The EMG profiles of 3 lower body resistance exercises

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By

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Abstract

Introduction: Resistance training has previously been demonstrated to contribute to the improvement of athletic performance. The back squat and deadlift have both been heavily researched in the field of sEMG but remain complex exercises. The hip thrust however is a much simpler exercise, which loads the bar in a different movement plane. The sEMG activity of these three lifts have previously never been compared against one another in the one study. **Aim:** The primary aim of the study was to establish and compare sEMG profiles of the lower leg musculature. During the concentric phase of the back squat, deadlift and hip thrust, in non - resistance trained individuals (n=22), in maximal and sub – maximal efforts. **Methods:** Participants completed 2 separate testing sessions, 7 days apart. The first, acted as a normalisation to testing procedures with no data collection, where participants underwent 1RM testing with sEMG electrodes placed at 4 regions of the lower limb musculature: the upper and lower *Gluteus Maximus, Vastus Lateralis* and *Bicep Femoris*. The second session again required 1RM testing, but this time also recorded sEMG data in maximal and submaximal efforts. **Results:** Analysis of peak sEMG in the 1RM and 85 % of 1RM found there to be no difference in gluteal activation between the three lifts. Further analysis through coding split the concentric phase of the lift into three equal tertiles. This allowed for the comparison of sEMG amplitude throughout the concentric phase. Analysis of the 1RM tertiles data found that the deadlift had a significantly greater level of sEMG activity when compared to the squat and hip thrust. **Conclusions:** The data suggests that any of these 3 exercises would effectively target the gluteus muscles. However, the deadlift seems to result in greater electrical activity at the selected sites out of the three exercises.

Key Words: Gluteus Maximus, squat, deadlift, hip thrust, sEMG

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Declaration

I hereby declare that all work included in this thesis is my own, and I fully understand the severity and consequences associated with committing plagiarism. All references which have been used in this thesis have been acknowledged. The work within this thesis has been submitted for the award of MPhil.

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List of table and figures

Abbreviations

Gluteus Maximus	GM
Semimembranosus	SM
Semitendinosus	ST
Vastus medialis	VM
Rectus Femoris	RF
Vastus Intermedius	VI
Upper Gluteus Maximus	UG
Lower Gluteus Maximus	LG
Vastus Lateralis	VL
Bicep Femoris	BF
Surface Electromyography	sEMG
Change of direction	COD
Counter Movement Jump	CMJ
Relative Muscular Effort	RME
Root Mean Squared	RMS
Analysis of variance	ANOVA
Standard error of the mean	SEM
Rep Max	RM

CHAPTER 1: LITERATURE REVIEW

1.1. General Introduction

The performance of resistance training (RT) is often associated with professional athletes, who may compete in individual or team-based sports. Athletes will perform resistance exercises as part of their overall training, to gain strength and develop maximal power to improve athletic performance. The current body of literature surrounding RT is heavily focussed on a trained population of athletic participants with studies investigating the performance outcomes after a training cycle, muscle activation during resistance exercises and debating which exercises are best suited when seeking certain performance outcomes (Askling *et al*., 2005; Begalle *et al.*, 2012; Andersen *et al.*, 2017; Bishop *et al.*, 2017). The body of literature surrounding RT is heavily focussed on some form of either the barbell back squat (BS) or the barbell conventional deadlift (DL). Although, previous studies have conducted investigations in trained populations due to the technical difficulty of these 2 lifts (Escamilla *et al.*, 2000; Jensen and Ebben, 2000; Weiss *et al*., 2000; Ebben, 2009; Andersen *et al.*, 2017) . Practitioners and researchers have theorised how a simple and easy to perform lift such as the barbell hip thrust (HT) might compare against these 2 exercises which are often considered paramount in any RT programme. The BS, DL and HT may all target the same lower limb musculature, the hip extensors, but they are 3 very distinct exercises. The squat and DL are technical exercises which require a high amount of co - ordination and technique to perform correctly (Haff, and Triplett, 2016). However, the HT is a very simplistic lift which presents little technical difficulty (Contreras et al., 2011). Is it then possible that this easy–to-learn and easy–to-perform resistance exercise may be more beneficial at targeting the hip extensors, primarily the GM, compared to the BS and DL? This question has arisen due to the direction in which force is applied during the lift differing from the BS and DL, in a horizontal plane. A further question that remains is how does the sEMG amplitude of muscles alter during the concentric phase, amongst these 3 exercises? In addition, are certain muscles activated to a higher degree at different parts of the concentric phase? For example, do the levels of electrical activity in the glutes differ at parts of the concentric phase in the BS, DL and HT? This is an area which has never been investigated before and is currently unknown to the literature.

This study is both the first to compare the muscle activation profiles of all 3 exercises against one another and the first to do so in a non-resistance trained population. What is currently lacking within the literature is the presence of research surrounding RT in an untrained population. Not every person will perform RT to improve athletic performance, but simply for recreational or general health purposes. Further research must be carried out in this untrained population to understand which exercises may be the most beneficial for a new lifter. Therefore, it is necessary to understand the different reasons why both populations may perform RT, and the benefits it has to offer.

1.2 The health benefits of resistance training

In recent years RT has become more popular within the general population. This occurrence is largely due to published research granting a greater insight into the benefits it can provide to a person, both physically and mentally (Westcott *et al.*, 2009; O'Connor, Herring and Caravalho, 2010; Flack *et al.*, 2011; Heden *et al.*, 2011; Westcott, 2012). This continued research is advancing our knowledge and understanding of the benefits RT offers in both the fields of health and physical performance. Previous research has found that the introduction of a RT programme to an untrained population resulted in increases in lean body mass (Westcott *et al.*, 2009). This increase in lean mass occurred across a vast participant sample, with no significant differences shown between increases in lean mass, and age groups ranging from 20 – 60 years old (Westcott *et al.*, 2009). In addition, performance of the RT programme resulted in a decrease in fat mass across all participants. This decrease could partly have been due to the increase in lean muscle mass. as it has previously been shown that increases in muscle mass correlate to increases in metabolic rate (Heden *et al.*, 2011). RT in older men has led to greater than 50 % increases in strength in 3 lower limb lifts after a 16-week period (Hagerman *et al.*, 2001). One literature review investigating the effects of RT on the prevention of heart disease, stated that the results are just as effective as that of aerobic training at reducing risk factors (Strasser and Schobersberger, 2011). Furthermore, two meta-analyses have also concluded that the performance of RT significantly reduces a person's resting blood pressure, aiding in the prevention of atherosclerosis and heart disease (Kelley, 1997; Cornelissen and Smart, 2013). These studies demonstrate some of the possible health benefits from performing RT: with decreases in blood pressure, risk factors associated with heart disease and fat mass and increases in a person's strength and lean muscle mass. Current NHS guidelines within the United Kingdom advise that people perform a minimum of 2 sessions of strength exercises per week. However, the performance of RT does not only have a positive impact upon a person's physical health. Mental health is currently a severe ongoing issue in our society, and RT has been demonstrated to be one of the best ways to combat mental health related illnesses (Gordon *et al.*, 2018; Tasci *et al.*, 2018). A review investigating the effect that RT has on mental health disorders, demonstrated a positive relationship between RT and the reduction of symptoms of fatigue, anxiety and depression (O'Connor, Herring and Caravalho, 2010). One of the positive effects of performing regular RT is the multiple health benefits it provides for both athletes and recreational lifters who have just started. However, there are also many recreational athletes who fall into this non - resistance trained category. Those of whom may already be decreasing health risk factors through aerobic exercise, but are missing out on the possible performance benefits which RT can influence in an athlete's given sport.

1.3. Performance variables in sport

There are several performance variables which determine an athlete's ability to perform within their given sport, and why they may be more suited in one sport compared to another. These are their maximal sprinting, jumping, and change of direction (COD) ability. Although individual sports may focus on possibly only one aspect of these 3 movements, all 3 are incorporated to some degree within the world of team sports. For example, basketball players regularly exhibit powerful vertical jumping ability to rise above their opponents to score points for their team. A movement which is performed up to 50 times per game (Montgomery et al., 2010). However, both high speed running and COD are skills required in most team - based sports to beat an opponent. One study reviewed the physical demands during competitive gameplay in basketball, finding a mean of 345 COD's per game with players performing various modes of shuffling in attempts to evade opponents (McInnes *et al.,* 1995). Within contact-based sports, maximal sprinting and COD may be considered two of the most important factors, with limited jumping performed within the games. Sports such as rugby 7's require players to sprint at maximal speeds and perform at a higher intensity compared to other team sports. This has previously been demonstrated whenever comparing GPS data between rugby 7's and union. This study found that rugby 7's players covered approximately 45 % greater total distance per minute and ran 135% further at high running intensities (>5m.s^{-1}) whenever compared to their 15's counterparts (Higham *et al.*, 2012). In addition, although jumping performance is not a major part of the 7's game, it has previously been demonstrated that there appears to be a large correlation between effectiveness in the attacking ruck and countermovement jump performance in International 7's players (Ross *et al.,* 2015). This would suggest that the ability to effectively produce maximal horizontal force may contribute towards a successful ruck in rugby.

The evidence in the literature would suggest that the development of these 3 basic variables – running, jumping and COD ability, should be of upmost importance to athletes aiming to play at the highest competitive level in their sport. One study on American collegiate football players compared the performance scores of athletes across the top 3 divisions (D1 – D3). It was found that athletes in D1 (the top tier) had significantly faster 40-yard dash times and CMJ's whenever compared to the lower tiers (Fry and Kraemer, 1991). This would suggest that improved performance in these variables contributes towards being a greater athlete capable of playing in the top leagues. Another study which focussed on youth soccer players across a season, found that the most consistent starting first team players had significantly lower sprint times over 30 metres (Gravina *et al.*, 2008) . Therefore, it appears that for athletes to compete at the elite level it is critical for them to be able to produce powerful vertical and horizontal forces. This is also prevalent in most individual sports. A gymnast attempting to jump higher, or a boxer attempting to punch harder are both powerful movements utilising vertical and horizontal forces respectively. Training programmes aiming to increase vertical and horizontal force production in the lower body should then focus on the development of the prime movers in these actions – the hip and knee extensors

1.4. The importance of the hip and knee extensors in jumping and running

The hip and knee extensors consist of several muscles which control both the flexion and extension of both structures. This movement of flexion and extension is vital for both everyday movement and performance in sport. The hip extensors consist of the *Gluteus Maximus* (GM) and 3 heads of the hamstring – *Bicep Femoris* (BF) *Semimembranosu*s (SM) and *Semitendinosus* (ST). Whilst the knee extensors consist of the quadricep muscles – *Rectus Femoris* (RF) *Vastus Lateralis* (VL), *Vastus Medialis* (VM) and *Vastus Intermedius* (VI). The literature has shown a strong relationship between running speed and the hip extensors. By which, as running speed increases there is an increase in hip to knee extensor moments by approximately 304%. This suggests that as sprint speed increases greater force is produced by the hip extensors (Schache *et al.*, 2011). A similar relationship is displayed when investigating jump height. As jump height increases, there is an increase of 163% in the role of the hip extensors when performing a high intensity jump, compared to a low intensity one (Lees and Clercq, 2004). Therefore, as intensity increases in running and jumping actions, the hip extensors appear to play a greater role than the knee extensors by eliciting a change from knee to hip dominance within the lower limb musculature. These data clearly demonstrate rationale of the possible importance of the hip extensors to athletic performance, with the requirement for them to be capable of producing large magnitudes of force in an athletic setting. RT can be used to increase the forces which these muscles can generate. As the literature has previously demonstrated the transference of strength and power developments which arise from RT to athletic performance (Young, 2006). For this transference to occur, RT must be specific to the athletic movement a coach aims to improve. One method of identifying which exercises may be best suited for developing select muscle groups and movement patterns, is by investigating the muscular recruitments in each lift through electromyography.

1.5. Electromyography

Surface electromyography (sEMG) is a technique which is used to investigate the neuromuscular status of muscles in response to different stimuli. By placing several electrodes on the skin's surface, this non-invasive method is a safe and easy way to measure a muscles' electrical activity. This allows for constant recording of the muscle from a state where it is at rest, to the point of maximal contraction. Through these measures, it is possible to estimate the recruitment patterns and firing rates of different muscles in a way that can be visually noted (Cram and Criswell, 2011). This visualisation of a muscle's electrical activity allows practitioners to identify which muscle groups may be highly active in different movements, or in this case RT exercises. However when interpreting sEMG data, many forget that it is simply a measure of the muscle's electrical activity, neither its strength or force (Cram and Criswell, 2011 and Vigotsky et al., 2018). It is used to estimate which muscles may be recruited, through the assumption that a higher electrical amplitude equates to a greater number of a muscle's motor units firing. Much of the research conducted on resistance exercises which cause the most electrical activity of the hip extensors has investigated both the barbell back squat (BS) and barbell deadlift (DL).

1.6. The Back Squat

The BS is one of the most commonly used compound lifts in athletic training, due to its ability to develop both power and strength in an athlete's lower body (Wilson *et al.*, 1993). Performance of the lift involves a person standing with a barbell positioned at the base of their neck, resting across the trapezius muscle, with feet shoulder width apart. The beginning of the lift involves a controlled descent, through the eccentric contraction of the hip and knee extensors, until the top of the thighs are parallel or below to the floor (O´Shea, 1985; Kushner *et al.*, 2015). The concentric phase of the lift involves a powerful drive upwards through stored kinetic energy, generated during the descent by the hip and thigh muscles, as well as thrusting the hips forward and under the bar to return to the upright position (O'Shea, 1985; Kushner *et al*., 2015). The depth to which the eccentric phase of the BS is performed varies depending on a person's purpose for performing the BS – either strength, performance benefits or rehabilitation. The depth to which a squat should be performed is a common quarrel amongst strength and conditioning coaches and researchers. One study which compared the peak force production between partial and parallel squats, found partial squats elicited significantly greater levels of peak power (Drinkwater and Moore, 2012). The possible benefits from performing partial squats was investigated further, with one study finding a strong correlation between partial squat 1RM strength and sprint speed and jump height (Wisløff *et al.*, 2004). These data would appear to suggest that quad dominant squatting may transfer into athletic movements. However, a study investigating the differences in vertical jump performance in an untrained population following a 9-week training block of either deep or shallow squats, found there to be no difference in performance outcomes between either form (Weiss *et al.*, 2000).

Another former belief was that the performance of a full squat was needed to elicit maximum hamstring activation in the BS. However, this was disproved by an investigation into the relationship between squat depth and hamstring activation - which showed no significant differences (Jensen and Ebben, 2000). The performance of partial depth BSs therefore may be useful to individuals or athletes looking to develop maximal power in a training cycle. Contrary to this, it has been suggested that partial squats may be limiting the development of the most powerful hip extensor – the GM. When investigating the sEMG activity of the hip and thigh muscles, it has previously been demonstrated that whenever the squat was performed to a depth of parallel or below, there is an increase in recruitment of the GM during the concentric phase (Caterisano *et al.*, 2002). These findings suggest that the deeper a squat is performed, the greater the recruitment of the GM. Though as previously mentioned in a review of the BS, the major limitation of this study was the calculation of relative load across all depths instead of keeping the load constant at all depths (Clark *et al.,* 2012). The GM is highly regarded as the main prime mover of the squatting movement and the muscle which many perform the exercise to target (Clark *et al*., 2012). Through mathematical modelling, previous research has estimated the relative muscular effort (RME) of the hip and knee extensors, and ankle plantar flexor during varying squat depths (Bryanton *et al.* (2012). Throughout the entire lift, as depth and load increased the hip extensors had a greater level of RME in comparison to the knee extensors, showing the demand placed on the GM during the BS (Bryanton *et al.* (2012).

The importance of gluteal strength and its role in sporting performance, as well as the consequences of muscular imbalance or weakness in this muscle, are often overlooked by many recreational lifters. Previous research has reported how a lack of endurance and rate of firing in the GM was common in individuals who suffered from lower back pain, a troublesome injury for both athletes and the general population (Nadler *et al.* (2002). By strengthening the hip extensors, athletes may be able to avoid such problems which could potentially shorten their careers, or for the average person, their quality of life. Several studies have shown that lower body strength correlates strongly with a broad range of performance measures (Chelly *et al.*, 2009; McBride *et al.*, 2009; Seitz *et al.*, 2014). For instance, it has been demonstrated that RT resulted in improvements in youth soccer players' power production, vertical jump and sprint times following a 2 month training block with the BS (Chelly *et al*., 2009). Furthermore, previous research has demonstrated a significant correlation between 10 and 40 metre sprint times and 1RM BS strength in a sample of footballers (McBride *et al*. (2009). This correlational data is supported by a meta - analysis, in which the data suggested a significant carry over of strength in the squat to athletic performance. This data would seem to suggest that the stronger an athlete's BS, the lower their sprint trial times (Seitz *et al.*, 2014). The BS is highly regarded by many as the staple to any weightlifting programme, due to the data which seems to support a transfer to sports performance. However, one downfall of performing the BS is the lack of activation of the BF. To avoid muscular imbalance, a posterior chain exercises such as the deadlift (DL) is commonly programmed in conjunction with the BS.

1.7. The Deadlift

The DL is one of the most common lifts used by both athletes and the general population. It is theorised that performance of the DL may improve athletic performance, due to the demand it places on both the knee and hip extensors (Farley, 1995). The hip extensors are the main prime mover in this lift. The role of the knee extensors in the DL are to work antagonistically to the contraction of the hamstrings to secure the tibia and prevent movement (Begalle *et al.,* 2012). This lift can be performed in several variations. Though the most commonly used forms of the full lift are the sumo DL – a wider stance that results in a higher EMG amplitude of the quadriceps, in which the bar has over a 6% decreased vertical displacement. Or the more commonly used conventional style (Mcguigan and Wilson, 1996; Escamilla *et al.*, 2000). Both forms of the DL place the load of the exercise on different muscles, due to their biomechanical differences. Previous literature has demonstrated that the conventional style requires double the level of muscle activation in the erector spinae compared to the sumo style (Horn, 1988). To perform the conventional DL a person must place a loaded barbell on the floor and stand directly behind it. Their feet should be positioned hip - width apart and the barbell positioned over the balls of the feet. The bar can be grasped in either a forehand grip - in which straps or the hook grip technique can be used, or the more common mixed grip - with one forearm supinated and the other pronated. This mixed grip form of the lift is often discouraged in elite athletes, due to the risk of a possible bicep injury in the supinated arm. As well as a lack of transfer of grip strength to Olympic movements, such as the clean and jerk or snatch. The hands should be positioned either side of the legs, brushing the thighs, to reduce the distance one must pull the bar. Knees should be slightly bent with a neutral hip and back position, the scapula depressed, and shoulder blades retracted with the elbows fully extended. In this braced position, the hips should be at a higher position than the knees, but lower than the shoulders. After taking a large breath to brace the abdominal wall, the position is secured through engaging the *Latissimus Dorsi* and keeping the chest up. The concentric phase is then performed. This phase is executed by driving through the heels and engaging the hip extensors to explosively move the body and the bar to an erect upright position. The eccentric part of the movement is then performed by lowering the bar back to the ground through flexion of the hips and knees whilst maintaining a neutral spine (Farley, 1995; Haff and Triplett, 2016).

What little research that has been done on the DL has mainly focussed on the sEMG activation of the lower limb musculature. With a greater focus on the stiff leg variation of the exercise. One such study investigated the sEMG profiles of different resistance exercises for the hamstrings (Ebben, 2009). This data showed that out of 4 different exercises which required knee flexion, the stiff legged DL proved to generate the second highest level of muscular recruitment in the *Bicep Femoris*. With the isolated leg curl, an open kinetic chain exercise, placing first. Previous literature has also found that the conventional DL utilises the posterior chain and elicits higher levels of BF activation when compared to the hex bar DL (Camara *et al.*, 2016). These findings are also supported by Andersen *et al.* (2017) whose investigation found the DL to elicit greater levels of sEMG in the BF compared to the barbell hip thrust (HT) (20% higher) and hex bar DL (28% higher). However, the DL has not only been proven to develop the posterior chain, with research showing that 10 weeks of DL training caused increases in muscle activation of the thigh in an isometric leg extension (Stock and Thompson, 2014).

Unlike the BS, the literature for the performance benefits of the DL is severely lacking and an area which should be investigated further. Due to the demand the DL places on the musculature of the lower limbs, it may potentially elicit increases in athletic performance by overloading both the hip and knee extensors. With the starting position of the DL being one in which if an athlete is strong, it may be transferable into sport situations which require a stable and neutral spine whilst simultaneously performing high levels of lower limb power. An example of such movement would be the scrum or tackle in rugby, American football and other contact sports. To the authors' knowledge, the only data which has currently investigated the effect of the DL on performance focused on the countermovement jump. This study investigated the effects of a 10-week training block with the DL on CMJ performance and rate of torque development in the hip and knee extensors. Participants demonstrated a 25% increase in their CMJ performance following the training block, as well as an increase in RTD in both the hip and knee extensors (Thompson et al., 2015). Previous data has shown that as the load of the DL increases, the ratio of hip to knee extensor moments also increases by 33.3% when the load was increased from 10 % to 80% of 1RM (Swinton *et al.*, 2011). These data clearly show the importance of the hip extensors to athletic performance, and the success which developing this group of muscles can evoke.

Each of these studies have shown that the prime movers of both the conventional and stiff legged variations of the DL are the hip extensors. With the large gap in the literature, one main area which has not been addressed is how does the DL compare against the BS as a training stimulus to activate the hip extensors. However other than the BS and DL, the question remains if there are potential exercises which may be more transferrable to performance. Or better suited to an athlete's sport, due to the lift involving force production in a similar manner as a fundamental movement / skill within the sport. This idea forms the basis around the use of force vector training.

1.8. Force vectors

Force Vector training suggests that exercises which elicit force in the same direction as a specific sporting action is performed are superior for enhancing performance in that sport. An example being the strong evidence of research in which the BS leads to improvements in vertical jump height, a display of maximal vertical force production. Several studies within the literature seem to support this hypothesis, demonstrating a strong relationship between horizontal force production and sprinting. The relationship between an athlete's force production in the vertical and horizontal planes as sprint speed increases was investigated in in 32 Australian rules footballers. It was found that vertical force increased up to speeds of 60 % of max velocity and thereafter plateaued by the time that 80 % was reached. Contrary to this, horizontal force began to steadily increase form 40% of max velocity onwards. Continuing to do so until the athletes reached their max sprinting velocity (Brughelli *et al*., 2011). Another study continued this notion by examining the relationship between force production and 100 metre sprint performance. It was found there were positive correlations between horizontal force and acceleration, with no effects correlated from the production of vertical force (Morin et al., 2011). A further 2 studies had similar conclusions, with their results demonstrating in both sprinters and long - distance runners that horizontal force is correlated to acceleration and maximal sprint performance (Kuitunen *et al*., 2002; Nummela *et al*., 2007). These studies support the theory of force vector training warrants further investigation. Determining how certain exercises may be superior for eliciting specific performance improvements than others. What is clearly exhibited in the research is a linear relationship between horizontal force production and sprinting ability. Suggesting that horizontal force production is critical for sports which involve high speed running. Within the current body of literature, it remains to be investigated whether a horizontally loaded movement may be superior to a vertically loaded movement. If one were to follow the theory of force vectors, it should be. A specific horizontally loaded exercise which has gained popularity in recent years is the barbell hip thrust (HT).

1.9. The Hip Thrust

The HT has recently emerged in the literature with interest in its possible aid to athletic development. This is due to the direct load it places on the hip extensors throughout the entirety of the movement, predominantly on the GM. As well as this, it is a movement in which the loaded barbell is moved in a horizontal plane. Through the theory of Force Vectors, this would suggest it may be more transferable to sports which require high levels of sprinting and acceleration due to the HT's anteroposterior force vector. With force being applied from the back of the body towards the front throughout the movement. A movement which could improve horizontal force production. This hypothesis was tested in a 2017 study which compared a 6-week training programme of either the front squat or the HT, and the performance changes each elicits. It was found that each training group improved their strength within their retrospective group, however the front squat showed greater effect sizes in the jumping tests, whilst the HT showed a large effect size in 20 m sprinting improvements (Contreras *et al.*, 2017). This was concluded to be due to the front squat being greater for movements performed in an axial plane, and HT's for movements on a horizontal one. Only one study to date has profiled the sEMG activity of the hip musculature within the lift, identifying the GM as the prime mover (Contreras *et al.,* 2015). The same study's findings also suggest that the HT elicits a greater level of activation of the GM when compared to the BS. An exercise which for years has been commonly associated with GM training. The HT is performed by sitting on the floor, with legs outstretched and a barbell loaded with 2 Olympic size weight plates to elevate the bar high enough above the thighs. The participant's upper back should be resting against a bench or plyometric box, approximately 16 inches in height. The participant then rolls the loaded barbell over their thighs to rest in the crease of their hips, slightly above the pelvis. Due to the stress placed across the lower abdomen and pubic region, the lift should be performed with a foam barbell pad to minimise discomfort. The position is then secured by placing the feet just outside shoulder width and retracting the feet towards the buttocks, until at a distance that will create a 90-degree angle at the knee joint whenever extending the hips. By doing so, this will prevent excessive strain on the hamstrings and allow for greater recruitment of the hip extensors and therefore power production. From this start position, a deep breath is taken, and the core braced. Driving through the heels and the bench, the bar is propelled upwards through the contraction of the hip extensors. The glutes should be squeezed at this top position to achieve full hip extension before the bar is then lowered to the floor to the starting position in a controlled manner. The most important thing throughout the lift is that the spine is kept neutral to prevent any injury through hyperextension. This is easily done by keeping the head secured and slightly tilted at a 45-degree angle by looking upwards and ahead. By the head remaining in this position, it prevents any backwards movement of the head and the participant looking back behind themselves. A position which results in hyperextension of the spine. Proper form of the HT requires full control through all phases of the lift (Contreras *et al*., 2011).

With the HT only emerging within the literature several years ago in a NSCA review article, there is very little research which has been carried out on the exercise or its transference to performance (Contreras *et al*., 2011). One study investigated the effects of an 8-week training programme with the HT in collegiate level baseball players upon strength and performance variables. Training with the HT correlated to increases in squat strength and HT 3RM strength, however no differences were found in the performance measures (Kun-Han Lin *et al.*, 2017). A similar study also investigated the effects of an 8 - week training programme of the HT and its effect upon sprint performance, with no significant improvements being reported (Bishop *et al.*, 2017). However the latter study's participant sample consisted of both males and females. This makes it difficult to interpret the results of the study, due to the problems which arise when using a mixed gender cohort. Males and females have vast physiological differences, with females typically having lower levels of lean muscle mass than males (Kraemer *et al.*, 1991)**.** This difficulty is noted within the study's discussion, as the author believes the females having slower sprint times may have affected the results. Due to the presence of these slower times, the mean sprint times of all participants would increase and may interfere with the true results of training. As well as this, both studies incorporated a loading scheme and coaching of the lift which did not focus on athletic power development. Instead the studies used slow and controlled repetitions which would increase levels of time under tension, a method commonly associated with hypertrophy training. As opposed to performing explosive and powerful repetitions. Over the 8-week training period, the lead investigators of the baseball players study did not programme any repetitions which are within the ranges of strength or power training until weeks 7 and 8 (Kun-Han Lin *et al.*, 2017).

There are many who perform or utilise the HT in their training that believe the position of this lift is a superior method of training the hip extensors. Due to the load being applied horizontally whenever performing the lift, it is speculated that this will allow superior training of the GM due to highest levels of tension being at full hip extension. Contrary to standing exercises where tension on the GM is believed to decrease as an exerciser returns to full hip extension due to the activation of the hamstrings. Other horizontally loaded movements have already demonstrated a positive effect on performance, such as a training programme using kettlebell swings elicited improvements in the half squat and jump squat (Lake and Lauder., 2012). This training method of the benefits which horizontally loaded movements may have towards certain areas of athletic performance is based around the theory of resistance training within certain force vectors.

1.10. Aims and objectives

Previous research has demonstrated the benefits of performing RT for health and sporting performance. The most thoroughly researched exercise is the BS, followed by different variants of the DL. Both compound lifts are technically difficult and take time for non - resistance trained individuals to learn and execute accurately. The HT is an exercise which is much simpler to perform, and which some practitioners feel may be more transferable to areas of sporting performance than the BS or DL (Contreras *et al.*, 2011, 2015, 2017). The literature has demonstrated the role of the hip extensors in fundamental sporting actions, theorising the possible improvements training of them may bring. What is currently unknown is how these 3 exercises compare against one another in a non - resistance trained population in terms of muscle activation profiles. Each exercise has separately been documented in different populations, but never together in the one study and population. This study will therefore be the first to compare the BS, DL, and HT in a non - resistance trained population. It is also the first to observe the sEMG profiles of the 3 exercises in the hip and knee extensors across the concentric phase, by dividing the concentric phase into tertiles.

Therefore, the main aims of this investigation were:

- To profile the sEMG activity of the selected hip and knee extensors in the BS, DL and HT.
- To determine which of the 3 lifts resulted in the greatest levels of EMG amplitude in the UG, LG, VL and BF in untrained participants.
- To compare the concentric phase of all 3 lifts in tertiles, in order to visualize the differences in activation throughout the movement in untrained participants.

The main hypothesis for the study was that the HT would elicit superior levels of GM activation when compared to the BS and DL. With our secondary hypothesis being that the HT would have the highest levels of GM activation in the 3rd tertile of the concentric phase, compared to the BS and DL.

Chapter 2: Methods

2.1. Overview of the testing protocol

The study was approved by the University of Stirling Ethics board (SSREC number #876) and all participants were required to sign a written informed consent form (Appendix 2) prior to participating in the study. The study was conducted in accordance with the Declaration of Helsinki (2008) and all participant data and information remained confidential in accordance with the Data Protection Act (1998). Each participant was required to attend 3 separate sessions (Figure 1). The first session involved the collection of the relevant paperwork and health screening to ensure participants were suitable for recruitment. The second session acted as a familiarisation to the testing procedures, and the sEMG data was collected during the third session. Participants performed 1RM's of all 3 lifts in both sessions 2 and 3. This structure was chosen as participants were untrained and had previously not performed 1RM's of any of the three lifts. By having a familiarisation session, participants were able to become accustomed to 1RM testing with lab equipment attached. In addition, this therefore allowed for accurate sub maximal loads to be calculated the following week, which were performed in the lead up to 1RM testing. The lead investigators decided to use 1RM testing as it is considered the gold standard of muscular strength assessment, and previous literature has commonly used submaximal (3RM) data when assessing the HT. All of the investigator's coaching and knowledge of the 3 lifts were assessed by a UKSCA accredited coach prior to the study.

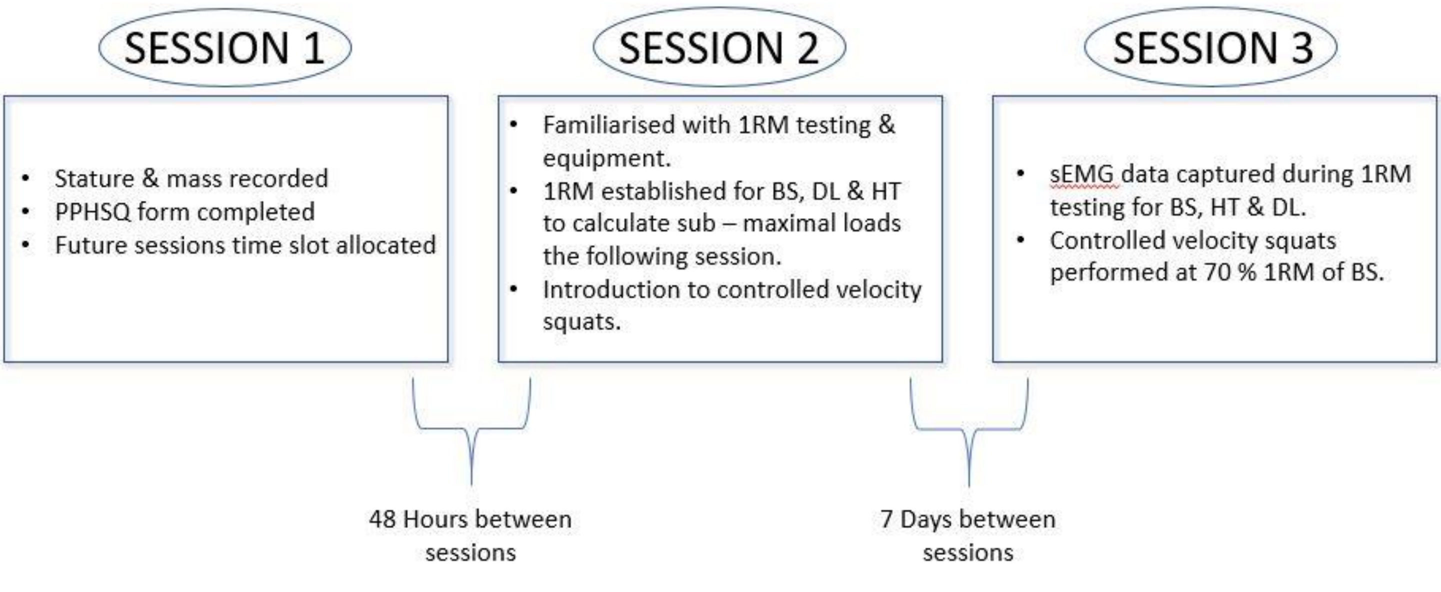

Figure 1: Schematic depicting the 3 separate sessions which were attended by participants over the course of the study.

2.2. Participants

This study recruited 22 non - resistance trained males at the University of Stirling (descriptive characteristics are presented in Table 1). Of the 22 recruited, only 19 were used for data analysis. This was due to either a distorted sEMG trace or not completing the session or required lifts. Non – resistance trained individuals had either never performed any lower body RT or not done so in the last 12 months. Participants were required to be physically fit due to the nature of the testing, as well as to have been free of any injury to the lower limbs for at least 6 months. Prior to testing, participants were also required to complete a PPHS-Q (Pre Participation Health Screen Questionnaire) due to the nature of the testing to ensure they were of suitable health (Appendix 4). Each participant was provided with a food and exercise diary (Appendix 3) to account for the 72 hours prior to entering the lab, however were not required to be fasted during testing. Participants were requested to repeat the same eating habits prior to the 3rd testing session. Both testing sessions were completed at the same time of day 1 week apart to account for circadian variation (Atkinson and Reilly, 1996).

2.3. Procedures

Stature and mass were recorded during the 1st session and participants were screened for any health issues through completion of the PPHS – Q form. If completion of the test presented no identified risk for the participant, then a time slot was allocated for the following session to take place. Beginning the 2nd session, participants entered the lab to undergo their familiarisation to testing procedures session. Each subject was provided with a pair of Lycra shorts, in which a hole was cut out at the relevant position of the participant's GM site. This was due to a previous pilot study carried out prior to this investigation, which had identified this method to be superior in eliciting EMG data without interference from clothing. Participants had 4 separate sites shaved and abraded on their dominant leg; the upper and lower regions of the *Gluteus Maximus* (UGM) (LGM), in addition to the VL and BF. Two bipolar electrodes (Ambu WhiteSensor ECG diagnostic electrodes, Ballerup, Denmark) were placed vertically for the BF and VL, and horizontally for GM sites in accordance with the

Surface Electromyography for the Non–Invasive Assessment of Muscles (SENIAM) guidelines for the relevant sites (Appendix 6). UGM sites were identified as being the upper portion of the GM, approximately an inch above the firmest portion of the muscle belly. LGM sites were identified as being the lower portion of the GM, approximately an inch below the firmest portion of the muscle belly. Two reference electrodes were also placed with one on the lateral femoral condyle, and one on the medial femoral condyle. These electrodes were attached with the output recorded and root mean squared (RMS) calculated via the software used to operate the EMG system (AcqKnowledge 3.8.1, Biopac Systems Inc., Santa Barbara, CA). Participants had sEMG readings recorded from their dominant leg via a wireless system sampled at 2000Hz. Transducer measurements (Celesco PT5A-125-S47-UP-10K-M6, Chatsworth, California, USA) were used during each lift over both sessions to accurately track the eccentric and concentric phases.

Participants were instructed to perform their own warm up and dynamic stretching of the lower limb musculature prior to 1RM testing (Eleiko Sport, Halmstad, Sweden). The orders of performing the squat, HT, and DL were counterbalanced with each new phase of testing to prevent any bias towards lifts being performed before another. However, the DL was never used as the first lift to be performed due to safety concerns for the following 1RM's to be collected. As the participants were untrained, it was decided the DL would always be performed as either the final or middle lift during testing, due to the taxing demands of the lift and its technical complexity.

Safety bars were set at the appropriate height in the squat rack, which the bar would be lowered onto if failure occurred at the bottom of the lift. Each participant also had 3 spotters (one at each end of the bar and one directly behind them) throughout 1RM testing. This structure allowed for the participant to be safely raised or lowered if failure occurred at the appropriate stage of the BS. Failure of the lifts were either determined by being unable to complete the rep, an RPE of 10, a participant wishing not to continue increasing the weight, or the lead investigator deciding the form was not to the standard of a successful lift. It was crucial that the participants kept strict form throughout their testing. For the squat the adequate depth set was that of the top of the thighs being parallel to the floor. This had previously involved the use of an electric goniometer in pilot testing to determine adequate squat depth. For the DL, the participant had to successfully lift the weight with minimum curving of the thoracic spine in a controlled manner. A successful lift in the HT required participants to reach full hip extension and keep control of the loaded bar before being told to lower the bar back to the starting position.

Since each participant had no previous knowledge of any of the three lifts, a rate of perceived exertion scale was used to determine the increments for increasing the weights during 1RM attempts (Appendix 4) (Zourdos *et al.*, 2016). Participants reported an RPE after every set. If participants' RPE was between 1 and 8, the load was increased by 5kg. If the participants RPE was a score of 9, the load was increased by 2.5kg. Finally, if an RPE of 10 was given, 1RM testing would end with a participant's 1RM being the load of their last completed lift. At the beginning of both testing sessions, this RPE scale was fully explained to participants. Throughout 1RM testing the RPE scale was attached to the power rack and was directly in front of participants. This protocol was designed by the investigators. It was used as this allowed for a safe and controlled progression in weight towards a 1RM.

Adequate time was spent before testing began making sure each participant could perform each lift competently and safely. The beginning of 1RM testing started with the performance of 10 repetitions, with only the bar for the BS and 5 kg Olympic plates either side for the HT and DL. The participant then gave an RPE for their given set. From this RPE score and the lead investigators observation of the participant's form and the bar speed during the movements, weight was increased accordingly. This process was repeated for further submaximal sets of 5, 3, and 2 repetitions. Once the final sub maximal set of 2 was completed, the first weight was selected for participant's first 1RM attempt. 2 minutes of rest was allowed between each 1RM attempt. Once a participant's 1RM for the given lift was achieved, 5 minutes of rest was allocated until beginning the next lift. Following their 1RM testing participants were familiarised with how to perform controlled velocity squats, a previously used normalisation method as opposed to maximal voluntary contractions (Balshaw and Hunter, 2012). This would be performed the following week to normalise the sEMG data collected for the 3 lifts. Participants completed as many squats as necessary with an unloaded barbell until they were accustomed to performing squats to the beat of a metronome. This metronome was set at a 2 second inter-tone duration dictating the beginning of the eccentric and concentric phases of the lift. After practicing the controlled velocity squats, participants were led through static stretching exercises and exited the lab.

The second session began with the same warm up and stretching as had been recorded the previous week. Due to the participant's 1RM being determined the previous session, accurate loads were able to be determined for the sub maximal sets in the lead up to 1RM testing. Participants performed: 10 reps at 50% 1RM, 5 reps at 70% 1RM, 3 reps at 85% 1RM, 2 reps at 90% 1RM 1 rep at 95% 1RM. Participants then performed 1RM testing in an attempt to beat their previous session's load. The same RPE loading scheme and rest periods between 1RM attempts from the previous session were applied to the second 1RM session. After the BS 1RMs participants performed the controlled velocity squats which were practiced the previous week, at 70 % of their 1RM. This data was collected to be used in the normalisation procedure for sEMG data, as a previous study had found it to have a greater reliability than several other methods of normalising sEMG data for the VL and BF (Balshaw and Hunter., 2012). 2 minutes of rest were then given before finally performing a set of 3 repetitions at 85% of their 1RM. These submaximal sets following the new 1RM score were only performed for the BS. Both the DL and HT followed the same sub maximal loads. Again, at the end of the session participants were provided with a protein shake and instructed to perform a cool down and static stretching of the lower body.

2.4. Data Extraction

All sEMG data was extracted manually from Acqknowledge. To extract only the concentric phase, several of the recorded channels were used to allow the lead investigator the accurately select where the eccentric phase ended, and the concentric phase of each lift began. This was done by manipulating the software to locate the highest or lowest point of the transducer data for the appropriate lift on the transducer output channel. Next, the lead investigator was then accurately able to select from this marker onwards until the transducer trace displayed the end of the concentric phase. This method allowed for the accurate selection of only the concentric phase of the sEMG data for the several muscle groups. The data was processed with the number of samples set to average across 200, due to the capture rate being 2000 Hz. The maximum and mean values for each of the sEMG channels was then extracted into a master database on Excel. This was extraction method was performed on the 1RM data and the 2nd repetition of the 85% of 1RM data. The second repetition was chosen due to it being the middle value of the set. The data extracted from the 70 % 1RM controlled velocity squats that were used to normalise all the sEMG data. This was done through calculating the average sEMG values across five repetitions at 70% 1RM for each muscle group. This average value was then used to divide the 1RM or 85% of 1RM value and multiplied by 70, due to the load being 70% of 1RM (Balshaw and Hunter, 2012).

In order to view the concentric phase of the 1RM sEMG data in tertiles, a python script was derived in which the Acknowledge file was processed into a Microsoft Excel sheet (Appendix 5). A visual example of the tertiles split is presented in Figure 2. Once the sEMG data was processed into the file, the beginning and end of the lift had to be set manually by the lead investigator, which was again done using the data from the transducer. Once this was done, the programme split the concentric phase of the lift into tertiles and provided an output giving the mean values for each tertile.

Figure 2A: An example of the concentric phase of the BS being divided into 3 tertiles. Where the 1st tertile begins at the end of the eccentric phase of the squat and 3rd tertile ends when the hips and knees are fully extended.

Figure 2B: An example of the concentric phase of the HT being divided into 3 tertiles. Where the concentric phase begins at the initial rise of the bar, and ends when the hips are in full extension.

Figure 2C: An example of the concentric phase of the DL being divided into 3 tertiles.

Where the concentric phase begins as the bar leaves the ground and ends when the hips and knees are fully extended.

2.5. Data Analysis

Data were analysed using Graphpad Prism. Of the 22 recruited participants, analysis of the peak 1RM and 85 % of 1RM data was only completed for 19 of them. This was due to 3 participants having incomplete data sets from either not performing a lift, or problems having occurred during the collection of the data. A one-way repeated measures analysis of variance (ANOVA) was used for analysis of the peak sEMG 1RM and 85% of 1RM data with exercise and muscle set as the values. For analysis of the tertiles data, 2- way repeated measures ANOVAs were used with tertile and muscle, and tertile and exercise set as the values respectively. Following the ANOVAs, a pairwise comparison post hoc analysis was conducted using the Tukey's test to account for random error due to the multiple comparisons. All tests had an alpha value of 0.05.

Chapter 3: Results

3.1. Participant Characteristics

Descriptive characteristics of our subject sample are presented in (Table 1). Data are presented as the mean followed by standard deviation (SD) and standard error of the mean (SEM).

Participant Characteristics					
	Height	Weight	Squat 1RM	Hip Thrust 1RM	Deadlift 1RM
Mean	180.4 cm	82.4 kg	92.4 kg	136 kg	118.5 kg
St. Dev	± 6.6 cm	± 11.2 kg	± 19.6 kg	± 24.8 kg	± 21.6 kg
SEM	± 1.4	± 2.4	± 4.2	± 5.3	± 4.6

Table 1: The descriptive characteristics displaying the mean, ± SD and ± SEM for all participants loads lifted on each of the exercises.

3.2. Peak EMG Amplitude

Total barbell displacement and peak sEMG amplitude were assessed during the 1RM and 85% of 1RM efforts. Reflecting the biomechanically distinct nature of the 3 exercises, we found that total barbell displacement was significantly higher in the BS compared to the HT (p = <0.0001, 95% CI = 0.08009, 0.2166) (Figure 3). However despite the increased range of motion of the BS and the higher load of the HT, no significant differences in peak sEMG amplitudes were found for the 1RMs in the UG or LG across all 3 exercises. The VL was found to produce significantly lower sEMG amplitudes in the HT compared to the BS (p = 0.0019, 95% CI = 40.34, 171.3) and DL (p = 0.0007, 95% CI = -152.1, -43.36) (Figure 4). In addition, the BF was found to produce significantly higher sEMG amplitudes in the HT (p= 0.0056, 95% CI = -331.2, -56.04) and DL (p= .0006, 95% CI = -334.8, -96.45) when compared to the BS (Figure 4).

In addition to analysing the sEMG amplitudes during 1RM efforts, we also analysed the sEMG amplitudes during the submaximal sets at 85% of 1RM. All analysis presented was carried out on the 2nd repetition. The results of the submaximal sets mirrored those of the

1RM's. No differences were found in the peak sEMG amplitude, in the UG or LG (Figure 4). We found the VL sEMG amplitude to be significantly lower in the HT, when compared to the BS (p = 0.0244, 95% CI = 6.314, 97.74) (Figure 4). We also found the sEMG amplitude of the BF to be higher in the HT (p = 0.0064, 95% CI = 55.9, 395.7) and DL (p = 0.0431, 95% CI = 4.4668, 344.3) when compared to the BS (Figure 4). There appeared to be a relationship between the LG site on the 1RM and 85% of 1RM, whereby the sub maximal set elicited higher levels of sEMG amplitude. However when analysed using a paired t test, no significant difference was found (p= 0.9518, 95% CI = -37.56, 35.43).

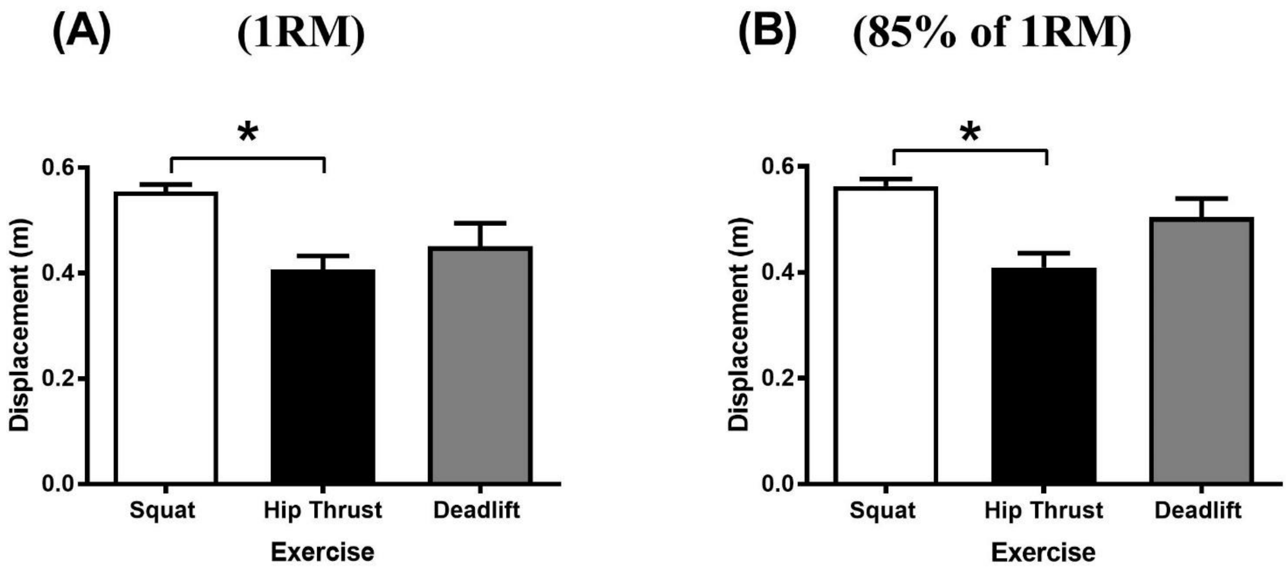

Figure 3: Total displacement data for each of the 3 lifts performed in both the participants' (A) 1RM and (B) 85% of 1RM lift. Values are mean ± SEM. * indicates a significant difference (P<0.05) between the 2 marked exercises.

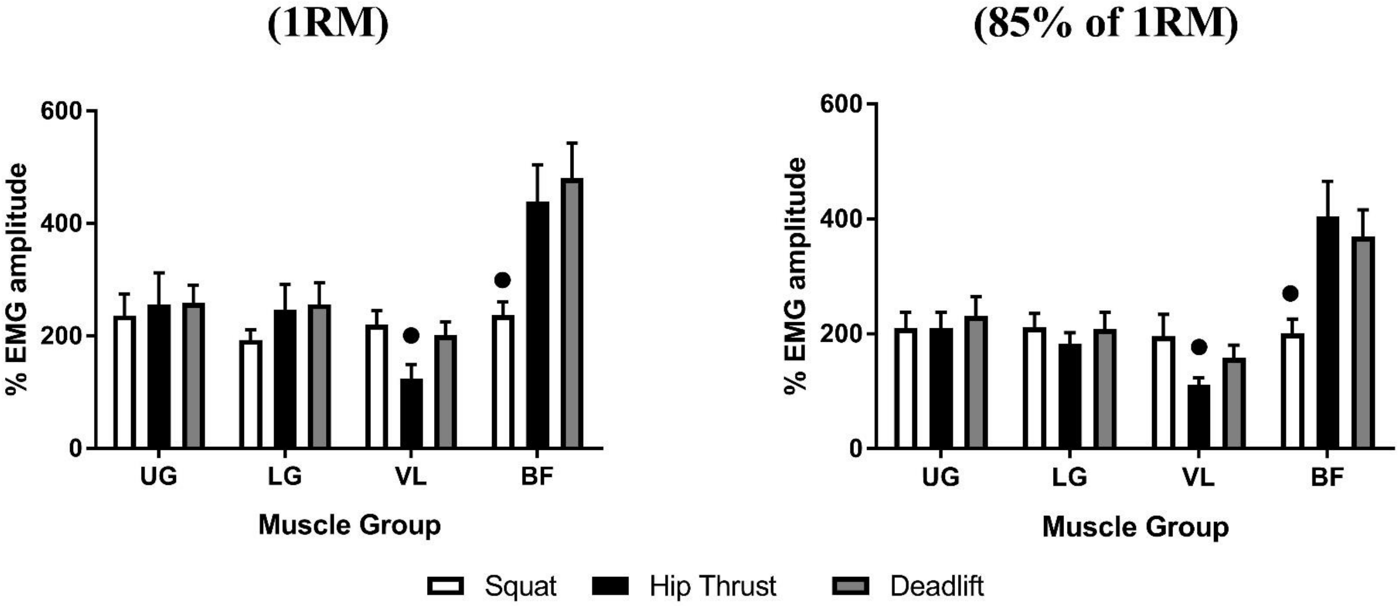

Figure 4: The peak sEMG amplitude of each muscle during the concentric phase of each lift in 1RM testing. Displacement data for each exercise is inset. The peak sEMG amplitude of each muscle during the concentric phase of the submaximal sets at 85% of 1RM. Displacement data for each lift is inset. Values are mean ± SEM. ● indicates a significant difference (P<0.05) compared to the other 2 lifts. UG = Upper Glutes, LG = Lower Glutes, VL = Vastus Lateralis, BF = Bicep Femoris.

3.3 sEMG analysis across tertiles by muscle

To gain a better understanding of the muscle activation required by the hip and knee extensors throughout the lifts, we analysed the profile of each muscle's sEMG amplitude in tertiles across the concentric phase of the 1RMs. This allowed for the inclusion of all participant data and a clear sEMG profile for each of the 3 exercises. Analysis of the BS found a significant decrease (p = 0.0292, 95% = CI 4.343, 88.32) in EMG amplitude in the UG between the 2nd and 3rd tertiles (Figure 5). Significant differences were also found in the LG between both the 1st and 2nd tertiles (p = 0.0254, 95% CI = -36.78, - 2.256) and 2nd and 3rd tertiles (p = 0.0240, 95% CI = 4.084, 61.84) (Figure 5). The 3rd tertile of the VL was found to be significantly lower in sEMG amplitude tertile when compared to the 1st (p = 0.0082, 95% CI = 8.758, 60.32) and 2nd (p=0.0214, 95% CI = 3.576, 47.55) tertiles. A significant increase in sEMG amplitude of the BF was also found when comparing the 1st and 2nd tertiles (p=0.0036, 95% CI = -91.85, -2.256) and decrease in activation between the 2nd and 3rd tertiles (p= 0.0454, 95% CI 0.9421, 99.57) (Figure 5).

For the HT, no significant differences were found across the 3 tertiles in any of the measured muscle sites. (Figure 5).

Analysis of the DL displayed a significant difference in sEMG amplitude in the UG in the 1st and 2nd tertile ($p = 0.0445$, 95% CI = 1.01, 101.9) and 1st and 3rd tertile ($p = 0.0004$, 95% CI = 33.47, 134.4) (Figure 5). The 2-way ANOVA displayed no significant differences in the LG. The sEMG amplitude of the VL was found to significantly increase from the 2nd to 3rd tertile during the concentric phase of the DL ($p = 0.0266$, 95 % CI = -82.28, -4.17) (Figure 5). Lastly, analysis of the BF displayed a significantly lower sEMG amplitude in the 3rd tertile when compared to the 1st (p = <0.0001, 95% CI = -68.05, 32.85) and 2nd (p = < 0.0001, 95% CI = 92.31, 193.2) tertiles during the concentric phase of the lift. No difference was found in analysis between the 1st and 2nd tertiles (Figure 5). Due to a trend across the tertiles in a visual decrease in sEMG amplitude in the LG, further analysis of the DL tertiles in this muscle group was examined through a one-way repeated measures ANOVA. A significant difference was found in this test for the LG between the 1st and 2nd tertiles (p= 0.0085, 95% CI 7.43, 54.24) (Figure 5)

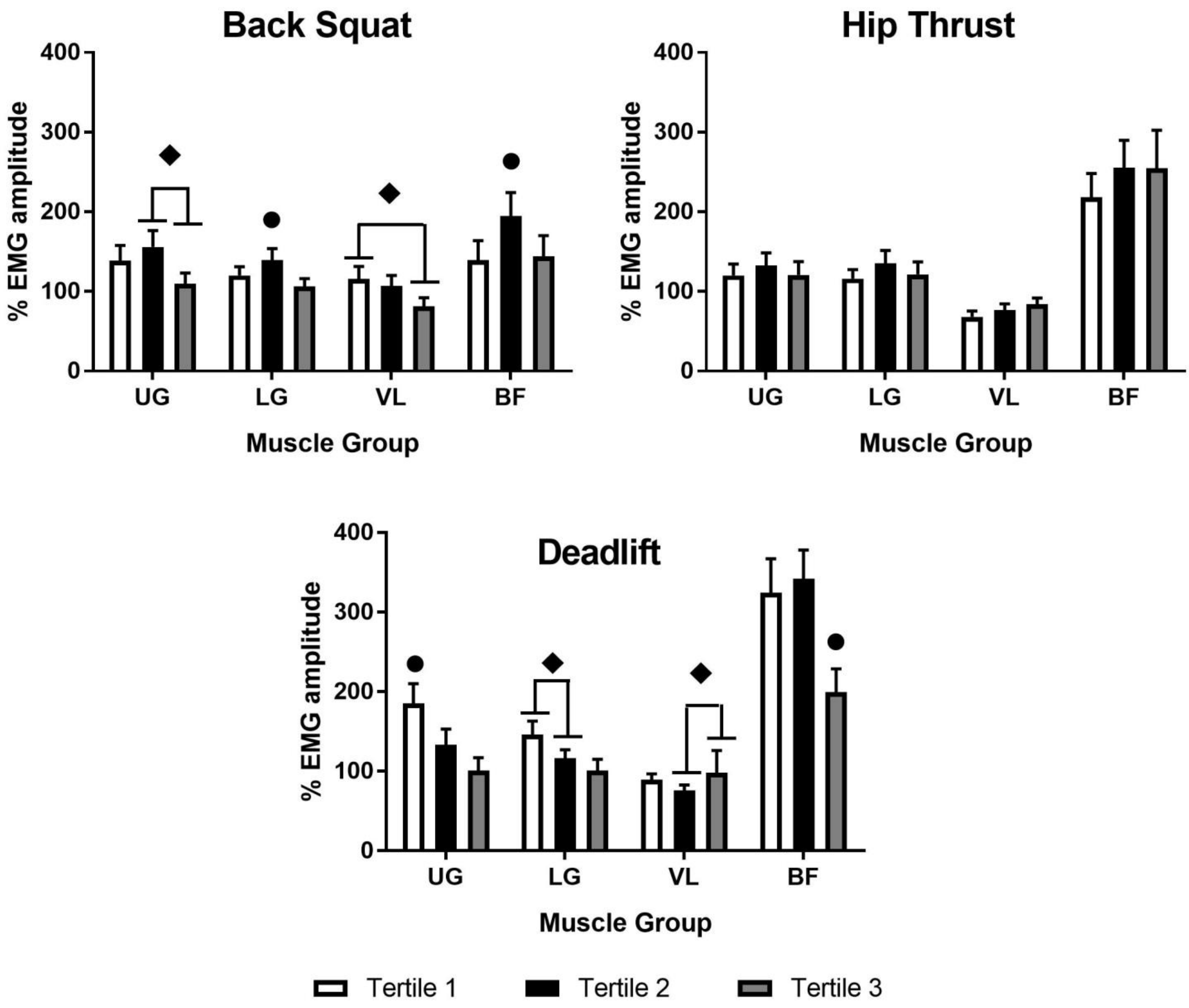

Figure 5: The mean sEMG amplitude of each muscle group in the back squat in each tertile of the concentic phase. The mean sEMG amplitude of each muscle group in the hip thrust in each tertile of the concentric phase. The mean sEMG amplitude of each muscle group in the dead lift in each tertile of the concentric phase. Values are mean ± SEM. ◆ indicates a significant difference (P<0.05) between marked tertiles. ● Indicates a significant difference from the other 2 tertiles. ■ Indicates a significant difference between all 3 tertiles. UG = Upper Glutes, LG = Lower Glutes, VL = Vastus Lateralis, BF = Bicep Femoris.

3.4. sEMG analysis across tertiles by exercise

Our GM sEMG data were at odds with previously published research. Therefore, we analysed the sEMG data by tertile across the concentric phase of each movement in the selected muscles. We hypothesised that the 3rd tertile of the HT would produce a greater mean sEMG amplitude than the 3rd tertile of the squat. As during the 3rd tertile both lifts approach full extension, the effort required by the glutes to maintain full extension is likely much higher with the HT than with the squat. We found no significant difference in GM sEMG amplitudes between the squat and HT in any of the 3 tertiles. However, we found that the DL produced the highest sEMG amplitude of all exercises in the 1st tertile when compared with the BS ($p = 0.0302$, 95% CI = -90.33, -4.191) and HT ($p = 0.0007$, 95% CI = -93.94, -26.14) (Figure 6A). No differences in sEMG amplitude were found between the squat and HT for all 3 tertiles in either of the GM sites (Figure 6B). A significantly lower level of EMG amplitude of the VL was found during the 1st tertile in the HT whenever compared to both the BS ($p = 0.0008$, 95% CI = 19.51, 71.29) and DL ($p = 0.0006$, 95% CI = -34.62, -9.734) respectively (Figure 6C). Both tertiles 2 and 3 showed no difference in sEMG amplitude between the 3 lifts. However, a significant increase was shown in DL VL sEMG amplitude whenever comparing tertiles (Figure 3C. The 3rd tertile displayed an increase in sEMG amplitude compared to the 2nd ($p = 0.0266$, 95% CI = -82.28, -4.17). Analysis of the BF found significantly greater levels in EMG amplitude in all 3 tertiles. Tertile 1 displayed significant differences between the BS and HT ($p = 0.0305$, 95% CI = -154, -5.837) the BS and DL ($p = <0.0001$, 95% CI = -231.9, -103.8) and the HT and DL ($p = 0.0064$, 95% CI = -172, -23.85) (Figure 6D). Whilst tertile 2 displayed significant differences between the BS and HT ($p = 0.0453$, 95% CI = -149.4,-1.278 and BS and DL ($p = < .0001$, 95% CI [-214.2, -66.05] (Figure 6D). The 3rd tertile displayed a significant difference between only the BS & HT ($p = 0.0054$, 95% CI = -173.8, -25.66) (Figure 6D). Further analysis of the DL found significant differences between the 1st and 3rd tertiles ($p = 0.0005$, 95% CI [49.71, 197.9]) and 2nd and 3rd tertiles ($p = 0.0002$, 95% CI = 57.87, 206) (Figure 6D) for the BF. This analysis also displayed a significant difference for the VL in the 2nd and 3rd tertiles of the DL ($p = 0.0266$, 95% CI = -82.28, -4.17). No significant difference in EMG amplitude was found between the HT and DL in the 2nd or 3rd tertiles for the BF.

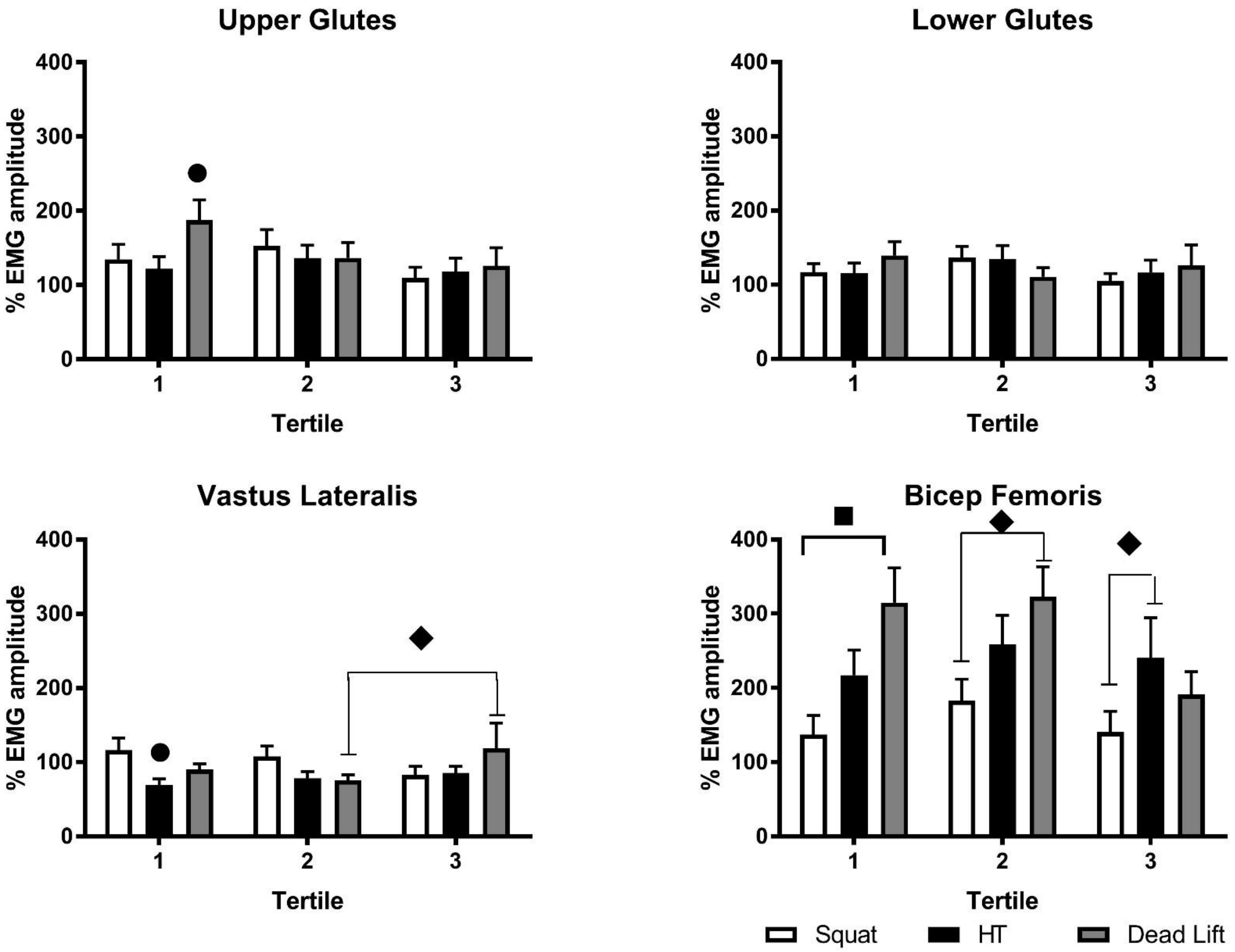

Figure 6: The mean sEMG amplitude of the Upper Glutes (UG) across the 3 tertiles of the concentric phase of each lift. The mean sEMG amplitude of the Lower Glutes (LG) across the 3 tertiles of the concentric phase of each lift. The mean sEMG amplitude of the Vastus Lateralis (VL) across the 3 tertiles of the concentric phase of each lift. The mean sEMG amplitude of the Bicep Femoris (BF) across the 3 tertiles of the concentric phase of each lift. Values are mean ± SEM. ● indicates a significant difference compared to the other 2 lifts (P<0.05). ◆ Indicates a significant difference (P<0.05) between marked tertiles. ■ Indicates a significant difference between all 3 lifts (P<0.05).

Chapter 4: Discussion

4.1. Summary of findings

In this study we compared the sEMG profiles of the key prime movers during the BS, HT and DL over several intensities matched across the individual lifts. The population used for this study were untrained. The average bodyweight to load ratio for each of the 3 lifts (Table 1) was significantly lower in our participants than what would be expected for a trained participant. For example, one study in rugby league players investigating the change in relative back squat strength to bodyweight in pre-season had mean baseline values of 1.78 and post values of 2.05 the player's bodyweight (Comfort et al., 2012). Contrary to previous findings (Contreras *et al.*, 2015) we did not detect a significant difference in the sEMG amplitudes of the GM between the BS and HT. Our data indicated that the BS is superior for increasing the sEMG amplitudes of the VL compared to the HT and DL, whilst the DL and HT are superior for increasing the sEMG amplitudes of the BF. Furthermore, this study is the first to have ever performed tertile analysis the concentric phase of these 3 exercises. Tertile analysis of the sEMG profiles during the 1RM, indicate that the DL is superior for GM sEMG amplitudes in the 1st tertile among the 3 lifts. Analysis also revealed that the sEMG amplitudes of the prime movers are relatively stable across the movement of the HT, whilst there is an undulating sEMG profile of the prime movers on the SQ and DL. For instance, BF and GM sEMG amplitudes are greater during the 2nd tertile of the squat, whilst for the DL they are higher in the 1st tertile. These data indicate that the 3 different lifts are not only biomechanically distinct, but are also different regarding their neuromuscular patterns. This finding itself is novel and has not been previously demonstrated within the current body of literature allowing for a greater understanding of how these prime movers co – ordinate with one another throughout the concentric phase.

4.2. 1RM & triples

Our findings contrast with previously published research, in which Contreras *et al*. (2015) found the HT to elicit greater levels of sEMG amplitudes when compared to the BS. They also contrast previous findings which found that the HT produced significantly greater sEMG amplitudes in the GM than the DL (Westcott *et al.*, 2009). However, our study did replicate these authors findings in that the HT is more effective than the SQ (Contreras *et al*, 2015) and as effective as the DL (Andersen *et al.*, 2017) in elevating the sEMG amplitudes of the BF.

These differences between studies may have arisen from differences in experimental design. This study's sEMG data were collected during a 1RM test where participants are lifting a maximal weight – mean of 92.4 (±19.6) kg for BS and 132.6 (±24.8) kg for HT, in addition to a set of 3 at 85% of their 1RM. During maximal efforts, untrained participants may tend to compensate whenever trying to lift a heavy load, which could be the cause for contrary findings to previously published research. However, our results in the 1RM mirror those of the set at 85% of 1RM, which would suggest the lack of difference in sEMG amplitude in the GM sites is not due to intensity. One example of previous research used a loading scheme of a 10RM – with a mean weight of 53.2 kg and 87.4 kg for the BS and HT respectively in their participant sample (Contreras *et al*., 2015). However, our participants had their 1RM tested on 2 occasions – the familiarisation and data collection session. As a result, our sEMG data captured during the 1RM and during the sub maximal sets are likely more representative of a true maximum effort. Performance of a 10RM focuses more on a participants' muscular endurance rather than maximal strength. If someone is not used to training in that way, their predicted 1RM would not be as accurate. Furthermore, Clark *et al.*, (2012) found in their review of the BS that the electrical activity of the GM shared a linear relationship with barbell load. Therefore, it is possible that although previous research in sEMG amplitudes of the GM displayed differences at a lighter load, this increased load through a maximal effort may mask any differences in sEMG amplitudes. As the number of motor units required and muscular recruitment is much higher for a maximal lift. In addition, the aforementioned study's sEMG analysis took place during 2 'iso – hold' movements in which an isometric contraction is performed. Whilst our sEMG data was collection through the concentric phase of each movement. For the HT 'iso-hold' a participant held the movement at the end of the concentric phase, in full hip extension. Whilst for the squat 'iso – hold', participants held the position at the end of the eccentric phase where a participant has achieved parallel depth, with the hips in a state of flexion. Therefore, it is not surprising that the HT proved to have significantly greater levels of EMG amplitude, as it is a comparison of 2 different positions of the hip musculature. This would be more of a fair comparison if the squat iso hold was performed in the same position with a fixed bar. Whereby the participant is trying to extend their hips forcefully to move the bar. Our findings also showed a difference in EMG amplitude of the VL between squat and HT, which further disagrees with previous findings (Contreras *et al*., 2015). This difference in VL sEMG amplitudes could possibly be due to the difference in populations between both studies. Contreras *et al*. (2015) used resistance trained adolescents, whereas the participants but non-resistance trained participants aged 18 – 40 years old. It is possible that the untrained participants being new to the exercises and maximal testing may have lacked the neuromuscular co–ordination a person develops through regular resistance training (McDonagh and Davies, 1984). The reduced GM sEMG amplitudes in the HT could be explained by the high levels of peak BF sEMG amplitude (Figure 5), a secondary muscle the HT has been previously shown to activate (Contreras *et al*.,2015). As previously stated, this could be due to our untrained participants struggling to recruit the GM due to a lack of neuromuscular efficiency (McDonagh and Davies, 1984).

A surprising finding was that the peak sEMG amplitude the BF produced was not significantly different in the HT from those which the DL produced. As the DL or the stiff leg variation is commonly chosen to train the posterior chain and BF (Ebben, 2009; Camara *et al.*, 2016). Our findings from the 1RM and triples peak EMG data displayed that there is no significant difference between the BS, HT and DL regarding activation of the UG and LG at maximal and 85% of 1RM loads (Figure 5) . The HT and DL have higher levels of sEMG activity in the BF compared to the BS, in which the BF is minimally recruited. The higher level of VL activation found in the DL when compared to the HT is not unusual when considering the biomechanical nature of the two exercises (Figure 5). When performing a HT, the knee is constantly in a state of flexion with a minimal angle of 90 degrees. Whilst performance of the DL requires extension of the legs to attain an upright position.

4.3. Tertiles – Profile of lifts and of muscles

Through analysis of the concentric phase by tertiles, we were able to plot an sEMG profile of the concentric phase in each lift and individual muscle. In the BS, the UG proved to elicit their highest sEMG amplitudes in the 2nd tertile, with a significant decrease in the 3rd (Figure 2A). This would suggest that the highest activation of the UG in the squat occurred during the mid- point of the concentric phase, whereby the knee angle is approaching 45 degrees (Figure 2). From previous findings of sEMG amplitude and squat depth by Caterisano *et al.*, (2002) it would be expected that the highest sEMG amplitude would be in the 1st tertile and decrease thereafter (Caterisano *et al.*, 2002). However, as our participants were resistance training naïve they may have been 'quad dominant' as evidenced by the relatively higher sEMG amplitudes of the VL in the 1st tertile. This could have occurred if during the 1RM a participant's weight shifted from the back of their heel to the balls of their feet. This shift in weight would cause the VL and other quadricep muscles to be recruited to a greater degree, whilst less activation would occur in the GM. This is not uncommon in people new to resistance training, as whenever the barbell load increases in the BS, many often find it difficult to keep their chest up and distribute the weight to the back of their foot. By letting the chest fall, the displacement of the barbell moves away from bodies centre of mass, causing the load to shift to the front of the foot in an attempt to balance and regain control.

Analysis of the HT tertiles demonstrated no differences in sEMG amplitude for all of the muscles measured. We hypothesised that UG and LG sEMG amplitudes would be highest in the 3rd tertiles, where full hip extension occurs. However, our data would suggest that the HT instead allows for constant activation of all muscle groups throughout the concentric phase. This could be due to the distinct biomechanical nature of the lift. As the load of the barbell is placed on the hips, the body must move the load in an anteroposterior force vector (back of the body to the front of the body). Therefore, the load could be constant throughout the entirety of the movement as our findings suggest. As well as this, the high BF activation recorded during the lift could again be due to this neuromuscular naivety in this studies participant sample. Through a lack of neuromuscular control, participants may have not been able to fully recruit their glutes and instead recruited their hamstrings when attempting to drive through their heels. This could easily occur if a lifter was instead applying force through the back of their foot and almost trying to pull towards their centre of mass, rather than directly down. However, due to the HT having never been performed in an untrained population, this gives insight into the possible issues someone new to resistance training may have with the lift. Also, this finding of similar electrical activity expands the knowledge within the current literatures for the HT, suggesting the lift could be unique due to this constant tension placed on the prime movers. Therefore for individuals who may struggle to perform the mechanics of the BS or DL or even for new lifters, the HT would allow for a similar level of constant tension throughout the movement to be placed on the hip extensors.

Previous sEMG data on the DL has focussed mainly on the stiff legged variation (Wright *et al*., 1999; Ebben, 2009; Bezerra *et al*., 2013). Our findings showed that the greatest sEMG amplitudes in the UG and LG occurred in the 1st tertile of the concentric phase. We detected significant reductions in sEMG amplitude of the UG/LG from the 1st to 2nd and 3rd, and from 1st to 3rd respectively. However, the BF followed a different activation pattern and did not peak until the 2nd tertile. With a significant decrease in sEMG amplitude by the 3rd tertile. This coincides with the activation of the VL peaking in the 3rd tertile, at the end of the hip extension movement where the participant's legs are almost in full extension. Our data would suggest that the glutes may play an important role in the initiation of the DL exercise. Further analysis of the tertiles 1RM data allowed for a comparison between each of the 3 lifts across the 4 different muscles. A surprising finding was that out of the 3 lifts, the DL displayed the greatest sEMG amplitude in the UG during the 1st tertile (Figure 3A). This may have been due to the coaching of the DL, where participants were encouraged to push their hips back under the bar (to fully engage the GM). This coaching method was used to prevent participant's from 'lifting with their back', a common mistake when performing the DL, placing unnecessary strain on the lower back. However, no differences were found in the LG site's EMG activity which suggests that the UG and LG may play different roles in hip extension during the DL. (Figure 6).

Contrary to previous research (Contreras *et al*., 2015), the VL displayed the lowest levels of sEMG amplitude in the HT when compared to the other 3 lifts. This lack of VL activation could be explained by the increased levels of BF electrical activity which occurred in this study. As an increase in BF activity would lead to a reduction in recruitment of the VL. An interesting finding in this study was noticed in analysis of the DL sEMG profile, where VL activation was significantly greater from the 2^{nd} to 3^{rd} tertile. Previous research has shown the BF to be one of the key muscles required in this lift (Wright *et al*., 1999 and Escamilla *et al*., 2002**).** Our data adds to the current literature by expanding our understanding of the muscular profiles of the DL. Suggesting the importance of the knee extensors in the final portion of the lift's concentric phase.

Tertile analysis of the BF EMG amplitude of the BF in the HT was significantly greatest across all 3 tertiles in comparison to the squat, but not the DL. The high activation levels of the BF may be due to the load the movement places on the hip extensors during the lift, as previously stated when discussing the HT findings. Our findings of the low levels of electrical activity of the BF during the BS compared to the HT and DL further the findings of previous research where the HT and DL have increased BF sEMG levels (Jensen and Ebben, 2000; Contreras *et al.*, 2015).

4.4. Limitations

This study's data were collected using sEMG which displays the electrical activity of measured muscle sites. Whilst this is a highly useful and globally recognised method, it is not without its limitations. It is not uncommon for electrodes to be obstructive when performing dynamic movement due to cable leads and the positioning of wireless receivers. This is particularly difficult when performing RT and having to take a barbell and platform into consideration. Participants can often feel restricted in their movement and may compensate and not move as naturally as they would if they were performing recreational training. Researchers are also often limited to only being able to measure a few muscle sites at a time, due to sEMG receivers usually only having a finite number of channels available. This can often mean disregarding a muscle which a researcher had previously planned to investigate, due to a lack of practicality. There is also the possibility of 'cross talk' occurring when measuring two different muscles which are near one another. This involves the activity from one muscle group being picked up in the recording site of another, leading to a false signal. In addition, it should be noted that differences in EMG amplitude may not always be due to an increase in muscular effort, but just from the fact that selected areas have greater levels of muscle mass. A muscle which is greater in mass will produce a higher amplitude due to the greater number of motor units being recruited. The normalisation method for all 3 lifts in this study was used controlled velocity squats at 70% of participant's 1RM, as described by Balshaw and Hunter. (2012). This can cause an exaggeration of the sEMG data in other lifts in which muscles are at higher levels of activation compared to the BS – the BF in the HT and DL. The use of sEMG can also prove problematic when wishing to compare multiple exercises to one another, as there are several factors which can affect the amplitude and quality of the signal (De Luca, 1997; Cram and Criswell, 2011). The technique allows us to visually see the electrical activity of a muscle during a given activity, which allows us to speculate the levels of muscle activity that is occurring. However, it is impossible when comparing lifts to be able to state that one causes the measured muscles to produce greater force and activation than another (De Luca.,1997). This is especially significant to our study as our data were collected in a population which had never previously performed any of the 3 exercises, or resistance training.

Our participant sample was also a physically fit but 'non – resistance trained' population who were either new to resistance training or had not performed it within the past 6 months. Were this study to be performed in a population who were highly trained in all 3 lifts and had the neuromuscular developments attained through long – term resistance training we may see different results. The use of a non - resistance trained population also corresponds to a limitation in the participant's strength levels. Were this study to have investigated individuals who are stronger and would be classed as 'well trained', this may have produced disparate results. It would be interesting to directly compare the profiles of muscle activation across the 3 lifts in trained vs untrained participants. Due to the neuromuscular and strength advancements a trained population would have over the untrained one (Cannon *et al.,* 2007). Our study also did not counterbalance the 3 lifts in each phase of testing we performed – mainly due to safety concerns. We designed the exercise order to minimise the risk of injury or fatigue, and therefore never placed the most technically difficult and straining lift, the DL, at the start of the session. As a result, we always tested the squat first. Our data are also limited to 1RM and a submaximal set at 85% of 1RM, which are loads that are typically used in strength training programmes. A regular gym goer and even athletes are unlikely to train at this intensity, unless the focus of the training block is on strength gains for the latter population. Therefore results of the sEMG profiles of the 3 lifts may differ at different load variations which fall below 85% of a person's 1RM, as previous research has displayed (Wright *et al.*, 1999; Chelly *et al.*, 2009; Clark *et al.*, 2012; Bezerra *et al.*, 2013; Contreras *et al.*, 2015; Kun-Han Lin *et al.*, 2017).

4.5. Future Research

To further develop the literature and gain a greater understanding of the muscle activation in these 3 lifts, it would be beneficial to investigate the sEMG profiles in a trained population. A long - term training study where participants have performed one of the 3 lifts over a training cycle would allow a better insight of the differences in muscle activation which occur in each of these lifts, as well as any possible carry over into one another. Previous research by Cannon *et al.* (2007) has demonstrated the effect a training cycle can have on EMG amplitude, with a 20% rise in their testing sample post training. This increase is due to both neural and physiological factors, as is discussed by Moritani and DeVries. (1979). Therefore, a training study would allow a greater insight as to the possible hypertrophy responses from these 3 lifts, and for them to be compared to one another in the targeted muscle groups. Another possible study could investigate the different contributions the UG and LG make to hip extension. As the findings of our study seem to suggest a difference in the activation levels of the UG and LG at certain parts of the concentric phase in these 3 exercises. The question also remains as to whether there is a difference in sEMG profiles at different loads in both the untrained and trained populations. A study which could compare the sEMG profile of a maximal / near maximal lift with a lower sub maximal lift would bridge this gap in the literature providing data which may be more relevant to the recreational lifter.

4.6. Conclusions

Contrary to our initial hypothesis and some of the existing literature (Contreras *et al*.,2015; Andersen *et al.,* 2017), our investigation found there to be no difference in glute activity between the squat and HT. Instead, the DL appeared to be superior for glute activation – at least in the first tertile of the movements. The HT and DL both elicit similar sEMG amplitudes in the BF, to a greater degree than the squat. The HT also elicits the lowest levels of VL activation out of the 3 lifts. These data would suggest that the deadlift would be the superior exercise of the 3 lifts measured in an untrained population. It was the only lift out of the 3 which utilised each of the selected muscles. The HT results in a loss of VL activity, a muscle which is important in extension of the knee. Whilst the BS is renowned for its low levels of BF activation. Both of these muscles are important in sporting actions such as the vertical jump and high speed running (Lees and Clercq, 2004; Schache *et al.*, 2011).

Our findings suggest that it may be beneficial for someone new to RT to perform the DL for optimal activation of the lower limb musculature. However, beginners who struggle with the technicality of the DL could perform the HT. This would also be appropriate for beginners due to the suggested constant tension on the prime movers throughout the concentric phase our data has displayed. It remains unclear how the sEMG profiles of these 3 exercises would appear in a trained population, with the focus being to develop an athlete's athletic performance. Therefore, the results of this study can only raise possible suggestions for an untrained population, whilst the sEMG profiles in trained athletes are currently unknown. Based on the current literature in RT athletes, if coaches were to only choose one of the lifts, this could prove to be a limitation to their athlete's development. Inclusion of the BS would aid in vertical jump ability and activation of the VL and GM. However, our findings and the current literature indicate that activation of the BF is low in this lift, which may cause muscular imbalance and injury if a hamstring focused exercise is not also programmed (Askling *et al*., 2005; Croisier *et al.,* 2008). By including some form of eccentric or concentric overload - performing either the HT, or a variation of the DL in their programme, athletes would adequately balance the strengthening of their lower limb musculature.

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Appendices

Appendix 1: RPE scale as used in ; Zourdos, M., Klemp, A., Dolan, C., Quiles, J., Schau, K., Jo, E., Helms, E., Esgro, B., Duncan, S., Garcia Merino, S. and Blanco, R. (2016). Novel Resistance Training–Specific Rating of Perceived Exertion Scale Measuring Repetitions in Reserve. *Journal of Strength and Conditioning Research*, 30(1), pp.267-275.

RESISTANCE EXERCISE-SPECIFIC RATING OF PERCEIVED EXERTION (RPE)

Rating	*Description of Perceived Exertion*
10	*Maximum effort*
9.5	*No further repetitions but could increase load*
9	*1 repetition remaining*
8.5	*1-2 repetitions remaining*
8	*2 repetitions remaining*
7.5	*2-3 repetitions remaining*
7	*3 repetitions remaining*
5-6	*4-6 repetitions remaining*
3-4	*Light effort*
1-2	*Little to no effort*

Appendix 2: Informed consent form

CONSENT BY VOLUNTEER TO PARTICIPATE IN:

Which is best for improving strength/sprint/jump/agility performance; Squats, hip thrusts or dead lifts?

Name of Volunteer:

...

Name of Study: **Assessing skeletal muscle adaptive responses and performance improvements with 3 different lower limb strength exercises.**

Principal Investigator: Andrew Ryan

I have read the patient/volunteer information sheet on the above study and have had the opportunity to discuss the details with Andrew Ryan and ask questions. The principal investigator has explained to me the nature and purpose of the tests to be undertaken. I understand fully what is proposed to be done.

I have agreed to take part in the study as it has been outlined to me, but I understand that I am completely free to withdraw from the study or any part of the study at any time I wish. I understand and agree that my participation in the study is entirely at my own risk.

I understand that these trials are part of a research project designed to promote medical or scientific knowledge, which has been approved by the Sports Studies Ethics Committee, and may be of no benefit to me personally. The Sports Studies Ethics Committee may wish to inspect the data collected at any time as part of its monitoring activities.

I also understand that my General Practitioner may be informed that I have taken part in this study if any unusual or surprising observations are made.

I hereby fully and freely consent to participate in the study which has been fully explained to me.

Signature
of Volunteer: ....

Date: ....

I confirm that I have explained to the patient/volunteer named above, the nature and purpose of the tests to be undertaken.

Signature of Investigator:

...

Date : ....

Appendix 3: Food diary

DAY OF THE WEEK………..	
1 TIME	2 DESCRIPTION OF FOOD OR DRINK CONSUMED

DATE:………………………………………………………………				
3 WEIGHT	4 WEIGHT LEFT OVER		5 PLEASE LEAVE THESE COLUMNS BLANK	

Appendix 4: PPHS-Q form

Health & Exercise Sciences Research Group

UNIVERSITY OF STIRLING | Scotland's University for Sporting Excellence

Date	Physiologist	Signature

Pre-Participation Health Screen Questionnaire (PPHS-Q)

PPHS-Q is an exercise – specific checklist for classification of training categories.
Accuracy in completion of the PPHS-Q is of the utmost importance

The purpose of the Fitness Centre (FC) pre-participation health screen is:

- To optimise safety during exercise testing and programme description.
- To identify medical risk factors which may contra-indicate exercise.
- To identify those with special needs.

Name:____________________ Age:________ FC no________

Address____________________________ Gender:________

____________________ Tel:________(H) ________(W)

Doctor's name:____________________ Tel:________(H)________(W)

Section A: Medical History Summary and Recommendations	
Date:	
Date:	
Date:	

Section B: Coronary Heart Disease Risk Index		**Date**	**Date**	**Date**
Group				
1. 1-10	No supervision required – exercise at will			
2. 10-17	No supervision required – use general exercise guidelines			
3. 18-27	No supervision required – use prescribed programme only			
4. 28-40	Use prescribed programme – Personal Training recommended			
5. 41+	Use prescribed programme – Personal Training and re-test within 8 weeks recommended			

Section C: Physical Activity Index					
		Date:			
Activity Level	**Times per week**	**Risk level**			
Inactive	0 occasional	Very High			
Semi-active	1	High			
Active	2-3	Moderate			
Very active	4 or more	Low			

SECTION A **MEDICAL HISTORY**

Have you ever been told that you have had or have any of the following conditions? If yes, please mark with an X in the appropriate box:

CARDIAC (Heart Related Diseases)

- o Heart Attack
- o Coronary thrombosis (blood clot)
- o Narrowing of arteries
- o High cholesterol
- o High blood pressure
- o Rheumatic fever
- o Angina / Chest Pain
- o Congenital Heart Disease
- o Further / comments

PULMONARY (Lung Diseases)

- o Asthma
- o Chronic Bronchitis
- o T.B.
- o
- o Exercise-induced asthma
- o Emphysema
- o Other / comments

OTHER

- o Type I Diabetes (insulin dependent)
- o Anaemia (ion deficiency)
- o Kidney disease
- o Rheumatoid Arthritis
- o Type II Diabetes (non-insulin dependent)
- o Rheumatic fever
- o Angina / Chest Pain
- o Congenital Heart Disease
- o Pregnant
- o Other / comments

ORTHOPAEDIC SURGERY (Musculo Skeletal)

Surgery

- o Neck
- o Back
- o Shoulder
- o Arm
- o Hip
- o Knee
- o Ankle
- o Foot
- o Other / comments

INJURY

Have you suffered any of the following injuries? If so, how long ago?

- o Neck vertebrae
- o Rotator cuff
- o Tennis elbow
- o ITB
- o Achilles Tendonitis
- o Back vertebrae
- o Impingement Syndrome (shoulder)
- o Runner's knee
- o Lower leg
- o Plantar Fascitis
- o Other / comments

MEDICATION

Do you use medication at present for any of the following? (If yes, please state the drug)

- o Heart rhythm
- o Blood clotting.
- o Asthma
- o Emphysema
- o Diabetes
- o Cholesterol
- o Kidney
- o Arthritis
- o Blood pressure
- o Blood circulation
- o Bronchitis
- o Flu
- o Thyoid dysfunction
- o Anaemia
- o Liver
- o Muscle injury
- o Other / comments

SECTION B **CARDIOVASCULAR DISEASE RISK INDEX**

Please read the following questions carefully and answer each accurately. Mark your choice with an X.

History of heart attack or bypass surgery / angioplasty					
0	o	None	5	o	1 – 2 years ago
2	o	Over 5 years ago	8	o	< 1 year ago
4	o	3 – 5 years ago			

Family history of heart disease		
1	o	No known history
2	o	1 relative with cardiovascular disease over the age of 60
3	o	2 relatives with cardiovascular disease over the age of 60
4	o	1 relative with cardiovascular disease under the age of 60
6	o	2 relatives with cardiovascular under the age of 60
8	o	Heart – related sudden death:
	o	Male, first degree relative before the age of 55
	o	Female, first degree relative before the age of 65

Age / Gender Index			**Smoking status**		
0	o	Male / female under 30 years of age	0	o	None
1	o	30 – 40 years of age	1	o	Pipe
2	o	Female 40 - 50 years of age	2	o	1 – 10 cigarettes daily
3	o	Male 40 – 50 years of age	3	o	11 – 20 cigarettes daily
3	o	Female 50 – 60 years of age	4	o	21 – 30 cigarettes daily
4	o	Male 50 – 60 years of age	5	o	31 – 40 cigarettes daily
4	o	Male / female 60+ years of age	6	o	41 – 60 cigarettes daily
			8	o	+ 60 cigarettes daily
			State how long you have smoked for:		
			Years		months

How would you describe your bodyweight?			**Total Cholesterol**		
0	o	Ideal weight	0	o	< 5 mmol / L
2	o	0 – 5kg overweight	1	o	5.0 – 5.2 mmol / L
4	o	6 – 10kg overweight	3	o	5.3 – 5.9 mmol / L
6	o	11 – 15kg overweight	5	o	6.0 – 6.2 mmol / L
8	o	+ 15kg overweight	6	o	6.3 – 6.9 mmol / L
10	o	Underweight	7	o	7.0 – 7.5 mmol / L
			8	o	> 7.5 mmol / L
				o	Not sure

Systolic Blood Pressure			**Diastolic Blood Pressure**		
0	o	< 130 mmHg	0	o	< 80 mmHg
1	o	130 – 140 mmHg	1	o	81-90 mmHg
2	o	141 – 150 mmHg	2	o	91 – 100 mmHg
3	o	151- 160 mmHg	3	o	101 – 110 mmHg
4	o	> 160 mmHg	4	o	> 110 mmHg
	o	Not sure		o	Not sure

Diabetes			**Occupational activity level**		
0	o	None	1	o	Intense physical labour
1	o	Type 11 (non-insulin dependent)	2	o	Moderate (walk often etc.)
2	o	Type 1 (insulin dependent)	3	o	Sedentary

Work Stress Tension		
0	o	No stress, very relaxed
1	o	Moderate work stress and relaxed personality
2	o	High work stress but cope well
3	o	Very high work stress and tense personality
4	o	Very high work stress, highly strung personality

Physical Activity Status (for a minimum of 30 minutes a session)		
1	o	Exercise 4 or more times per week
2	o	Exercise 2 – 3 times per week
3	o	Recreational sport once a week
4	o	Recreational sport occasionally or complete lack of exercise

SECTION C **EXERCISE PARTICIPATION**

Do you participate in any of the activities more than twice weekly?
(Please tick all relevant activities)

- o Jogging more than 5 km
- o Cycling more than 45 min.
- o Swimming more than 600 m
- o Gym (Combined strength / aerobic)
- o Gym (weights only)
- o Gym (aerobic only)
- o Aerobic classes 45 min
- o Tennis 90 min
- o Squash 45 min.
- o Team sport (outdoor) – rugby hockey, soccer
- o Team sport (indoor) – basketball, netball, etc
- o Canoeing / Rowing 45 min

SECTION D

I have read, understood and completed this questionnaire to the best of my knowledge.
I am aware of the risk involved in fitness testing and understand the test procedures that I will perform. I give consent to participate in this assessment.

TEST 1

Date:________________________

SIGNATURE:________________________ WITNESS:________________________
(for a minor)

SIGNATURE OF PARENT:________________________

TEST 2

Date:________________________

SIGNATURE:________________________

WITNESS:________________________

SIGNATURE OF PARENT:________________________ (for a minor)

TEST 3

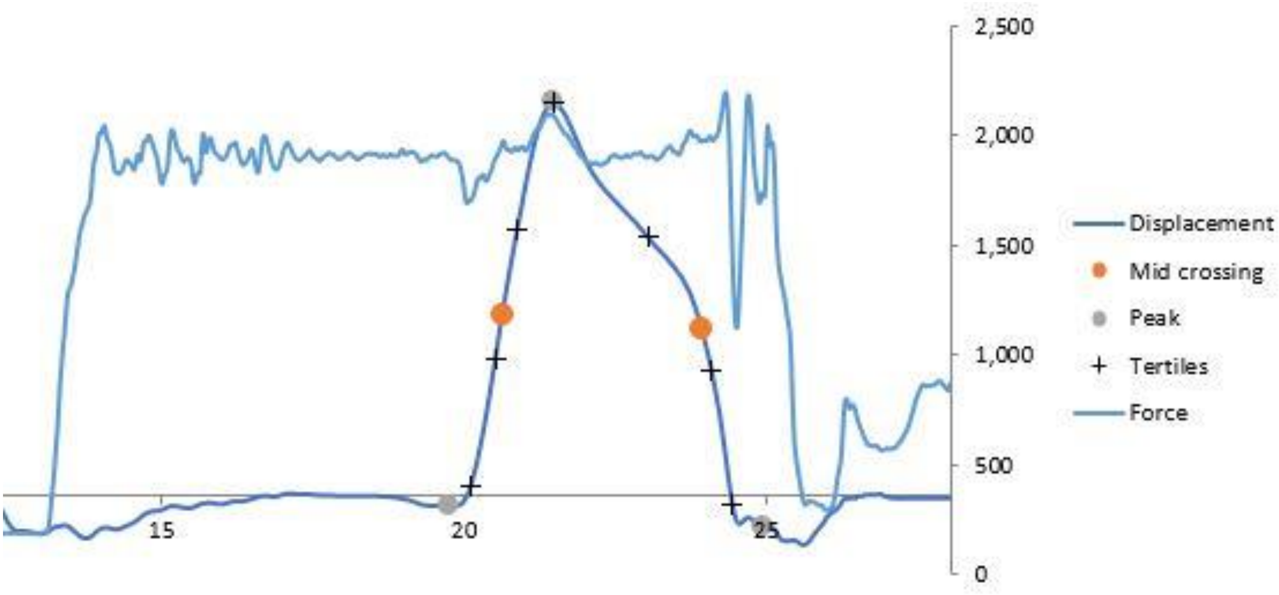
Date:________________________

SIGNATURE:________________________

WITNESS:________________________

SIGNATURE OF PARENT:________________________ (for a minor)

Appendix 5: Tertiles Excel Output



Using the transducer trace (Displacement line) the onset and end of movement (1st and final grey dots) were manually inputted into the file. The mid-point of the lift was automatically calculated as the highest peak in the transducer trace (2nd grey dot). This allowed for the calculation of the tertiles data, which automatically outputted into a data table with readings for the measured muscles.

Appendix 6: Electrode Placement Guidelines and Examples.

Muscle	
Name	Biceps femoris
Subdivision	Long head and short head
Muscle Anatomy	
Origin	Long head: distal part of sacrotuberous ligament and posterior part of tuberosity Short head: lateral lip of linea aspera, proximal 2/3 of supracondylar line and lateral intermuscular septum.
Insertion	Lateral side of head of fibula, lateral condyle of tibia, deep fascial on lateral side of leg.
Function	Flexion and lateral rotation of the knee joint. The long head also extends and assists in lateral rotation of the hip joint.
Recommended sensor placement procedure	
Starting posture	Lying on the belly with the face down with the thigh down on the table and the knees flexed (to less than 90 degrees) with the thigh in slight lateral rotation and the leg in slight lateral rotation with respect to the thigh.
Electrode size	Maximum size in the direction of the muscle fibres: 10 mm.
Electrode distance	20 mm.
Electrode placement	
- location	The electrodes need to be placed at 50% on the line between the ischial tuberosity and the lateral epicondyle of the tibia.
- orientation	In the direction of the line between the ischial tuberosity and the lateral epicondyle of the tibia.
- fixation on the skin	(Double sided) tape / rings or elastic band.
- reference electrode	On / around the ankle or the proc. spin. of C7.
Clinical test	Press against the leg proximal to the ankle in the direction of knee extension.
Remarks	

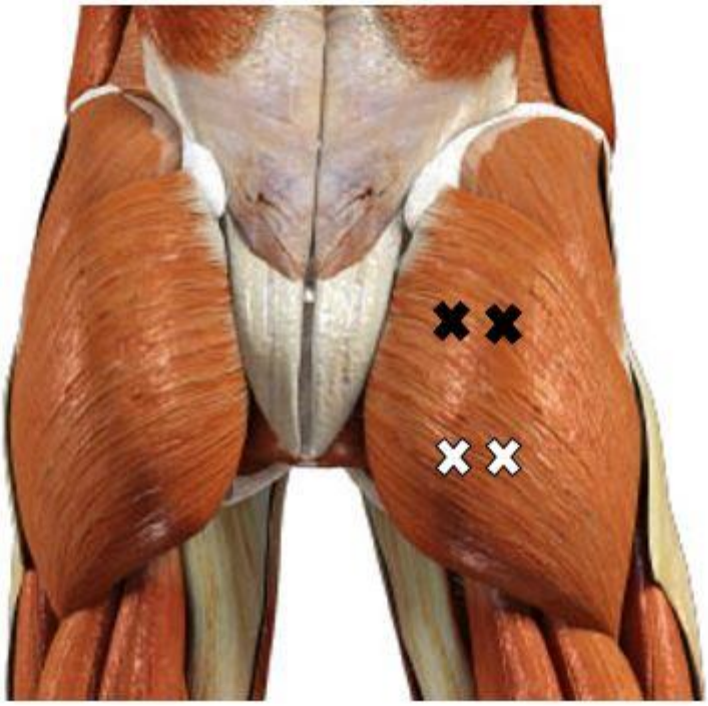
Click on image for larger view

Bicep Femoris, available at: http://seniam.org/bicepsfemoris.html

Vastus Laterlis, available at: http://seniam.org/quadricepsfemorisvastuslateralis.html

Muscle	
Name	Quadriceps Femoris
Subdivision	vastus lateralis
Muscle Anatomy	
Origin	Proximal parts of intertrochanteric line, anterior and inferior borders of greater trochanter, lateral lip of gluteal tuberosity, proximal half of lateral lip of linea aspera, and lateral intermuscular septum.
Insertion	Proximal border of the patella and through patellar ligament.
Function	Extension of the knee joint.
Recommended sensor placement procedure	
Starting posture	Sitting on a table with the knees in slight flexion and the upper body slightly bend backward.
Electrode size	Maximum size in the direction of the muscle fibres: 10 mm.
Electrode distance	20 mm.
Electrode placement	
- location	Electrodes need to be placed at 2/3 on the line from the anterior spina iliaca superior to the lateral side of the patella.
- orientation	In the direction of the muscle fibres
- fixation on the skin	(Double sided) tape / rings or elastic band.
- reference electrode	On / around the ankle or the proc. spin. of C7.
Clinical test	Extend the knee without rotating the thigh while applying pressure against the leg above the ankle in the direction of flexion.
Remarks	The SENIAM guidelines include also a separate sensor placement procedure for the vastus medialis and the rectus femoris muscle.

Click on image for larger view



Gluteus Maximus: An example of the approximate positioning of the two GM electrode sites. Whereby the black crosses mark the placement of the UG electrodes, and the white crosses mark the placement of the LG electrodes.