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Comparison in muscle activity between the back squat, Romanian deadlift and barbell hip thrust during hip extension

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Comparison in muscle activity between the back squat, Romanian deadlift and barbell hip thrust during hip extension

This thesis is presented in fulfilment of the requirements
for the degree of
Master of Science (Sports Science)

Jose Delgado

School of Medical and Health Science
EDITH COWAN UNIVERSITY
2017

USE OF THESIS

CERTIFICATE OF AUTHORSHIP

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To my family, papa, mama y los chinos. You are the bedrock on which my dreams stand; none of my accomplishments are possible without you by my side.

ABSTRACT

Common resistance-training exercises such as back squat, Romanian deadlift (RDL), and hip thrust have been used by strength and conditioning specialists to target the musculature used during hip extension. Little is known about the differences in muscular activity of the hip extensors between these exercises, so it is not known which is the most effective as a hip extensor exercise. The primary purpose of this study was to compare muscle activity of several muscles during the high-bar back squat, RDL and barbell hip thrust, using men with a minimum of 1 year of lower-body resistance-training experience. Surface electromyography (EMG) was used to record muscle activity from the vastus lateralis (VL), vastus medialis (VMO), biceps femoris (BF), semitendinosus (ST) and gluteus maximus (GM) during a submaximal repetition of each exercise at 60 kg and a 1-repetition maximum (1RM). EMG during the exercises was compared to the EMG of each muscle during a maximum voluntary contraction (MVIC), performed on an isokinetic dynamometer. The results showed that hip thrust displayed higher GM activity than the back squat (mean Δ ± 95% confidence interval; 62.7 ± 58.0 mV, effect size = 1.39. *P* = 0.038), but no significant differences were seen when comparing the hip thrust and RDL (-37.0 ± 75.7 mV; -0.49. *P* = 0.285). While the hip thrust displayed higher GM activity when compared to the back squat, no significant differences in EMG activity between a 1RM to an MVIC were seen for the GM (-33.4 ± 58.0 mV; -0.35. *P* = 0.215), BF (16.1 ± 137.9 mV; 0.16. *P* = 0.791) and ST (-49.3 ± 71.1 mV; -0.51. *P* = 0.145), demonstrating high activation of hip extensors. Highest knee extensor activity at 1RM was seen in back squat. VL activity was largely different between RDL and back squat (-247.5 ± 126.8 mV; -1.36. *P* = 0.002) and hip thrust and back squat (183.6 ± 120.1 mV; 2.27. *P* = 0.009), with higher VL activity during the back squat than others. Further, VMO displayed large differences in EMG activity when comparing RDL (268.6 ± 224.8 mV; 3.31. *P* = 0.026) and barbell hip thrust (151.2 ± 128.8 mV; 0.90. *P* = 0.027) to back squat, with back squat displaying higher VMO activity at 1RM. These findings highlight the benefits of the back squat when training for athletic movements involving hip and knee extension, as the squat showed the highest knee extensor activation and high hip extensor activity relative to an MVIC. Therefore, while hip thrust may be a valuable movement for those wishing to isolate the hip extensors for rehabilitation or bodybuilding purposes, the back squat still likely has greater application as a functional movement pattern that translates better to the sport setting.

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ETHICS

The following study involved human subjects and received approval from the Ethics committee:

“Differences in muscle activity during hip extension in three resistance - training exercises”

Ethics approval number 15469 by the Human Ethics Committee of Edith Cowan University on 22 June 2016.

CHAPTER 1

INTRODUCTION

Background

Strength and conditioning professionals often use resistance-training exercises such as the back squat, the Romanian deadlift (RDL), and the barbell hip thrust [1-3] to increase force production during hip extension. Previous research [4-6] suggests improvements in sport performance after resistance training are most marked for tasks with movement patterns similar to the resistance training exercises themselves (i.e. specificity). As a result, increases in lower body strength transfer positively to movements such as running and jumping [7]. It has also been shown that heavy resistance exercise induces high levels of neuromuscular activation, which over a prolonged training period yields muscle hypertrophy, gains in muscle strength and enhanced neural drive to the muscle fibers [8-11]. EMG has been previously used to quantify the relative level of muscle activity during a specific movement in various studies[12-19]. Previous research [14, 17, 19-24] has measured muscle activity of various muscle groups during different exercises, but an empirical comparison between three commonly used exercises to train hip extension is yet to be conducted. Determining which exercise produces the highest level of muscle activation will provide coaches with sound reasoning behind the selection of exercises targeting hip extension musculature.

The back squat has been a prolific exercise for the development of athletic performance in many sports [25-28] for many decades [29-31]. Consequently, muscle activity during the squat and its transference to athletic performance has been extensively studied. The squat involves moving both the hip and knee from full flexion to full extension and therefore elicits great activation of the hip and knee musculature. However, there are several factors influencing muscle activation (as measured by EMG) of the squat, which include depth, load and stance width. Caterisano et al. [17] suggested that as squat depth increases, the GM, rather than the biceps femoris (BF), the vastus medialis oblique (VMO), or the vastus lateralis (VL), exhibited higher EMG activity throughout the concentric range. However Clark et al. [23] suggest that the selected test load during Caterisano’s study [17] may have influenced the results, since the relative load varied between squat trials due to the differing squat depths performed. Further results investigating muscle activation of the squat suggest a wide stance has demonstrated a greater activation of the GM [24], while Signorile et al. [15] investigated foot positioning in the squat and found no significant differences in quadriceps activation. Wretenberg et al. [32] compared quadriceps and hamstring EMG between national weightlifters and powerlifters and found a higher mean peak muscular activity in powerlifters; possibly due to the fact that the powerlifters lifted heavier relative loads than the weightlifters. Further, differences in bar placement/technique between powerlifters and weightlifters (i.e., high-bar vs. low-bar) may have an effect on hip activation due to an increased forward lean in the low-bar squatting technique. Previous studies suggest increasing external resistance is a more effective method of increasing EMG activity than increasing the number of repetitions performed with lighter weights when the set is performed to volitional failure [14]. Therefore, any investigation comparing hip extension exercises needs to carefully equate for stance width and relative loads across the different actions.

The RDL is another commonly used exercise, utilized by strength and conditioning coaches with the aim of improving sprint performance and strengthening the gluteal and hamstring muscle groups as well as the spinal erectors [29, 33]. The RDL has also been used in the prevention of hamstring injuries [34] and it is considered a crucial movement in the development of the Olympic-style lifts[3]. It is believed that exercises that strongly activate the hip extensors would be more specific to maximum-speed sprinting, as opposed to exercises that target the quadriceps, which would be specific to the acceleration phase of a sprint [35]. While muscle activation of the hamstring muscle group has been previously measured during the RDL [36], GM is yet to be investigated during the RDL and compared to other exercises. Additionally, while hip extension torque accelerates the body upward and forward from a position of hip flexion, such as when pushing off into a sprint, arising from a deep squat, or climbing a very steep hill [37], the knee extensors are also involved in these athletic movements. Therefore, studies investigating hip extension activity in movements used to improve athletic performance need to consider knee extensor activity during these exercises.

It has been recently suggested that the barbell hip thrust may be superior to the back squat in eliciting higher gluteal muscle activity, developing terminal hip extension strength in the gluteus maximus musculature, increased horizontal force production, and increases in the contribution of the gluteus maximus relative to the hamstrings during hip extension movement [2]. Research by Contreras et al. [19] recently demonstrated that mean and peak surface EMG of the GM and BF was superior during the barbell hip thrust when compared to the back squat, although no significant difference was found between exercises in peak or mean VL EMG. With these findings, Contreras et al. [19] suggest a need for the barbell hip thrust to be included in exercise programs to develop the hip extension musculature. Before such a recommendation should be followed, however, the work of Contreras should be critically examined.

There are several limitations to the results found by Contreras et al. [19]. Firstly, concerning the placement of the EMG electrodes Contreras et al. [19] uses two different sites for measuring GM activation, termed the upper and lower GM, based upon previously described procedures [38, 39]. However signals recorded at different locations over the muscle may differ substantially due to muscle fiber distribution and the generation of the action potentials at the endplates [40], standard electrode positioning is necessary in EMG recordings, according to the SENIAM guidelines [41]. A further limitation of the study by Contreras et al. [19] are the procedures used to collect of the maximal voluntary isometric contractions (MVICs). In healthy individuals, normalizing EMGs by using the EMG recorded from a MVIC as the reference value may allow the researcher to assess what percentage of the maximal activation capacity of the muscle the task EMG represents [42]. Contreras et al. [19] uses two different positions to normalize gluteus maximus EMG signals. The first method is the one described by Boren et al., [12] in which MVIC was recorded during the prone bent-leg hip extension securing a strap around the distal femur during trials to ensure standardization of resistance. The second method involved a muscle contraction, described as a “standing glute squeeze”[19, p. 07]. As it has been previously stated that to produce a maximum activation of a muscle a very good fixation of all involved segments is crucial [43], the validity of the methods used by Contreras et al. [19] is questioned.

While Contreras’ work indicates the superiority of the hip thrust to elicit activation of the GM over the squat, there are several methodological issues with his study. As previously mentioned, EMG activity has been shown to increase as external load increases [14, 44], which is important to consider when empirically comparing these exercises; as due to the smaller range of motion during the barbell hip thrust, a higher load is often used compared to the back squat or RDL. The squat and RDL are widely used exercises to improve sporting performance due to their documented ability to highly activate the knee and hip extensors [25-27, 36, 45], however the question remains if the hip thrust has the benefits reported by its proponents [46-48]. The central aim of this study is to investigate the potential differences in muscle activity during the barbell hip thrust, high-bar back squat and RDL in resistance-trained individuals.

Significance of this study

The data collected in this project will provide necessary information about three commonly used exercises and how they target the different muscle groups when compared to one another. This in turn will provide coaches with sound reasoning behind the selection of exercises targeting hip as well as knee extension musculature for the athletes they are coaching. Coaches may be able to prescribe more efficient weight lifting programs for athletes and in turn save them training time by using an exercise that has a higher transference to sport.

Further, the ability to evaluate which exercise elicits higher neuromuscular activation of the different muscle groups during each exercise may offer insight into the recruitment patterns used to perform hip and knee extension with the resistance placed along different planes of movement (i.e. sagittal versus frontal).

Purpose of this study

The rationale for this project is based on the idea that certain barbell exercises target the different lower body muscles to different extents. Therefore, the primary purpose of this research is to investigate the potential differences in muscle activity during the barbell hip thrust, high-bar back squat and Romanian deadlifts in resistance-trained individuals. To meet this aim, 12 resistance-trained males will be asked to perform randomized trials of squats, RDL's and barbell hip thrusts using a submaximal, standardized load of 60 kg, and 100% of their maximum load lifted (1RM) for each exercise. The reason for the use of 60 kg across all exercises is to have an absolute submaximal load across all three movements, which may provide an indication of different activation patterns across the same load. Further, while these three exercises all target hip extension musculature, these are three distinct movements and its performance may be affected by different anthropometric variables such as femur length and stance width. Therefore, stance width and femur length will be measured in centimeters (cm) and compared between participants as well as different performance measures. Also, as increases in load may have an effect on muscle activity, a comparison of the maximal loads to be lifted between exercises will be determined. Surface Electromyography (EMG) will also be used to assess muscle activation from the subjects' hip and knee extension musculature to evaluate maximal activation. EMG data will be expressed as the root mean square (RMS) value collected during the concentric phase of each exercises and compared to the RMS value of an initial maximum voluntary isometric contraction (MVIC) to assess for differences in muscle activation. This project has one specific aim: to determine the potential differences in muscle activity during the barbell hip thrust, high-bar back squat and Romanian deadlifts in resistance-trained males.

Research questions

1) Does the barbell hip thrust elicit higher hip extensor (i.e. GM, BF and ST) activation when compared to the back squat and Romanian deadlift?
2) Does the back squat elicit higher knee extensor (i.e. VL and VMO) activation when compared to barbell hip thrust and Romanian deadlift?
3) Does the barbell hip thrust allow participants to lift heavier loads when compared to the barbell back squat and the Romanian deadlift?
4) Do anthropometric variables such as femur length give an advantage to weight lifting performance?

Hypotheses

1) The barbell hip thrust will elicit comparable (i.e. GM, BF and ST) activation when compared to the Romanian deadlift and back squat.
2) The back squat will elicit higher knee extensor (i.e. VL and VMO) activation when compared to barbell hip thrust and Romanian deadlift.
3) Participants will be able to lift significantly heavier loads during the barbell hip thrust when compared to the back squat and the Romanian deadlift.
4) Participants that have shorter femurs will be able to lift relative heavier loads than the participants with longer femurs.

CHAPTER 2

REVIEW OF THE LITERATURE

Resistance training is a modality of exercise that is commonly used as a form of athletic training as it has been shown to play a role in increasing muscular strength, power, speed, hypertrophy, local muscular endurance, motor performance, balance, and coordination [49-52]. Strength and conditioning professionals use resistance training exercises to improve movements that relate to sporting performance involving hip and knee extension, as there is a high degree of specificity when training these particular movements to improve overall performance [4-7, 53]. When designing a resistance-training program, it is important for strength and conditioning coaches to consider the principle of specificity when designing training sessions as adaptation involving human movement encompasses specific movement patterns and force-velocity characteristics [53]. In order to effectively prescribe exercises that will aid in the development of sport performance, coaches should be aware of differences between the exercises that are most commonly used to improve hip and knee extension. A way of determining which resistance training exercise elicits the desired response on the muscle targeted is through the measurement of muscle activation during the exercise with surface electromyography (EMG)[18]. In training, the adaptation elicited is dependent on how the stimulus is applied, the intensity and volume of training, energy systems involved, muscle groups trained, range of motion, speed of movement and the muscle actions involved [49]. Therefore, while strength and conditioning coaches employ a variety of movements to improve athletes' particular movement patterns on the sporting field, little is known on which training movement elicits higher hip and knee extension musculature activation.

Physiology of muscle contraction

Muscle contraction is achieved after a series of events, called "excitation-contraction coupling", originating at the neural (central nervous system) level, resulting in contraction at the musculoskeletal (peripheral nervous system) level. The process of force production in skeletal muscle starts from a nerve impulse, called an action potential, at the motor cortex area of the brain. This signal then travels down the spinal cord, through the nerve cells (motor neurons) in the peripheral nervous system, finally reaching the area in which synaptic contact with striated muscle is made, called the motor end plate.

The propagation of an action potential down the motor neuron is triggered by the movement of ions (i.e. Na^+ and K^+) across its membrane through voltage-gated channels. As one channel depolarizes from its resting potential of -70 mV up to +60 mV, it triggers the next channel to depolarize in a chain reaction along the length of the axon. The channel then returns to its resting potential of -70 mV through passive (e.g. electrical and concentration gradients) and active (e.g. Na^+, K^+ pump) processes [54]. During the repolarization process the channel cannot depolarize again, referred to as its refractory period, thus preventing the action potential from moving back “up” the neuron; it can only move “down” (i.e. away from the brain, towards the muscle). This cycle of depolarization and repolarization can occur at a frequency as low as 10Hz to as high as 200 Hz. Thus, the activation signal discharged by a motor neuron comprises brief electrical impulses, which activate the voltage-gated channels of the subsequent neuron, this way preserving the signal transmission from one neuron to the next.

As the action potential reaches the motor end plate, voltage dependent Ca^{2+} channels at the axonal membrane are then opened, releasing Ca^{2+} into the axon terminal. This release of Ca^{2+} causes the release of the neurotransmitter acetylcholine into the synaptic cleft, which then binds to acetylcholine receptors on the nerve-muscle synapse. This binding causes depolarization of the membrane, which causes the membrane potential to become either less negative (depolarized) or more negative (hyperpolarized) [54]. This depolarization – repolarization cycle forms a depolarization wave or electrical dipole [55] which travels along the surface of a muscle fiber. This electrical signal can be detected through the skin and interpreted to infer muscle activity: the greater the electrical activity measured, the more active the muscle.

Force production

Previous studies have found correlations between increases in voluntary strength and increases in integrated EMG, indicating that strength-trained subjects can more fully activate prime mover muscles in maximal voluntary contractions[56-58]. The amount of force that a muscle generates will be dependent on the number of motor units activated and the rate at which these discharge action potentials. These two properties are known as recruitment and rate coding [54].

In order to produce a muscular contraction, motor units must be recruited; as more force is required, more motor units are recruited. The recruitment of the motor units within the motor pool seems to follow a set of rules. Foremost amongst these rules is the size principle [59], which states that the order in which motor neurons are activated is dependent on their size, from smallest to largest. The entire motor unit pool is seldom used in everyday activities, as the number of units activated depends on the type of activity. When high force is required, particularly when that force is required to be produced rapidly, larger motor units are recruited.

Force generated by the muscle due to a single action potential is called a twitch. This twitch is characterized by contraction time, peak force and the time it takes for the force generated to decay to half of its peak force value [54]. The contraction times in human motor units range from 20 ms to 120 ms, which has resulted in the classification of 'slow twitch' and 'fast twitch' fibers. The differences in contraction times between motor units is due to histological variations such as enzyme myosin ATPase, which is involved during the cross-bridge cycle, the rate in which $Ca^{2+\text{ is}}$ released into the sarcoplasmic reticulum, and the arrangement of the fibers in the muscle [54]. The slow-twitch type motor units, which contract slowly but are fatigue-resistant, are recruited during all contractions, as they are the first to be recruited in the size principle. Fast twitch motor units are not only faster but are also usually larger and thus are capable of producing greater force. Fast twitch motor units are therefore less commonly recruited since they are only needed for high force, rapid contractions. In situ, muscle fibers do not contract as individual twitches but fuse a series of twitches to form a sustained (tetanic) contraction. Slow twitch motor units will fuse at stimulation rates as low as 10Hz, while fast twitch motor units will usually fuse at >60 Hz. Thus, the motor units that are used most frequently are those resistant to fatigue, but when higher force is required the fast-twitch motor units are then recruited. It has also been previously recorded, that the upper limit of motor unit recruitment occurs at about 85% of maximal force for most muscles [60, 61]. Therefore, in order to improve maximal force production, athletes must train with training loads that are 85% of their 1 repetition maximum (1RM) or more.

The frequency at which action potentials are discharged by a motor unit influences both the force and the rate in which this force is produced [62], as it has been shown that motor unit discharge rates during steady isometric contractions increase with force production [63]. It has been reported that an increase in neural drive to the muscle fibers is also likely to mediate some of the increases in the speed of contraction after dynamic training [62]. Also, very high firing rates are reported to occur during maximal “ballistic” contractions, in which the subject is asked to contract as quickly as possible [56, 64]. Repeated bouts of contracting rapidly, such as explosive training, may therefore increase the ability to fire motor units at high rates, thus improving rate of force development. Further, motor unit synchronicity regards the simultaneous or near-simultaneous firing of two motor units, which occurs more often than would be expected by chance [65]. Synchronization is believed to enhance force output, is greater at higher forces and its been previously reported that resistance-trained subjects elicit greater synchronization than in untrained subjects [65, 66]

Electrical activity in the muscle – EMG

The previously described electrical activity of muscle has long been studied by recording from the surface of a muscle or the skin, with a technique that has been found to be simple and reliable enough to be used routinely in the diagnosis of many diseases of muscles and their motor nerves [67]. Surface electromyography (EMG) signals measures voltages that are reflective of nerve conduction velocity and number of depolarization waves between two electrodes [18], which can be interpreted as an indication of the motor units activated to produce a contraction. The force produced by a muscle during a voluntary contraction is dependent on the motor units that are activated and the rate in which these discharge action potentials. These two features of motor unit activity are known as recruitment and rate coding, respectively [54]. EMG has been previously used to quantify the level of muscle activity during a specific movement in various studies [12-19], and has the advantage that the mean signal recorded (measured after rectification and smoothing) varies linearly with the force generated at constant length[67]. It has also been shown that there is a significant tendency for the units recruited with larger forces to contribute a greater voltage to the surface EMG[67]. The information collected through EMG can then be used to guide strength and conditioning coaches in developing resistance-training programs that use forceful movements in training to improve strength.

Methodological problems and issues with EMG

While surface electromyography has been widely and reliably used in previous studies, researchers need to minimize artifacts and noise from the surface EMG signal in order to collect valid information. Equipment considerations that need to be made in order to ensure adequate collection of the EMG signal include the use of electrodes, amplifiers, filters, recording and displaying devices [68].

It has been previously shown that surface EMG recordings display a smaller frequency than that of intramuscular EMG, which must be accounted for by the filtering of the signal. Because the frequency characteristics of surface EMG and intramuscular EMG recordings are different, filtering limits should also be different. Filtering settings should not eliminate the predominant frequencies one is attempting to record in EMG [68]. It has also been reported that surface EMG is inevitably contaminated by various noise signals or artifacts that originate at the skin-electrode interphase[69]; therefore surface EMG is more prone to electrical artifacts, mechanical artifacts, and contamination from the activity of other muscles (both agonists and antagonists) than intramuscular EMG [68].

Aside from using proper skin preparation and correct electrode placement on the skin, one of the means used to increase the validity of the surface EMG signal is to filter the maximum amount of noise while retaining as much of the desired EMG signal frequency spectrum as possible[69]. Therefore, EMG data in the applied setting must be filtered and rectified, as well as properly collected following recommended guidelines. The European recommendations for surface electromyography (SENIAM) [41] account for these issues by providing instructions on the location and the direction in which the electrode should be placed, how to prepare the participant's skin and what electrodes to use. Placement location of electrodes may influence the validity of the signal as neighboring muscles may produce a significant amount of electrical activity that may be recorded by the local electrode site. Skin preparation must be carefully considered as electrical conductivity is affected by tissue type, therefore the removal of hair and dead skin in the location where the electrode will be placed is recommended. A bipolar configuration of electrodes is also suggested as a bipolar recording fully enables the noise-supressing capacity of an amplifier and it avoids the disadvantages present in monopolar recordings [68].

Movement specificity

If forceful movements are frequently used in training, and an increase in activation of the prime mover muscles is an adaptation that aids athletic performance, it is important to know the differences in muscle activity during different exercises commonly used in training. Strength and conditioning professionals must match the type of training employed with the demands of the sport, a concept referred to as specificity. While there are many types of specificity to consider, including energy systems and movement velocity, biomechanical specificity is the most relevant for the current purpose.

As there are a wide variety of different movements that are performed in the sport setting, strength and conditioning professionals look to mimic certain movements in training in order to improve sporting performance. Biomechanical specificity explains the strength transfer effects resistance training has on movements that are featured in training. Consequently, the greatest improvements in strength are observed if dynamic conditions are paired with dynamic training, and conversely, isometric training has shown greater improvements in static strength, tested under isometric conditions, than dynamic training does [5].

It has also been shown that the recruitment order of some motor units in multifunctional muscles is task dependent, thus some motor units may be preferentially recruited for certain tasks. This task-specific activation of the prime movers during repetitive bouts of exercise may be part of the basis for the observed specificity of movement patterns in resistance training [56]. Previous research has measured muscle activity while performing many different tasks such as sprinting, walking and jumping [70-74], as well as during exercises that are performed in the gym setting and under different loads [14, 17, 19-24, 75]. Strength training effects have also been shown to be specific to the type of contraction employed during training (i.e., concentric, eccentric, isometric)[5, 53], which furthers the importance of specificity in a strength-training program and the need for careful consideration when selecting the movements athletes will perform during training.

Biomechanical specificity is evident in increased strength improvements with the same range of motion and joint angles performed during training [6], while velocity specificity concerns the velocity in which the muscles contract during training. There appears to be a greater degree of velocity specificity in training responses at the higher end of the velocity spectrum [5, 75], therefore coaches must consider the velocity in which the athlete is performing the movement in training if the purpose of the training session is to improve movement speed.

Biomechanical specificity also concerns the structural elements performed during the movement, such as posture and limb position, and it has been previously proposed that an exercise that is performed in a standing position has a greater carryover to most types of athletic performance than a similar movement performed in a seated or supine position [5]. If the purpose of the training program is to improve movements that are performed while standing, such as running, lunging and jumping, resistance-training exercises such as the back squat and the deadlift would have a greater transference to sport than the barbell hip thrust and the seated leg press. This aspect of biomechanical specificity should be closely looked at when determining which training exercises to prescribe. The direction in which the force is applied during the training movement may determine the magnitude of transference to the sport setting, which may explain why back squat strength has been found to be correlated to sprint performance and vertical jump height in soccer players [27]. Therefore, the unique dynamic component of knee as well as hip extension during the back squat may have a very specific carryover to improving athletic performance.

Improving athletic performance

Concerning the transference of strength improvements through resistance training into the sporting field, strength and conditioning professionals select exercises that best represent the movements used in competition (i.e. biomechanical specificity). According to a review by Cronin, et al., [76] significant performance improvements in leg strength and running speed were most frequently reported in studies that prescribed the squat and/or jump squat variations. It is also reported that the squat and/or jump squat appear to be specific exercises associated with improvements in lower body strength and ultimately running speed [76]. While there are many training exercises that mimic hip extension, the back squat is commonly used in training to improve vertical power production and forceful hip extension.

The back squat has been a prolific exercise for the development of athletic performance in many sports [25-28] for many decades [29-31]. Consequently, muscle activity during the squat and its transference to athletic performance has been extensively studied. The squat involves moving both the hip and knee from full flexion to full extension and therefore elicits great activation of the hip and knee musculature in a way that is biomechanically similar to running and jumping [14, 17]. Further, high performance in jumping has been attributed to synergistic movement patterns of the muscles relative to the hip, knee and ankle joints [74]. Therefore, as performing the back squat to full depth takes the joints at the hip, knee and ankle through their entire range of motion, its biomechanical specificity may prove to be superior to other hip extension alternatives. However, there are several factors influencing muscle activation of the squat, which include depth, load and stance width. Caterisano et al. [17] suggested that as squat depth increases, the GM, rather than the biceps femoris (BF), the vastus medialis oblique (VMO), or the vastus lateralis (VL), exhibited higher EMG activity throughout the concentric range. However Clark et al. [23] suggest that the selected test load during Caterisano's study [17] may have influenced the results, since the relative load varied between squat trials due to the differing squat depths performed (i.e. greater squat depth required lighter loads). Further results investigating muscle activation of the squat suggest a wide stance has demonstrated a greater activation of the GM [24], thus indicating that exercises that place the feet close together perhaps may not be ideal for GM activation, while Signorile et al. [15] investigated foot positioning in the squat and found no significant differences in quadriceps activation.

Interestingly, increasing external resistance is a more effective method of increasing EMG activity than increasing the number of repetitions performed with lighter weights when the set is performed to volitional failure [14]. Additionally, wretenberg et al. [32] compared quadriceps and hamstring EMG between national weightlifters and powerlifters and found a higher mean peak muscular activity in powerlifters; possibly due to the fact that the powerlifters lifted heavier relative loads than the weightlifters. As a result, any investigation comparing hip extension exercises needs to carefully equate stance width and relative loads across the different actions.

As with the squat, the Romanian deadlift (RDL) has been utilized by strength and conditioning coaches with the aim of improving sprint performance by strengthening the gluteal and hamstring muscle groups as well as the spinal erectors [29, 33]. The RDL has also been used in the prevention of hamstring injuries [34] and it is considered a crucial movement in the development of the Olympic-style lifts[3]. It is believed that exercises like the RDL that strongly activate the hip extensors would be more specific to maximum-speed sprinting, as opposed to exercises that target the quadriceps, which would be specific to the acceleration phase of a sprint [35]. Although muscle activation of the hamstring muscle group has been previously measured during the RDL [36], GM is yet to be investigated during the RDL and compared to other exercises. Since the GM and the hamstrings do not work in isolation during sporting movements, investigating the interaction of these two muscle groups would be of value.

Hip extension

Hip extension torque accelerates the body upward and forward from a position of hip flexion, such as when pushing off into a sprint, arising from the eccentric portion of a jump, or climbing a very steep hill [37]. These are movement patterns that are widely used in the sporting environment, thus the interest to improve hip extension torque by strength and conditioning professionals, who often use resistance-training exercises such as the back squat, the RDL, and the barbell hip thrust [1-3] to increase force production in the lower extremities and hip musculature. The GM has an important role in facilitating hip extension due to its fibers aligning perpendicularly to the sacroiliac (SI) joint. This fiber alignment allows GM contraction to produce compression of the SI joint and therefore contributes to the transfer of force from the lower extremity to the pelvis through the SI joint during dynamic activities [77]. Placing emphasis on training the GM due to its anatomical structure may then be useful when looking to improve sporting performance with a forceful hip extension. As a result, increases in lower body strength transfer positively to movements such as running and jumping [7]. The hamstring muscle complex is composed of three distinct muscles: the BF, the ST and semimembranosus (SM). These are involved in knee flexion and hip extension as well, as the hamstrings cross both the hip and the knee joints [78]. It has also been shown that heavy resistance exercise induces high levels of neuromuscular activation, which over a prolonged training period yields muscle hypertrophy, gains in muscle strength and enhanced neural drive to the muscle fibers [8-11].

Knee extension

Resembling hip extension, knee extension has also been investigated due to the knee extensor's involvement in activities widely used in the sport setting [79-82]. The quadriceps muscle complex consists of the VL, the VMO, vastus intermedius (VI) and rectus femoris (RF). The quadriceps muscle group acts as primary extensors of the knee and is one component of the extensor mechanism. The additional extensor mechanism components include the quadriceps tendon, the patella, the patellar tendon and patellar retinaculum. All of these structures work in concert to provide knee extension [78]. Weakness, atrophy and variations in the attachment location of the VMO have all been shown to be causes of patellofemoral instability and maltracking. Thus, strengthening the VMO is often an integral part of the physical therapy and rehabilitation protocols when such pathology is suspected [78]. Further, the VL, in combination with the lateral patellar retinaculum, is responsible for the lateral force that counteracts the VMO to stabilize the patella during flexion and extension of the knee [78, 83].

The barbell hip thrust

It has been recently suggested that the barbell hip thrust may be superior to the back squat in eliciting higher gluteal muscle activity, developing terminal hip extension strength in the hip extensor musculature, increased horizontal force production, and increases in the contribution of the gluteus maximus relative to the hamstrings during hip extension movement [2]. Research by Contreras et al. [19] recently demonstrated that mean and peak surface EMG of the GM and BF was superior during the barbell hip thrust when compared to the back squat, although no significant difference was found between exercises in peak or mean VL EMG. With these findings, Contreras et al. [19] suggest a need for the barbell hip thrust to be included in exercise programs to develop the hip extension musculature. Before such a recommendation should be followed, however, the work of Contreras should be critically examined.

There are several limitations to the results found by Contreras et al. [19]. Firstly, concerning the placement of the EMG electrodes Contreras et al. [19] uses two different sites for measuring GM activation, termed the upper and lower GM, based upon previously described procedures [38, 39]. Contreras et al. [19] references Hermens et al., [41] however, who recommends to follow the SENIAM guidelines for EMG electrode placement, with GM electrode placement to be on the greatest prominence of the middle of the buttocks, well above the visible bulge of the greater trochanter. While Lyons et al. [38] used fine-wire EMG to isolate the upper and lower GM, the surface EMG used by Contreras et al. [19] would likely have the "upper" GM signal contaminated by gluteus medius. Importantly, Lyons et al. [38] does not provide any rationale as to why the "upper" and "lower" gluteus maximus sites were chosen to measure GM activity. Finally, Fujisawa et al. [39] states that the gluteus maximus is functionally divided into upper and lower sections, however cites the article previously mentioned by Lyons et al. [38] and by Lieberman et al., [84] who compare the structural anatomy of humans and apes, clearly stating that the most substantial difference is the absence of the gluteus maximus ischiofemoralis in humans, with only an enlarged gluteus maximus poprius portion of the muscle existing (hereafter referred to as the human GM). Therefore, both Lyons et al. [38] and Fujisawa et al. [39] are both inappropriate references for "upper" and "lower" GM. Since signals recorded at different locations over the muscle may differ substantially due to muscle fiber distribution and the generation of the action potentials at the endplates [40], standard electrode positioning is necessary in EMG recordings as according to the SENIAM guidelines [41].

A further limitation of the study by Contreras et al. [19] are the procedures used to collect of the maximal voluntary isometric contractions (MVICs). In healthy individuals, normalizing EMG by using the EMG recorded from a MVIC as the reference value may allow the researcher to assess what percentage of the maximal activation capacity of the muscle the task EMG represents [42]. A previous study by Earp et al. [13] demonstrated that using joint angle-dependent normalization results in significantly different values than normalizing to the peak value obtained in a reference contraction. These data support the need for considering joint angle when reporting EMG in large ROM movements or in movements where peak EMG is believed to occur at different joint positions (i.e. in different movements or in the same movement but at different intensities). Contreras et al. [19] use two different positions to normalize gluteus maximus EMG signals. The first method is the one described by Boren et al., [12] in which MVIC was recorded during the prone bent-leg hip extension securing a strap around the distal femur during trials to ensure standardization of resistance. The second method involved a muscle contraction, described as a "standing glute squeeze"[19, p. 07]. One concern with the first method, as previously stated by Earp et al., [13] is that if referenced values are not representative of maximal muscle activity under the specific movement conditions, such as when the movement being assessed is referenced to a contraction in which EMG activity is obtained at a different joint angle (or muscle length), the validity of such comparisons becomes questionable. Burden [42], however, states that EMG signals do not appear to be affected by contraction mode or joint kinematics, particularly for the elbow flexors, yet endorses EMG from an isometric MVIC as a normalization reference value. Secondly, according to Konrad [43], MVIC contractions should be performed against static resistance and a "standing glute squeeze" has not yet been demonstrated to be a valid and reliable procedure for the measurement of MVICs. To produce a maximum activation of a muscle, a very good fixation of all involved segments is crucial [43]. Similarly, Robbert and Harlaar [85] demonstrated that muscle length and joint position influences EMG amplitude, therefore measuring EMG during standing hip extension may not be indicative of a true MVIC. Furthermore, it has been previously stated that in order to achieve improvements in muscular strength, EMG muscle activity should reach a minimum of 40 – 60% of MVIC [8]. Therefore achieving maximal contraction in order to have an adequate reference value in research is of utmost importance for correct interpretation of the results.

Conclusions

Applying the concept of specificity to the design of a resistance training program can have a positive effect on athletic performance. Thus, the careful selection of the exercises used in training may have implications on the transference of training effects, in particular with hip extension. One way of quantifying the neural stimulus a training movement has is through the electrical impulses measured on the surface of the skin, directly above the muscle. These electrical impulses can be used as a marker of muscle activation and neural drive, which can be used as an indication of how much stimulus is received by the muscle during a movement. As the GM has such an important role in hip extension, determining which exercise elicits a higher stimulus to the GM may provide strength and conditioning coaches with sound reasoning behind the selection of training exercises.

While Contreras' work indicates the superiority of the hip thrust to elicit activation of the GM over the squat, there are several methodological issues with his study, not the least of which is his conflict of interest considering his commercial interests in the movement [86]. As previously mentioned, EMG activity has been shown to increase as external load increases [14, 44], which is important to consider when empirically comparing these exercises; as due to the smaller range of motion during the barbell hip thrust, a higher load is often used compared to the back squat or RDL. The squat and RDL are widely used exercises to improve sporting performance due to their documented ability to highly activate the knee and hip extensors [25-27, 36, 45], however the question remains if the hip thrust has the benefits reported by its proponents [46-48]. The central aim of this study is to investigate the potential differences in muscle activity during the barbell hip thrust, high-bar back squat and RDL in resistance-trained individuals.

CHAPTER 3

MATERIALS AND METHODS

Participants

A power analysis (G*Power 3.0) [87] was conducted using a repeated measures ANOVA (α=0.05, β=0.80, effect size=0.25, ICC for EMG=0.80 using three groups (i.e. hip thrust, squat, RDL) over three repetitions (MVIC, 60 kg, and 1RM) and showed a minimum participant number of 9. The reliability of EMG (ICC) for G*Power was estimated based on the results of Fauth et al (2010) [88]. These results indicate that the reliability of EMG on lower body dynamic movements averages approximately ICC=0.80. Resistance-trained men, 18-30 years old with minimum of 1 year of lower-body resistance-training experience were asked to participate in the study. Their average age, height and body mass were 25 ± 3.3 years, 177.9 ± 6.5 cm, and 83.7 ± 6.7 kg, respectively. Participants were required to be able to squat 150% of their bodyweight, go to a squat depth in which the thighs are parallel to the ground or deeper, and were asked to abstain from their training 48 hours prior to each testing session. If the subject was undergoing a training schedule at the time of testing, they were asked to fill in a training log, which was used to match training volume (in kg). This was done to abrogate the need for abstinence from training if the subject maintained a consistent training regimen throughout their participation in the study. The experimental procedures were approved by the Edith Cowan University Human Research Ethics Committee (approval number: 15469) and were in agreement with the principles of the Declaration of Helsinki [89]. Participants were asked to provide signed informed consent.

Study design and overview

This study followed a repeated measures design. Participants were asked to attend one familiarization session (~30min) and 1 testing session (3-7 days apart) approximately 3 to 4 hours long. Sessions took place at the same time of day on each occasion. Session 1 took approximately 30 minutes and was used to familiarize the participants with the testing procedures and for completion of all required documentation. Session 2 was used to record participant's height and weight, electrode placements, normalization protocol and 1RM testing of the back squat, RDL and barbell hip thrust, including a warm up set with a standardized submaximal load of 60 kg.

Electromyography (EMG) electrodes were used to quantify muscle activity during the normalization procedure as well as the weight lifting exercises. Additionally, each participant's foot placement while performing the lifts was recorded to maintain a standardized stance width throughout the study. EMG collected during the testing session was compared to reference MVICs in the normalization protocol [90-92] performed at the beginning of both testing days.

The study was scheduled as follows:

- Session 1: Familiarization of testing procedures
- Session 2: Anthropometrics, normalization, 1RM testing

EMG Electrode placement

All skin preparation procedures followed the SENIAM guidelines [41] and EMG signals were recorded using pairs of silver chloride surface electrodes (2.0 cm diameter; Noraxon Dual Electrodes, Noraxon USA, Inc.) through a wireless EMG system (Zero Wire System, Aurion, Italy) recording at 2000Hz using a telemetry transmitter (Wave Wireless, Cometa Systems, Milan, Italy), which was analyzed using LabChart 8 software (PowerLab system, version 6.1.3, ADInstruments, NSW, Australia). All electrodes were placed according to the SENIAM guidelines [41] on the subject's dominant side for consistency between subjects, as it has been suggested by Adam et al. [93] that a lifetime of preferred use may cause adaptations in the fiber composition of the dominant muscle. Following electrode placement, a reading of less than 5 kΩ achievable through skin impedance was deemed as acceptable to continue the procedure.

For the quadriceps musculature, EMG electrodes measuring vastus lateralis activity were placed at 2/3 of a line measured by a measuring tape, connecting the anterior spina iliaca superior to the lateral side of the patella, in the direction of the muscle fibers. Electrodes were also placed on the vastus medialis, at 2/3 of a line marked by a measuring tape, connecting the anterior spina iliaca superior to the medial side of the patella.

For the hamstrings muscle group, electrodes measuring the bicep femoris were placed at 50% of a line measured by a measuring tape, connecting the ischial tuberosity and the lateral epicondyle of the tibia. Electrodes measuring the semitendinosus muscle were placed at 50% of a line measured by a measuring tape, connecting the ischial tuberosity and the medial epicondyle of the tibia.

Electrodes measuring the gluteus maximus were placed at 50% of a line measured by a measuring tape, connecting the sacral vertebrae and the greater trochanter, in the direction of the line from the posterior superior iliac spine to the middle of the posterior aspect of the thigh.

Normalization (MVICs)

Limb fixation for the MVICs followed Konrad's instructions on normalization [43] and was comprised of three MVICs for each muscle group individually, in order to assess maximal EMG activity. Subjects were strapped to the isokinetic dynamometer (Biodex System 3 Pro, Biodex Medical System, Shirley, New York) and were asked to extend or flex maximally for 3 repetitions at three different positions. For the quadriceps musculature, subjects were asked to maximally extend their leg fixed at 70° of knee flexion (0° = leg fully extended). For the hamstrings muscle group, subjects were asked to maximally flex their leg set at the same angle of 70° of knee flexion (0° = leg fully extended). Lastly, for the gluteus muscle group, subjects were asked to lie down in a pronated position and maximally extend their hip with their upper leg fixed at 180° of hip flexion. Subjects were given 1-minute rest between MVICs and 2-3 minutes of rest between muscle groups. Normalization took place immediately before performing each exercise separately. After a normalization session for each muscle group in the isokinetic dynamometer, all participants were asked to perform the three weight lifting exercises until failure, in randomized order, with 10 min rest in between warm ups for each exercise.

Session 2

1RM warm-up and assessment procedure

Following the measurement of muscle activity during MVICs, subjects followed the same National Strength and Conditioning Association protocol by Earle [94] consisting of a warm up with light resistance that easily allowed 5 to 10 repetitions. After a 1-minute rest period, a load of 15-20 kg was added to the standard 45 kg barbell and the subject was instructed to perform 3 to 5 repetitions, followed by a 2-4-minute rest period. Load was gradually increased and this process was repeated until a weight was reached where failure of technique occurred or the participant was not able to perform more than one repetition, without exceeding 3-4 attempts at the maximal weight. The 1RM was recorded as the highest successfully lifted barbell load with correct technique. For the back squat, the participant were asked to rest the bar over the upper trapezius in a high-bar position and flex the hips and knees to a depth in which the thighs were parallel to the ground or deeper, maintaining a tight upper and lower back. For the barbell hip thrust, peak barbell height was recorded at the point of maximal hip extension during the initial repetitions of the warm up and the 1RM was recorded as the highest lifted load until the subjects could not reach peak barbell height at the end of the concentric action. Subjects were asked to place their upper backs on a bench 16 inches high, with the barbell placed at the crease of their hips and a barbell pad to minimize discomfort. Subjects were instructed to extend through the hips, maintaining a tight core with their feet firmly planted on the ground. For the RDL 1RM, the bar was be placed on a rack set at the participant's hip level. The subjects were be asked to use weight lifting straps, lift the weight, take two steps back and perform a Romanian deadlift with a tight lower back, extending through the hamstrings. Range of motion in the RDL was standardized to the barbell reaching the bottom of the patella for every subject. 1RM was recorded as the highest lifted load with correct technique or until the subjects could not reach peak barbell height at the end of the concentric (upward) motion. There were resting periods of 10 minutes between the back squat, the RDL and the barbell hip thrust.

Statistical analysis

Differences in the EMG RMS (MVIC to exercise) and changes between the 3 exercises were determined during a one second window at peak torque produced in the MVIC and during the concentric phase of each exercise at 1RM and 60 kg. A comparison of the maximal loads (1RM) lifted between exercises as well as the intensities (%1RM) lifted during a 60 kg repetition was determined as well. Additionally, stance width during the performed exercises was measured as well as femur length in centimeters (cm) and these were compared to performance variables such as knee extension torque and squat 1RM to bodyweight ratio. Qualitative descriptors of standardized effects were assessed using the criteria: trivial, 0.19; small, 0.2–0.59; moderate, 0.6–1.19; large, 1.2–1.99; and very large, 2.0 [95]. Precision of estimates were derived from a repeated-measures ANOVA and expressed with 95% confidence limits, which defines the range representing the uncertainty in the true value of the (unknown) population mean. Differences were determined to be statistically significant at $P<0.05$. Reliability of the EMG was calculated from the typical error of measurement and intraclass correlation coefficient between repeat trials.

CHAPTER 4

RESULTS

Exercise performance

All subjects but one (subject A) were able to meet the previously established minimum inclusion of 150% bodyweight squat, with a lowest relative back squat of 144% and a highest relative back squat of 200% lifted amongst participants during 1RM load testing.

The average load lifted across exercises is shown on Figure 1. Large significant differences were found in the loads lifted between the back squat and the other two exercises, with participants lifting lighter loads for the squat when compared to the Romanian deadlift (22.9 ± 17.8 kg, mean Δ ± 95% confidence interval; effect size = 1.19. *P* = 0.019) and when compared to the barbell hip thrust (20.1 ± 15.4 kg; 1.05. *P* = 0.018). As EMG was also recorded during an absolute load of 60 kg lifted across the three exercises, 60 kg represented a higher relative intensity (i.e. % of 1RM) in the back squat when compared to the RDL and the barbell hip thrust. Figure 2 shows the average intensity lifted for the 60 kg load in relation to 1RM. Large significant differences were found, with a higher relative intensity lifted in the back squat when compared to the Romanian deadlift (-5.9 ± 3.9 %; -1.07. *P* =0.009), and when compared to the barbell hip thrust (-5.5 ± 4.5 %; -1.00. *P* = 0.024).

Figure 1. Average load lifted (kg) during the back squat, the Romanian deadlift and the barbell hip thrust at 1RM. * Significant difference ($P < 0.05$) comparing the back squat to the Romanian deadlift and barbell hip thrust. Error bars represent the standard deviation.

Figure 2. Average intensity at 60 kg back squat, Romanian deadlift and barbell hip thrust in relation to 1RM. * Significant difference ($P < 0.05$) comparing the back squat to the Romanian deadlift and barbell hip thrust. Error bars represent the standard deviation.

Gluteus maximus EMG dynamic versus isometric

GM RMS values during a one second window at peak torque produced in the MVIC were compared to RMS values recorded during the concentric phase of each exercise at 1RM. Small or trivial differences with no statistical significance were found when comparing the MVIC to the concentric phase of the barbell hip thrust (29.3 ± 73.0 mV; 0.30. $P = 0.375$), the RDL (-7.7 ± 71.9 mV; -0.08. $P = 0.806$) and the back squat (-33.4 ± 58.0 mV; -0.35. $P = 0.215$) as seen on Figure 3. Small non-significant differences were also found when GM RMS during MVIC when performed with 60 kg was compared to the barbell hip thrust (-21.3 ± 74.8 mV; -0.22. $P = 0.523$). GM activation was higher during the MVIC, with large significant differences found when comparing MVIC to the concentric phase of the back squat (-124.5 ± 63.6 mV; -1.29. $P = 0.002$) at 60 kg, as well as the RDL (-112.1 ± 69.0 mV; -1.16. $P = 0.006$), as seen on Figure 4.

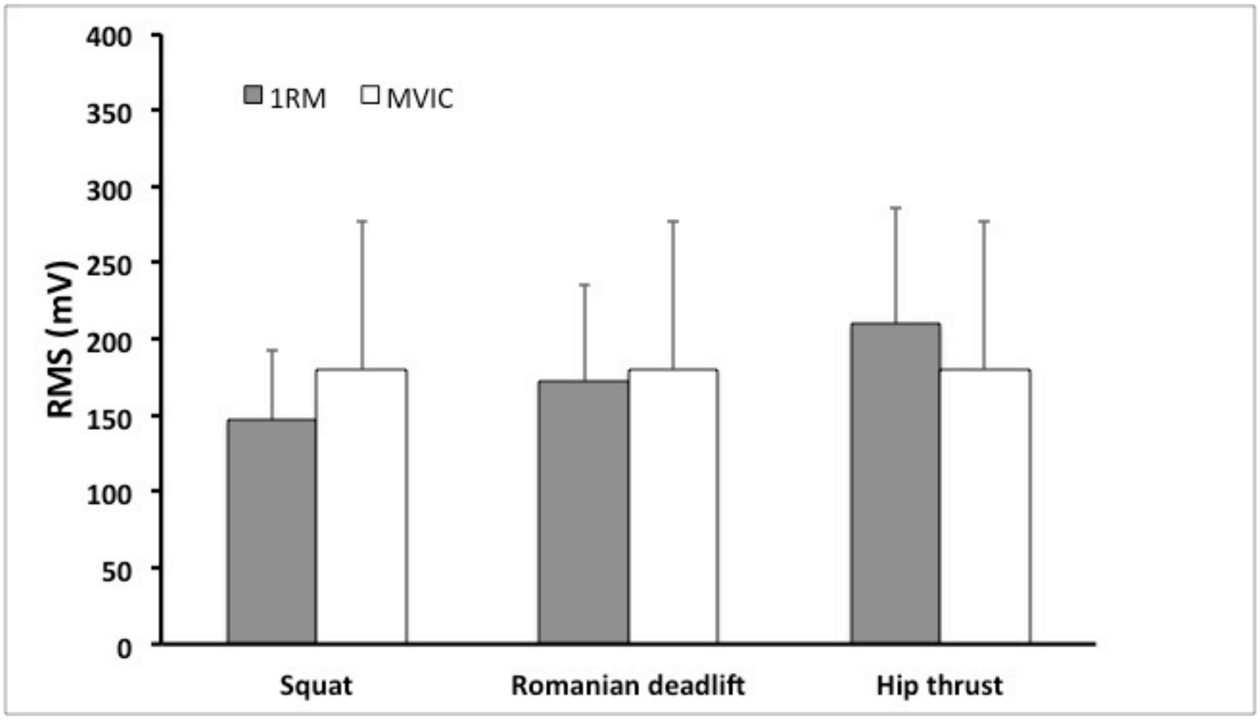

Figure 3. Mean RMS (root mean square) values of gluteus EMG activity during the concentric phase the back squat, the Romanian deadlift and the barbell hip thrust at 1RM versus mean gluteus RMS during a MVIC in isokinetic dynamometer. Error bars represent the standard deviation.

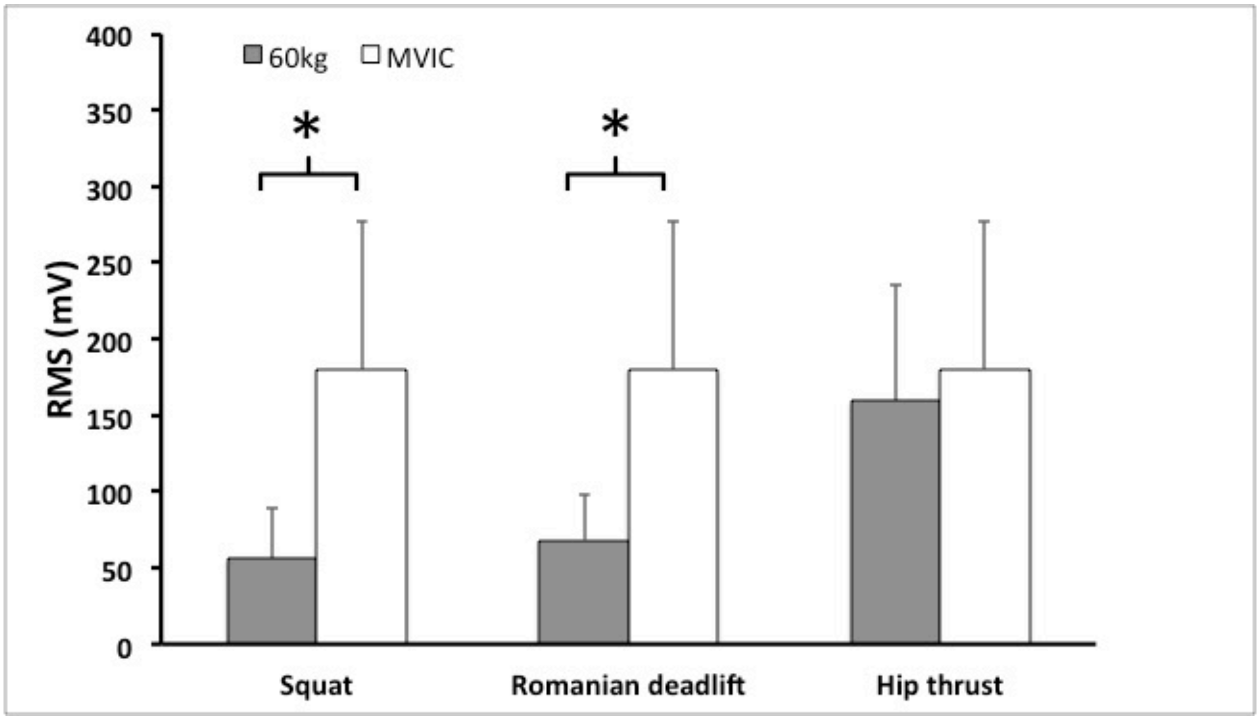

Figure 4. Mean RMS (root mean square) values of gluteus EMG activity during the concentric phase the back squat, the Romanian deadlift and the barbell hip thrust at 60 kg versus mean gluteus RMS during a MVIC in isokinetic dynamometer. * Significant difference ($P < 0.05$) between MVIC RMS and back squat as well as RDL RMS. Error bars represent the standard deviation.

Gluteus maximus EMG compared at different loads

Across the three exercises tested, the barbell hip thrust displayed higher GM RMS values than the RDL and back squat for 1RM and 60 kg load. There was a significant difference between 60 kg and 1RM RMS during the back squat and RDL, with higher RMS values displayed at 1RM, but the hip thrust did not show the same results. A large significant (91.0 ± 28.4 mV; 2.74. $P < 0.001$) difference between the two loads was seen (Figure 5), with the GM displaying 61.9 ± 20.4% smaller RMS value for 60 kg load when compared to 1RM.

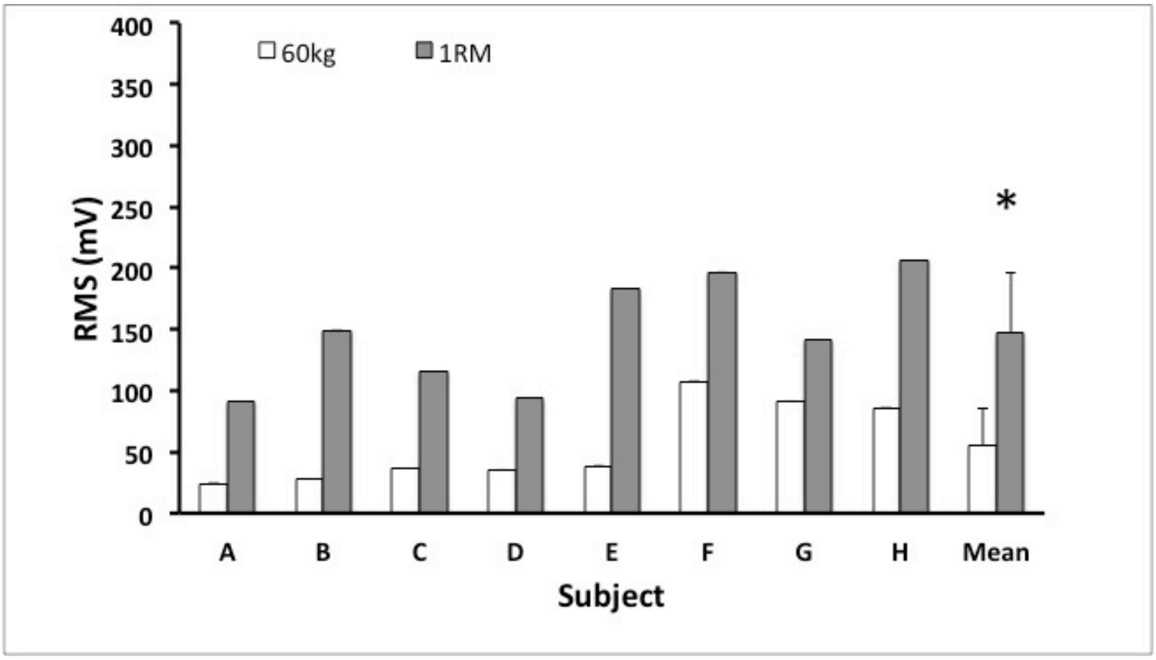

Figure 5. Root mean square of gluteus EMG activity during the concentric phase of the back squat at 60 kg and 1RM for individual subject (A-H) and their average ± SD (Mean). * Significant difference (P < 0.05) between 60 kg and 1RM. Error bars represent the standard deviation.

In the RDL, participants displayed similar results with higher GM RMS during 60 kg versus 1RM. Large significant (104.3 ± 44.1 mV; 3.56. *P* = 0.001) differences between the two loads was seen (Figure 6), with GM eliciting 60.4 ± 17.4% smaller RMS value for the 60 kg load when compared to 1RM during the RDL.

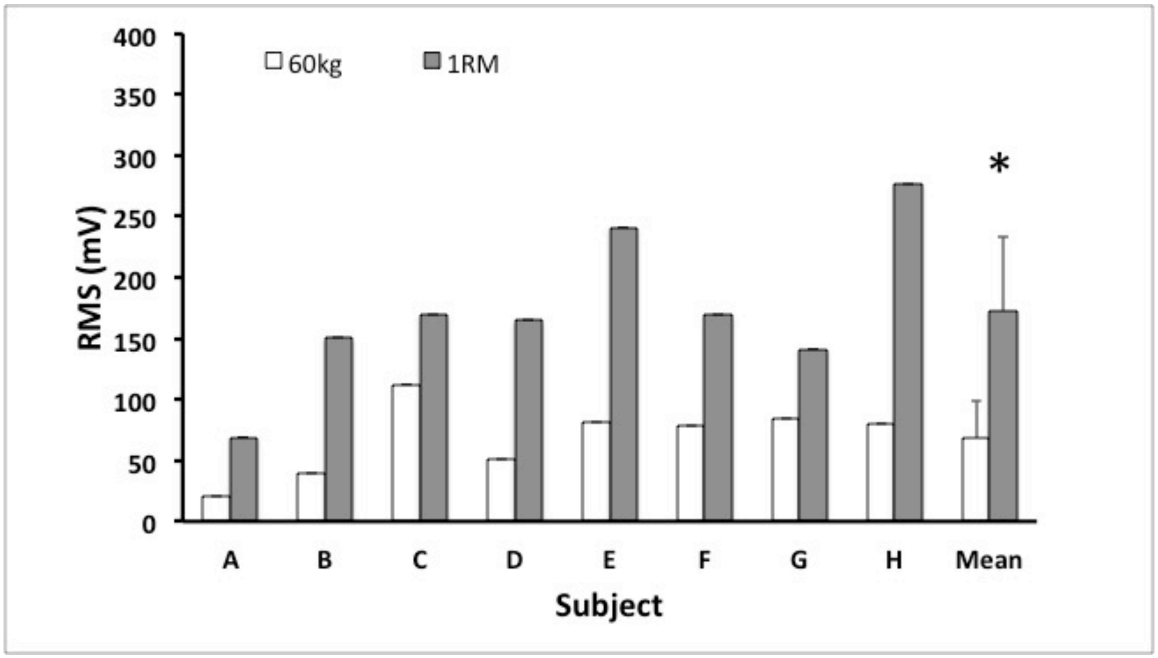

Figure 6. Root mean square of gluteus EMG activity during the concentric phase of the Romanian deadlift at 60 kg and 1RM for individual subject (A-H) and their average ± SD (Mean). * Significant difference (P < 0.05) between 60 kg and 1RM. Error bars represent the standard deviation.

Interestingly, as seen on Figure 7, the GM EMG activity in the barbell hip thrust displayed moderate non-significant (50.5 ± 66.3 mV; 0.67. *P* = 0.115) differences between 60 kg and 1RM, with some subjects (D, E and H) showing either higher or equal RMS values during the submaximal and maximal load. RMS during the barbell hip thrust was only 24.1 ± 38.1% lower for the 60 kg load when compared to 1RM.

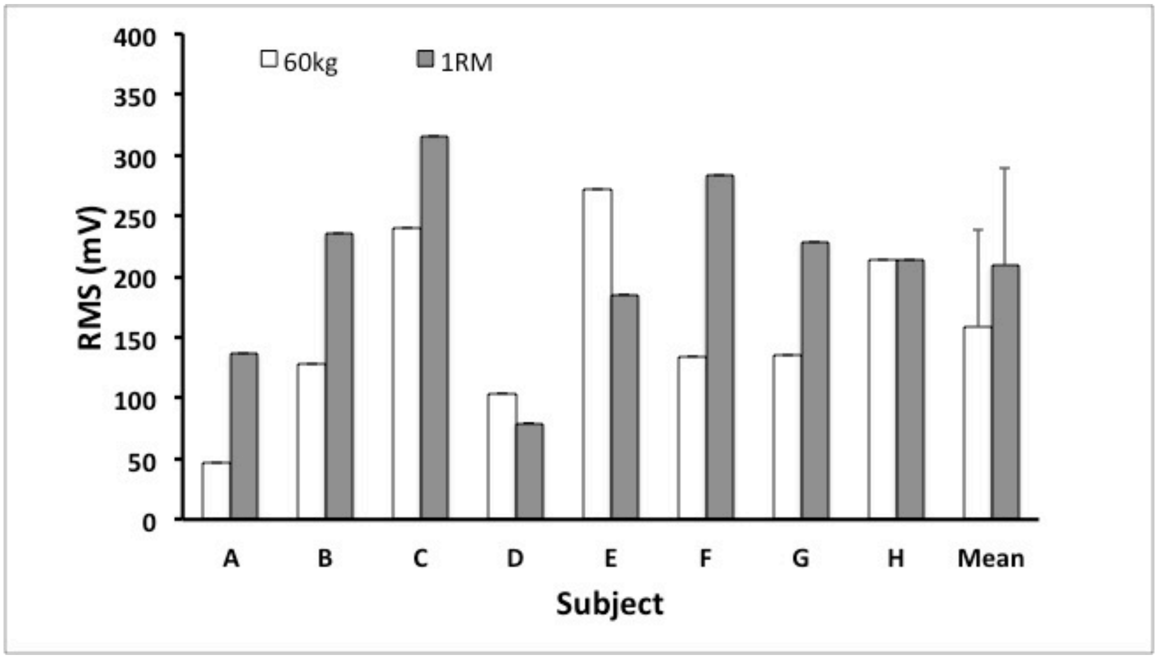

Figure 7. Root mean square of gluteus EMG activity during the concentric phase of the barbell hip thrust at 60 kg and 1RM for individual subject (A-H) and their average ± SD (Mean). Error bars represent the standard deviation.

Gluteus maximus EMG compared during exercises at maximal loads

At 1RM loads, the squat was significantly lower than both the RDL and hip thrust but there was no significant difference between the hip thrust and RDL. GM RMS showed a large significant difference between the back squat and the barbell hip thrust (62.7 ± 58.0 mV; 1.39. *P* = 0.038), with the barbell hip thrust eliciting higher GM activity, but small non-significant differences between the hip thrust and RDL (-37.0 ± 75.7 mV; -0.49. *P* = 0.285), as seen on Figure 8.

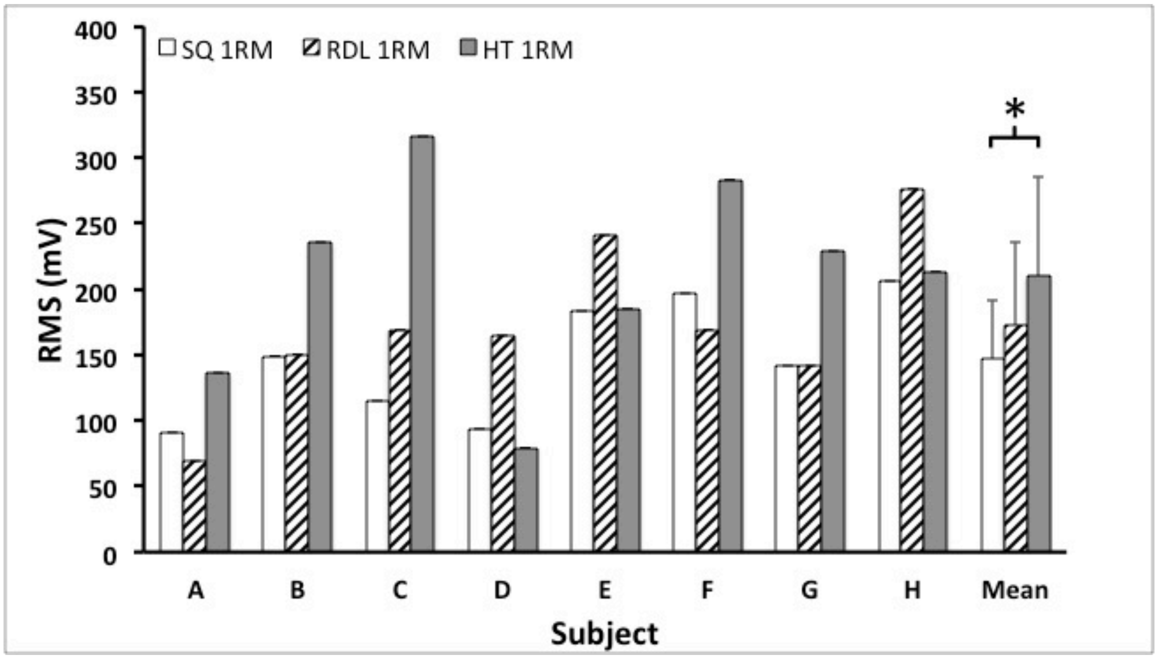

Figure 8. Root mean square of gluteus EMG activity during the concentric phase of the back squat, Romanian deadlift and barbell hip thrust at 1RM for individual subject (A-H) and their average ± SD (Mean). * Significant difference (P < 0.05) between back squat and barbell hip thrust. Error bars represent the standard deviation.

While the majority of the participants (5) displayed a higher GM EMG activity during the barbell hip thrust when compared to the back squat and RDL at 1RM, some subjects (D, E and H) showed higher activity during the RDL when compared to the other two exercises. Mean RMS values further show the difference between the barbell hip thrust and the back squat during maximal loads on Figure 9, with the hip thrust displaying significantly higher RMS values. Moderate non-significant (25.7 ± 35.0 mV; 0.57. *P* = 0.127) differences were seen at 1RM when comparing GM RMS during the back squat and the RDL, with the RDL displaying slightly higher GM RMS.

Figure 9. Mean RMS (root mean square) values of gluteus EMG activity during the concentric phase the back squat, the Romanian deadlift and the barbell hip thrust at 1RM. * Significant difference ($P < 0.05$) between the barbell hip thrust and the back squat. Error bars represent the standard deviation.

Gluteus maximus EMG compared during exercises at submaximal loads

At a load of 60 kg, all subjects displayed significantly higher EMG activity in the GM during the barbell hip thrust when compared to the back squat and RDL. Large significant differences in RMS values were seen when comparing the barbell hip thrust with the back squat (-103.2 ± 66.8 mV; -1.36. *P* = 0.008), with the hip thrust displaying higher RMS. The barbell hip thrust was also compared to the RDL, with large significant differences (-90.8 ± 46.4 mV; -1.20. *P* =0.002) displaying higher GM RMS during the hip thrust as seen on Figure 10.

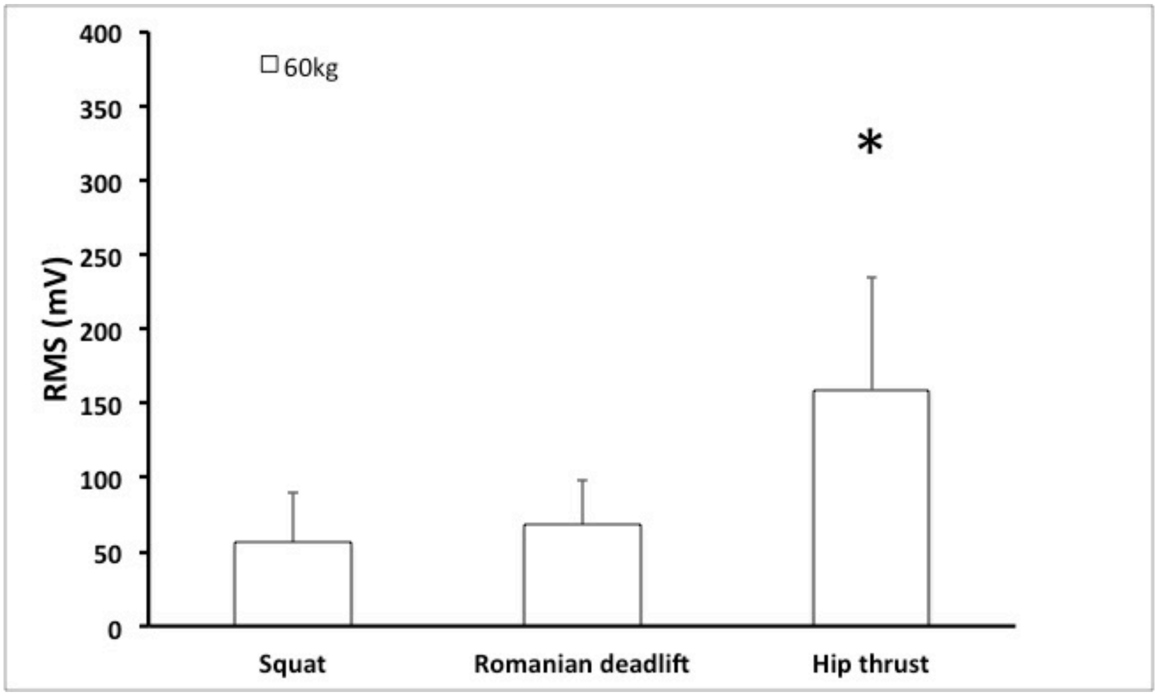

Figure 10. Mean RMS (root mean square) values of gluteus EMG activity during the concentric phase the back squat, the Romanian deadlift and the barbell hip thrust at 60 kg. * Significant difference ($P < 0.05$) comparing the barbell hip thrust to the back squat and Romanian deadlift. Error bars represent the standard deviation.

Additionally, small non-significant differences (12.4 ± 27.7 mV; 0.37. $P = 0.325$) were found when comparing the back squat to the RDL at 60 kg. Figure 11 further shows large significant differences in individual GM RMS values between the three exercises at 60 kg, with mean RMS values showing higher EMG activity during the hip thrust.

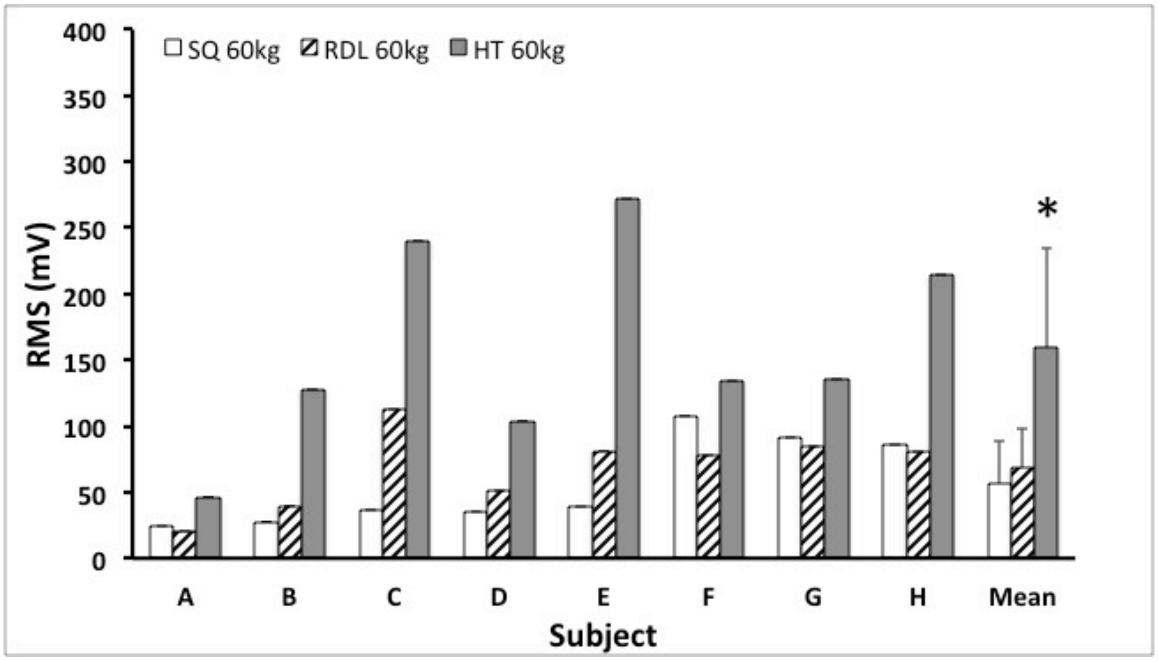

Figure 11. Root mean square of gluteus EMG activity during the concentric phase of the back squat, Romanian deadlift and barbell hip thrust at 60 kg for individual subject (A-H) and their average ± SD (Mean). * Significant difference ($P < 0.05$) between the barbell hip thrust, back squat and Romanian deadlift. Error bars represent the standard deviation.

Gluteus maximus EMG compared during the eccentric phase of each exercise

During the eccentric phase of each exercise, subjects displayed higher EMG activity in the GM during the barbell hip thrust at 60 kg and 1RM when compared to the back squat and RDL (Figure 12). At 60 kg, all subjects elicited higher GM RMS values by a large amount during the eccentric phase of the barbell hip thrust when compared to the eccentric back squat (-93.8 ± 41.7 mV; -1.58. *P* = 0.001) and eccentric RDL (-79.2 ± 35.2 mV; -1.34. *P* = 0.001). At 1RM, large significant differences were found when comparing eccentric phases of the barbell hip thrust to the back squat (-62.9 ± 26.1 mV; -1.30. *P* = 0.001) and RDL (-62.1 ± 38.0 mV; -1.28. *P* = 0.006), with the hip thrust displaying higher RMS. At 1RM, subjects elicited higher GM activity when comparing the concentric phase versus the eccentric phases of each exercise. Large significant differences were found in the barbell hip thrust (89.3 ± 48.2 mV; 1.84. *P* = 0.003), the back squat (89.5 ± 37.3 mV; 3.38. *P* = 0.001) and RDL (114.3 ± 39.9 mV; 4.84. *P* < 0.001), with all exercises displaying higher RMS values during the concentric phase. When comparing mean GM RMS during the eccentric phase of the exercise to the RMS elicited during the concentric phase at 1RM, the back squat elicited 39.1 ± 18% and the RDL displayed 33.8 ±

13.7% of total concentric activity. The eccentric phase of the barbell hip thrust displayed 57.4 ± 23.1% of GM concentric activity, showing higher eccentric activity both during the eccentric and concentric phases of the movement when compared to the other two exercises.

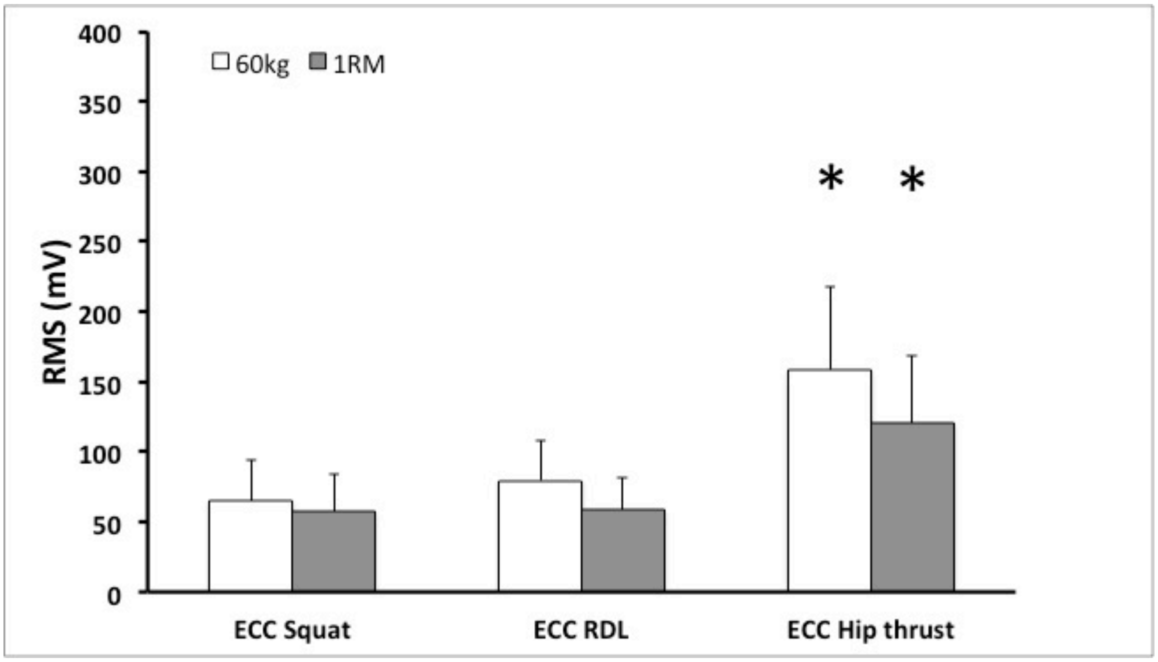

Figure 12. Mean RMS (root mean square) values of gluteus EMG activity during the eccentric phase the back squat, the Romanian deadlift and the barbell hip thrust at 60 kg and 1RM. * Significant difference (P < 0.05) comparing the barbell hip thrust to the back squat and Romanian deadlift at 60 kg and 1RM. Error bars represent the standard deviation.

Biceps femoris EMG

Regarding the hamstrings, biceps femoris (BF) activity was recorded during a MVIC in the normalization session, on the isokinetic dynamometer in a position of seated knee flexion, with the knee positioned at a 70° angle. BF RMS values during a one second window at peak torque produced in the MVIC were compared to RMS values recorded during the concentric phase of each exercise at 1RM. Large significant differences in BF activity were found when comparing the BF MVIC to the concentric phase of the barbell hip thrust (98.0 ± 42.4 mV; 0.99. *P* = 0.001) at 1RM, displaying higher activation of the BF during the barbell hip thrust (Figure 13).

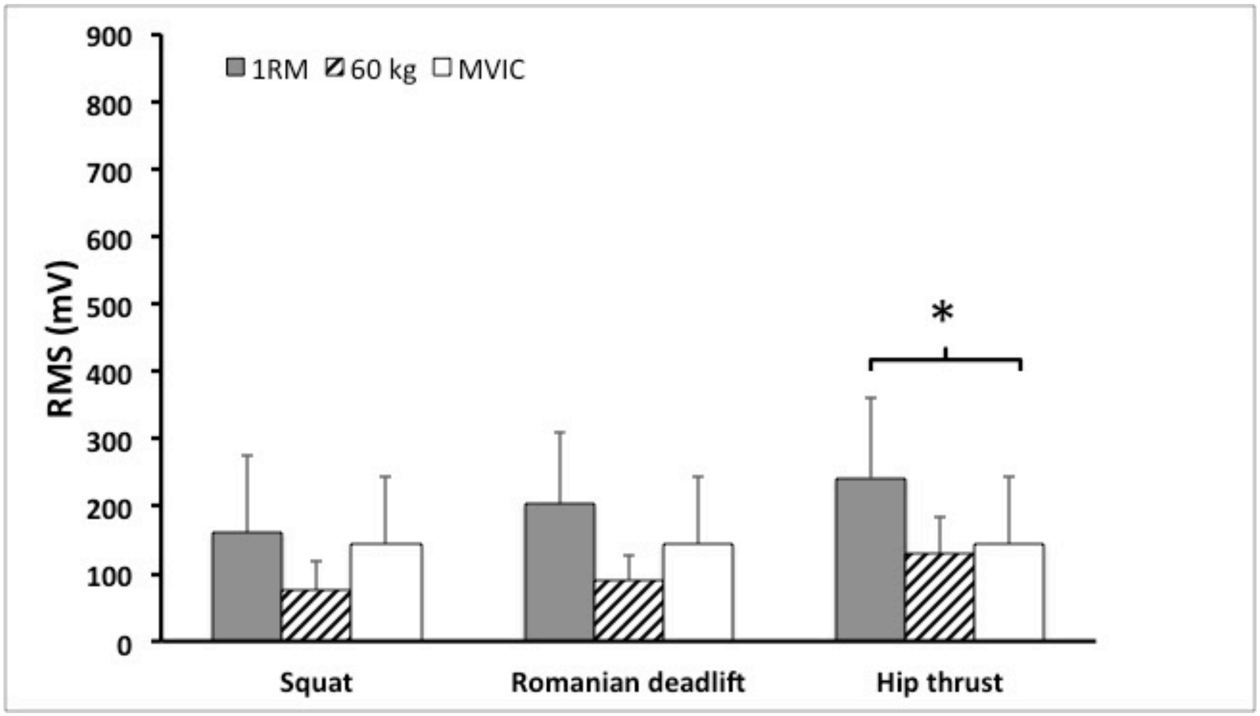

Figure 13. Mean RMS (root mean square) values of biceps femoris EMG activity during the concentric phase of the back squat, the Romanian deadlift, the barbell hip thrust at 60 kg and 1RM, and during an MVIC. * Significant difference (P < 0.05) comparing the barbell hip thrust 1RM to an MVIC. Error bars represent the standard deviation.

Moderate non-significant differences were found when comparing BF MVIC to the RDL 1RM (59.0 ± 126.8 mV; 0.60. *P* = 0.308) and trivial differences when compared to the back squat 1RM (16.1 ± 137.9 mV; 0.16. *P* = 0.791). BF RMS during MVIC was also compared to each exercise performed with at 60 kg; with trivial differences found when comparing the MVIC to the barbell hip thrust (-14.2 ± 62.5 mV; -0.14. *P* = 0.608), and moderate non-significant differences when compared to the RDL (-53.4 ± 72.2 mV; -0.54. *P* = 0.124) and the back squat (-68.5 ± 85.9 mV; -0.69. *P* = 0.101).

BF displayed small to moderate but not significant differences when comparing the exercises both at 1RM and at 60 kg**.** At 1RM loads, the BF RMS showed a moderate, non-significant difference between the hip thrust and the back squat (-81.9 ± 150.4 mV; -0.69. *P* = 0.239) and small, non-significant differences between the hip thrust and RDL (-39.0 ± 132.1 mV; -0.33. *P* = 0.508). Additionally, small non-significant differences (42.9 ± 68.2 mV; 0.38. *P* = 0.181) were found when comparing the back squat to RDL at 1RM.

Large to moderate differences in BF RMS were found when comparing the exercises at a load of 60 kg. Highest EMG activity in the BF was recorded during the barbell hip thrust when compared to the back squat and RDL. Large differences trending towards significance in RMS values were seen when comparing the barbell hip thrust with the back squat (-54.3 ± 61.5 mV; -0.98. *P* = 0.075) and the barbell hip thrust with the RDL (-39.2 ± 44.9 mV; -0.71. *P* =0.078), with the hip thrust displaying higher RMS values. Small non-significant differences (15.1 ± 33.9 mV; 0.35. *P* = 0.326) were found when comparing the back squat to the RDL at 60 kg.

When comparing 60 kg to 1RM, all exercises displayed higher BF RMS values at 1RM with large significant differences seen in the hip thrust (112.1 ± 68.1 mV; 2.02. *P* = 0.006), the back squat (84.6 ± 73.4 mV; 1.98. *P* = 0.030) and RDL (112.3 ± 74,4 mV; 3.19. *P* = 0.009).

Semitendinosus EMG

Semitendinosus (ST) activity recorded during a MVIC in the normalization session was done on the isokinetic dynamometer in a position of seated knee flexion, with the knee positioned at a 70° angle. ST RMS values during a one second window at peak torque produced in the MVIC were compared to RMS values recorded during the concentric phase of each exercise at 1RM. Small to moderate non-significant differences in ST RMS were found when comparing the MVIC to the concentric phase of the barbell hip thrust (31.6 ± 51.6 mV; 0.33. *P* = 0.191), the RDL (44.7 ± 78.1 mV; 0.47. *P* = 0.218) and the back squat (-49.3 ± 71.1 mV; -0.51. *P* = 0.145) at 1RM loads. ST RMS during MVIC was also compared to each exercise performed with a 60 kg load, with non-significant small differences found in ST RMS when comparing MVIC the barbell hip thrust (-43.4 ± 67.1 mV; -0.45. *P* = 0.170) and the RDL (-32.4 ± 63.5 mV; -0.34. *P* = 0.266). Moderate differences trending towards significance were seen when comparing MVIC to the 60 kg back squat (-73.3 ± 91.1 mV; -0.76. *P* = 0.099), with higher ST activity seen in the MVIC.

ST activity collected while performing the exercises at 1RM displayed moderate but not quite statistically significant differences when comparing the barbell hip thrust to the back squat (-80.9 ± 84.8 mV; -0.72. *P* = 0.059), trivial differences when comparing the hip thrust to the RDL (13.1 ± 91.8 mV; 0.12. *P* = 0.746) and large significant differences when comparing the back squat to RDL (94.0 ± 44.9 mV; 2.79. *P* = 0.002), with the RDL eliciting higher RMS (Figure 14).

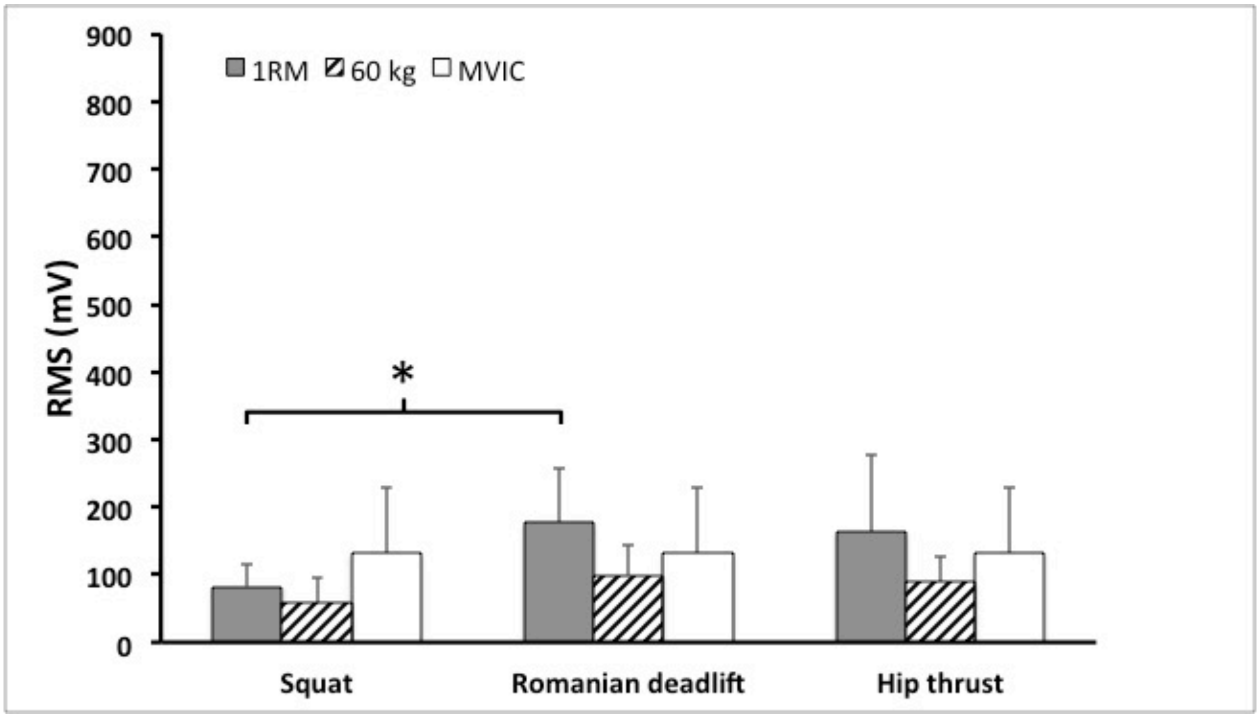

Figure 14. Mean RMS (root mean square) values of semitendinosus EMG activity during the concentric phase of the back squat, the Romanian deadlift, the barbell hip thrust at 60 kg and 1RM, and during an MVIC. * Significant difference (P < 0.05) comparing the back squat to the RDL at 1RM. Error bars represent the standard deviation.

At 60 kg, large significant differences in ST RMS were found when comparing the back squat to the RDL (40.9 ± 36.4 mV; 1.07. *P* = 0.033), with the RDL eliciting higher ST activity. Moderate but not significant differences were found when comparing the barbell hip thrust to the back squat (-29.9 ± 39.1 mV; -0.78. *P* = 0.114) and small non-significant differences between the hip thrust and RDL (11.0 ± 16.9 mV; 0.29. *P* = 0.168) at 60 kg load. When comparing submaximal to maximal loads in the RDL, large significant differences were found for the ST between 1RM versus 60 kg (77.1 ± 39.6 mV; 1.73. *P* = 0.002), with higher activity recorded during 1RM. Further, large significant differences were seen in ST RMS during the hip thrust when comparing at 60 kg to 1RM (75.0 ± 70.8 mV; 1.96. *P* = 0.041), with higher RMS values displayed during 1RM and moderate but non-significant differences were found in ST RMS between 60 kg and 1RM during the back squat (24.0 ± 38.8 mV; 0.63. *P* = 0.188) with ST RMS values seen slightly higher during 1RM.

Vastus lateralis EMG

Vastus lateralis (VL) activity recorded during a MVIC in the normalization session was collected on the isokinetic dynamometer in a position of seated knee extension, with the knee positioned at a 70° angle. VL RMS values during a one second window at peak torque produced in the MVIC were compared to RMS values recorded during the concentric phase of each exercise at 1RM. Large significant differences in VL RMS were found when comparing VL MVIC to the back squat (110.8.0 ± 67.7 mV; 0.90. *P* = 0.006), with the back squat displaying higher RMS values at 1RM. Large significant differences were also found when comparing VL MVIC to 1RM RDL (-136.7 ± 74.8 mV; -1.11. *P* = 0.003), with higher RMS values displayed during the MVIC. Also, when comparing VL MVIC to the barbell hip thrust, moderate differences with statistical significance were seen with higher VL RMS recorded during the MVIC (-72.8 ± 71.0 mV; -0.59. *P* = 0.046). VL RMS during MVIC was also compared to each exercise performed with a 60 kg load, displaying significantly higher VL activity during the MVIC when compared to the barbell hip thrust (-152.3 ± 77.0 mV; -1.23. *P* = 0.002) and RDL (-181.8 ± 92.5 mV; -1.47. *P* = 0.002). Further, trivial non-significant differences were found when comparing VL MVIC to the back squat (-4.7 ± 56.2 mV; -0.04. *P* = 0.848) at 60 kg.

At 1RM, the VL elicited higher activation in the back squat when compared to the RDL and the barbell hip thrust (Figure 15).

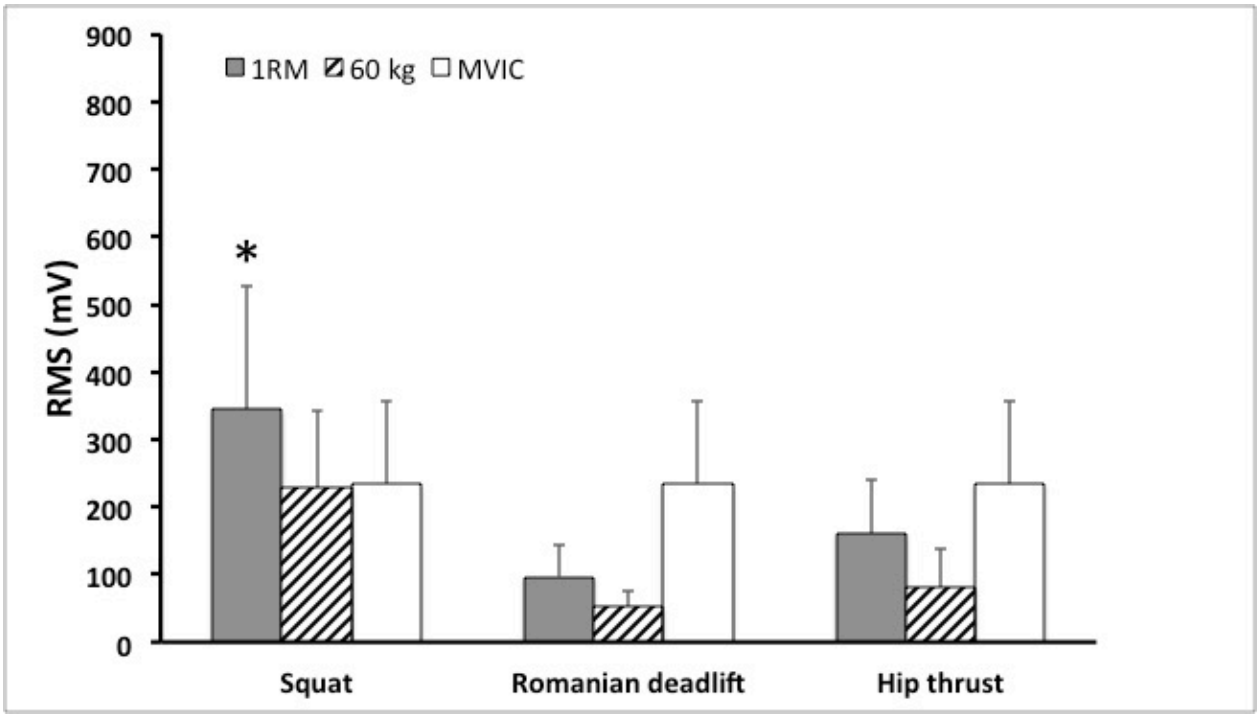

Figure 15. Mean RMS (root mean square) values of vastus lateralis EMG activity during the concentric phase of the back squat, the Romanian deadlift, the barbell hip thrust at 60 kg and 1RM, and during an MVIC. * Significant difference (P < 0.05) with the squat displaying highest RMS values when compared to barbell hip thrust and RDL at 1RM. Error bars represent the standard deviation.

Large significant differences in VL RMS were found when comparing the back squat to the RDL (-247.5 ± 126.8 mV; -1.36. *P* = 0.002) with higher VL RMS displayed during the back squat. The barbell hip thrust was also compared to the back squat with large significant differences found (183.6 ± 120.1 mV; 2.27. *P* = 0.009) at 1RM, with higher VL RMS during the squat. When comparing the barbell hip thrust to the RDL, moderate but significant differences (-63.9 ± 61.9 mV; -0.79. *P* = 0.045) were found with higher VL RMS during the barbell hip thrust. At 60 kg, large significant differences in VL RMS were seen with higher VL RMS during the squat when comparing the RDL to the back squat (177.0 ± 84.6 mV; 7.77. *P* = 0.002) and the barbell hip thrust to the back squat (147.6 ± 62.6 mV; 2.54. *P* = 0.001). Moderate but not significant differences between the barbell hip thrust and RDL (-29.4 ± 41.8 mV; -0.51. *P* = 0.140) were found. Additionally, statistically significant differences were found when comparing VL activity in the three exercises at 60 kg versus 1RM, with higher VL RMS at 1RM in the back squat (115.5 ± 74.7 mV; 1.01. *P* = 0.008), the barbell hip thrust (79.5 ± 44.3 mV; 1.37. *P* = 0.004) and RDL (45.1 ± 23.9 mV; 1.98. *P* = 0.003) when compared to 60 kg.

Vastus medialis EMG

Vastus medialis (VMO) activity recorded during a MVIC in the normalization session was collected on the isokinetic dynamometer in a position of seated knee extension, with the knee positioned at a 70° angle. VMO RMS values during a one second window at peak torque produced in the MVIC were compared to RMS values recorded during the concentric phase of each exercise at 1RM. Higher VMO RMS was collected during the MVIC with large significant differences found when compared to the concentric phase of the RDL (-188.5 ± 149.4 mV; -0.93. *P* = 0.020). In contrast, small non-significant differences were found when comparing VMO MVIC to the concentric phase of the barbell hip thrust (-71.1 ± 84.7 mV; -0.35. *P* = 0.088) and the back squat (80.1 ± 98.6 mV; 0.39. *P* = 0.096) at 1RM. VMO RMS during MVIC was also compared to each exercise performed with a 60 kg load, with large significant differences displaying higher VMO activity during the MVIC when compared to the barbell hip thrust (-219.8 ± 158.7 mV; -1.08. *P* = 0.014) and RDL (-255.5 ± 166.1 mV; -1.26. *P* = 0.008). Trivial differences were seen when comparing VMO MVIC to the back squat (-28.4 ± 57.2 mV; -0.14. *P* = 0.278) at 60 kg.

At 1RM, the VMO elicited higher activation in the back squat when compared to the RDL and the barbell hip thrust (Figure 16).

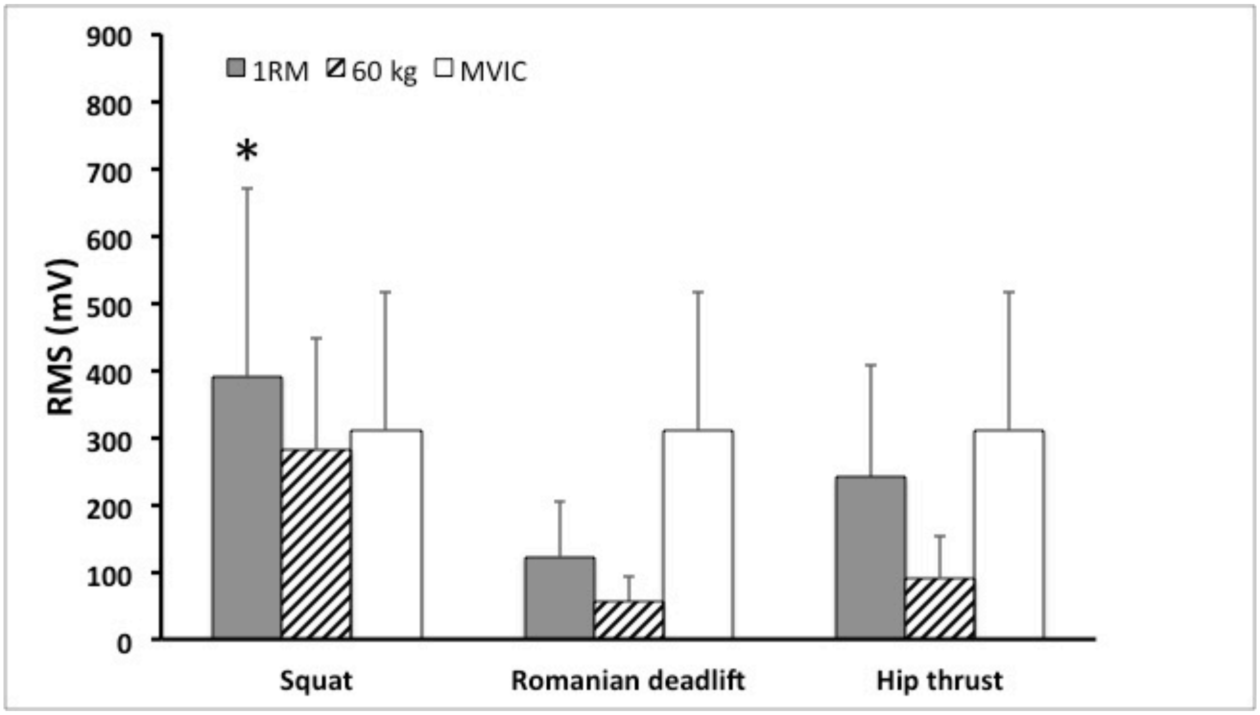

Figure 16. Mean RMS (root mean square) values of vastus medialis EMG activity during the concentric phase of the back squat, the Romanian deadlift, the barbell hip thrust at 60 kg and 1RM, and during an MVIC. * Significant difference (P < 0.05) with the squat displaying highest RMS values when compared to barbell hip thrust and RDL at 1RM. Error bars represent the standard deviation.

Large significant differences were found when comparing the RDL to the back squat (268.6 ± 224.8 mV; 3.31. *P* = 0.026) and the barbell hip thrust to the back squat (151.2 ± 128.8 mV; 0.90. *P* = 0.027) at 1RM, with the back squat displaying higher VMO RMS. When comparing the barbell hip thrust to the RDL at 1RM, moderate non-significant differences were found (-117.4 ± 139.6 mV; -0.70. *P* = 0.087) with the hip thrust eliciting slightly higher VMO RMS but not enough to reach statistical significance. At 60 kg, large significant differences were seen when comparing the RDL (227.1 ± 133.5 mV; 6.20. *P* = 0.005) and the barbell hip thrust (191.4 ± 120.0 mV; 3.06. *P* = 0.007) to the back squat, with the VMO eliciting higher activity during the squat. Moderate but non-significant differences were also found in VMO RMS between the barbell hip thrust and RDL (-35.7 ± 63.0 mV; -0.57. *P* = 0.222) when compared at 60 kg. Further, statistically significant differences were found when comparing VMO activity in the three exercises at submaximal versus maximal loads, with higher VMO RMS at 1RM during the barbell hip thrust (148.7 ± 128.4 mV; 2.38. *P* = 0.029) and RDL (67.1 ± 51.8 mV; 1.83. *P* =

0.018) when comparing 60 kg to 1RM. Also, moderate differences approaching significance were seen in VMO RMS between 60 kg and 1RM loads while performing the back squat (108.5 ± 109.5 mV; 0.66. *P* = 0.052), with 1RM showing higher VMO activity.

As the VL and VMO exhibited the highest activity compared to the other muscle groups, average values for the GM during 1RM, 60 kg and MVIC are also displayed (Figure 17) at a maximum scale of 900 mV to be compared to the values seen from the other muscle groups.

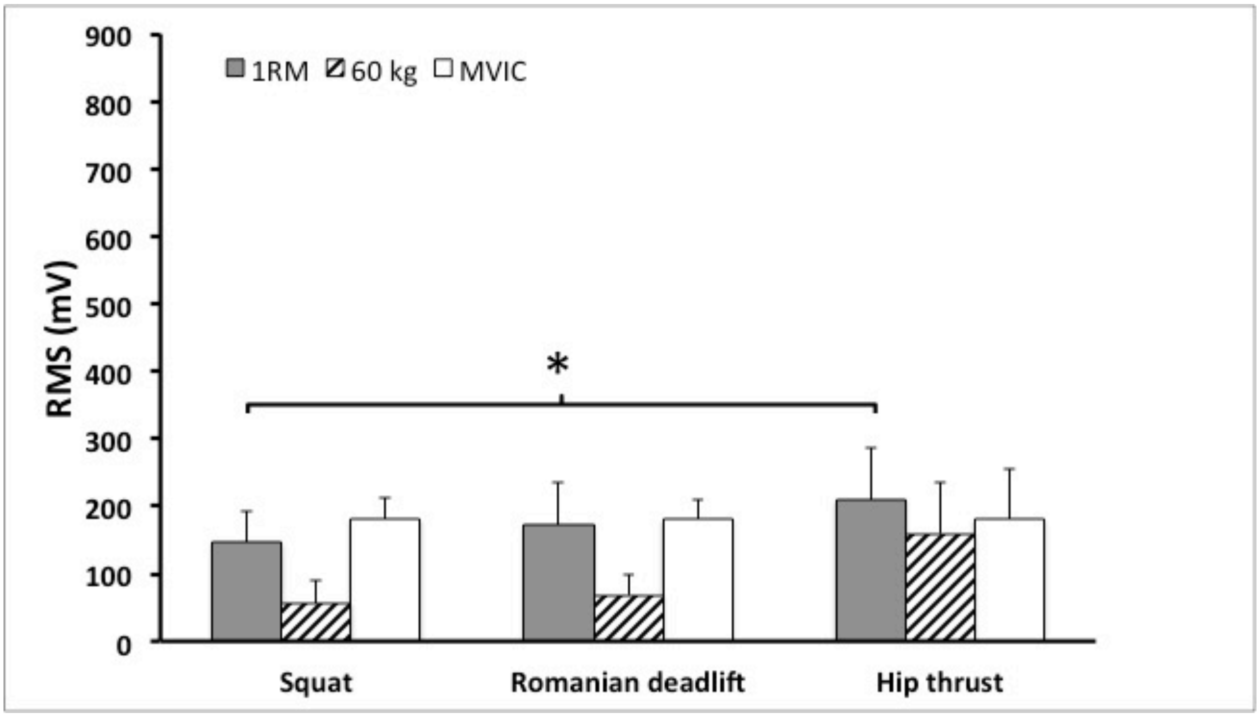

Figure 17. Mean RMS (root mean square) values of gluteus EMG activity during the concentric phase of the back squat, the Romanian deadlift, the barbell hip thrust at 60 kg and 1RM, and during an MVIC. * Significant difference (P < 0.05) comparing the barbell hip thrust to the back squat at 1RM. Error bars represent the standard deviation.

A summary of the average RMS values collected during the concentric phase of each exercise at 1RM, as well as the average RMS values obtained during a MVIC on the isokinetic dynamometer, are displayed on Table 1. Additionally, the average RMS values collected during the concentric phase of each exercise performed with 60 kg are also displayed on Table 2.

Table 1. Summary of mean RMS values during the concentric phase of each exercise for every muscle group tested at 1RM and during a maximal voluntary isometric contraction.

Muscle group	Mean RMS Squat 1RM (mV) ± SD	Mean RMS RDL 1RM (mV) ± SD	Mean RMS HT 1RM (mV) ± SD	Mean RMS MVIC (mV) ± SD
GM	147.0066 ± 45.08	172.6797 ± 62.94	209.6926 ± 76.20	180.4195 ± 96.70
BF	160.2148 ± 113.99	203.1017 ± 105.76	242.0743 ± 118.11	144.1208 ± 98.98
ST	82.5678 ± 33.67	176.5468 ± 81.41	163.4574 ± 112.98	131.8853 ± 95.86
VL	344.3169 ± 181.32	96.8264 ± 46.30	160.706 ± 80.85	233.504 ± 123.51
VMO	391.6746 ± 279.03	123.0792 ± 81.12	240.4509 ± 168.38	311.5394 ± 203.38

Table 2. Summary of mean RMS values during the concentric phase of each exercise for every muscle group tested at 60 kg and during a maximal voluntary isometric contraction.

Muscle group	Mean RMS Squat 60 kg (mV) ± SD	Mean RMS RDL 60 kg (mV) ± SD	Mean RMS HT 60 kg (mV) ± SD	Mean RMS MVIC (mV) ± SD
GM	55.9646 ± 33.24	68.3439 ± 29.32	159.1678 ± 75.75	180.4195 ± 96.70
BF	75.6321 ± 42.64	90.7599 ± 35.20	129.9359 ± 55.56	144.1208 ± 98.98
ST	58.6099 ± 38.18	99.4691 ± 44.64	88.4779 ± 38.26	131.8853 ± 95.86
VL	228.778 ± 114.25	51.7423 ± 22.79	81.1584 ± 58.08	233.504 ± 123.51
VMO	283.1289 ± 164.15	56.0242 ± 36.64	91.7624 ± 62.47	311.5394 ± 203.38

Table 3. Summary of 1RM loads lifted in kg for every subject, along with the mean values and standard deviation.

Subject	Squat 1RM (kg)	RDL 1RM (kg)	Hip Thrust 1RM (kg)
A	130	150	170
B	180	170	180
C	145	170	153
D	155	155	165
E	145	180	170
F	130	155	135
G	117	145	170
H	150	210	170
Mean	144.00	166.88	164.13
SD	19.18	21.03	13.95

Anthropometry and performance

For each participant, stance widths were measured in centimeters to determine the differences between exercises (Figure 18). Large differences with statistical significance were found when comparing the back squat to RDL (-18.6 ± 6.9 cm; -4.74. $P < 0.001$) and the back squat to the hip thrust (-7.5 ± 7.3 cm; -1.91. $P = 0.045$) with the subjects having a wider stance in the squat. Additionally, when comparing stance widths between the RDL and the hip thrust, large differences were seen (11.1 ± 9.2 cm; 1.38. *P* = 0.025) with the subjects having a wider stance during the hip thrust.

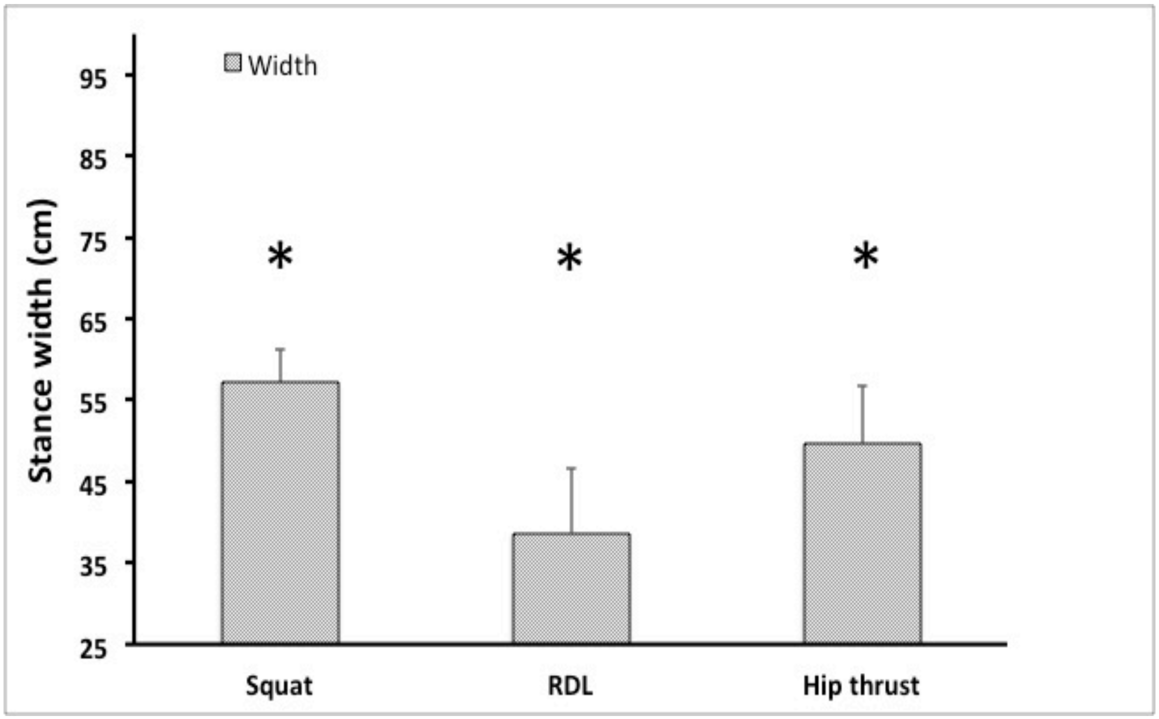

Figure 18. Average stance width (cm) during the back squat, the Romanian deadlift and the barbell hip thrust. * Significant differences ($P < 0.05$) between back squat, the Romanian deadlift and barbell hip thrust. Error bars represent the standard deviation.

Femur lengths for every participant were also measured and compared to the maximal torque produced on the isokinetic dynamometer during a knee extension MVIC (Figure 19) and no correlations ($r = 0.398$, correlation coefficient; $P = 0.329$) were found between femur length and torque production during knee extension. Femur lengths were also compared to squat-to-bodyweight ratio (1RM load/bodyweight) and no correlations ($r = 0.062$; $P = 0.883$) were found between squatting ability and femur length (Figure 20).

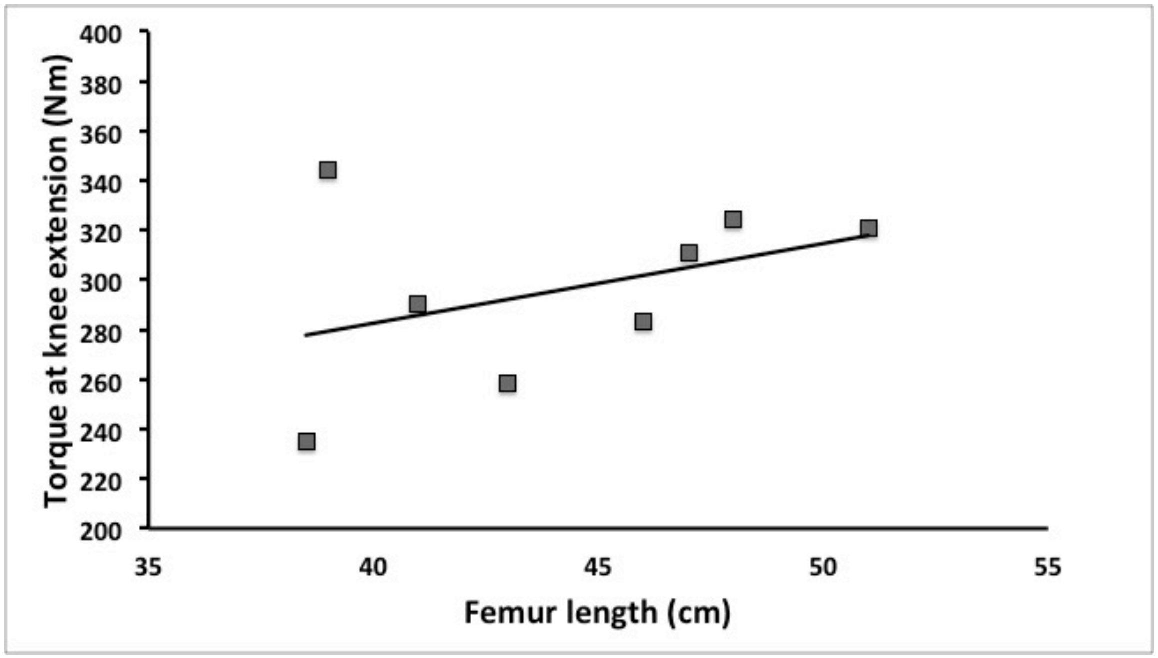

Figure 19. Maximal knee extension torque versus femur length

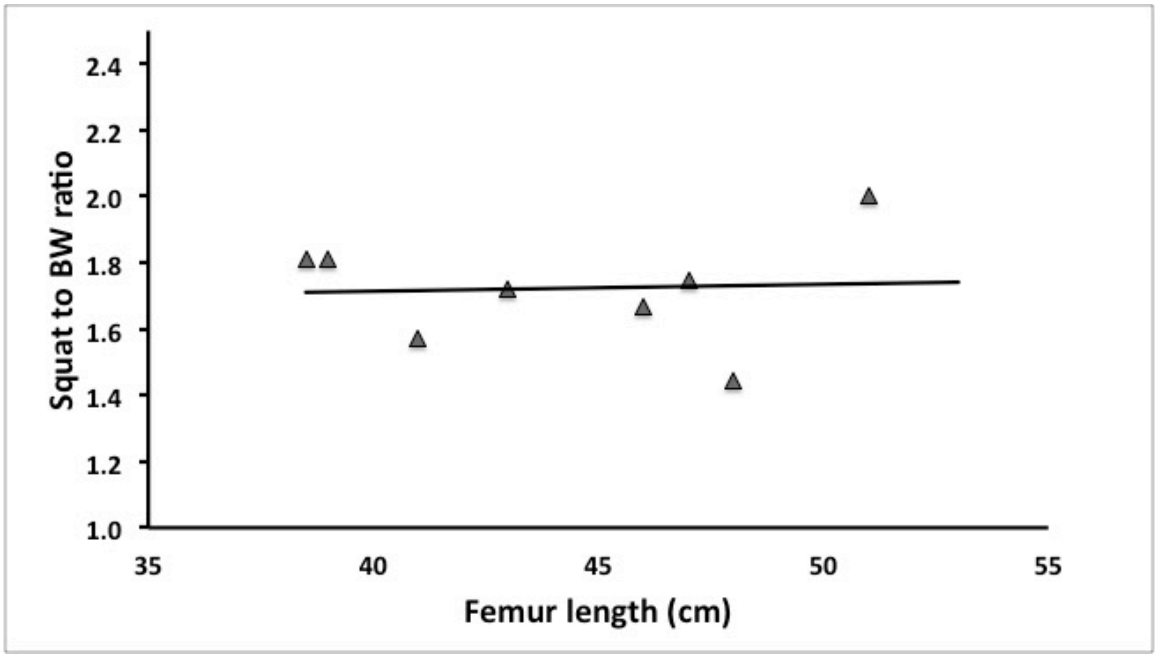

Figure 20. Squat to bodyweight ratio (1RM load/ bodyweight) versus femur length

CHAPTER 5

DISCUSSION

At 1RM loads, the barbell hip thrust and the RDL elicit higher GM activity when compared to the back squat (Figure 9, 17). As the load lifted has been shown to have an effect on EMG activity [14, 44], the average 1RM loads were compared between the back squat, the hip thrust and the RDL (Figure 1), with significantly lower loads lifted during the back squat (Figure 1). GM RMS was also compared between exercises at a standard 60 kg load across all three lifts, with the hip thrust eliciting higher average GM RMS than the RDL and back squat (Figure 10). GM RMS collected during an MVIC on the isokinetic dynamometer was also compared to the exercises performed at 1RM and 60 kg; there were no differences found between the hip thrust at 60 kg and an MVIC, displaying high activation of the GM in the hip thrust even during submaximal loads (Figure 4). No differences were seen when comparing GM RMS collected during the exercises at 1RM and an MVIC (Figure 3), displaying high levels of GM activity in all exercises at 1RM relative to an MVIC. Therefore, the conclusion can be made that while the HT elicited higher RMS than other exercises, all three exercises elicit high levels of GM activity during 1RM loads relative to an MVIC, but the barbell hip thrust achieved high GM activation without the need to increase external load.

Gluteus maximus

Higher activity displayed in the GM at both the 1RM and the 60 kg load could possibly be attributed to an isometric contraction produced at the top of the concentric action of the barbell hip thrust, while the load is applying resistance directly against maximal hip extension. For each plane of motion, a muscle's actions are based primarily on the orientation of its line of force relative to the joint's axis of rotation [37]. Consequently, while hip extension occurs along the sagittal plane for all exercises, the placement of the load on the body may have an effect on muscle recruitment. Load placement during the hip thrust providing resistance against movement along the sagittal plane may favor hip extensors, as opposed to the squat and RDL, in which the load applies resistance against movement along the frontal plane. Further, load positioning could explain the trivial and small non-significant differences seen in both of the investigated hamstring muscles' (i.e. BF and ST) activity when comparing the hip thrust at 60 kg to an MVIC, as the end of the concentric phase of the hip thrust is held in an isometric fashion against the load, which could possibly increase the RMS values at the end of the repetition. Previous research has shown that strength training effects are specific to the type of contraction (i.e., concentric, isometric) [5, 53], with this research supporting this assertion by showing differences in maximal dynamic versus maximal isometric activity in the GM (Figure 3). As previously stated, due to the lighter loads and the position in which the load is applied, the end of the range of motion of a submaximal hip thrust may have an isometric contraction by the GM allowed by maximal extension of the hip. This may explain the lack of differences seen between an MVIC and the GM, BF and ST during the barbell hip thrust at 60 kg. In contrast, at the end of the concentric movement of the back squat, the hips are fully extended with the load applying force downward on the back of the subject, not directly against hip extension. This could also be the case at the end of the concentric action of the RDL, as the load held by the subject is applying force downwards, pulling on the subject's arms, not acting directly against hip extension. Additionally, the hip thrust is performed in a way that places the subject in a position of knee flexion with slight lateral hip rotation, which has previously reported to favor the GM and lower ST activity in therapeutic exercises [96]. Further adding support to the contention that it is the direction of force application that matters, there were only small non-significant differences between the GM RMS in the hip thrust when comparing 60 kg to 1RM (Figure 7), with some subjects (D, E and H) displaying equal or higher GM RMS at 60 kg when compared to 1RM. The standard submaximal load of 60 kg represented a different relative intensity (Back squat: 42.30% of 1RM; RDL: 36.41% of 1RM; Hip thrust: 36.81% of 1RM) due to every exercise having a different 1RM load (Figure 2). The 60 kg load represented a higher relative intensity in the back squat when compared to the RDL and hip thrust. Despite this higher relative load during the back squat, there was higher GM activation during the hip thrust regardless of the low intensities. Conversely, GM RMS during the squat and RDL expectedly increased with an increase in load (Figure 5, 6). Therefore, the ability to perform an isometric contraction against resistance may be the reason for higher activity in the hip extensors during the 60 kg hip thrust. Further, no differences in GM activity between the RDL and hip thrust performed with maximal loads were seen. This supports the theory that the superiority of the hip thrust for activating the GM and BF may simply be a factor of the direction of force application and the reliance of the hip extensors to achieve hip lockout only at the end of the movement. Thus, if the objective is to elicit maximal GM activity with loads higher than 85% of 1RM, with the aim of improving strength development [60, 61], the RDL and hip thrust offer equal benefit with regards to eliciting maximal activation.

As common normalization methods analyze EMG during dynamic contractions as a percentage of MVIC, GM RMS was compared between maximal dynamic (1RM) contractions in each exercise and a MVIC at 180° of hip extension on the isokinetic dynamometer (Figure 3). For all of the three exercises, small non-significant differences were found displaying similar activation levels between the two types of maximal contraction (i.e. 1RM and MVIC), although some subjects displayed higher values in dynamic contractions when compared to isometric (Figure 3). While there were no statistically significant differences between the two types of maximal contraction in any of the lifts between MVIC and 1RM, significant differences were seen between the back squat and hip thrust 1RM, displaying maximal GM activity in the squat relative to an MVIC but not as high as seen during the barbell hip thrust. This finding highlights the potential to elicit higher activation of the GM during the barbell hip thrust when compared to the squat, which would be unseen if both exercises elicit 'maximal activation' relative to an MVIC. This further suggests that using an MVIC may not truly represent maximal activity in the muscle if the aim is to compare EMG during maximal dynamic movement. There are discrepancies in the literature regarding the selection of a reference value for normalization of EMG with common practice being to normalize to an MVIC [22, 77, 92, 97, 98]. The Journal of Electromyography and Kinesiology's guidelines for reporting research states that it is common to normalize EMG in relation to the value from an MVC, and that normalization of the EMG from one contractile condition can occur using the EMG from another condition [42, 99]. The SENIAM guidelines [41] have also instructed to divide the EMG collected by a reference contraction and suggest the use of an maximal voluntary contraction for this. However, as Burden [42] points out, both guidelines imply the use of an isometric contraction for the maximal voluntary contraction, but recognize it could also be dynamic, and neither group suggests when to use dynamic versus isometric. The findings in the present study highlight differences between maximal isometric and maximal dynamic contractions, and with common criticism of common methods of normalization yielding outputs that are higher than 100% of maximal activation [100, 101], a normalization method for maximal dynamic contractions is warranted.

Maximal levels of GM activation relative to an MVIC were seen during 60 kg submaximal loads when compared to an MVIC in the three exercises (Figure 4). GM displayed no differences in RMS between the hip thrust and MVIC, even though the subjects were lifting low relative intensities with an average of 36.8 ± 3.5% of 1RM in the barbell hip thrust (Figure 2). As mentioned, the differences seen between exercises at submaximal loads possibly highlights the subjects ability to fully contract the gluteus against resistance at the top of the concentric action, comparable to the MVIC produced at 180° of hip extension on the isokinetic dynamometer. GM RMS was also compared between exercises during each eccentric phase, with higher activity seen in the barbell hip thrust at 60 kg and 1RM. Higher eccentric activity in the GM during the hip thrust once again shows high GM recruitment when compared to the back squat and RDL, with high levels of activity during submaximal loads. Higher activity during the eccentric phase of the hip thrust compared to the squat and RDL could further the claim that hip extensors are highly active even with submaximal loads, possibly due to load positioning acting directly against hip extension.

Regarding the GM, this research shows that the barbell hip thrust elicited the highest activity of the three exercises, though there were no statistically significant differences between the barbell hip thrust and RDL. Additionally, even though the loads lifted were significantly lower in the back squat at 1RM, high GM RMS was still seen, as no differences were seen when compared to an MVIC, indicating high GM recruitment during the squat. Most importantly, no differences in GM RMS were seen when comparing 60 kg to 1RM in the hip thrust, which is interesting as the intensities lifted at 60 kg were significantly smaller for the hip thrust when compared to the back squat (Figure 2). Also, no differences were found when comparing a GM MVIC to the hip thrust at 60 kg, showing high GM activity without the need to increase the load. This may be useful for strength and conditioning professionals, as the hip thrust may be an uncomfortable exercise to perform with heavy loads. If the goal is to elicit high GM activity, heavy loads during the barbell hip thrust may not be necessary to accomplish it.

Biceps femoris

BF RMS was compared between exercises at 1RM and small differences with no statistical significance were seen (Figure 13). While BF RMS was expected to be higher during the RDL when compared to the back squat, knee extensor co-contraction [102] possibly attributes to the increased activity of the BF during the back squat at maximal loads of 1RM.

Previous research has established the RDL as an exercise which elicits high hamstring EMG activity [36, 44, 103], and this study found no significant differences in BF RMS between the RDL and hip thrust at 1RM. This shows high levels of hamstring activity in both of these exercises. This is important to point out as the hip thrust seems to target the BF just as much as an exercise that is known to be used for hamstring development. While differences were small and non-significant at 1RM, large differences trending towards significance were seen in BF RMS when performing the exercises at 60 kg, with the higher BF RMS recorded during the barbell hip thrust when compared to the back squat ($P = 0.075$) and RDL ($P =0.078$). Higher BF activity during the hip thrust at the sub-maximal load further supports the reliance on full hip extension with the load applying downward force against the hips, which is also seen in the GM, supporting this contention. With the hip thrust performed in a supine position and the load resisting along the sagittal plane, the hamstrings possibly act as primary movers during hip extension. Further, evidence has been previously found that state that the GM is less active in the prone position when the knee is flexed [104]. In contrast, the back squat has been previously reported to primarily use the knee extensors to move the load [105] and the RDL has been previously advocated to strengthen the back extensors [106], suggesting high back musculature recruitment to move the load. While no significant differences were found between all three exercises at 1RM, large significant differences in BF RMS were found between the hip thrust at 1RM and an MVIC performed at 70° of knee flexion (Figure 13). Higher BF RMS was displayed during the hip thrust at 1RM when compared to an MVIC, highlighting the BF acting as a primary mover during the hip thrust. Additionally, moderate but non-significant differences were seen between the BF MVIC and 1RM RDL, with the RDL displaying slightly higher RMS values for the BF. Again, using an MVIC as a reference for maximal activation may not be the best approach as the BF elicited significantly higher activity during dynamic movement. Furthermore, moderate to trivial differences with no statistical significance were found when comparing BF MVIC to the exercises performed at 60 kg, which shows comparable BF activity between the three exercises at submaximal loads and an MVIC at 70° of knee flexion.

These findings show high levels of BF activity during the barbell hip thrust even with lighter loads when compared to the other two exercises. Additionally, while there is an increase in BF activity when comparing 60 kg to 1RM in the three exercises, BF RMS at 60 kg shows no statistically significant differences when compared to the BF RMS at MVIC indicating high activation of BF with submaximal loads for all three exercises. The barbell hip thrust again shows higher activity in the hip extensors with submaximal loads when compared to the back squat and RDL, but similarly to the activity recorded from the GM, and at maximal loads there seem to be no statistically significant differences between exercises.

Semitendinosus

In contrast to the BF, ST RMS showed large significant differences when comparing the back squat to RDL at 1RM, showing higher ST activity during the RDL (Figure 14). Trivial, non-significant differences were seen when comparing the hip thrust to the RDL and moderate differences approaching significance were seen between the hip thrust and the back squat ($P = 0.059$), with the hip thrust eliciting higher ST activation than the squat at 1RM. As previously seen with the GM and BF muscle groups, these findings further show the hip thrust favoring the hip extensors just as much as the RDL and more so than the back squat during maximal loads. Similarly to 1RM loads, when comparing the exercises at 60 kg, ST RMS was higher during the RDL when compared to the squat. Small, non-significant differences were seen between the RDL and the hip thrust and moderate but non-significant differences were seen between the back squat and the hip thrust with 60 kg. This finding is interesting, as the hip thrust displays higher BF activity during submaximal loads when compared to RDL, but no differences are seen in ST RMS when comparing RDL to hip thrust. High ST RMS during the RDL agrees with previous findings [36, 96] that display maximized ST activity during the RDL due to the exercise performed in a position of knee extension. While stance width has shown no effect on thigh musculature activity in the back squat [24], no research was found on hamstring activity differences due to stance width in resistance training exercises that focus on hip extensor musculature. When comparing stance width between the back squat, RDL and hip thrust, significantly narrower stances were seen when performing the RDL (Figure 18). While it has been previously shown that exercises performed with knee extension favor semitendinosus activity more than exercises done with knee flexion [96], stance width may also have an effect on hamstring activity. When comparing ST RMS between 60 kg and 1RM loads, large differences were seen in the RDL and hip thrust, with 1RM loads eliciting higher activity compared to submaximal loads in both exercises, displaying increased recruitment of the ST in these two exercises as the load increases. In contrast, moderate but non-significant differences were seen in the back squat when comparing loads, with ST activation seen to be higher during 1RM. These findings highlight the biarticular properties of the hamstrings musculature, which agree with previous research and further suggest that the ST is highly active in exercises that perform hip extension along with knee extension [96]. In contrast to the BF, which is shown to elicit high RMS in exercises that perform hip extension along with knee flexion (i.e. back squat and hip thrust). No differences were found when comparing exercises at 1RM to an MVIC, displaying equal levels of ST activation during dynamic movement and maximal isometric contractions in all exercises, which show high ST activity during the back squat relative to an MVIC. When ST RMS was compared between the exercises performed at 60 kg and a MVIC, small non-significant differences were found comparing MVIC to RDL and MVIC to hip thrust, displaying high levels of ST activity with submaximal loads during the RDL and hip thrust relative to an MVIC. Moderate differences trending towards significance were seen when comparing MVIC to the back squat ($P = 0.099$), displaying slightly higher ST RMS values during the MVIC. This finding shows that the hip thrust and RDL both favor ST activity when performing hip extension and further shows high activity, relative to an MVIC, without the need to increase the load.

Findings on ST RMS suggest high levels of ST activity during the RDL and hip thrust when compared to the back squat at 1RM. Moderate differences approaching significance were seen between the hip thrust and back squat displaying slightly higher ST RMS in the hip thrust, and large significant differences seen when comparing the back squat and RDL, with RDL displaying higher ST activity. Trivial differences between the RDL and hip thrust at 1RM were seen, supporting the inference that the hip thrust uses hamstring musculature just as much as the RDL to perform hip extension. Furthermore, the differences between BF and ST in the RDL and hip thrust during submaximal loads may be due to the RDL performing hip extension along with knee extension. This has been previously shown to favor ST activity [96] compared to exercises that are done with knee flexion. Comparable levels of ST activity between 60 kg RDL and hip thrust and an MVIC further show high levels of ST without the need to increase to maximal loads for these two exercises. These findings benefit strength and conditioning coaches, as the prescription of high loads may not be necessary if the goal is to maximize ST activity. Further, the hip thrust and RDL display higher activity for the ST when compared to the back squat, supporting the contention that the RDL and hip thrust target hip extensor musculature more than the back squat. Importantly, even though the RDL and hip thrust show higher levels of activity in the ST when compared to the back squat; the ST RMS shows no differences between 1RM back squat and MVIC, displaying high ST activation during the squat at maximal loads.

Vastus lateralis and vastus medialis

When comparing quadriceps (VL and VMO) activity at 1RM between exercises, VL and VMO activity was expectedly higher during the back squat when compared to the hip thrust and RDL (Figure 15, 16) since there is little flexion or extension of the knee during RDL or hip thrust. Differences between VL and VMO activity are seen when comparing an MVIC during a knee extension to the exercises at 1RM. VL RMS was significantly higher during the back squat 1RM when compared to an MVIC, as opposed to the VMO, which showed no significant differences when comparing an MVIC to the 1RM back squat and 1RM hip thrust. While VMO RMS was higher in the back squat when compared to the other exercises, no differences were seen in VMO activity when comparing an MVIC to the barbell hip thrust, which shows high VMO activity in the hip thrust relative to an MVIC. Higher VMO activity during the hip thrust could be attributed to the very high loads lifted and the increased activity of the hamstrings during the hip thrust. Previous research has shown that VMO activity is higher as the load increases around the knee joint [107] and with the hip thrust eliciting high biceps femoris activity, possible quadriceps co-contraction has a significant effect on maintaining knee stability [108]. This difference between VL and VMO was interesting, as with the other exercises RMS values were higher in maximal dynamic movement compared to an MVIC when the muscle was a prime mover during the exercise performed. Displaying no significant differences in VMO activity between an MVIC and 1RM back squat could possibly suggest that relative to an MVIC, the VL was used to a greater extent than the VMO when performing the back squat at 1RM. It could also indicate that the knee extension angle used for the MVIC is adequate to elicit maximal activity in the VMO but not the VL. RDL and hip thrust were also compared at 1RM and showed moderate differences between VL and VMO RMS, with the hip thrust favoring higher VL and VMO activity than the RDL. This finding could be attributed to the hip thrust being performed with the knees bent at 90° as opposed to the RDL, which is performed with only slight knee flexion. This research shows that while the back squat elicits higher knee extensor activity compared to the RDL and the hip thrust, high activity of the VMO relative to an MVIC is seen during the hip thrust when comparing maximal dynamic and isometric contractions. This finding may be due to the VMO previously shown to be highly active in exercises that involve hip adduction [109]. Since hip adductors (i.e. GM and BF) [37] are shown to be highly active during the hip thrust, a component of hip adduction may be responsible for the VMO eliciting high activity, by providing knee stability during hip extension on the hip thrust. No differences in VL and VMO RMS were seen when comparing 60 kg back squat to an MVIC, which again shows very high activity during easily performed submaximal loads when compared to a maximal effort MVIC.

This study shows that VL and VMO activity is higher in the back squat when compared to the hip thrust and RDL at 1RM and 60 kg (Figure 15, 16). Differences in VL and VMO were seen as the VL had higher RMS during 1RM back squat when compared to MVIC, but VMO displayed no differences between MVIC and 1RM during the hip thrust. High VMO activity during the hip thrust suggests the involvement of knee extensors in order to provide knee stability during the lift. This is an important finding for strength and conditioning professionals, as the hip thrust may be used as an alternative to the back squat when looking to elicit high VMO activity without the need for knee extension, which may be useful during rehabilitation exercises. Comparing the exercises at 60 kg to an MVIC again provides an indication of the muscles that are used as prime movers during the exercise. VL and VMO showed no differences between RMS collected during an MVIC and the back squat performed with 60 kg, which further shows high activation during submaximal dynamic contractions relative to an MVIC.

Anthropometric measures

Analysis of anthropometric measures in each subject show no relationship between femur length and the subject's ability to produce maximal torque during an MVIC at 70° of knee extension (Figure 19), or squatting ability measured by squat to bodyweight ratio (1RM in kg/ bodyweight) (Figure 20). Previous research by Schoenfeld [105] has investigated squatting kinematics and the different characteristics with respect to the ankle, knee and hip joints that affect squat performance, but no studies were found that directly assessed the relationship between femur length and squat strength. While many anatomical variations (i.e. mobility, hip anatomy, ratio of torso length to leg length) may predispose athletes to have disadvantages in achieving desired positioning during the back squat [110]; femur length, along with subject's height and tibial length has been shown to account for the subject's ability to maintain the heels on the ground when squatting [111, 112], which may have an effect on squat strength. Though femur length is only one of the many characteristics that affect squat performance, no correlations were seen between the better squatters, measured by squat-to-bodyweight ratio (Figure 20); suggesting squat strength and the ability to squat heavier loads relative to one's bodyweight is not limited to femur anatomy, but a combination of different anatomical and physiological factors. This lack of relationship may be of use to strength and conditioning coaches, as it is often believed that long femurs negatively impacting squatting ability and weight lifting performance.

Conclusions

Though differences in muscle activation are seen during maximal dynamic movement, differences in muscle activity may not be indicative of which muscles are used as prime movers due to maximal co-contraction and increased overall activity during maximal effort. However, investigating the differences in RMS values when comparing the exercise performed with submaximal loads to an MVIC might provide an indication of which muscle group is active to a greater extent throughout the movement, though the differences in relative intensities (Figure 2) may affect the movement patterns, which in turn may affect muscle activity levels. This was observed for the GM, with the hip thrust displaying no differences between 60 kg and MVIC, as well as for the ST, on which the RDL and hip thrust show no difference between 60 kg and MVIC. This is also seen for the VL and VMO, which show no differences when comparing 60 kg back squat to an MVIC as well. Conversely, for the BF, when comparing muscle activity in this manner, there were no differences when comparing an MVIC to the three exercises performed at 60 kg, which could indicate high BF activation during these three movements or that the MVIC performed at 70° of knee flexion may not be entirely suitable position to elicit high BF activity. Furthermore, higher or equal RMS values seen when comparing the back squat, the RDL and hip thrust to an MVIC; even during submaximal loads ranging from 28 – 51% of 1RM, suggesting that if the goal is to elicit high activity in the muscle, increasing external load in these exercises may not be necessary.

Another important finding is the subjects' ability to elicit higher or equal RMS values between the exercises performed with a submaximal load and a MVIC isolating each muscle group. This was unexpected as the subjects were told to maximally contract their muscle during the MVIC after a series of warm ups that allowed for them to reach perceived 100% of maximal effort. In contrast, performing the exercises with a load of 60 kg, which ranged in intensity from 28 – 51% of 1RM across the different lifts, was far from maximal yet displayed equal or higher activity in some muscle groups for each exercise. This finding may be of use for future research that aims to investigate muscle activation during dynamic movement and emphasizes the differences between maximal isometric and dynamic contractions. While most of the literature uses maximal isometric contractions as a reference of maximal activity in the muscle, other researchers have normalized dynamic movement [113, 114] to dynamic contractions, though these methods are used during gait analysis, which is submaximal in nature. To analyze maximal dynamic contractions, such as the ones performed in resistance training exercises, another form of normalization may be warranted for EMG collected during maximal dynamic movement. The present study showed that muscle groups elicited significantly higher RMS values during 1RM, as well as submaximal loads in some cases when compared to MVIC. Thus, in order to make valid inferences for dynamic movement, a method to elicit 100% of muscle activity is needed.

In conclusion, the present study demonstrates that there are significant differences in muscle activation for the back squat, the RDL and barbell hip thrust, however clearer differences between exercises are seen when comparing the exercises to a MVIC. Findings suggest that the barbell hip thrust elicits greater GM activity when compared to the back squat and RDL, though no significant differences were seen between the hip thrust and RDL and the back squat still displayed high GM activity relative to an MVIC. Additionally, it may not be necessary to increase the external load in order to elicit higher GM activation during the barbell hip thrust. This is a very important finding for strength and conditioning professionals, as the hip thrust is often used as a strength-building exercise, requiring the athletes to lift high intensities relative to their 1RM. It is also important to identify that with maximal loads during the hip thrust, subjects in this study anecdotally reported discomfort on the hips where the bar rests, even while using a lifting pad on the barbell. This discomfort caused the subjects to express inability to finish the repetition not because of lack of strength, but due to the pain felt at the hips from the heavy loads. In contrast with the back squat, higher loads lifted for the barbell hip thrust may be attributed to different biomechanical characteristics such as greater hip extensor musculature involvement, lack of knee extension and load placement directly on the hip crease. Therefore, strength and conditioning coaches who aim to isolate hip extensor musculature activation may equally benefit from prescribing the hip thrust and RDL. Further, the back squat displayed the highest levels of knee extensor activity as well as high hip extensor activity relative to an MVIC at 1RM loads; which still places the back squat as a fundamental exercise to be part of any resistance training program involving movements that encompass both knee and hip extension.

CHAPTER 6

RECOMMENDATIONS

Practical implications

This study has shown that there are significant differences in muscle activation between three resistance training exercises that target the development of the lower body musculature. While the barbell hip thrust elicited greater activation of the GM when compared to the RDL and back squat at 1RM loads, no significant differences seen between the RDL and hip thrust, thus demonstrating the RDL is equally as effective as the hip thrust if the aim is to elicit high GM activity. The ability for the hip thrust to elicit higher neuromuscular activation of the GM with a submaximal load of 60 kg is an important finding for strength and conditioning coaches looking to prescribe this exercise, as the barbell hip thrust poses to be an uncomfortable movement to perform with maximal loads. The hip thrust eliciting near maximal muscle activation at 60 kg represents that its effectiveness for GM activation is likely related to the direction of force application and the isometric hold at the end of the range of motion. While there is no direct evidence for this contention, further investigation of where in the range of motion maximal muscle activation is achieved in the hip thrust could elucidate the answer.

The back squat elicited high activation of the GM relative to an MVIC, as well as high activation of the BF and quadriceps at 1RM loads. The ability for the back squat to elicit high activation of hip extensors as well as knee extensors is an important finding for strength and conditioning coaches, as most movements involved in the sporting field encompass a combination of hip extension as well as knee extension. Therefore, the hip thrust may be useful at submaximal loads if the aim is to isolate the GM for hypertrophic purposes, but the back squat's ability to simultaneously elicit high activity in the knee and hip extensors may prove to be more useful if the goal is to improve athletic ability.

The main limitation of this study is the inability to normalize muscular activity collected during 1RM to a maximal dynamic voluntary contraction that elicits true maximal activation. While the SENIAM guidelines were followed, it is previously stated by Konrad (2005) [43] that systematic research studies on the effectiveness of MVIC positions for maximal muscular activation are still missing, thus the positions used for the normalization protocol may be the reason for resistance training activities exceeding the established threshold for 100% activation. Further, while the knee extension angle in this study was appropriate for maximal activation [43], the same angle was used to measure hamstring activation during knee flexion, which may have underestimated hamstring activity. Additionally, this study displays differences between maximal isometric and maximal dynamic contractions and the need to elicit maximal activity is warranted in order to make valid inferences. Another limitation was the inability to quantify hip extension angles during each exercise accurately, as the electronic goniometer used based the degrees measured from the voltage change provided by the strain gauge. At deep hip flexion angles, folding of the skin or clothing would interfere with the results displaying inconsistently higher or lower degree values. Therefore, further research is needed to determine if indeed the maximal activity of the GM during the hip thrust is caused by a MVIC at the top of the concentric action, or if there are any differences in activation throughout the concentric phase in each exercise. Further research is also needed to examine the influence each of these exercises has on sporting field performance over a prolonged training period. While high activity of the musculature measured provides an indication of how these exercises recruit each muscle group, ultimately the goal of a strength and conditioning coach is to determine the exercises that provide maximal transference of physiological adaptation into the sporting field. Research that investigates which exercise translates better to increases in performance markers such as sprinting or jumping, may provide further reasoning behind the selection of the back squat, RDL or hip thrust if the aim is to improve physical performance.

Recommendations for further research

The need to elicit maximal activation of a muscle during dynamic movement is still warranted, as this study shows higher neuromuscular activity when performing dynamic tasks during maximal loads than a maximal isometric contraction. Also, the comparison of muscle activity between exercises involving hip extension will need to consider the careful measurement of hip angles during dynamic movement, as the back squat has component of knee adduction while the RDL does not and this may have an effect on hip extensor activity.

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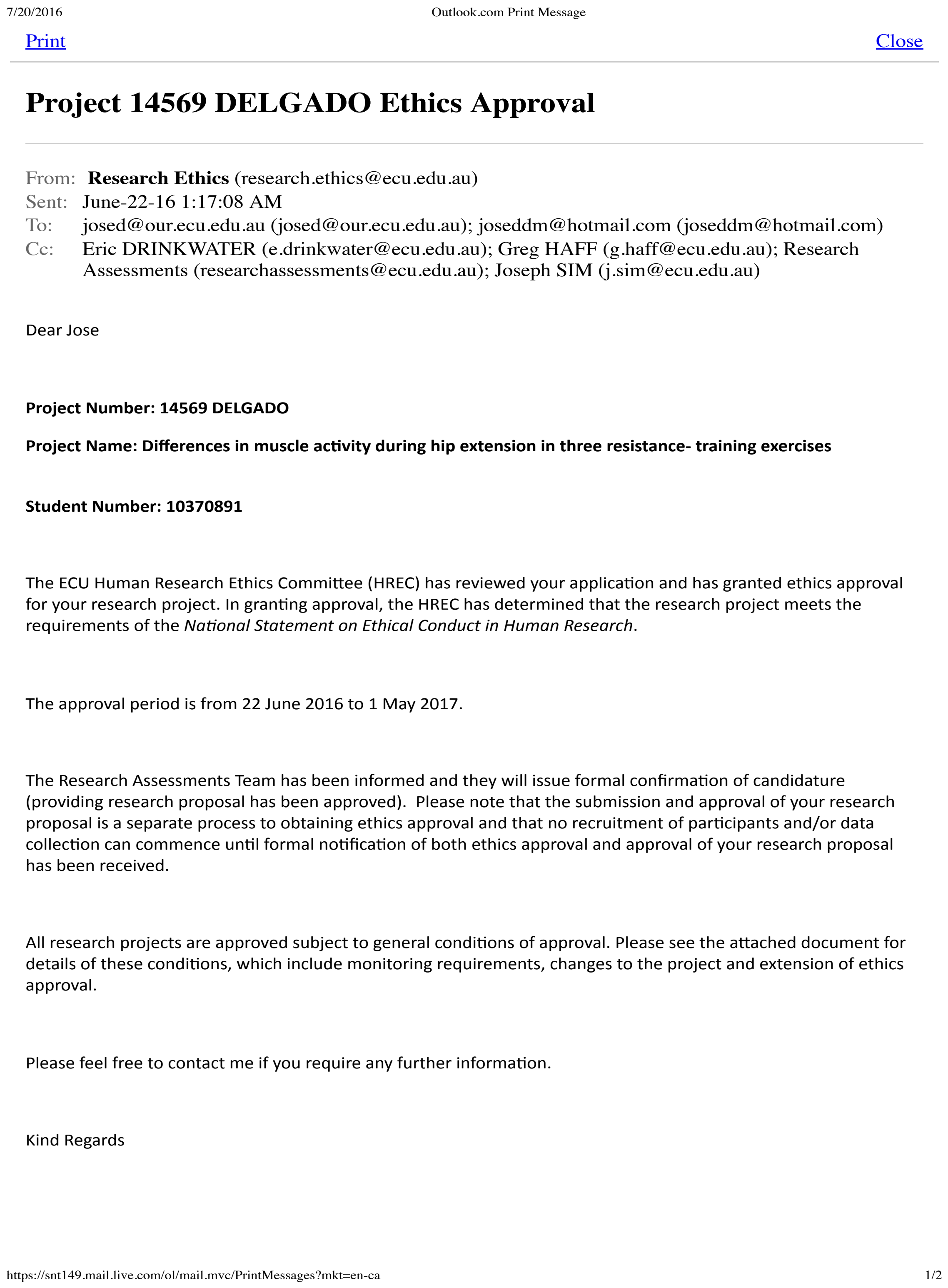
APPENDIX A

Ethics Approval Letter



7/20/2016 Outlook.com Print Message

Print Close

Project 14569 DELGADO Ethics Approval

From: **Research Ethics** (research.ethics@ecu.edu.au)
Sent: June-22-16 1:17:08 AM
To: josed@our.ecu.edu.au (josed@our.ecu.edu.au); joseddm@hotmail.com (joseddm@hotmail.com)
Cc: Eric DRINKWATER (e.drinkwater@ecu.edu.au); Greg HAFF (g.haff@ecu.edu.au); Research Assessments (researchassessments@ecu.edu.au); Joseph SIM (j.sim@ecu.edu.au)

Dear Jose

Project Number: 14569 DELGADO

Project Name: Differences in muscle activity during hip extension in three resistance- training exercises

Student Number: 10370891

The ECU Human Research Ethics Committee (HREC) has reviewed your application and has granted ethics approval for your research project. In granting approval, the HREC has determined that the research project meets the requirements of the *National Statement on Ethical Conduct in Human Research*.

The approval period is from 22 June 2016 to 1 May 2017.

The Research Assessments Team has been informed and they will issue formal confirmation of candidature (providing research proposal has been approved). Please note that the submission and approval of your research proposal is a separate process to obtaining ethics approval and that no recruitment of participants and/or data collection can commence until formal notification of both ethics approval and approval of your research proposal has been received.

All research projects are approved subject to general conditions of approval. Please see the attached document for details of these conditions, which include monitoring requirements, changes to the project and extension of ethics approval.

Please feel free to contact me if you require any further information.

Kind Regards

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APPENDIX B

Informed Consent Documents

Subject Informed Consent Form

I ____________________________, consent to participating in the research project entitled: "**Differences in muscle activity during hip extension in three resistance-training exercises**"

Declaration

- I have carefully read, and clearly understand the content contained within the information letter and consent form.
- I agree to participate in this study, and provide my consent freely, without any undue pressure or expectation.
- I understand that all study procedures will be performed as outlined in the information sheet, a copy of which I have retained for my own records.
- I am aware of the physiological measures that will be taken (i.e. EMG, rate of force development, 1-repetition maximums of back squat, hip thrust and Romanian deadlift).
- I have had any and all questions answered to my satisfaction.
- All questionnaires related to this study have been completed to the best of my knowledge.
- I am aware that I may withdraw from this study at any stage, without any reason or prejudice.
- I agree that the data collected from this study may be published, providing my name and any information containing my identity is removed. This includes data related to my 1-repetition maximum back squat, barbell hip thrust and other variables associated with this assessment as outlined in the information letter.
- I am aware that all information collected during this research will be preserved for possible future use in another research project. I am aware that all data collected will be stored

securely on ECU premises and kept for 15 years after the completion of the project and then destroyed.

The researcher certifies that the subject has a full understanding of the procedures and their involvement as a participant, as outlined in this form. The subject has provided verbal confirmation of their understanding, which meets the researchers satisfaction prior to signing the form.

Please provide a next of kin contact information in case of emergency

Name ________________________ **Contact number** __________________________
Relationship to participant ____

Participant Name __________________________ **Date (DD/MM/YYYY)** ____________
Participant Signature ______________________

Researchers Name __________________________ **Date (DD/MM/YYYY)** ____________
Researchers Signature__________________________

If you have any questions or require further information about the research project, please contact chief investigator Jose Delgado at 043 707-2069, email josed@our.ecu.edu.au. If you have any concerns or complaints about the research project and wish to talk to an independent person, you may contact:

Research Ethics Officer
Human Research Ethics Officer
Edith Cowan University
100 Joondalup Drive
JOONDALUP, WA 6027
Phone (08) 6304-2170 Email: research.ethics@ecu.edu.au

Information Letter to Participants

Title of the Project: Comparison in muscle activity between the back squat, Romanian deadlift and barbell hip thrust during hip extension

Chief investigator: Jose Delgado **Email:** josed@our.ecu.edu.au

Supervisors: Prof. Ken Nosaka and Dr. Eric Drinkwater

Thank you for expressing an interest in this study. The purpose of this information letter is to fully inform you of the purpose and the nature of this study, as well as provide you with an overview of the study in which you may participate. Please read all information carefully and do not hesitate to contact the chief investigator if anything is unclear or requires further explanation.

Be advised that this research project is being undertaken as part of the requirements of a Masters of Science degree at Edith Cowan University.

Background

Hip extension plays an important role in sports performance, as rapid acceleration of the lower limbs is critical during powerful movements such as sprinting and jumping. Strength and conditioning professionals aim to train athletes' muscles involved in hip extension to improve sporting performance with three commonly used exercises: the back squat, the Romanian deadlift (RDL) and the barbell hip thrust. Recent research has demonstrated the barbell hip thrust to be superior to other exercises that target hip extension, but a proper comparison to establish which exercise activates hip extension musculature to a greater extent is yet to be conducted. This research will provide coaches with sound reasoning behind the selection of exercises targeting hip extension musculature.

Purpose of the study

The purpose of this study is to investigate the potential differences in muscle activity of hip extensors during the barbell hip thrust, high-bar back squat and Romanian deadlifts in resistance-trained individuals.

Methods

Participants

As a volunteer, you must be a male, 18-30 years of age. You must have at least one year of strength-training experience, be able to perform the high-bar back squat with 150% of your body weight, and must be without any current musculoskeletal injuries. Data collected from you in this study will be kept in a secure cabinet on the university premises for 15 years. No one will have access to the data collected about you, aside from the researchers involved in this investigation. Prior to the onset of this study you must complete an informed consent form, a lifting history questionnaire, medical questionnaire and pre-exercise checklist.

You will be required to demonstrate proficient high-bar back squat technique and will be screened for contraindications to exercise with the use of an adult pre-exercise screening tool, provided by Exercise & Sport Science Australia (ESSA), in order to participate in this investigation. Medical clearance will be required if any positive responses are revealed from the ESSA form. The adult pre-exercise screening tool (ESSA) form is designed to eliminate anyone who is unhealthy or would be at risk if they were to perform strenuous exercise.

Procedure

As a participant in this study you are required to attend one familiarisation session (~30min) and 2 testing sessions (3-7 days apart) approximately 3 to 4 hours for each session. Sessions will take place at Edith Cowan University, Joondalup Campus, commencing in the Physiology Lab (building 19, room 19.150) and the Strength Lab (building 19, room 19.149).
The first session will take approximately 30 minutes and will be used to familiarize you with the testing procedures, as well as completing all required documentation.

The second session will be used to record your of height, weight, perform two flexibility tests, electrode placements, normalisation protocol and 1RM testing of the back squat, RDL and barbell hip thrust. Electromyography (EMG) electrodes will be used to quantify muscle activity during the procedures and ultrasound will also be used to determine proper electrode placements before every session. This will be recorded in order to determine the loads (%1RM) that will be used for session 3.

Session 3 will consist of the same normalisation protocol used in session 2, at the beginning of the session, followed by the exercises (i.e., back squat, barbell hip thrust or Romanian deadlift) with a load of 85% of the already measured 1RM in Session 2.

The study will be broken down as follows:

- Session 1: Familiarisation of testing procedures
- Session 2: Anthropometrics, normalisation, 1RM testing
- Session 3: Anthropometrics, normalisation, 85%RM of each exercise

Session 2

Anthropometrics

After recording your weight and height, you will be asked to perform two flexibility tests to determine your hamstring/hip flexibility. The flexibility tests will be performed on both days prior to skin preparation for the EMG electrodes. The first test will be the modified back-saver sit and reach test, in which a standard meter ruler will be placed on the floor between the legs, with the reading 0 cm in line with the heel position for each test. You will be asked to reach forward as far as you can without bending your knee. The furthest point on the ruler will be recorded after 3 trials. The second test will be the active & passive knee extension test. First, you will be placed in a supine position, hips set at 90° by a goniometer. You will be asked to extend your knee without moving from the set 90° hip flexion position. This angle of extension at the knee will be measured with a goniometer and recorded. Next, you will be asked to relax at the same hip flexion angle, on which the researcher will passively extend your knee and record the angle of passive knee extension after 3 trials. These measurements will be taken before and after each testing session.

Ultrasound

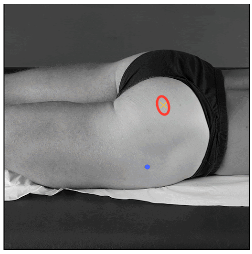
An ultrasound scan is a medical test that gathers images from inside the body by using high frequency sound waves. The use of this technology will ensure proper placement of EMG electrodes, as well as validity of the signal recorded. Muscle fiber pennation angles will be determined with ultrasound imaging in order to ensure proper EMG electrode placement along the line of the muscle fibers. The skin on top of the muscle to be analysed will be applied with a special lubricating gel, which prevents friction so the ultrasound transducer can be rubbed on your skin.

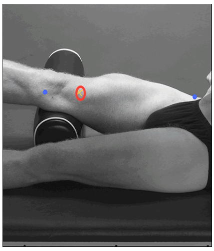
EMG Assessment

At the beginning each session, your skin will be cleaned and an electrode will be attached to the skin above the belly of each muscle analyzed. These electrodes will measure the electrical activity created as your muscles contract during the series of tests you will perform.

EMG of the hip and upper leg muscles, gluteus maximus (GM), vastus medialis (VMO), vastus lateralis (VL), semitendinosus (ST) and biceps femoris (BF) will be collected from the dominant side during testing.

Placement of electrodes:


(GM)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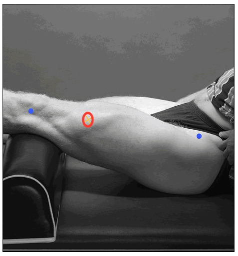
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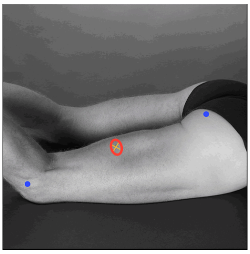
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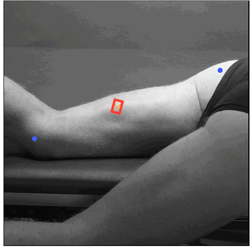

(ST)

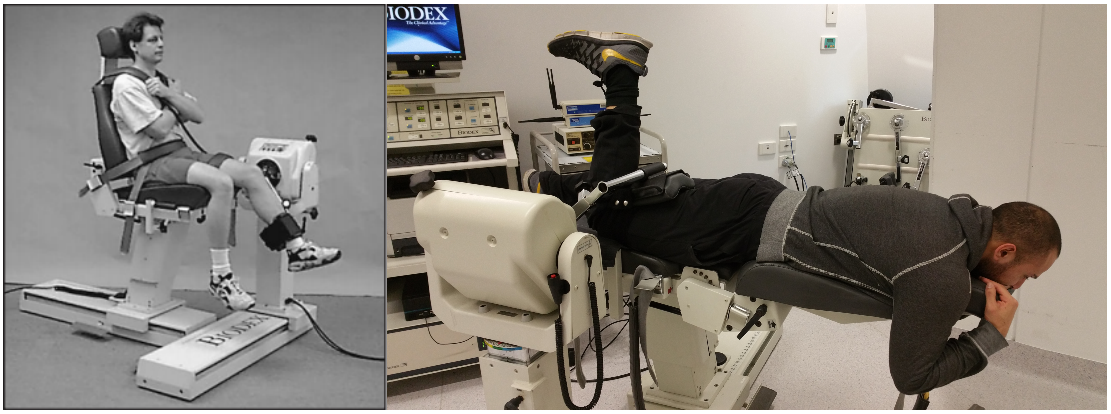
Hip flexion angle measurement

An electronic goniometer will be used in order to determine your hip flexion angles during testing. The top of the electronic goniometer will be placed at the iliac crest, following the line of the femur, down the right side of the hip.

Normalisation protocol (MVICs)

After a standardised, bodyweight warm up, you will be asked to perform 3 maximal isometric contractions for each muscle group (i.e., quadriceps, hamstrings and gluteus), at a determined angle of knee/hip flexion. You will be instructed to extend or flex maximally against a fixed position, sitting on an isokinetic dynamometer.
For the quadriceps musculature, sitting in an upright position on the isokinetic dynamometer, you will be asked to maximally extend your leg fixed at 110° of knee flexion. After 1-minute rest, you will be instructed to repeat the procedure twice.
For the hamstrings muscle group, sitting in an upright position on the isokinetic dynamometer, you will be asked to maximally flex your leg set at 110° of knee flexion. After 1-minute rest, you will be instructed to repeat the procedure twice.
Finally, for the gluteus muscle group, laying down on the isokinetic dynamometer, you will be asked to maximally extend your hip set at 180° of hip flexion. After 1-minute rest, you will be asked to repeat the procedure twice.

Normalisation will take place immediately before moving to the strength lab and performing the weight lifting tests.
Two positions on the Biodex during normalization:



1 repetition-maximum (1RM) Testing

EMG will be collected during 1RM testing. After following the normalisation protocol, you will perform a warm-up procedure with light resistance that easily allows 5 to 10 repetitions. After a 1-minute rest period, a load of 15-20kg will be added to the barbell followed by a 2-4-minute rest period. This process will be repeated until a weight is reached where failure of technique occurs, within 3-4 attempts. The 1 repetition maximum (1RM) will be recorded as the highest successfully lifted barbell load for the back squat with correct technique. The order of the exercises tested will be randomized.

For the barbell hip thrust, the same warm-up protocol will be used and peak barbell height will be recorded at the point of maximal hip extension during the initial repetitions of the warm up; the 1RM will be recorded as the highest lifted load until the subjects cannot reach peak barbell height at the end of the concentric (upward) action.

For the Romanian deadlift (RDL), the same warm-up protocol will be used. The load will be pulled from the rack, set at knee level with the barbell right below the patella. The 1RM will be recorded as the highest lifted load with correct technique or until the subjects cannot reach peak barbell height at the end of the concentric (upward) action.

Regarding rest periods, 10 minutes will be provided between back squat, barbell hip thrust and RDL testing. Two minutes passive recovery will be given between warm-up sets and three minutes between 1RM attempts.

Exercises performed:

Session 3

Testing protocol

After anthropometric measurements, ultrasound and EMG electrode placement, you will be asked to perform the exact same normalisation protocol performed in the beginning of session 2. Then, you will be transferred to the strength lab in order to perform one set of 3 repetitions of the three exercises at 85%RM, measured on day 2. The same warm-up protocol used to test 1RM will be used to reach 85%RM on this day. The order of the exercises on session 3 will be randomized as well.

Time commitment

All participants will be required to participate in a familiarisation meeting (~30min) and 2 testing periods, which are separated by least 3 days in between. Session 2 will last ~3 hours and will include anthropometrics, ultrasound, EMG electrode placements, normalisation protocol, 1-RM back squat, 1-RM barbell hip thrust and 1-RM RDL testing. The exercises tested on the session will be randomized in order. Session 3 will last ~3 hours and will include anthropometrics, ultrasound, EMG electrode placements, normalisation protocol and one set of three repetitions at 85%RM of the selected exercise (in random order).

Therefore, the total time commitment will be approximately 6.5.

Potential risks and discomforts

Ultrasound imaging has been used for over 20 years and has an excellent safety record. Although ultrasound imaging is generally considered safe when used prudently by appropriately trained health care providers, ultrasound energy has the potential to produce biological effects on the body. Ultrasound waves can heat the tissues slightly. In some cases, it can also produce small pockets of gas in body fluids or tissues (cavitation). The long-term consequences of these effects are still unknown.

With surface EMG there is a minimal risk to the participants, which can result in skin irritation as a result of abrasive cleaning of the skin during the preparation before applying the EMG electrode. This risk is considered minimal and causes no discomfort to the participant. Disposal of medical waste shall comply with the Codes of Practice on Medical Waste Management published by the Environmental Waste
Disposal Department of Western Australia

As with any physical activity there is the potential that the participant may develop muscle soreness 24-72 hours following some of the testing sessions. Furthermore, any lower body resistance training exercise such as back squats, Romanian deadlifts and barbell hip thrusts carries a certain risk of injury to the back as the load is applied by placing the barbell on the subject's shoulders or hip. However, such injury typically occurs only as a result of performing the movement with incorrect technique. As such, the participant will be comprehensively instructed on correct lifting technique and thoroughly familiarized with the procedures involved in the investigation by trained professionals.

Although very unusual in young and/or trained individuals, the possibility of certain changes occurring during testing activities does exist. These include abnormal blood pressure, fainting, fast or slow heart rhythm, and in extremely rare instances, heart attack, stroke, or death. Every effort will be made to minimize these risks by a) having subjects complete a medical history questionnaire and if deemed necessary clearance by the participant's local medical practitioner prior to reporting for testing, and b) through careful observation of subjects during the training and exercise test. Personnel trained in cardiopulmonary resuscitation will be present during all testing sessions. It should be pointed out that although it is extremely unlikely that any of these "rare instances" will occur during testing, it is our duty of care to each participant to inform them of all possible eventualities.

There are no inherent risks involved with the resistance training sessions that the subjects will undertake as part of this investigation. Resistance training may result in mild discomfort and muscle soreness, however, this will be minimized by all sessions being supervised and commencing with a warm-up and concluding with a cool-down period of mild stretching activities. It is also possible that some muscle soreness may result from baseline performance testing, however, all participants will undertake a warm-up period of stretching before beginning the full exercise program. The risk of discomfort and muscle soreness will also be minimized by a gradual increase in exercise intensity.

Though 1RM testing is frequently used throughout the world and is extremely safe, there is an increased risk of injury if the tests are performed with improper technique. To avoid potential risks, all participants will be screened for contradictions to exercise and must demonstrate proficiency in the exercises as well as resistance training experience. Researchers will provide guidance as all researchers have extensive experience in resistance training and will monitor all testing sessions. Other precautions include a familiarisation session to instruct participants on correct technique and testing methods; the use of safety racks; and the addition of two spotters standing either side of the barbell ready to assist should a failed lift occur.

In the event that an emergency occurs, the university security staff will be contacted, as well as the laboratory technicians. Researchers are CPR certified and will be able to provide first aid in the extremely rare circumstance of critical injury.

Potential Benefits

Some of the benefits include the information provided about musculoskeletal fitness, as well as being in contact with technology that is currently used to perform tests in the field of sport science (i.e., EMG and force plates). In addition, each testing session will consist of a training component in which the subject will receive coaching points on exercise technique and a workout for lower body musculature.
A summary of results for this study will also be provided upon request.

Privacy and Confidentiality

All information collected during this research will be preserved for possible future use in another research project. All data collected will be stored securely on ECU premises and kept for 15 years after the completion of the project. If for any reason you decide to withdraw, the data will be withdrawn from the project and will no longer be used.

Participation in the Study

The Edith Cowan University Human Research Ethics Committee has approved this study.

Be advised that this research project is being undertaken as part of the requirements of a degree. Participation in this research is entirely voluntary and you may refuse to participate or withdraw at any time without adverse consequences.

Questions: If you have any questions about the research project or require further information you may contact the following:

Student Researcher: Jose Delgado   Telephone: 0437072069
Email: josed@our.ecu.edu.au

Principal Supervisor: Prof. Ken Nosaka
Telephone: (61) 8 6304 5655
E-mail: k.nosaka@ecu.edu.au

If you have any ethical concerns with regards to your participation in this study you may contact:

Research Ethics Officer
Phone: (08) 9304 2170
Address: Human Research Ethics Committee, Edith Cowan University, 100 Joondalup Drive, Joondalup WA, 6027
Email: research.ethics@ecu.edu.au

Thank you for your time,
Jose Delgado