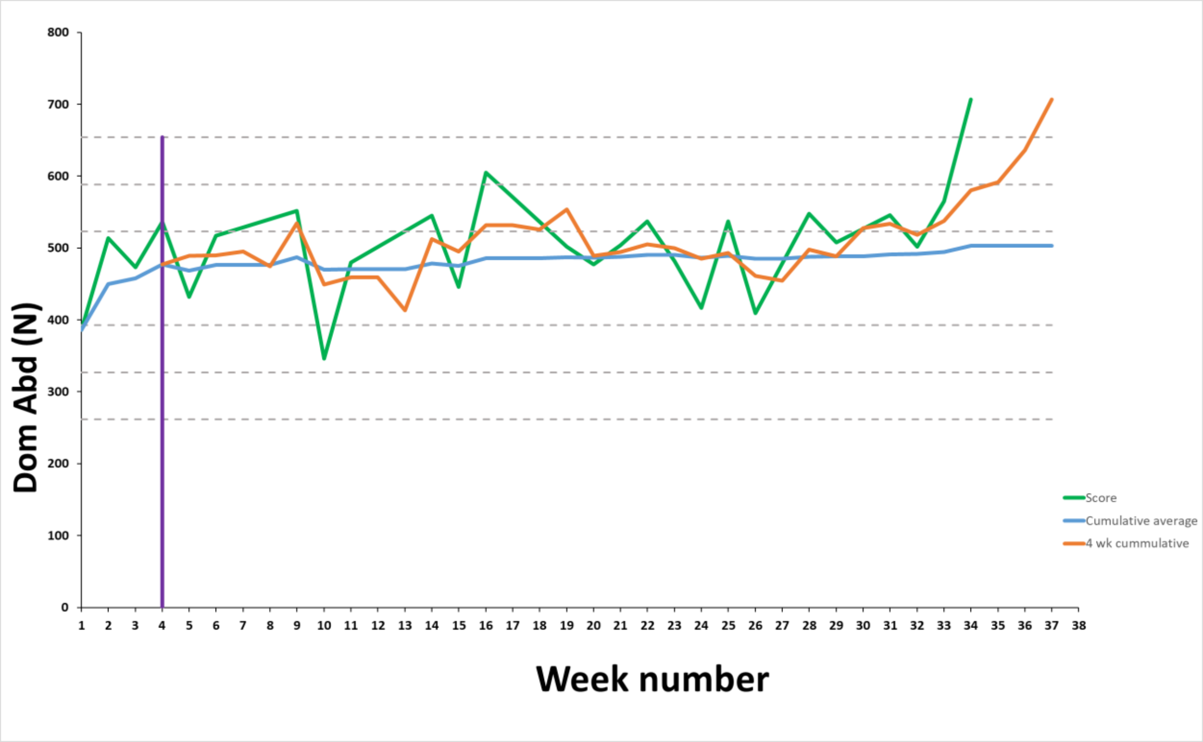


Figure 7 - Example Player Dominant Abduction

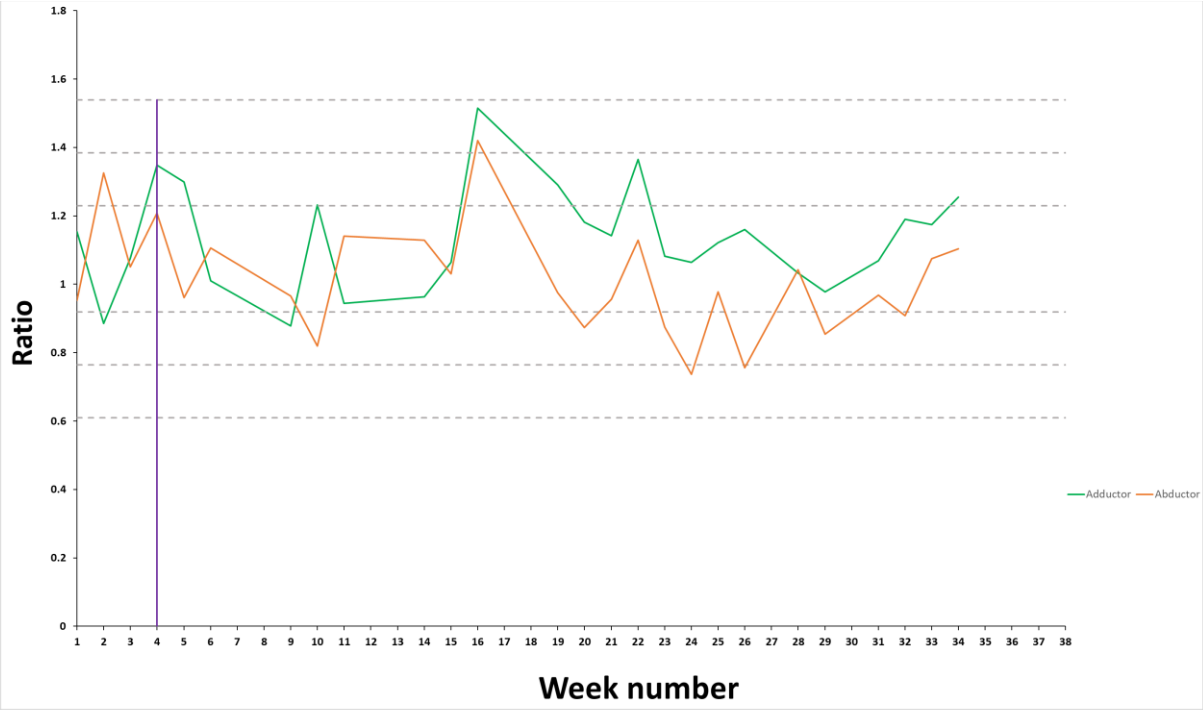


Figure 8 - Example Player Adductor and Abductor Ratios

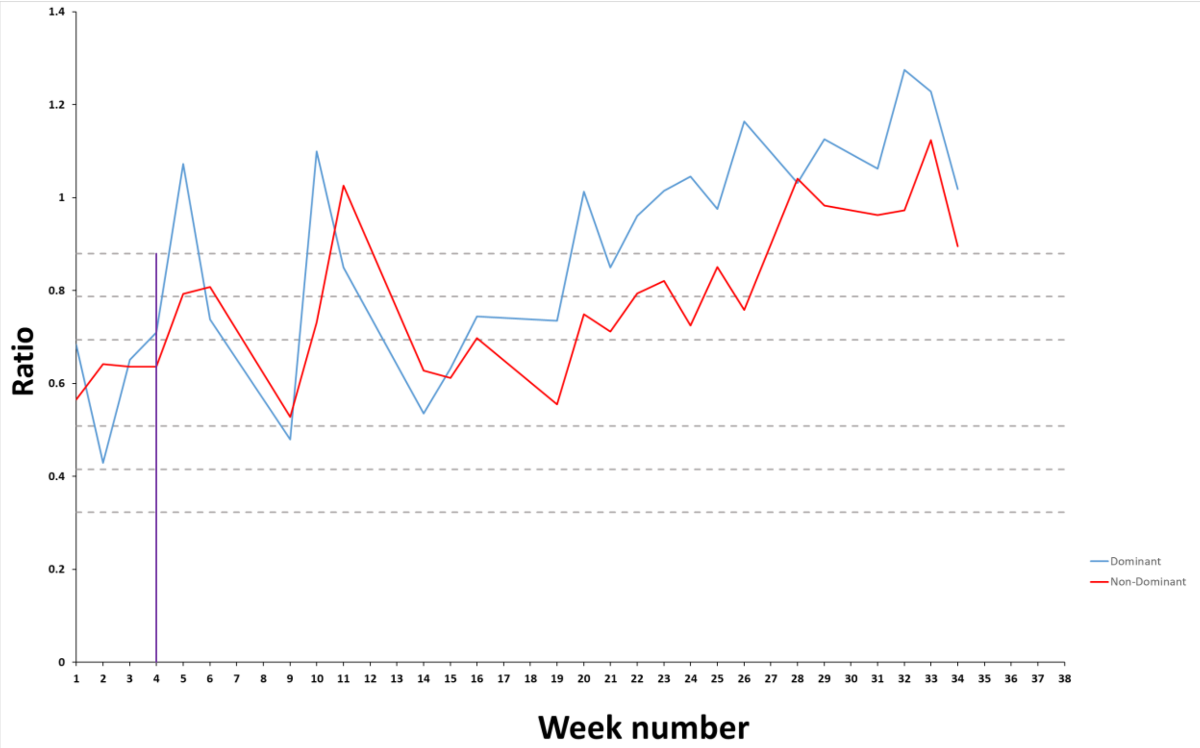


Figure 9 - Example Player Adductor:Abductor Ratios

5.4 Study Three – Summary

Initial findings from Study Three suggest that (although not statistically significant) there was a clinically significant increase in adductor strength between TP1 and TP2. Sedgwick (2014) describes clinical significance as a difference that is clinically important and may change clinical practice if observed. According to Ryan et al's (2018) reliability study on the similar fixed frame dynamometry system, the GroinBar, a change in strength of 6.3% or more can be interpreted as real change. Similarly, in 2020, Ransom et al (2020) reported a SME% of 3.3% for abduction and 4.8% for adduction. With these findings in mind, we can see a real change in strength between TP1 and TP2 for the dominant and non-dominant adductors, with a real change (decreasing strength) taking place between TP2 and TP3 for dominant and non-dominant abduction. Adductor and abductor ratios remained generally consistent. It could be speculated that these adductor strength gains occurred as players returned to training and competition, after experiencing a detraining effect during the off season due to lack of adductor sports specific exposure, while abductor strength was maintained through general off-season conditioning and then experienced a fatigue effect in the later parts of the season. The adductor and abductor strength trends occurring at different rates throughout the season in turn lead to differing adductor:abductor ratios throughout the season, while adductor and abductor ratios remain consistent. As the season progressed, limb dominance had no effect on adductor:abductor ratios. These findings are echoed when individual players profiles are examined. Generally, early season increases in adductor strength, late season decreases abductor strength, consistent adductor and abductor ratios and increasing adductor:abductor ratios are observed.

Consistent adductor and abductor ratios of approximately one agrees with current published research, while the adductor:abductor ratios establish in this study disagree (O'Brien et al, 2019; Thorborg et al., 2011b). However, as the season progressed adductor:abductor ratios approached one, similar to published findings. Results from this study indicate adductor and abductor ratios of approximately one can be used throughout the season in injury prevention and rehabilitation strategies. However, due to varying seasonal trends of adductor and abductor maximum strength, care must be taken when using adductor:abductor ratios for injury prevention and rehab return to play protocols at different stages of the season. Further research is needed to establish normative values for different seasonal time points. Return to baseline strength as a rehabilitation return to play criteria is not recommended. These findings remain true at an individual level, as with any injury prevention or rehabilitation programme it should be individualised to the specific athlete.

6 Discussion

6.1 Validity and Reliability

The aim of Study One was to establish the reliability and validity of the newly developed fixed frame isometric dynamometry system, the KangaTech, alongside the more standard method of isometric strength testing, the HHD. The HHD offers a cheap and accessible alternative to the gold standard of strength assessment, the IKD, and is commonly used in the assessment of isometric hip strength in clinic. However, the reliability and validity of the HHD has been heavily researched with varying results (Fulcher et al., 2009; Kemp at al., 2013; Thorborg et al., 2013). Key to this, is differences in the inter- and intra- rater reliability of the HHD, yet it is still widely considered standard practice in elite sports medicine environments. Fulcher et al. (2009) reported good to excellent inter-reliability (ICC=0.66-0.87) and intra-reliability (ICC=0.70-0.89) when assessing hip strength in athletes. Kemp et al. (2013) have also identified HHD as a reliable source of measuring isometric hip strength in healthy adults. Thorborg et al's (2013) study identified handheld dynamometers as being susceptible to between-tester bias, with tester experience and strength both influencing scores ($p<0.05$). This study concluded that to improve intertester reliability, the dynamometer likely needs external fixation.

The Kangatech offers a rigid frame of external fixation with force transducers embedded, avoiding any tester influence. Fully moveable sensors allow for it to be modified to any person’s body shape to allow use in all planes of movement. To the authors knowledge the Kangatech currently lacks any published validity and reliability data in comparison to HDD.

Results from the investigation into the validity used both a correlation test and difference test. The results demonstrated a strong positive correlation between score achieved with the HHD and those achieved with the KangaTech, when force was applied from the HHD sensor directly on to the KangaTech sensor ($r=0.996$, $n=50$, $p=<0.001$). Comparing any differences between the Kangatech and HHD, a Wilcoxon Signed Rank test was with the results showing there was no significant difference observed between the scores ($z=-.681$, $p=0.496$). Similarly, Arnold et al (2010), reported the HHD to be a valid measurement of lower limb isometric strength when being compared to other isometric dynamometer methods ($r = 0.57$-0.86; $p < 0.05$) , while Hirano et al (2020) reported, a significant positive correlation of ($r=0.71$, $p<0.01$) when assessing isometric knee extension with the HHD and the IKD.

Using ICC analyses, the reliability of both systems was tested on a ‘normal population’. ICC results from this study were interpreted following guidelines by Koo et al. (2016), therefore an ICC of: <0.50, was poor; between 0.50 and 0.75 was fair, and between 0.75 and 0.90 was good; above 0.90 was excellent. With these in mind both the Kangatech (ICC= L: 0.929; R: 0.929) and the HHD (ICC= L: 0.951; R: 0.931) were found to have excellent intra-rater reliability. These findings agree with common themes in the current literature. Ryan et al. (2018) found that a similar fixed frame isometric dynamometry testing system (GroinBar) to be reliable (ICC=0.94) in assessing hip and groin strength. Previous literature has reported the HHD to be reliable in assessing hip and groin strength (Fulcher et al. 2009; Kemp et al. 2013) with ICC's ranging from 0.66-0.89.

Findings from this research suggest that both the KangaTech and the HHD are reliable and valid methods of measuring isometric hip and groin strength, while also providing newly established normative values for isometric hip strength of a normal population using a fixed frame dynamometry system. The lack of tester influence on the KangaTech suggests it as a favourable method of assessing isometric hip and groin strength. However, a caveat to this investigation shows the results from both systems cannot be interpretated interchangeably. Results showed differing maximum results for each instrument, consider these ranges: KangaTech adduction = 336N-372N compared to HHD adduction = 167N-168N; and KangaTech abduction = 348N-358N compared to HHD abduction= 182N-183N. These results potentially stem from the testing position and procedure for each device (HDD, KangaTech) - the procedures differ when it came to the untested leg position during contraction, despite the position of the tested leg being identical for both pieces of equipment based on previous research (Delahunt et al. 2011; Lovell, Blanch and Barnes, 2012; O'Brien et al. 2019). The KangaTech is designed to test bilaterally while the HHD is most commonly used unilaterally. This meant that for the tester to have access to the sensor placement positions (femoral condyles) during the HHD testing, the untested leg remained at zero degrees hip flexion and zero degrees knee flexion.
Previous studies have identified phenomenon when it comes to forces applied during bilateral and unilateral maximal strength testing. The 'bilateral deficit phenomenon' has been described by Škarabot et al (2016, p 1) as "a reduction in the amount of force from a single limb during maximal bilateral actions" compared with the same

limb unilaterally. However, there are some inconsistencies in the literature with some studies suggesting a contrasting phenomenon known as “bilateral facilitation” (Secher 1975, Schantz et al. 1989, Howard and Enoka 1991), where the sum of the unilateral forces is less than the bilateral force. Although, the results of this study portray a “bilateral facilitation” rather than deficit, it is the authors opinion that it’s more likely that this novel finding is as a result of different positioning of the untested leg creating a lack of stabilisation, and therefore a lesser contraction potential of these muscles when being in the unilaterally testing position for HHD. Further research is needed to investigate the physiological explanation behind these findings.

With these results in mind, Study One’s research questions have been answered with the KangaTech and HHD both being reliable and valid sources of isometric hip strength measurement and normative values for a normal population established.

6.2 Elite football players vs normal population

6.2.1 Elite football players vs normal population; Maximum adductor and abductor strength

Another primary objective of this research project was to compare the isometric hip and groin strength profiles of elite football players to a normal population. Initial findings from this research show that there was no significant difference in non-dominant adduction scores between elite football players (M= 298.9 ±94.9N) and the normal population (331.2 ±81.2N), p=0.268, or in dominant adduction scores between elite football players (295±103.5N) and the normal population (334.7±72.7N), p=0.189. However, there was a significant difference in non-dominant abduction scores between elite football players (422.1±96.1N) and normal population (333±71.4), p=0.003 and in dominant abduction scores between elite football players (422.3±100.4N) and normal population (339.8±71.9N), p=0.001. Despite a lack of any concrete evidence to support this theory, it would be a common thought process that on average elite Premier League football players would be able to produce more isometric force in a lower extremity maximal strength test than recreationally active members the normal population. A 2006 study conducted using 54 young soccer players, found that level of competition (elite, sub elite and recreational) had a significant effect on maximum isometric force produced, with elite level competitors being the strongest. Although this remains to be the case in this research study for abduction maximum isometric strength scores, adduction maximum strength does not follow suit with similar scores to the normal population observed.

There are many possible explanations for this interesting finding, there may have been a detraining effect as described by Hortobágyi et al. (1993) during the off-season period meaning that the pre-season scores from the football players had returned to their ‘normal state’ in season. Alternatively, poor athlete engagement may have affected the data collection (Neupert et al, 2018) where the players are routinely tested and therefore may not engage fully in the process of testing. The results from this section of Study Two form components of further investigations in Study Three regarding potential reasoning for this novel finding.

6.2.2 Elite football players vs normal population: Ratios

Current research suggests that imbalanced hip and groin strength ratios are a risk factor for hip and groin injuries (Ryan et al. 2014; Engebretsen et al. 2010; O’Connor et al. 2004, Markovic et al. 2020). However, there has been some disagreement in the literature regarding normative ratios with some reporting no difference between limb (Thorborg et al. 2011b; O'Brien et al. 2019) and some reporting increased strength on the dominant side (Thorborg et al. 2011c; Bourne et al. 2019). This study aimed to establish adductor ratios, abductor ratios and adductor:abductor ratios for dominant and non-dominant sides in elite footballers and normal population as these have not previously been investigated and could offer valuable insights in to how the specific mechanisms of the sport and training protocols elite football players are subjected to can affect hip and groin health.

Initial findings show that there was no significant difference in adduction ratios (0.969±0.12; 1.01±0.08), p= 0.150 or abduction (1.05±0.09; 1.02 ±0.04), p= 0.188 between elite football players and the normal population, respectively. These findings agree with current research regarding between limb adduction and abduction ratios (O,Brien et al., 2019; Thorborg et al 2011b). Despite football being a predominantly unilateral sport there is no difference in dominant and non-dominant abductor and adductor strength, leading to similar ratios to that of the normal population. A possible rationale for this is the use of the non-dominant leg as a stabiliser during kicking actions (Thorborg et al., 2011b), and high EMG activity of the adductors bilaterally during a change of the direction (Dupre et al. 2021) leading to equal isometric adaptations bilaterally regardless of foot dominance.

However, there was a significant difference found in dominant side adductor:abductor ratios between elite football players (0.657±0.15) and the normal population (1.00±0.19), p=<0.001. Similarly, there was also a significant difference in non-dominant side adductor:abductor ratios between elite football players (0.72±0.17) and the normal population (1.01±0.21), p=<0.001. These findings somewhat contradict the current literature, that would suggest a ratio of approximately 1 for dominant and non-dominant adduction:abduction (O'Brien et al. 2019; Thorborg et al. 2011b). Although it is evident that the normal populations ratios remain consistent with the research, we can see that the elite football player's ratios fall below demonstrating an adductor weakness in relation to abductor strength. This result was expected given the reduced maximum adductor strength output from the elite football players in comparison to their abductor strength output. Possible explanations for this reduced output are explored in Study Three (6.3).

Finally, when analysing dominant and non-dominant side ratios within each population, there was no significant difference between dominant side (1.00 ±0.19) and non-dominant side (1.01±0.21), p=0.674 ratios in the normal population. However, a significant difference was found between dominant side (0.657±0.15) and non-dominant side (0.72±0.17), p=0.003 ratios in elite football players. This finding in the elite football player population again contradicts the current literature, while we see agreement within the normal population (O'Brien et al. 2019; Thorborg et al. 2011b). A possible explanation for this is the lack of sports specific game like intensity change of direction, acceleration and deceleration in the off-season period prior to this testing session, leading to the adductors being left potentially underloaded isometrically. The non-dominant adductor may potentially be exposed to less of a de-training effect and lose less isometric strength during the off season as it is be used as a stabiliser in sub maximal dominant leg ball striking (as part of a maintenance off-season programme)- thus leading to differing adductor:abductor ratios. However, with the lack of high intensity training and game like scenarios, the dominant side is being underloaded isometrically due to less frequent of reactive

CoD and non-dominant leg kicking. This finding strengthens the theory that high intensity, reactive and opposed change of direction/accelerations and decelerations/maximal kicking cause isometric adaptations in the adductor muscles.

6.2.3 Normative Values

Established through this research project was a set of normative values of isometric hip and groin strength for a normal population using a fixed frame isometric dynamometry system. To the authors knowledge no such data has been published previously. These values of a young recreationally active population are of use to clinicians in the rehabilitation of hip and groin injuries, specifically in the end stage return to play criteria (Clover and Wall, 2010). Although less commonly used in the rehabilitation of non-elite athletes, it is nonetheless a beneficial addition to the current literature. Alvarenga et al. (2019) published normative hip and groin strength values for young women using the HHD and reported its use in criteria for discharge, return to sports, or assessment of the impact of injuries in terms of loss of muscle strength. It is proposed that this date will be used in a similar fashion.

The comparison of an elite football player to a normal population gives us some insight into how the specialised and specific components of an elite football training programme affects the hip and groin area. It is proposed that the elite athletes may have experienced a detraining effect of the adductors over the course of the off-season period, similar effects have been seen by Hortobágyi et al. (1993) in power athletes. Results from Study Three show that the isometric hip strength of elite football players changes throughout a season. However, given a recreationally active member of the normal population would have a less intense and more consistent schedule of activity throughout the year, it is proposed that these findings can be used in the rehabilitation of a normal recreationally active person at any given time.

6.3 Seasonal Variation

Some unprecedented and interesting findings in relation to Study Two, most notably an apparent adductor weakness in elite football players, lead to further investigations of this data in Study Three. The aim of Study Three was to establish if the stage of the season had a significant effect on the hip and groin strength profiles of the elite football players and/or provide an explanation for this apparent weakness at the pre-season time point.

This study provided graphs as a visual analysis of the cumulative average, 4 week average and maximum score of each player's hip strength profile (Appendix 9.1). These illustrations provide visual results of global hip and groin strength profile trends as the season progressed. Of most note, to the author, was the vast increase in adductor strength in the first half of the season evident in the majority. Throughout, abductor strength remained relatively consistent and, in some cases, declined in the final half of the season. Adductor and abductor ratios generally remained around 1, while dominant and non-dominant adductor:abductor ratios varied throughout the season due to changes in maximum abductor and adductor strength. It was hypothesised that these maximum testing scores may be affected by player's adherence to testing protocols (Neupert et al., 2018). However, on analysis of these graphs, natural and gradual variation occurs throughout the season, something that the author believes would not be possible with consistent submaximal efforts. Similarly, the adductor and abductor maximum scores follow differing trends, which would not be evident if consistent self-determined sub maximal efforts were produced. Therefore, this hypothesis was refuted.

Three time points were selected for testing (Time point 1 – Pre-season (29/07), Time point 2 – Mid-Season (04/11), Time point 3 – Late Season (02/03)) in line with previous research from Dragijisky (2017) and Klij et al (2021). Initial statistical findings from the repeated measures ANOVA indicated a non-significant time effect on dominant adduction (Wilks Lamda = .781, F (2,15) = 2.106, p = 0.156) and non-dominant adduction scores (Wilks Lamda = .694, F (2,15) = 3.304, p = 0.65). Although no significant time effect was found for dominant adduction, a 12.5% increase from TP1 (304.40±98.60) to TP2 (342.70±101.32), and a 3% increase from TP2 (342.70±101.32) to TP3 (355.60±108.47) was observed. Similarly, although there was no significant time effect for non-dominant adduction, further analysis showed an 18% increase in dominant adduction scores from TP1 (294.70±108.96) to TP2 (347.90±105.75), and a 0% increase from TP2 (347.90±105.75) to TP3 (347.90±134.00). The repeated measures ANOVA also showed non-significant time effect for non-dominant abduction scores (Wilks Lamda = .867, F (2,15) = 1.147, p = 0.344) dominant abduction scores (Wilks Lamda = .792, F (2,15) = 1.971, p = 0.174) adduction ratios (Wilks Lamda = .936, F (2,15) = .509, p = 0.611) and abduction ratios (Wilks Lamda = .909, F (2,15) = .752, p = 0.488).

Although the difference in maximum strength scores between time points was not statistically significant, it is evident that there was an increase in strength between TP1 and TP2 for the adductor muscle group. Ryan at al's (2018) reliability study on the similar fixed frame dynamometry system, the GroinBar, suggested that a change in strength of 6.3% or more can be interpreted as real. Similarly, in 2020, Ransom et al (2020) reported a SME% of 3.3% for abduction and 4.8% for adduction. With these findings in mind, we can see a real change in strength between TP1 and TP2 for the dominant and non-dominant adductors, with a real change (decreasing strength) taking place between TP2 and TP3 for dominant and non-dominant abduction. This interesting finding may again be explained using an example from Hortobágyi et al. (1993). In this study a 'detraining effect' was observed with power athletes observing a 14-day cessation of training, the results showed a 12% decrease in force production. The changes in dominant and non-dominant adduction strength between TP1 and TP2, 12.5% and 18% respectively, demonstrate a real change. This suggests a clinically significant (Sedgwick, 2014) finding that the adductors adapt to training loads in the early stages of the season and 'return to normal strength levels' in a quicker fashion than the abductors. Subsequently, this may suggest that the adductors undergo a bigger 'de-training effect' during the off-season. An explanation for this potential adductor weakness at the pre-season time-point may be the lack of high intensity sports specific training during the post season break. There is an indication of a clinically significant change evident in the final part of the season on adductor strength where a decrease of 4.9% (Non-Dominant) and 5.2% (Dominant) can be seen suggesting a fatigue effect on the abductors.

During an off-season period (approx. 6 weeks), an elite football player would be given an 'off-season programme' with strength, cardiovascular and technical based exercises, where they are expected to recover from the previous season but also maintain levels of strength, cardiovascular fitness and technical ability leading to the next. These programmes usually incorporate all components of strength work and are finely tuned to make sure each athlete is adequately conditioned. The Copenhagen adductor exercise is often included in these programmes which has been proven to improve eccentric adductor strength (Ishøi et al. 2016). This is evident given Klij et al's (2021) research that showed no significant effect on eccentric adductor strength throughout 3 seasonal time points in Dutch League teams. However, it is possible that the lack of chaotic, opposed and intense change of direction and ball striking during an off-season period leaves the adductors underloaded isometrically given their use in stabilisation during these actions, while other muscle groups such as the abductors are maintained by the general off-season programming.

Electromyography (EMG) measures a muscles response to a stimulus through electrodes connected to the muscle. It is commonly used in sports medicine research to determine a muscles response to a particular activity (Hof, 1984). Studies have shown that the adductors have a high EMG activity during change of direction and kicking, two of the most important factors in football training and match play (Dupre et al. 2021; Brophy et al. 2007; Charnock et al. 2007). Dupre et al. (2021) found high EMG activity for the adductor longus (AL) and gracilis (G) during 90-degree cutting movements (AL=55.47%MVC, G=88.35%MVC) and inside of the foot passing (AL=43.79%MVC, G=42.87%MVC). In a 2020 study conducted on eight university football players, Watanabe et al (2020) reported high surface EMG of adductor magnus and adductor longus during side and instep kicking, that increased as the ball speed increased. Interestingly, this was reported for the kicking and the stabilising leg. Research by Lovell et al. (2012) showed the testing position used in this study (hips at 45 degrees, knees at 90 degrees) to have the highest EMG activation of the adductor longus (87.3%), the adductor magnus (78.1%) and the gracilis (87.2%). It is understood that reduced isometric strength is a risk factor for hip and groin injury (Ryan et al. 2014; Engebretsen et al. 2010) and that hip and groin injury incidence is highest during pre-season (Esteve et al. 2020b).

Therefore, it is plausible to suggest that there is a detraining effect during the off-season period, leading to weakness at this pre-season TP and a subsequent higher injury risk during pre-season (Esteve et al. 2020b) as players are too quickly exposed to high levels of sports specific training (Whittaker et al, 2015). Once players have been adequately exposed to the load of intense, chaotic and opposed training and match play, providing they avoid injury they subsequently undergo specific adaptations and strength increases allowing them to adapt to the load. There was no significant time effect on adduction or abduction ratios suggesting that, as these strength adaptations occur over the course of the season, they occur equally bilaterally, thus enhancing the hypothesis that the use of the adductors as a stabiliser induces strength adaptations. These ratios were maintained at approximately 1 throughout the season which coincides with results previously reported in the literature (Thorborg et al. 2011b; O'Brien et al. 2019). Therefore, in criteria-based rehabilitation programmes, it is reasonable for clinicians to use the contralateral limb as a reference value of strength regardless of the stage of the season.

Analysis from this study also indicated a non-significant time effect on non-dominant adduction:abduction side ratios, while a significant time effect was discovered on dominant side adduction:abductiom ratios. Paired sample T-Tests showed no significant difference between dominant side adduction:abduction ratios (0.74±0.16) and non-dominant side adduction:abduction ratios (0.78 ±0.14), p=0.158 at TP2, or, dominant side adduction:abduction ratios (0.8 ±0.19), non-dominant adduction:abduction ratios (0.83 ±0.211), p=0.239 at TP3. It is proposed that the apparent decreased adductor strength at the preseason time point and subsequent differing in season trends compared to abductor strength had a great effect on these ratios. Post-hoc analysis showed a significant difference between TP1 (0.64 ±0.17) and TP3 (0.80 ±0.21) conditions; t (16) = -2.891, p = .011. However, no significant difference was seen between TP2 and TP3. Furthermore, the statistically significant difference between dominant and non-dominant adductor:abductor ratios seen at pre-season (TP1) was not evident at TP2 or TP3. This suggests that as adductor strength adaptations occurred bilaterally and isometric adductor strength levels returned to ‘normal’, the adductor:abductor ratios also began to return to normal. However, throughout the season the adductor:abductor ratios peaked at approximately 0.8, which does not agree with the current literature that suggests a ratio of approximately 1 (Thorborg et al. 2011b; O’Brien et al. 2019). A proposed explanation for this is time of the season in which these ratios were collected. O’Brien et al. (2019) collected the data in June at the end of the 2016-17 Australian A-League season (which ran from October-May) when it may have been too early for any detraining effects on adductor strength to have occurred. While Thorborg et al. (2011b) collected data during a February mid-season break, where strength adaptations are likely to have already occurred, or at least started. It is plausible that if the ratios of the elite football players in this study had been assessed again at the end of the playing season, they may have been closer to that reported in the literature through further adductor strength gains. However, clinically this suggest that clinicians should be aware of the stage of the season when using adductor:abductor ratios as reference points for rehabilitation form injury. Further research is needed to establish normative adductor:abductor ratios for stages of the season in elite level football players.

6.4 Practical Applications

The present study aimed to contribute to the understanding of elite football player's hip and groin strength, how it compares to a normal population and how it behaves throughout a football season. Given the evidence provided from this research project some recommendations for future clinical practice are as follows;

- The KangaTech and HHD are both valid and reliable methods of assessing isometric hip strength and can be used clinically. However, results cannot be interpreted interchangeably between both.
- Normative values have been established for the use in the injury prevention and rehabilitation of the normal population.
- An apparent off-season detraining effect of the adductors may lead to weakness, subsequent increased injury risk and finally increase hip and groin injury incidence. Care should be taken during pre-season return to play with a gradual increase in chaotic and opposed change of direction and ball striking. Similar to the progressive reintegration of sprinting in elite programmes.
- Adductor and Abductor ratios should be approximately 1 and can be used irrespective of stage of the season in rehabilitation return to play protocols.

When using adductor:abductor ratios particular attention must be paid to the stage of the season, however more research is needed to establish normative ratios for each stage.

6.5 Confounding Factors

As discussed in section 6.1, bilateral facilitation phenomenon must be considered when analysing the results of study 1. Differences in between HHD and KangaTech scores for the same test on the same limb meaning results cannot interpreted interchangeably between the two devices. It is possible that these differences are a result of bilateral facilitation phenomenon, however, it is the authors opinion that there is not a phenomenon at work here and the differences are due to slightly different testing positions and therefore altered contraction potentials of the hip musculature.

Poor athlete engagement during testing has been shown to have an effect on training monitoring systems (Neupert et al. 2018). This research showed that modifications made to training as a result of the data collected (e.g data collected suggest fatigue and players training minutes reduced) and subsequent lack of feedback regarding reasoning for the modification from staff leads to ‘poor buy in’ from athletes. Although not thought to have had an effect on the data collected in this research project, it is a potential confounding factor that cannot be ignored. It is possible that the repetitive nature of weekly monitoring may lead to reduced athlete adherence and effort in testing protocols and engagement to which they perform maximal efforts. In contrast to this, the normal population were being tested during a once off session and were very eager to assist in the research project. This must be taken into consideration when interpreting the results of study 2.

Similarly, due to time constraints, elite athletes only conducted one maximal effort for each test during the season. As previously discussed, best practice is a warm-up effort followed by two maximal test efforts as described by Jeon et al (2019). It is unknown how this might affect the results of study 3, however it must be acknowledged when interpreting results.

6.6 Limitations

It must be noted that, for the purpose of this study, normative data was referred to as that of a normal population. However, this data is more representative of that of a young recreationally active healthy population.

This study did not use an IKD for the assessment of data which is considered the gold standard. However, previous research has shown that the HHD is valid measurement of hip strength compared to the IKD (Keep et al., 2016). This has led the HHD to be a standard tool to use in clinical practice to avoid the time constraints and expense of using an IKD. This study has shown there to be no significant difference between the KangaTech and HHD when measuring isometric hip strength. This extends where there is no difference between a HHD and KangaTech, we can therefore consider the KangaTech a valid source of isometric hip strength measurement.

Due to the COVID-19 pandemic some aspects of this study had to be modified. Restrictions placed on elite sport early in the pandemic made data collection difficult, therefore the desired outcomes had to be altered slightly for Study 2 and 3. It must be noted that, for the purpose of this study, normative data was referred to as that of a normal population. However, this data is more representative of that of a young recreationally active healthy population. This was due to limitations in participant gathering due to COVID-19 restrictions at the time of data collection.

The main effect that these alterations on the project was the sample size used, predominantly in study 2. Justification of sample sizes used can be seen below:

Study 1- Full sample of all responding applicants used.

Study 2- Due to alterations in the study aims limb dominance data had to be collected via email after the date of testing, as it was not initially being used. There were only 16 participants who responded with this data.

Study 3- Full sample of available data used limited by player injuries, transfers or international duty.

A final limitation as a result of the COVID-19 pandemic was postponement of the Premier League football season in March, with approximately 8 weeks of the season left to play. Due to Government restrictions no Premier League clubs could train or play games as a nationwide lockdown was introduced. This meant that no data were collected or analysed for the final period of the season.

7 Conclusion

The main objectives of the study were to establish the reliability and validity of the KangaTech and HHD measurement systems, to compare an elite football player's isometric hip and groin strength profile to a normal population's and to examine the variation of an elite football player's hip and groin strength profile over the course of a season.

Key findings from this research project identified both the KangaTech and the HHD as having excellent intra-rater reliability and validity. Normative isometric hip and groin strength for a normal population has been established. Initially, only maximum isometric abductor strength and adductor:abductor ratio's differed between the two populations. When analysed over the course of the season, it was found that elite football players had an apparent adductor weakness at pre-season. Adductor strength increased at a quicker rate than abductor strength in the early part of the season and both followed different trends as the season progressed. This lead to differing adductor:abductor ratios at varying stages of a season. No effect was seen on adductor or abductor ratios, which remained at approximately 1. Therefore, adductor:abductor ratios were affected by differing rates of strength increase between muscle groups.

As a result, in clinical practice it is proposed that the KangaTech and HHD can both be used to assess isometric hip strength. The apparent adductor weakness at pre-season which should be taken into consideration in gradual return to training programming. The use of contralateral adductor and abductor ratios in criteria-based rehabilitation programmes is advised, however when using an adductor:abductor ratio, time of the season must be considered.

In conclusion, this study observed some novel findings that can be used in the prevention of hip and groin injuries alongside the rehabilitation and return to play protocols of such injuries.

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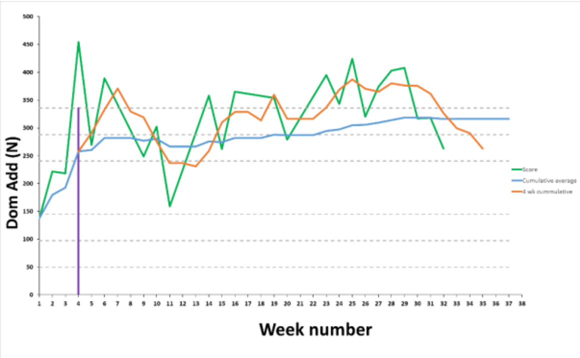
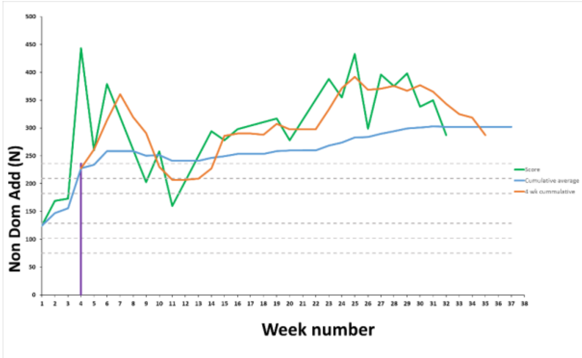
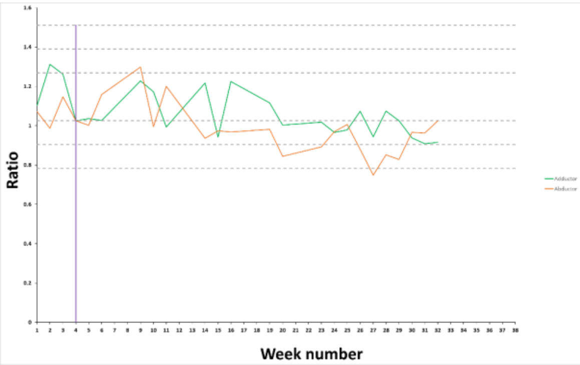
9 Appendix

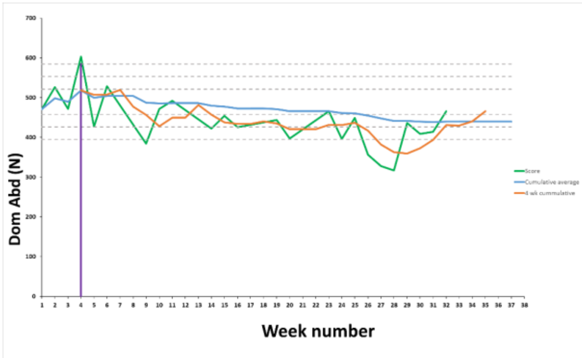
9.1 Seasonal Trend Graphs

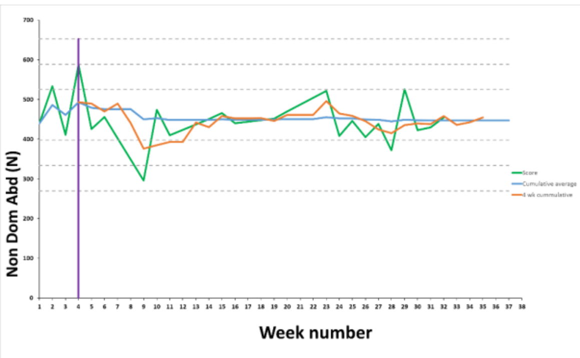
9.1.1 Player 1

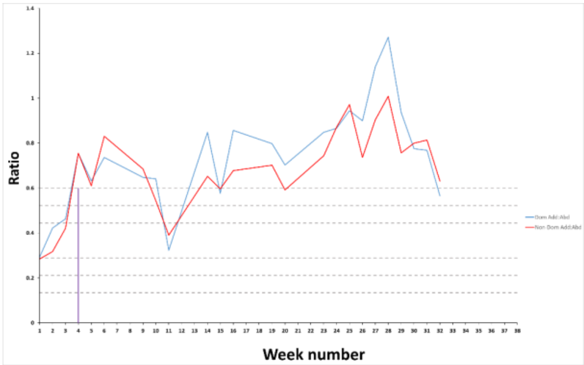












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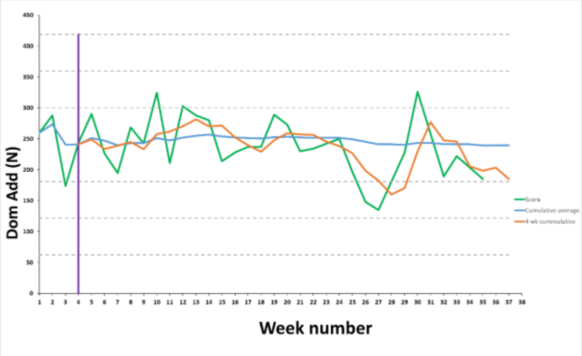
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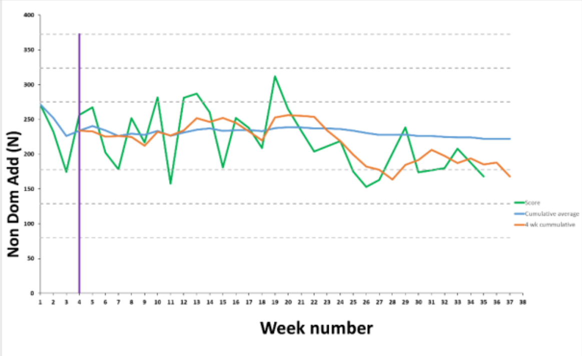
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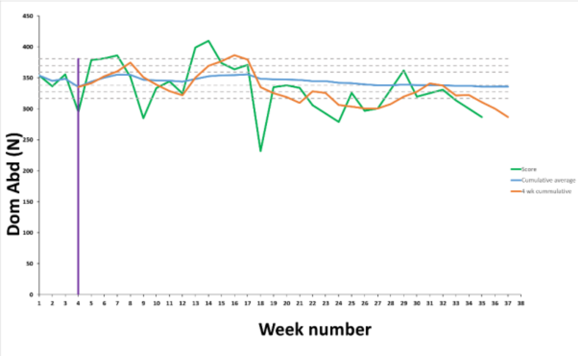
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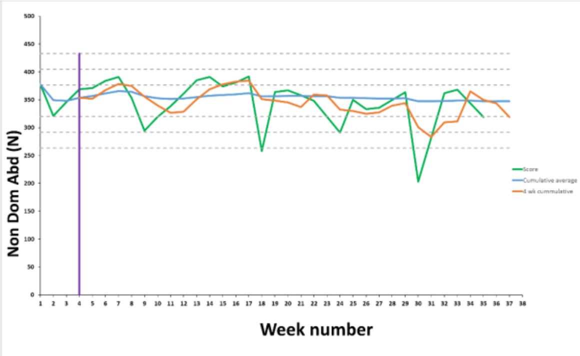
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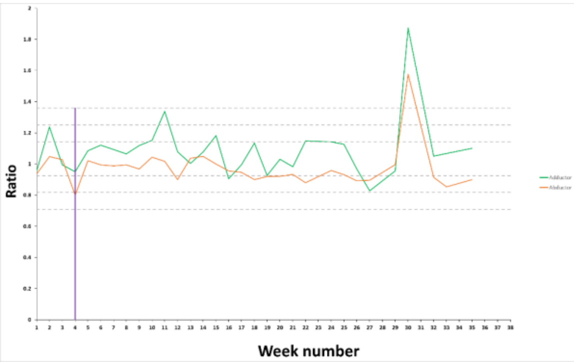
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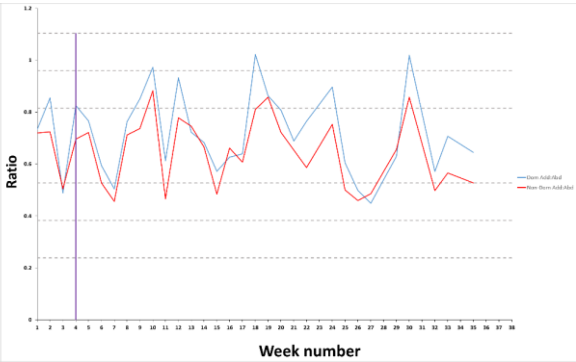
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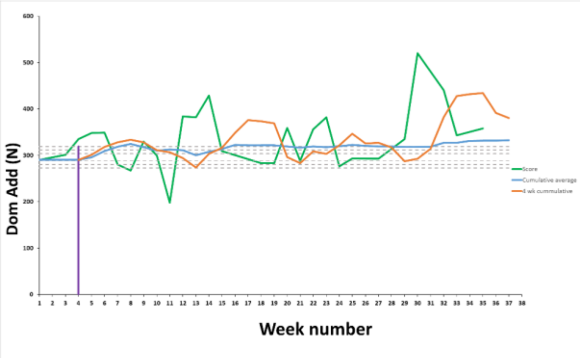
9.1.3 Player 3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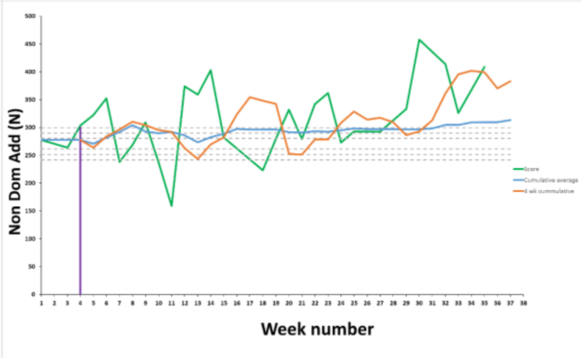
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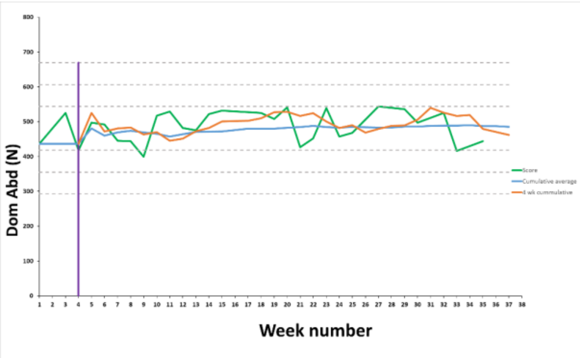
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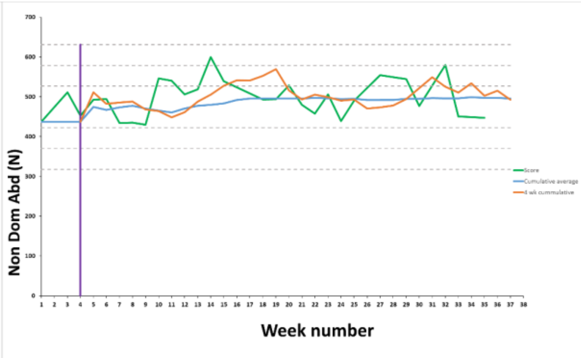
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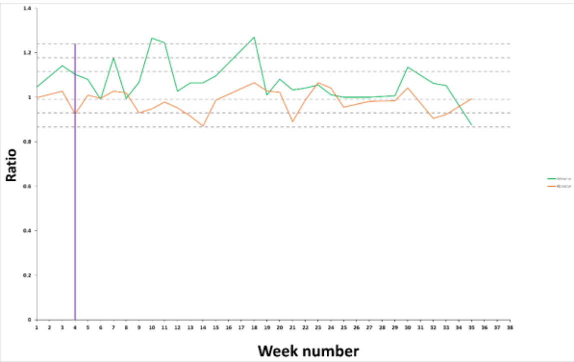
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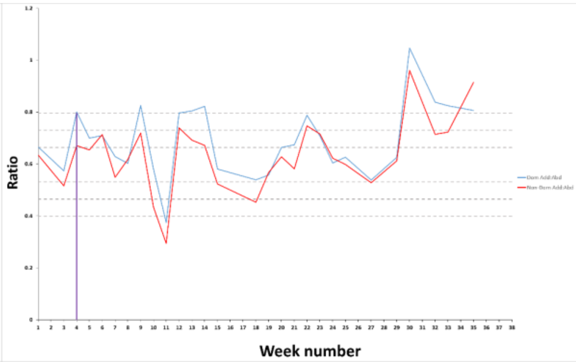
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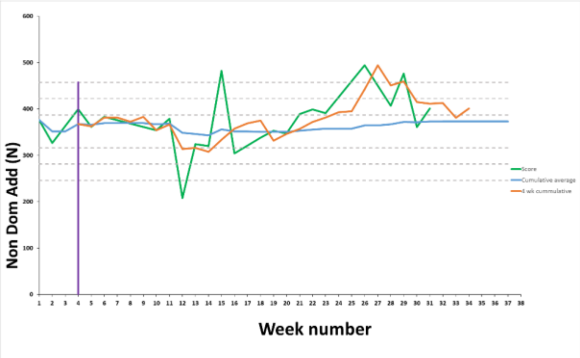
9.1.4 Player 4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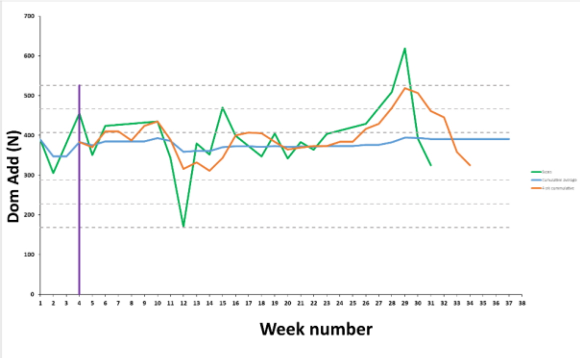
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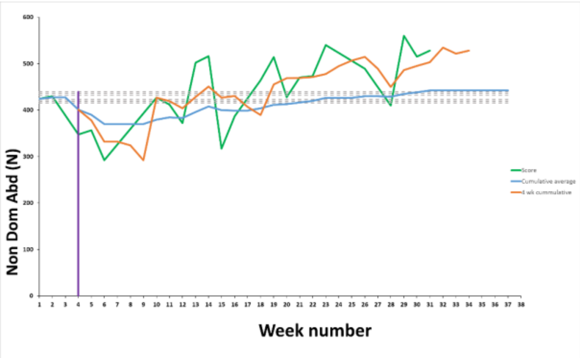
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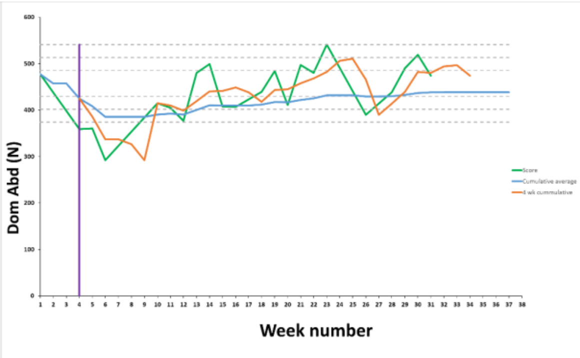
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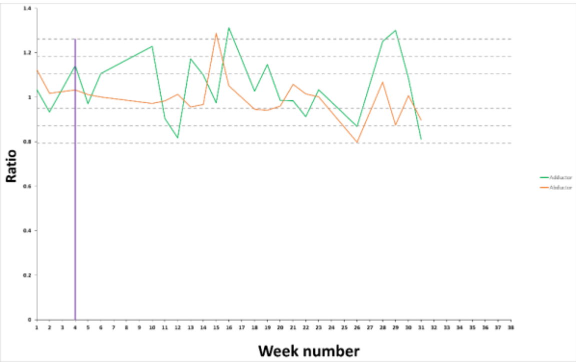
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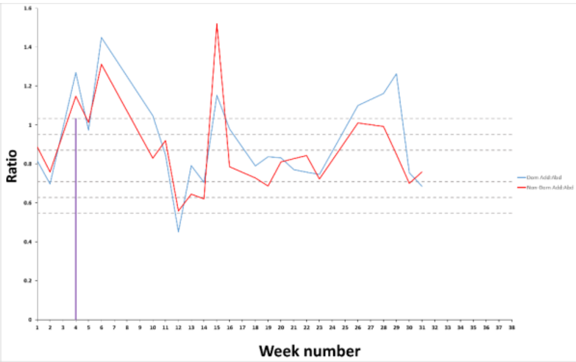
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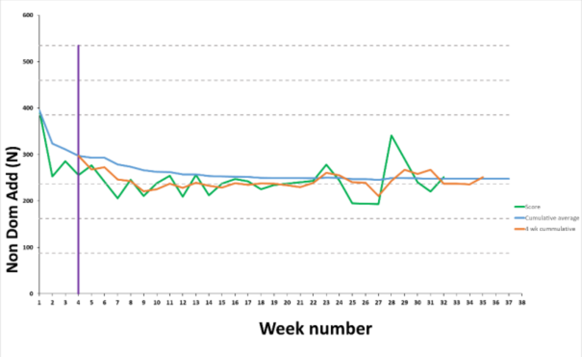
9.1.5 Player 5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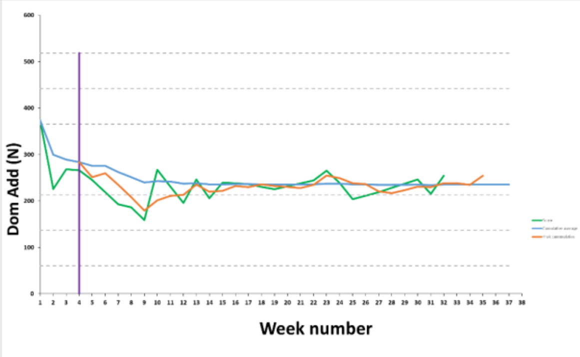
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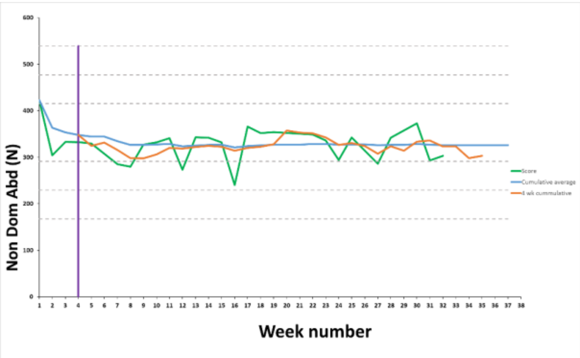
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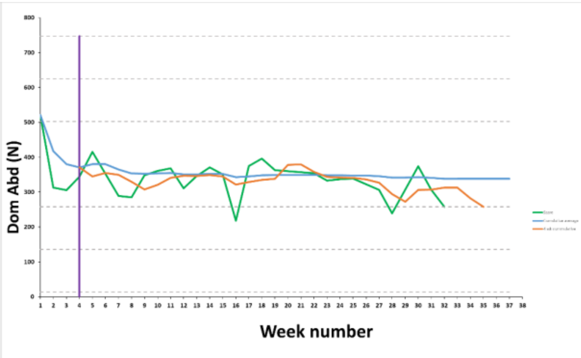
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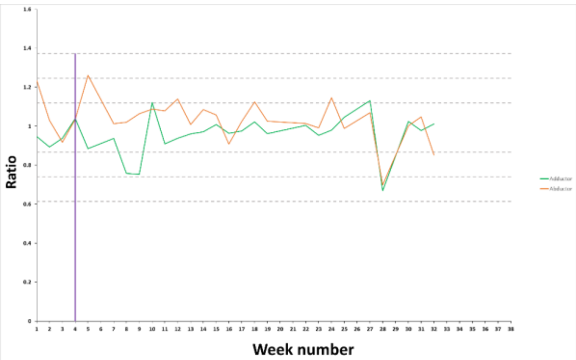
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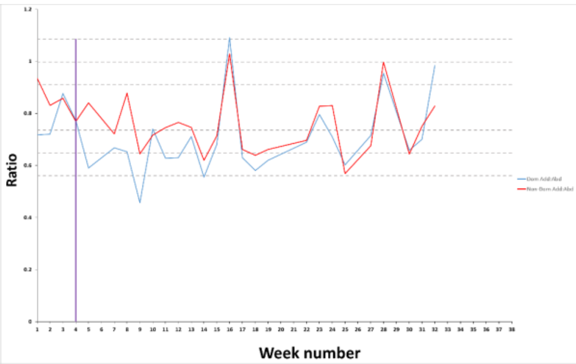
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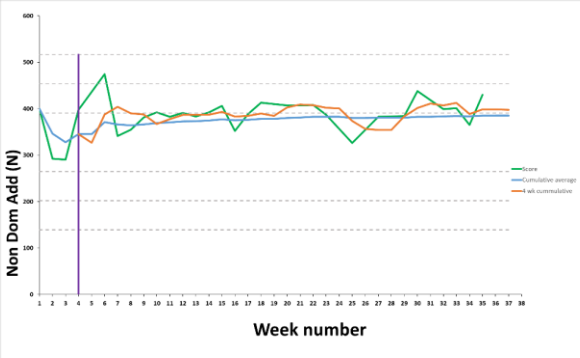
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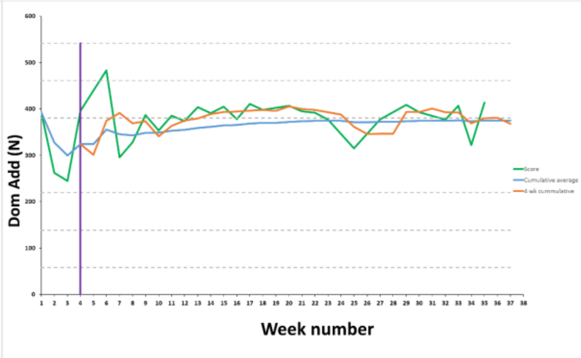
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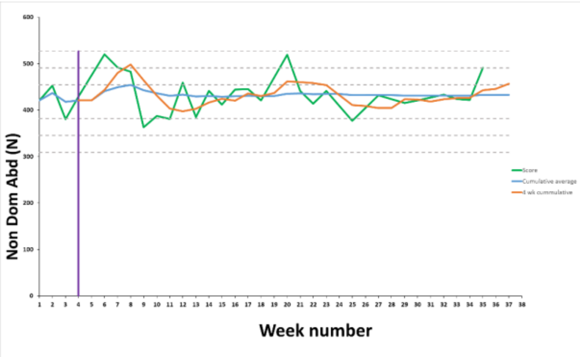
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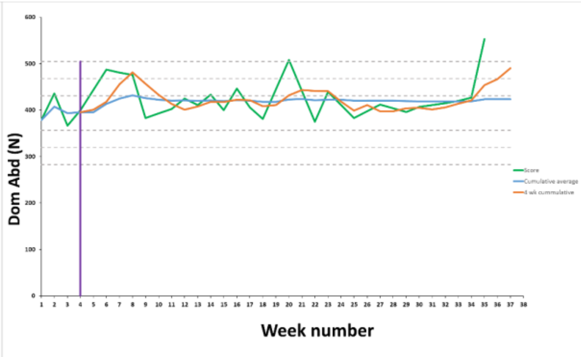
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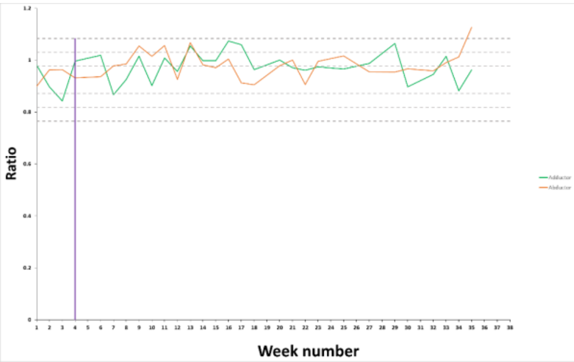
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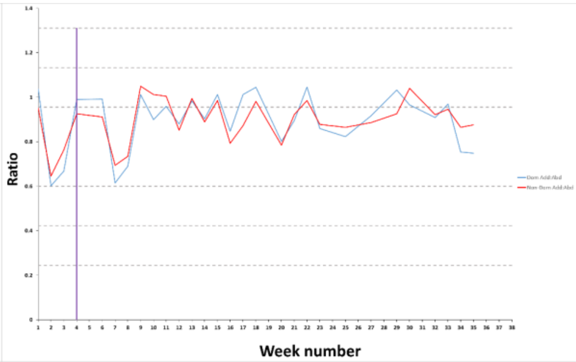
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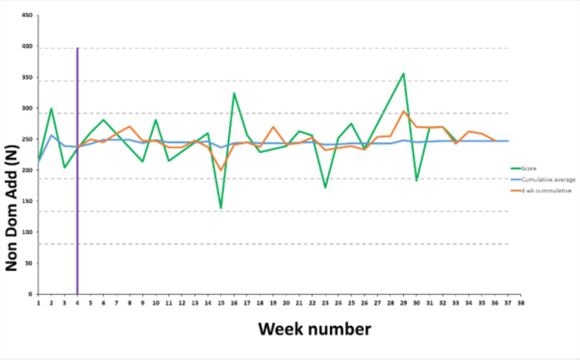
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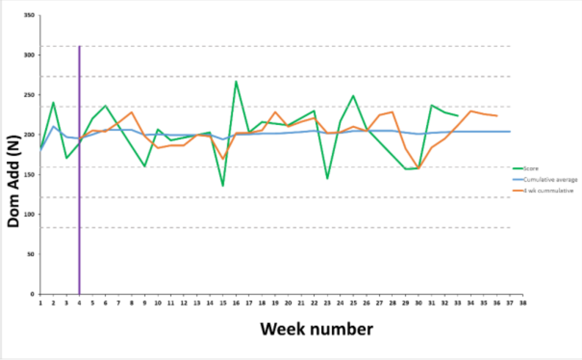
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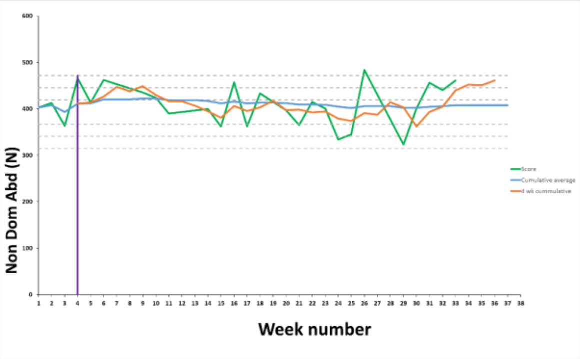
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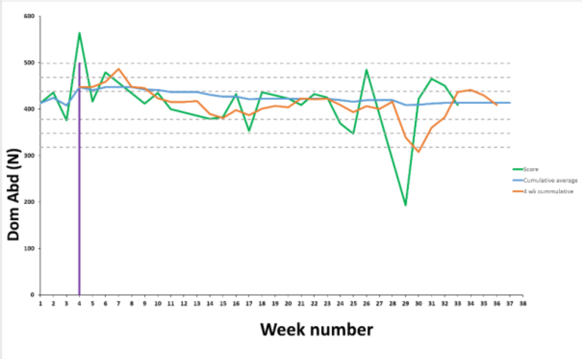
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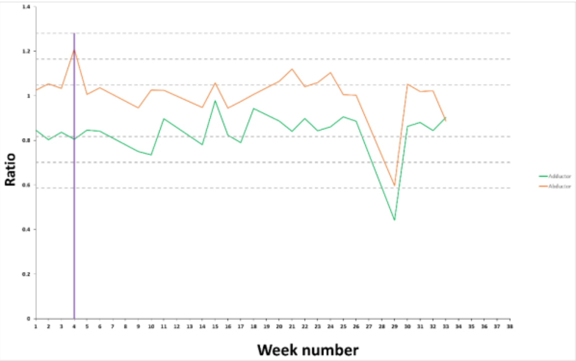
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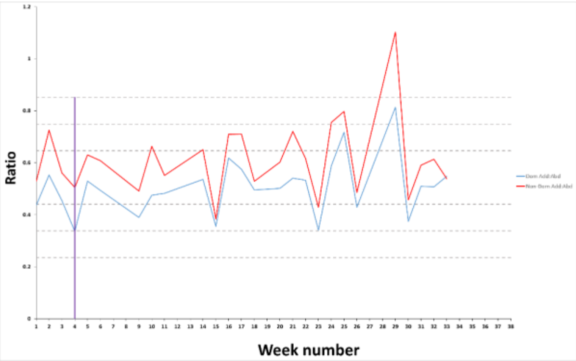
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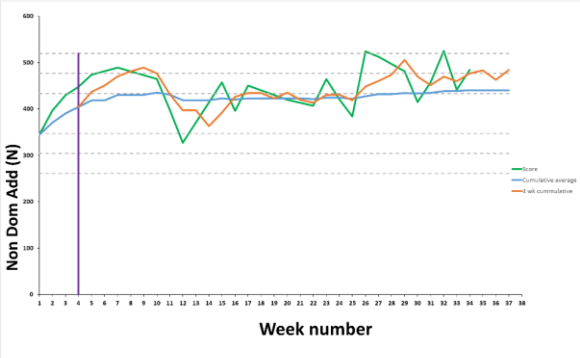
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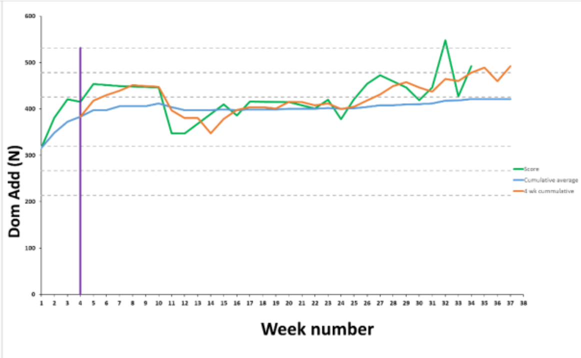
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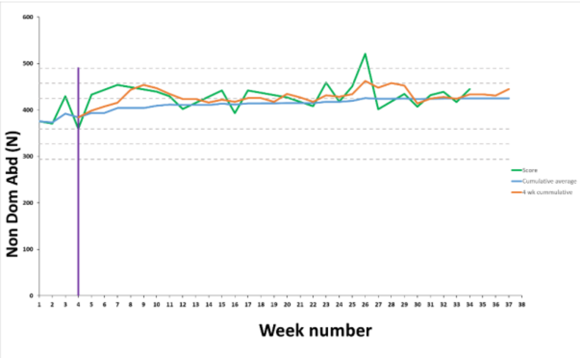
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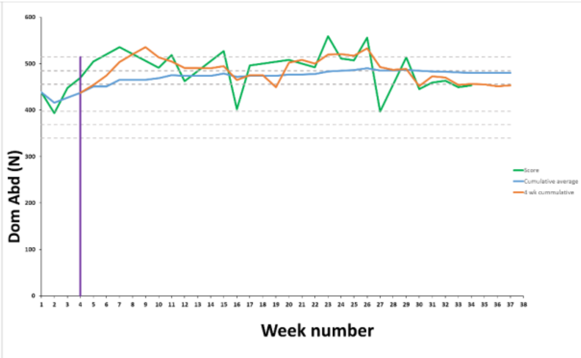
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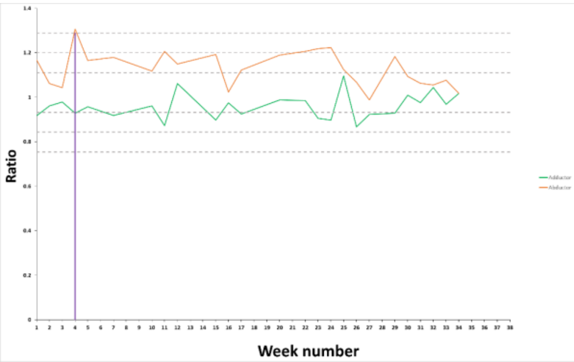
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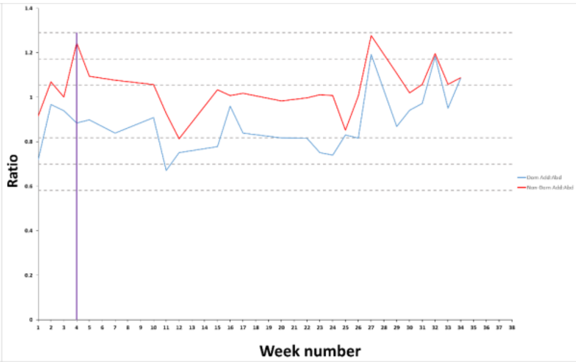
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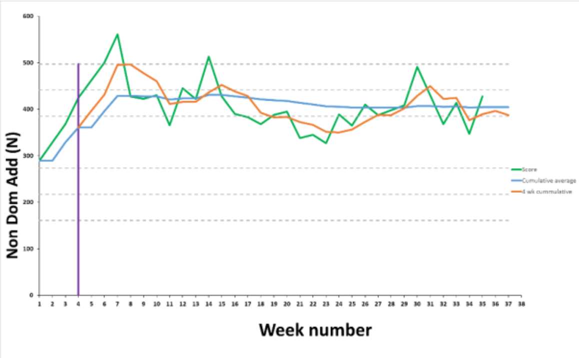
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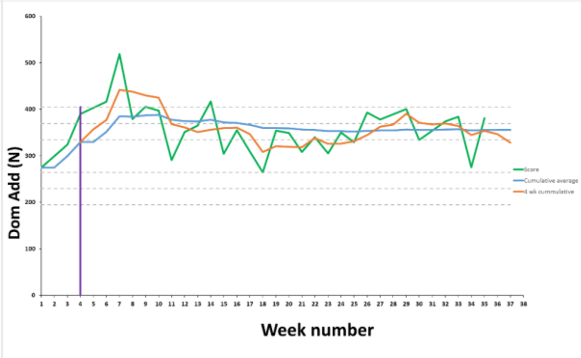
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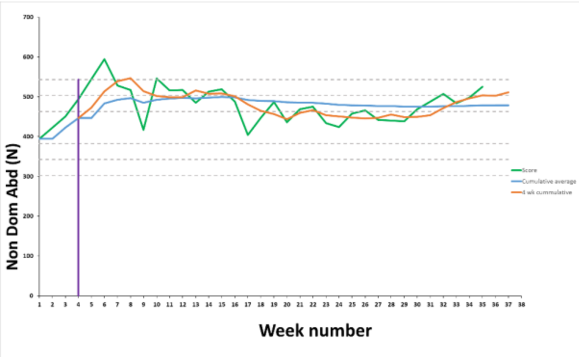
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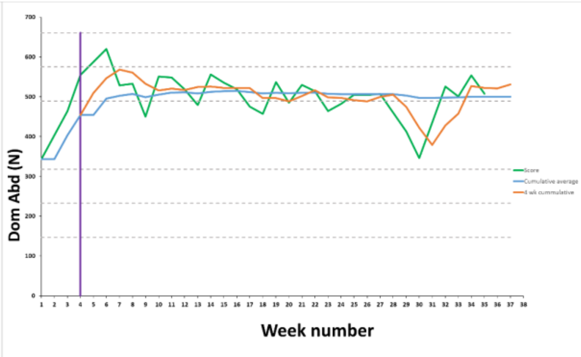
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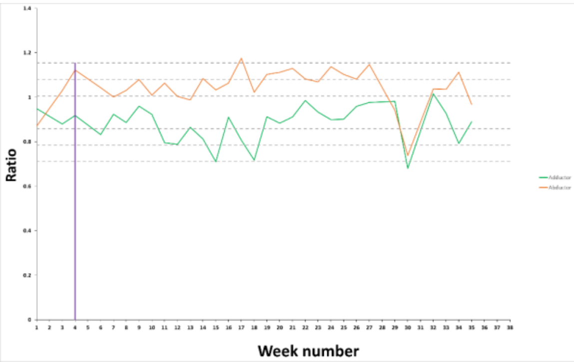
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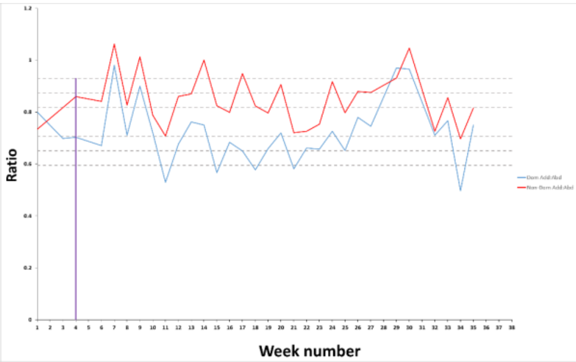
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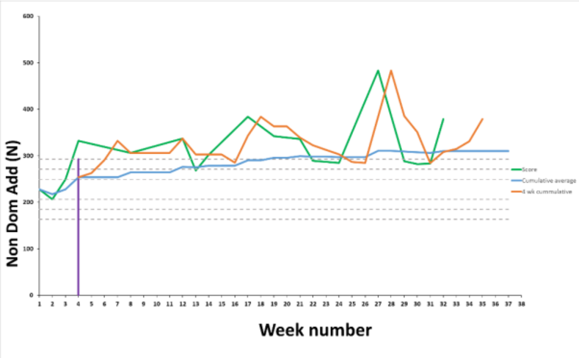
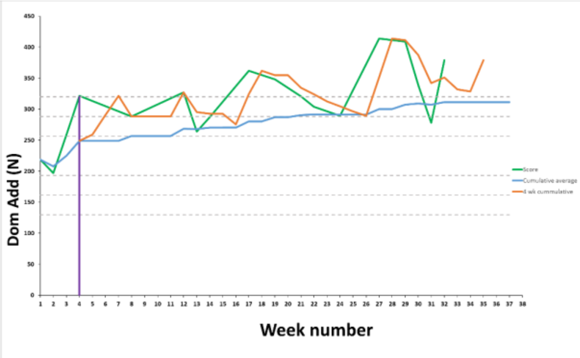
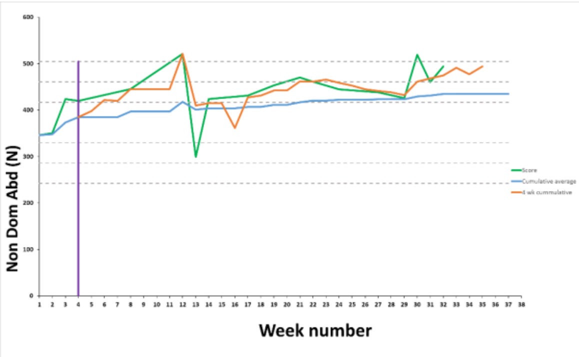
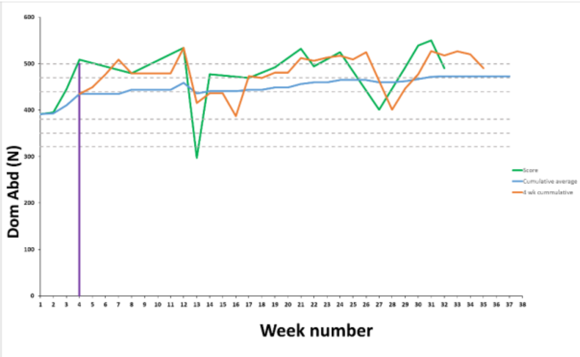
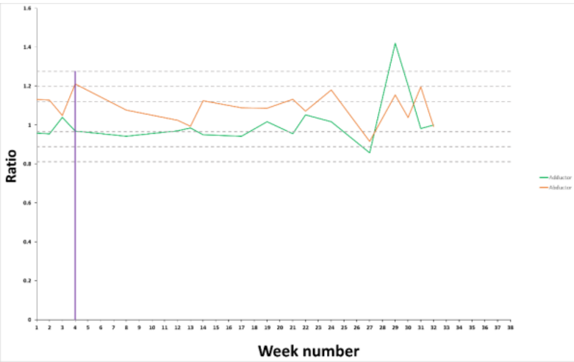
9.1.10 Player 10

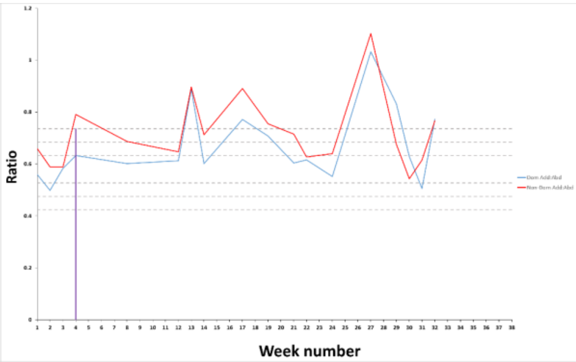












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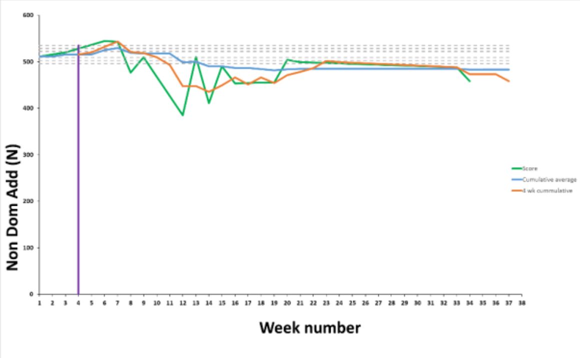

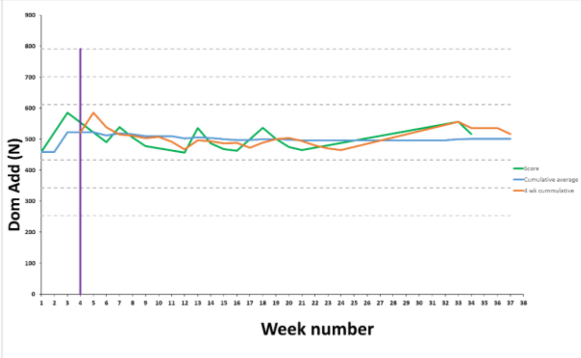

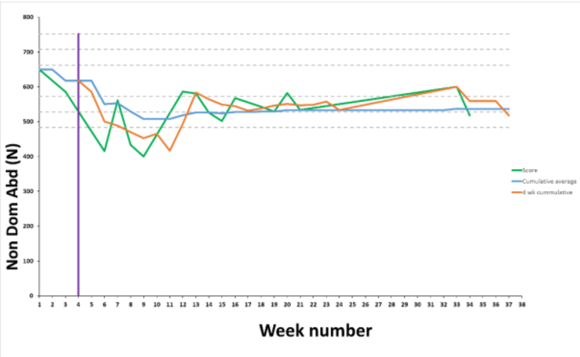

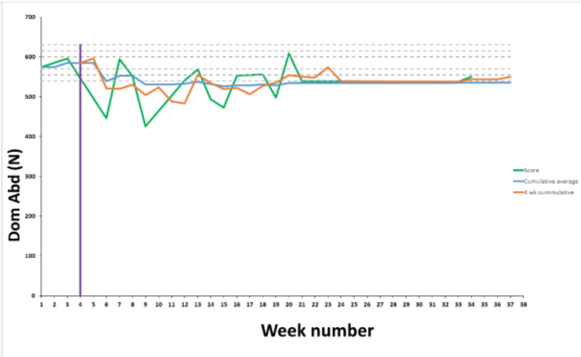

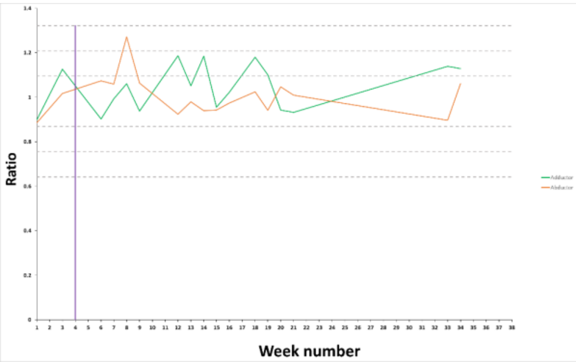

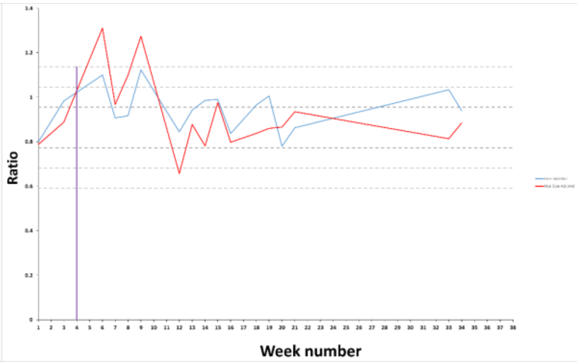

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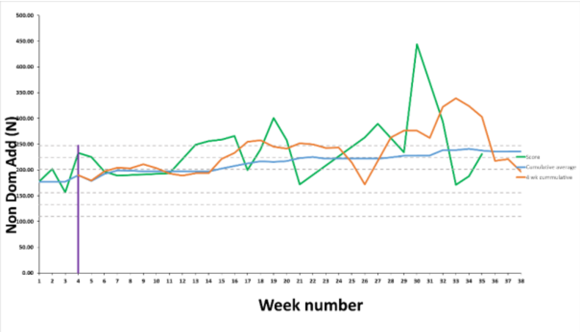

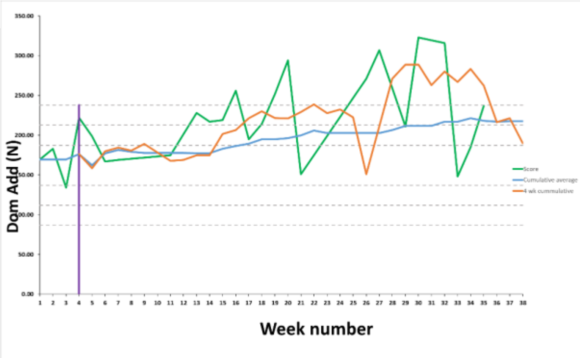

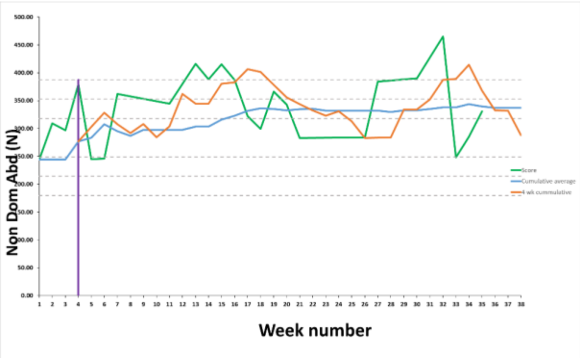

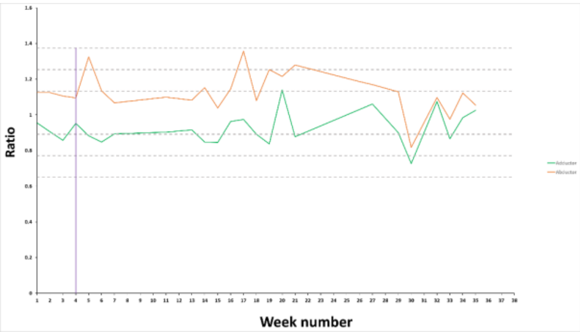

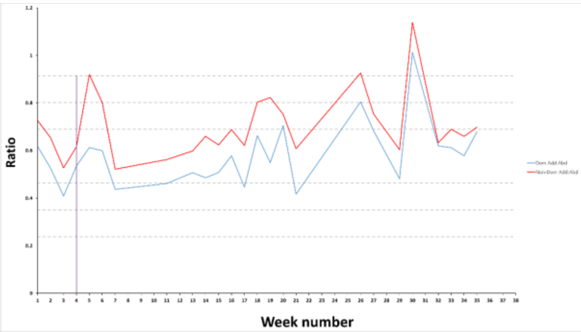

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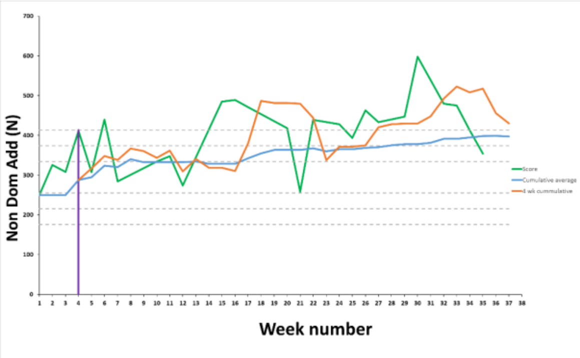

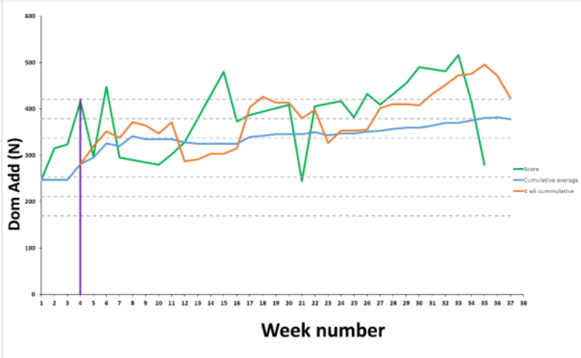

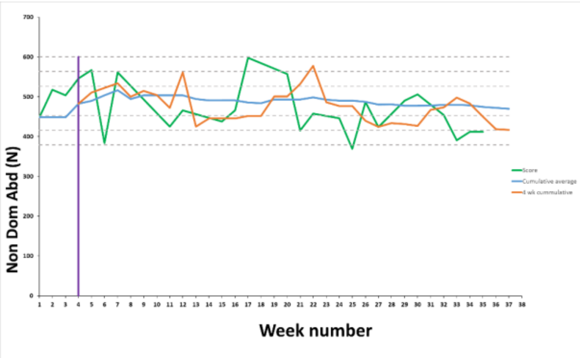

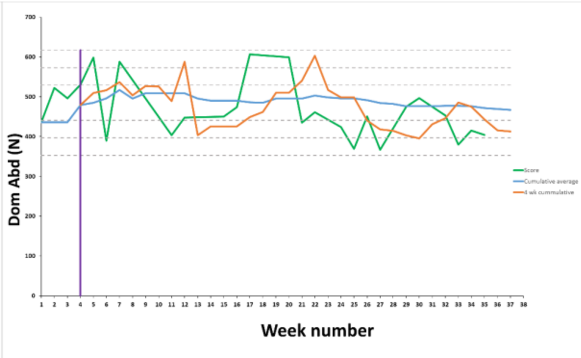

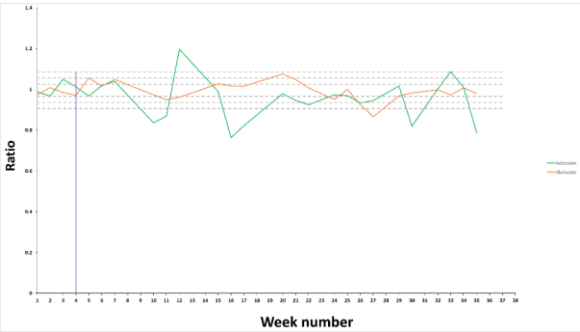

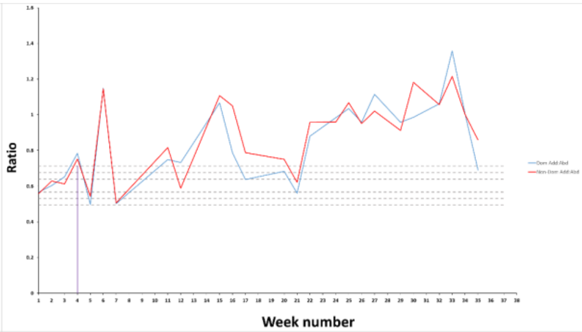

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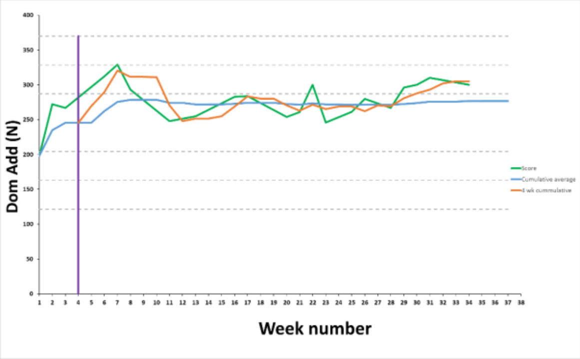

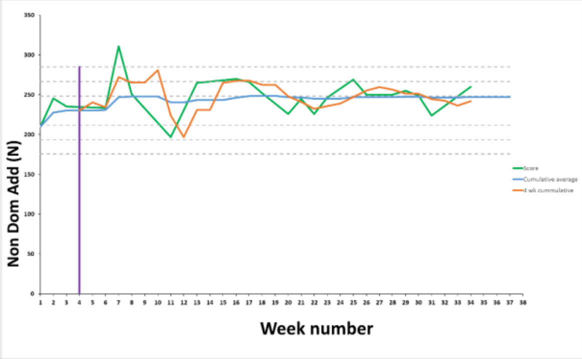

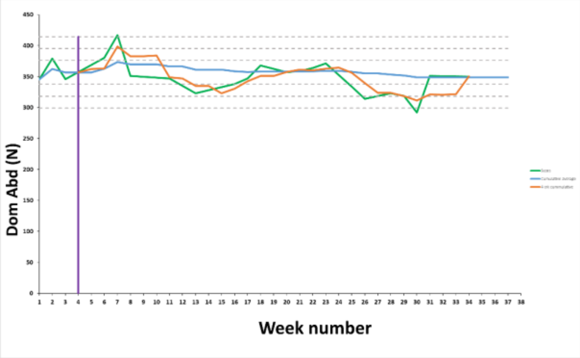

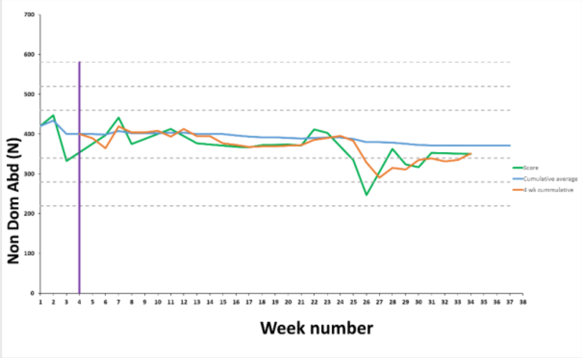

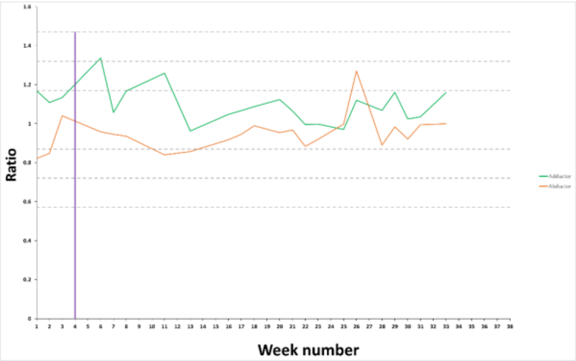

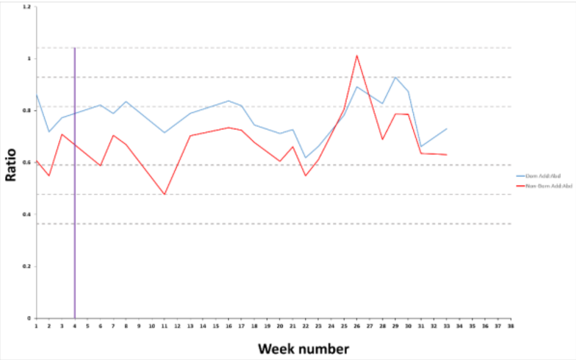

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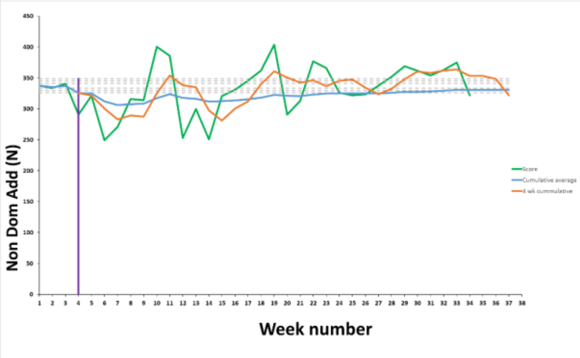

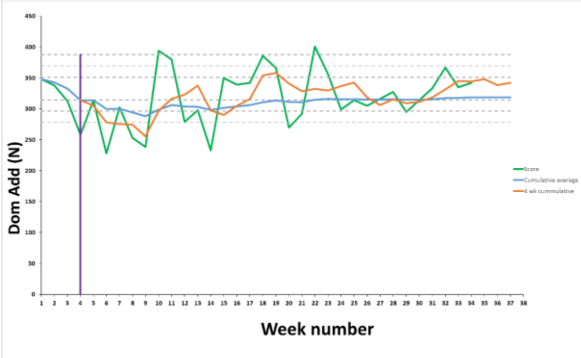

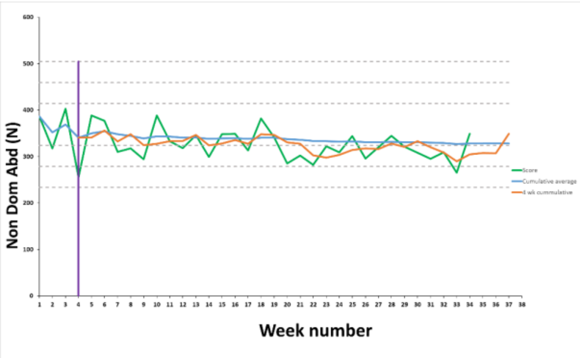

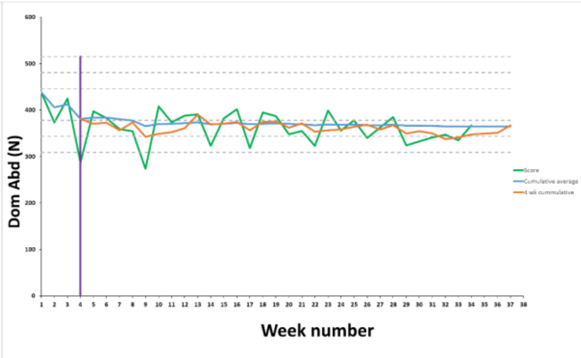

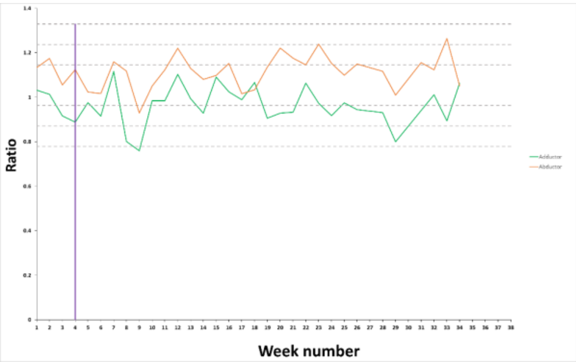

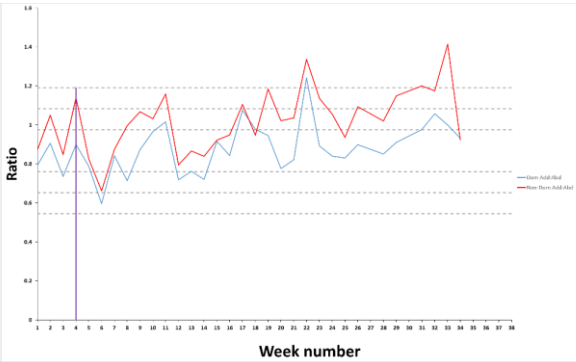

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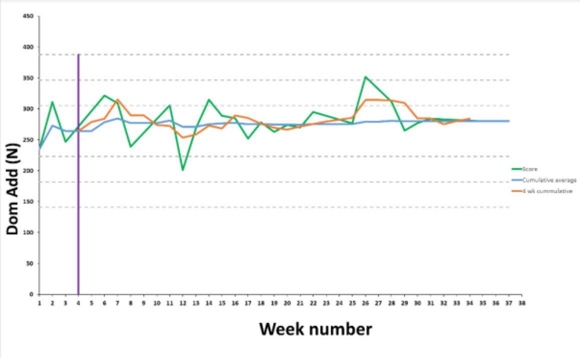

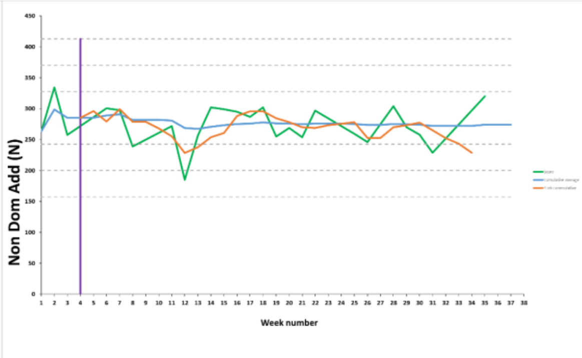

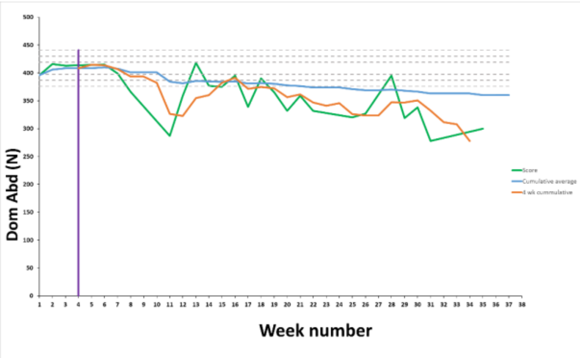

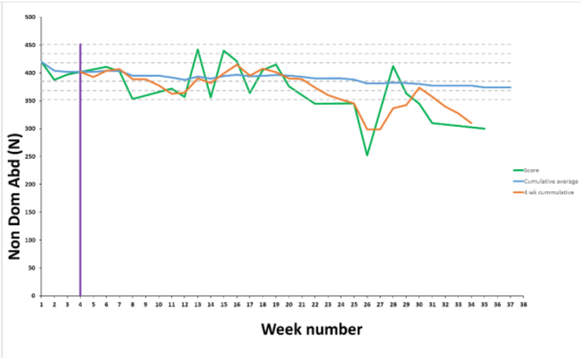

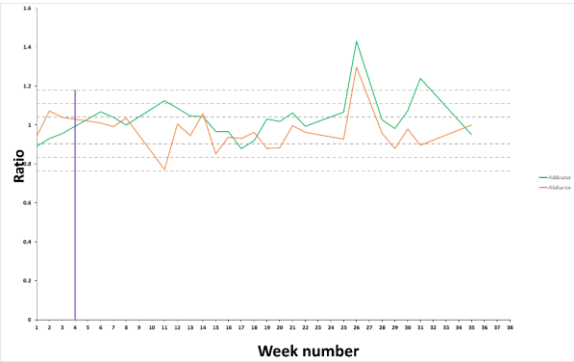

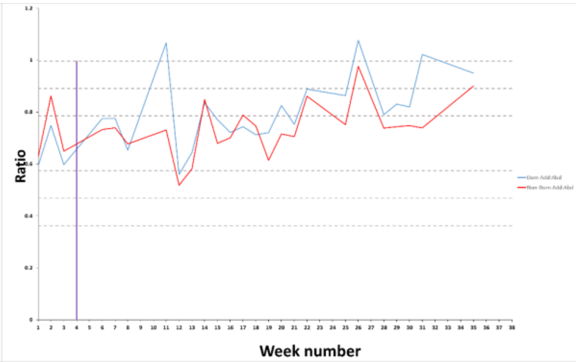

9.2 *Ethical Approval*

9.2.1 Ethical Approval - Study One

Bournemouth University

Research Ethics Checklist

About Your Checklist	
Ethics ID	29269
Date Created	20/11/2019 15:31:42
Status	Approved
Date Approved	13/12/2019 15:18:07
Date Submitted	29/11/2019 15:01:40
Risk	High

Researcher Details	
Name	Cian Dunne
Faculty	Faculty of Health & Social Sciences
Status	Postgraduate Research (MRes, MPhil, PhD, DProf, EngD, EdD)
Course	Postgraduate Research - HSS
Have you received funding to support this research project?	Yes
Is this external funding?	Yes
RED ID	11631
Please provide the External Funding Body	AFC Bournemouth
Is this internal funding?	No
Please list any persons or institutions that you will be conducting joint research with, both internal to BU as well as external collaborators.	AFC Bournemouth

Project Details	
Title	The Intra-rater Reliability and Validity in comparison to Hand-Held Dynamometer of the KangaTech.
Start Date of Project	01/07/2018
End Date of Project	25/07/2021
Proposed Start Date of Data Collection	02/12/2019
Original Supervisor	Joanna Thurston
Approver	Research Ethics Panel

9.2.2 Ethical Approval – Study Two and Three

Bournemouth University

Research Ethics Checklist

About Your Checklist	
Ethics ID	36096
Date Created	02/02/2021 14:15:17
Status	Approved
Date Approved	22/02/2021 13:54:57
Date Submitted	11/02/2021 13:29:24
Risk	Low

Researcher Details	
Name	Cian Dunne
Faculty	Faculty of Health & Social Sciences
Status	Postgraduate Research (MRes, MPhil, PhD, DProf, EngD, EdD)
Course	Postgraduate Research - HSS
Have you received funding to support this research project?	No
Please list any persons or institutions that you will be conducting joint research with, both internal to BU as well as external collaborators.	AFC Bournemouth

Project Details	
Title	The effect of limb dominance and seasonal variation on Isometric Hip strength scores in Elite Athletes.
Start Date of Project	11/02/2021
End Date of Project	25/07/2021
Proposed Start Date of Data Collection	16/02/2021
Original Supervisor	Andrew Callaway
Approver	Susan Dewhurst

Summary - no more than 600 words (including detail on background methodology, sample, outcomes, etc.)

Hip and Groin injuries are common in many sporting populations. They account for 12-16% of all injuries in a soccer season. There are many risk factors for hip and groin injuries in sport. Strength is a major risk factor in all sporting injuries and especially Hip and Groin injures. One way that strength is commonly assessed is using isometric strength testing devices.

There is currently contrasting evidence surrounding the effect of limb dominance on these strength scores and very little evidence regarding the seasonal trends of these scores in elite footballers. These are two factors which could effect strength measurements

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9.3 Participant Information

9.3.1 Study One – Participant Agreement Form

Ref & Version: KgTh1119_1

Ethics ID: 29269

Date: 24 January 2020

Participant Agreement Form

Full title of project: Assessing the Intra-rater Reliability of the Kangatech and it's validity in comparison to Hand-Held Dynamometer.

Name, position and contact details of researcher: Cian Dunne, Postgraduate Student, Bournemouth University – cdunne1@bournemouth.ac.uk

Name, position and contact details of supervisor:

Dr Joanna Thurston, Senior Lecturer, Bournemouth University - jthurston@bournemouth.ac.uk

Dr Andrew Callaway, Senior Lecturer, Bournemouth University - acallaway@bournemouth.ac.uk

Dr Jon Williams, Senior Lecturer, Bournemouth University - jwilliams@bournemouth.ac.uk

To be completed prior to data collection activity

Section A: Agreement to participate in the study

You should only agree to participate in the study if you agree with all of the statements in this table and accept that participating will involve the listed activities.

I have read and understood the Participant Information Sheet (KgTh1119_1) and have been given access to the BU Research Participant Privacy Notice which sets out how we collect and use personal information (https://www1.bournemouth.ac.uk/about/governance/access-information/data-protection-privacy).
I have had an opportunity to ask questions.
I understand that my participation is voluntary. I can stop participating in research activities at any time without giving a reason and I am free to decline to answer any particular question(s).

I understand that taking part in the research will include the following activity/activities as part of the research:
Undertaking physical exercise
Conducting maximal muscle contractions
I agree to being marked by a skin friendly medical marker
I understand that, if I withdraw from the study, I will also be able to withdraw my data from further use in the study **except** where my data has been anonymised (as I cannot be identified) or it will be harmful to the project to have my data removed.
I understand that my data may be included in an anonymised form within a dataset to be archived at BU's Online Research Data Repository.
I understand that my data may be used in an anonymised form by the research team to support other research projects in the future, including future publications, reports or presentations.

	Initial box to agree
I consent to take part in the project on the basis set out above (Section A)	

I confirm my agreement to take part in the project on the basis set out above.

Name of participant (BLOCK CAPITALS)	Date (dd/mm/yyyy)	Signature
Name of researcher (BLOCK CAPITALS)	Date (dd/mm/yyyy)	Signature

Once a Participant has signed, **please sign 1 copy** and take 2 photocopies:

Original kept in the local investigator's file

1 copy to be kept by the participant (including a copy of PI Sheet)

9.3.2 Study One – Participant Information Sheet

Participant Information Sheet

The title of the research project

Assessing the Intra-rater Reliability of the Kangatech and it's validity in comparison to Hand-Held Dynamometer.

Invitation to take part

You have been invited to take part in this research project. Before you make a decision on your participation it is important that you understand what the research is for and what we are trying to achieve. All the information has been included in this Participant information sheet, which you should take some time to read carefully. If you have any further questions do not hesitate to ask.

Who is organising/funding the research?

Cian Dunne, Postgraduate Student, Bournemouth University -cdunne1@bournemouth.ac.uk / cian.dunne@ucdconnect.ie
Dr Andrew Callaway, Senior Lecturer, Bournemouth University - acallaway@bournemouth.ac.uk
Dr Jon Williams, Senior Lecturer, Bournemouth University -jwilliams@bournemouth.ac.uk
Dr Joanna Thurston, Senior Lecturer, Bournemouth University - jthurston@bournemouth.ac.uk
This research is funded by AFC Bournemouth.

What is the purpose of the project?

The KangaTech is a muscle measurement system that can measure the force of muscle contractions at any joint in the body. To achieve this the force pads on the system are placed at predetermined landmarks, where the participant then produces a maximum contraction for 5 seconds and a force reading is produced.

The Hand-Held Dynamometer is currently one of the most practical and reliable method used to assess isometric muscle strength in elite sport. The aim of this study is to examine the intra-rater (between testers) reliability of the KangaTech system and the validity in comparison to the Hand-Held Dynamometer. The results from the testing could provide a baseline for sports teams and athletes to use as a tool for injury prevention and monitoring; before, during and after a sports season.

Why have I been chosen?

You have been chosen to participate in this research as you have expressed an interest in this study following a verbal invitation during one of your lectures.

If any of the following apply to you then you will be unable to participate in this study:

- Under the age of 18 at the time of the study;
- Any significant lower limb injury or surgeries in the past 12 months;
- Any significant medical illnesses or diseases;
- Any heart instability or disorders.

Do I have to take part?

It is up to you to decide whether to take part. If you do decide to take part, you will be given this information sheet to keep and be asked to sign a participant agreement form. All data in this study will be anonymised. If you decide to withdraw, any data collected about you will be removed from the study. Deciding to take part or not will not impact upon/adversely affect your treatment, care, education or studies at BU (or that of others).

Can I change my mind about taking part?

Yes, you can stop participating in study activities at any time and without giving a reason.

If I change my mind, what happens to my information?

After you decide to withdraw from the study, we will not collect any further information from or about you. Any information that we collect from you will be anonymised.

As regards information we have already collected before this point, your rights to access, change or move that information are limited. This is because we need to manage your information in specific ways in order for the research to be reliable and accurate. Further explanation about this is in the Personal Information section below.

What would taking part involve?

For this study you will be required to attend a testing session at the Vitality Stadium with the times and specific locations given to you once arranged. You will be required to wear clothing which would permit you to undertake physical testing e.g Shorts and T-Shirt. We will record your name (before anonymisation of the data), age, activity levels and will mark your skin with a skin-friendly medical pen.

There will be 3 different stations of testing, each one will consist of a warm up effort of 50% and two maximal 100% contractions. The stations will be testing hip abduction and adduction as follows:

- Bilaterally on the Kangatech System;
- Unilaterally using HHD;

You will be performing a warm up of 10 minutes at your own intensity on the stationary bike. You will be performing each test 3 times at each station (1 warm up effort with 2 max contractions). There will be 5 minutes rest between each station and a 60s rest between reps.

What are the advantages and possible disadvantages or risks of taking part?

Whilst there are no immediate benefits for those people participating in the project, it is hoped that this research will provide valuable information in the field of sports medicine, which subsequently would also benefit everyone involved in the future. Participants would also get the opportunity to observe and use some of the facilities at a Premier League football ground.
Maximum muscle contractions may pose a low risk for injury. However with adequate evidence-based rest, warm-ups, optimal positioning and appropriate tester training these risk factors will be eliminated.

Participants will be given data regarding their own muscle strength and any imbalances which may be present.

What type of information will be sought from me and why is the collection of this information relevant for achieving the research project's objectives?

We will collect basic demographic information which will all be anonymised. Data collected from you will include your name, age, activity level and previous injury history. The collection of this data will enable the research team to determine any difference between HHD and KangaTech, and achieve the research project aims.

Will I be recorded, and how will the recorded media be used?

You will not be filmed, or audio recorded during this research.

How will my information be managed?

Bournemouth University (BU) is the organisation with overall responsibility for this study and the Data Controller of your personal information, which means that we are responsible for looking after your information and using it appropriately. Research is a task that we perform in the public interest, as part of our core function as a university.

Undertaking this research study involves collecting and/or generating information about you. We manage research data strictly in accordance with:

Ethical requirements; and
Current data protection laws. These control use of information about identifiable individuals, but do not apply to anonymous research data: "anonymous" means that we have either removed or not collected any pieces of data or links to other data which identify a specific person as the subject or source of a research result.

BU's Research Participant Privacy Notice sets out more information about how we fulfil our responsibilities as a data controller and about your rights as an individual under the data protection legislation. We ask you to read this Notice so that you can fully understand the basis on which we will process your personal information.

Research data will be used only for the purposes of the study or related uses identified in the Privacy Notice or this Information Sheet. To safeguard your rights in relation to your personal information, we will use the minimum personally-identifiable information possible and control access to that data as described below.

Publication

You will not be able to be identified in any external reports or publications about the research without your specific consent. Otherwise your information will only be included in these materials in an anonymous form, i.e. you will not be identifiable.

The results from the data collection may form part of research outputs (such as postgraduate dissertation, journal article(s), conference papers). Your identity and participation will not be able to be identified in these.

Security and access controls

BU will hold the information we collect about you in hard copy in a secure location and on a BU password protected secure network where held electronically.

Personal information which has not been anonymised will be accessed and used only by appropriate, authorised individuals and when this is necessary for the purposes of the research or another purpose identified in the Privacy Notice. This may include giving access to BU staff or others responsible for monitoring and/or audit of the study, who need to ensure that the research is complying with applicable regulations.

Sharing your personal information with third parties

As well as BU staff and students working on the research project, we may also need to share data with other third parties (AFC Bournemouth). This data will be anonymised, and you will not be identifiable from it.

Further use of your information

The information collected about you may be used in an anonymous form to support other research projects in the future and access to it in this form will not be restricted. It will not be possible for you to be identified from this data. To enable this use, anonymised data will be added to BU's Data Repository: this is a central location where data is stored, which is accessible to the public.

Keeping your information if you withdraw from the study

If you withdraw from active participation in the study we will keep information which we have already collected from or about you, if this has on-going relevance or value to the study. This may include your personal identifiable information. As explained above, your legal rights to access, change, delete or move this information are limited as we need to manage your information in specific ways in order for the research to be reliable and accurate. However if you have concerns about how this will affect you personally, you can raise these with the research team when you withdraw from the study.

You can find out more about your rights in relation to your data and how to raise queries or complaints in our Privacy Notice.

Retention of research data

Project governance documentation, including copies of signed participant agreements: we keep this documentation for a long period after completion of the research, so that we have records of how we conducted the research and who took part. The only personal information in this documentation will be your name and signature, and we will not be able to link this to any anonymised research results.

Research results:
As described above, during the course of the study we will anonymise the information we have collected about you as an individual. This means that we will not hold your personal information in identifiable form after we have completed the research activities.

You can find more specific information about retention periods for personal information in our Privacy Notice.

We keep anonymised research data indefinitely, so that it can be used for other research as described above.

Contact for further information

If you have any questions or would like further information, please contact:
Cian Dunne, Postgraduate Student, Bournemouth University – cdunne1@bournemouth.ac.uk or
Dr Joanna Thurston, Senior Lecturer, Bournemouth University – jthurston@bournemouth.ac.uk

In case of complaints

Any concerns about the study should be directed to Dr Joanna Thurston. If your concerns have not been answered by Dr Joanna Thurston, you should contact Professor Vanora Hundley, Faculty of Health and Social Science, Bournemouth University by email to researchgovernance@bournemouth.ac.uk.

Finally

If you decide to take part, you will keep this information sheet. You will also sign an agreement form and a scanned copy of this can be sent to you for your records if you wish. For this, email cdunne1@bournemouth.ac.uk

Thank you for considering taking part in this research project.

Please find below an example of the piece of equipment that will be used during testing: