WILLIAM PATERSON UNIVERSITY OF NEW JERSEY

The Effects of Heel Elevation on Back Squat Performance

A THESIS

submitted in partial fulfillment of the requirements

for the degree of

MASTER of SCIENCE

in Exercise Physiology and Sport Studies

By

Matthew Pierce

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College/School: Science and Health   Thesis Supervisor: Racine Emmons, Ph.D.

Department: Kinesiology   Chairperson: Kathy Gill, Ph.D.

Abstract

Heel-elevated back squats have mainly been used in rehabilitative settings, research has suggested that the exercise promotes less trunk inclination and a more stable posture, furthermore, the restricted state of plantarflexion during the exercise requires less dorsiflexion, a common restriction preventing a complete back squat. There is little research support that these suggested biomechanical effects may have an impact on back squat performance. The purpose of this study was to examine the differentiating effects of muscle activation and barbell metrics at different heel elevations (0.0 in., 0.5 in., and 1.0 in.). Utilizing a repeated measures design, 10 resistance trained individuals ($N = 10$, RT years: 4.85 ± 2.789) performed three sets of 10 repetitions at 70% of their 1RM at the 3 predetermined heel positions. Testing days were randomized, participants were given at least 24 hours in between each session, and participants performed the exercise barefooted to avoid any additional heel elevation. Surface electromyography was used to obtain activation for the knee extensors (RF, VM, VL) and a single inertial measurement unit (IMU) centered on the barbell was used for force-velocity metrics. Mean muscle activation normalized to participants maximum voluntary contraction (MVC), movement velocity, peak power, peak force, and concentric distance were analyzed. Paired samples and repeated measures tests were analyzed to test for differences in muscle activation comparing a participant's testing day at 0.0 inches to the days with heel elevations and if there were any enhancements in performance during heel raised conditions. Paired sample results showed significance in RF activation at 0.5 inches ($p = 0.035$; $SD = 2.166\%$), VM activation at 0.5 inches ($p = 0.018$, $SD = 7.151\%$) and slight significance comparing 1.0 inches ($p = 0.055$, $SD = 9.544\%$), all showing a significant reduction in activation. Repeated measure results showed no significance among the obtained barbell metrics or fatigue related differences in muscle activation between sets 1 and 3. These findings support that in resistance trained individuals, biomechanical changes can affect muscle activation though not enough to alter performance.

Dedication

The process of completing this thesis could not be done without the unwavering support from my professors and peers. This project has allowed me to apply my academic knowledge to a research setting, something that could not be duplicated. I was faced with obstacles that I normally would not have encountered and have been able to work on a project that I can proudly reflect on. This unique opportunity has provided me with unmatched experience, and I feel it has better prepared me for my career in exercise physiology.

First and foremost, I would like to thank Dr. Racine Emmons for supporting me throughout the entire research process by providing me with useful insight in study design, instrumentation, the subject itself, while also providing clarity on any obstacles I faced, by doing so I was able to complete the project with confidence. I'd also like to thank Dr. Michael Figueroa, Dr. Jason Wicke, and the rest of the Kinesiology Department of William Paterson for helping me with accessing facilities, assisting me in the outreach for participating in the study, and supporting me in my academic endeavors in completing my graduate degree. Lastly, I'd like to thank my family, friends, and all who participated in this study, without their support the completion of this project could not have been done.

Table of Contents

List of Figures and Tables

CHAPTER 1

INTRODUCTION

The back squat (BS) is one of the most well researched and used exercises in rehabilitative and athletic settings. The functionality and movement patterns developed through the back squat movement are vital to activities of daily living and sports performance. The BS is a multi-joint compound movement that is used to assess neuromuscular function, as well as improve physical capabilities and build strength in the lower extremities and trunk (Johnston et al., 2017; Myer et al., 2014). Considered a fundamental exercise, performing the BS in a safe and effective manner is important to the participation of physical activity and decreasing risks of injury in activities of daily living and sport performance (Myer et al., 2014). The BS is broken into two distinct phases, ascent, and descent (Maddox, 2022; Myer et al., 2014, Tilaar et al., 2019). The descent phase is initiated by flexion of the ankles, knees, hips (Myer et al., 2014) and generally considered complete once the individual's femur is parallel to the floor or between 90-100 degrees of knee flexion (Escamilla et al., 1998). The ascent phase can be categorized by extension of ankles, knees, and hips to the starting position, the posterior back muscles work throughout both phases to maintain stability (Myer et al., 2014). Altering the movement itself is done frequently in training and in research to elicit specific training goals or to tailor to anatomical variability. A few examples are: an increasing load is attributed to increasing muscle activity and strength gains (Saeterbakken et al., 2016; Yavuz and Erdag, 2017), controlling depth has been associated with increasing knee extensor activation and hip involvement with increasing an depth (Todoroff, 2017), and heel elevation to reduce lumbar spine shear forces, increase knee extensor activation, and improve squat depth (Charlton et al., 2017; Johnston et al., 2017; Sato et al., 2012). Working around an individual's deficits or their variability through the alterations of movements is common practice and should be implemented with intervention to avoid injury and improve function.

The effects of heel elevation on performance during a BS have yet to be determined, with research supporting an increase in activity in the knee extensors, gastrocnemius complex, and improved squat depth; a conclusion is yet to be drawn on these indicators improving overall BS performance. BS performance has proven to be important to an athlete's development, with its coordination of multiple muscle groups it serves as a precursor to other athletic capabilities, including jumping, running, and other lifts (Myer et al., 2014). In an athletic setting, training has shifted toward velocity-based methods, as an evident relationship is seen between load and velocity. There is also strong support on daily-readiness and the velocity-based method, providing trainers with a more individualized approach that allows athletes to maximize each training session (Weakley et al., 2021; Zatsiorsky et al., 2021). With the use of velocity-based training (VBT) devices, which use force and velocity to analyze movement, trainers gain a more analytical and accurate understanding of the athlete's performance on a day-to-day basis. Barbell metrics provide a unique insight on the characteristics of displacement of an external load, knowing the BS is a fundamental movement to improving athletic performance through coordinated movements of the entire kinetic chain, researchers are now able to analyze the movement performance with these devices (Weakley et al., 2021). It is important for athletes to get the most out of the movement, though there is controversy among altering the aspects of a BS in fear of developing improper movement patterns. In the case of heel elevation, the ankle is in plantarflexion, restricting ankles mobility during the movement; the lack of mobility should be addressed in other loaded exercises involving its range motion, though the elevated heels may provide a more comfortable and stable movement outweighing its cons (Lu et al, 2022;

Tumminello, 2022) Heel elevation in studies have supported different outcomes; a definitive conclusion is yet to be drawn on its kinematic effects, with anatomical variation among individuals and genders, exploring muscle activity and performance can provide deeper insight (Lu et al., 2022).

The BS is used as a functional movement assessment, as well as an assessment of neuromuscular function. It has been well-documented that the movement is subject to change in conditions of biomechanical distress and when utilizing an external load, the neuromuscular component becomes much more evident (Martinez et al., 2022; Yavuz & Erdag 2017). Its multi-joint involvement allows practitioners to assess capabilities and any malformation of the entire kinetic chain, identifying muscles that could be tight, resulting in a decreased range of motion or weak musculature that does not adequately support joint movements comprising its structure (Padua & Hirth, 2007; Myer et al., 2014). The ability to perform the movement is a proven way to improve athletic performance, neuromuscular capabilities, and prevent injuries. Inexperience and lack of guidance are two leading factors in the resiliency of injuries during resistance training. Miletello et al., (2009), found differences in performance when comparing individuals at different skill levels during maximal loading during the BS, showing better performance in acceleration, deceleration, and peak angular knee velocity in the experienced lifters compared to novice. The researchers pointed out that acceleration was among the most significant of the findings, suggesting a prominent neuromuscular component in more experienced lifters as acceleration at higher loads show a strong neural drive regarding the recruitment and activation of muscle fibers (Mitello et al., 2009; Myer et al., 2005; Myer et al., 2014). These insights provide an understanding of how neural drive and neuromuscular components influence the performance of the BS, particularly when there is a heavy external load involved (Martinez et al., 2022; Tilaar et al., 201; Yavuz & Erdag, 2017). Studies using surface electromyography (sEMG) have been used to assess the effects of load, as well as variations of the back squat and the effects they may have on muscle activation. The size principle, the general theory of motor recruitment, states that the lowest thresholds motor units (MUs) are activated first with MUs innervating larger muscles being activated in ascending order to increase force production as needed, usually in response to an external load (Carpinelli, 2008), this provides the foundation of the external loads influence and muscle fiber activation. Variations in load and biomechanics have also produced conflicting findings, with more experienced populations experiencing greater influence than novice, imposing a strong neuromuscular component to the use of external load, along with variations to the movement itself (Miletello et al., 2009; Tilaar et al., 2017). Meaning, novice weightlifters do not yet have the neural drive capabilities to experience changes caused by biomechanical alterations. Elevating the heels may induce enough biomechanical changes that muscle activation through motor and fiber recruitment is altered in more athletic populations. (Charlton et al.,2017; Monteiro et al., 2022)

Variability among the BS is common with varying training experiences, nonetheless, the movement has a prominent correlation to the development of both biomechanical and neuromuscular performance in developing movement patterns that are vital to athletic performance and activities of daily living (Maddox, 2022; Myer et al., 2014). With many individual factors effecting the assessment of squat, as well as, individual preferences, it is difficult to identify an ideal squat movement for the consensus, universal observation can be made on certain deficits noted during the movement (knee valgus, trunk leak, ankle external rotation) (Padua & Hirth, 2007). Along with biomechanics, research has shown the importance of neuromuscular function in performing externally loaded compound movements, with individual improvements in moving heavier loads having a linear relationship to performance, the ability to move said load during a functional movement has been used to improve athletic performance and preparedness, increase injury prevalence, and recover from injuries. (Maddox,2022; Schoenfeld, 2010; Myer et al., 2014). Brown and Kimball (1983) estimated injury rates in adolescent male powerlifters at 0.29/100 hours of lifting, during heavy loaded training of the major compound exercises (squat, deadlift, bench-press). In a more recent study, Selhourst et al., (2017) found in 1025 adolescent athletes experiencing some form of low back pain, 30% were diagnosed with spondylosis

Considerations should be made that individuals may vary in their capabilities along with anatomical variations that alter the movement. With these considerations in mind, the search for the ideal back squat position for the general population may never be found due to the amount of anatomical variability. Exercise professionals should identify the individuals' goals and capabilities. Too often there are resistance training-related injuries due to poor form from lack of knowledge or previous training. These may not be acute injuries but overtime the compensation and wear on the joints will lead to complications. Heel elevation may provide the comfort and less restriction needed to perform a deeper squat, which also has controversy. It was almost universally accepted that deep squats were not necessary and sometimes even dangerous, which to an extent warrants some merit. In 1961, the US Army banned squat jumps, and in the same year, the American Medical Association disapproved of exercises that involve excessive knee flexion, believing it would degrade its supporting structures (Sato et al., 2012). Recent research has shown that peak forces on anterior cruciate ligaments (ACL) and posterior cruciate ligaments (PCL) are not at points beyond 90 degrees of flexion; and beyond that point of 90 degrees, PCL involvement is minimal, and a deep squat may provide better injury resilience due to the concept of loading through the joints entire range of motion (Hartmann et al., 2013; Sato et al., 2012). Tibiofemoral stress is significant during a deep squat but only detrimental in populations with existing conditions. Heel elevation during the movement may not only provide more functionality to the movement but also allow individuals to focus on activation of certain muscle groups (knee extensors) while limiting the need for significant ankle dorsiflexion, a common limiting factor of the movement, and improving their overall performance of the movement (Tumminello, 2022).

Purpose

With previous research reporting conflicting results and no present research found on heel elevation and its effects on barbell metrics, the present study looks to investigate supported findings of heel elevation, that is the increase in knee extensor muscle activation and if those supported findings have a significant effect on barbell metrics. Therefore, the present study will utilize 3 different heel elevations (0.0 in, 0.50 in, and 1.0 in.), all performed at the same load (70% of 1 RM), to find any changes knee extensor muscle activation, specifically the vastus medialis, vastus lateralis, and rectus femoris, and if any barbell metrics are subject to change, this will be done through the use of an inertial measurement unit (IMU) that’s placed directly on the barbell.

Hypothesis

Increasing heel height will increase muscle activation and the subsequent increase in muscle activation will improve barbell performance metrics

CHAPTER 2

LITERATURE REVIEW

Heel Elevation

Manipulating variables of a squat, or any exercise, is common practice to elicit specific training goals; load, repetitions, width, depth, barbell placement, and joint angles are all variables that should change based on the training goals of the individual. In heel-raised conditions during a back squat, at any height, the common goals are relieving lumbar spine forces, achieving desired joint angles, reducing the amount of ankle dorsiflexion needed to allow for a deeper squat, and increasing the activation of the knee extensor while limiting the involvement of the ankle by having it fixed in a state of plantarflexion (Charlton et al., 2017; Lu et al., 2022; Monteiro et al., 2022; Todoroff, 2017). Heel elevation is provided by using squat wedges, heel-lift shoes, or simply using an elevated surface (i.e., a barbell plate). Raising the heels will result in a posterior weight shift due to changes in center of mass, forcing a compensatory posterior trunk shift to regain the base of support which will allow less of a forward trunk lean while squatting (Todoroff, 2017).

The main biomechanical changes observed in heel-elevated conditions are a decrease anterior tibialis activity (Lu et al., 2022), an increase activation in the Vasti muscle group (Escamilla et al., 1998; Signilore et al., 1994), increase activation in gastrocnemius group (Johnston et al., 2017), reduction in forward trunk lean and subsequent reduction in trunk inclination angles (Charlton et al., 2017; Sato et al., 2012; Todoroff, 2017). The reduction in anterior tibialis activity is hypothesized to increase knee ROM and therefore increase muscle stretching. Konsgaard et al., (2006) showed a 26% increase in patellar tendon tension when comparing flat heel conditions to a 25-degree incline and normalized mean electromyography (EMG) amplitudes were significantly greater ($P<0.05$) in heel-elevated conditions compared to flat foot. The greater amount of stretching is hypothesized to increase activation, therefore, when tibialis activation is minimal, knee ROM can be greater. Charlton et al., (2017), found at peak knee flexion angles, there were significant differences in forward trunk lean during heel raised conditions but no significant changes in maintaining a neutral spine, suggesting elevating the heels does not reduce pelvic flexion, in the same study, muscle activity showed significant increase in gluteus medius activity and none in the rectus femoris (RF). At heights of 1.27 cm, 1.91 cm, and 2.54 cm, Johnston et al., (2017) found an increased activation in the superficial quadriceps muscles (vastus medialis and vastus lateralis) though they were not significant ($p>0.05$) and found significant differences in the gastrocnemius complex activation ($p<0.01$) (medial and lateral) at 1.91cm and 2.54 cm. A similar study done at a higher heel height (3.3 cm and 3.5 cm) (Lee et al., 2019) found no differences in knee extensor activation, suggesting a more precise range.

As heel height increases, ankle dorsiflexion is limited and greater knee flexion could be achieved. During a normal flat-footed squat, restricted ankle dorsiflexion would result in the heels coming off the ground at a certain point or significant forward trunk lean during the eccentric phase (Todoroff 2017, Monteiro et al., 2022). With greater heel elevation, Monteiro et al, (2022), found increased heel elevation (Barefoot, W25mm, W55mm) decreased trunk flexion and displacement and allowed for deeper knee flexion and displacement. Hip flexion ROM and displacement decreased as heel height increased and knee flexion ROM and displacement increased as heel height increased.

With greater range of motion there is an increase in time under tension of the attached musculature (Monteiro et al., 2022). Most studies suggest a limited increase in superficial quadricep muscle activation, though as heel height increases there is a steady increase in the suggested effects of elevating the heels to a certain point. Studies have limited or restricted subject range of motion, raising the heels during a squat has been used for individuals with restricted ankle and lumbar spine mobility. These often limit squat depth but even in healthy individuals, increasing heel height decreases the amount of sagittal ankle dorsiflexion by decreasing anterior tibialis activation. Additionally, the posterior weight shift due to a change in center of mass allows for a more comfortable neutral posture and less hip mobility is needed as decreased dorsiflexion allows for greater knee range of motion (Todoroff, 2017). Allowing subjects to squat to their most comfortable depth could help better understand variability among individuals and whether this is a general concept. Monteiro et al., (2022) suggests the increased ROM during heel elevated conditions results in greater stretching and subsequent activation in response. There's also no current research on how elevating the heels may increase performance through force, power, velocity, and barbell displacement. Velocity on its own can be an indicator of the other metrics as well as fatigue, velocity-based training is an excellent example as research has shown load and velocity have an inverse linear relationship.

Validity of IMU devices for barbell metrics

Understanding barbell mechanics has become a popular method of measuring performance and safety during exercises. These methods directly correspond to velocity-based training, with a strong, known, inverse relationship between velocity and load, intensity can be prescribed based on movement velocity. Inertial measurement units (IMU) use a combination of accelerometers, gyroscopes, and magnetometers to measure acceleration, angular rates, and gravitational force (Charlton et al., 2017; Held et al., 2021). IMUs are often used in measuring exercise performance, with their usage of different analysis of motion, they can provide accurate quantification of multiple factors related to performance (velocity, force, power, displacement, etc.) (Held et al., 2021). These factors are important in determining an athlete's capabilities at a more individualized level, making IMUs useful in velocity-based training, as well as looking at the acute effects of alterations during exercise. Mainly used for monitoring exercise performance outcomes, research often compares the efficacy of IMUs to linear transducers, force plates, and motion capture systems (Fritischi et al., 2021; Clemente, 2021). Clemente (2021) performed a systematic review on the use of IMUs and their validity for barbell assessments, finding most commercially available IMUs and their respective studies were reliable. Their findings also showed that IMUs are most commonly used in strength training studies, where motion is limited to a single plane (Clemente, 2021). In a similar study investigating IMU validity across various loading intensities, Abbott et al., (2020) reported that IMUs produce similar kinematic data as a 3D motion capture system, while also being much more practical. This study did find that at higher intensities, both systems showed higher kinematic values that were less accurate. Olmedo (2021) used the Enode pro (Magdeburg, Germany) (formerly known as Vmax Pro) in their study, at 75% of individuals 1-RM showed good-to-excellent intraclass correlation with little bias for back squats (0.01 ± 0.04 m*s^{-1}) measuring mean concentric barbell velocity and displacement compared to linear transducers. Kinematic variables can be found through any of the previously mentioned devices. Studies use them more often or in tandem to discover certain effects of training. IMUs offer a multidimensional approach, with load and velocity being the main factors; conclusions can be drawn on the individuals' movement speed, force, and power during exercise. It is important to note that the complexity of motion during an exercise may be more or less suitable for an IMU, exercises mainly done in a single plain of motion or involving repeated simple movements (i.e. flexion and extension) have proven to be more accurate in their measures (Clemente et al., 2021). In their systematic review, Clemente et al., (2021) reported 10 studies using the back squat and 9 using the bench press, showing the researchers aim to find validity among more simple, repetitive compound movements. The Enode pro (Vmax pro) is relatively light in research support, though it has shown high validity in its respective studies using the back squat (Cuartero et al., 2022; Fritschi et al., 2021; Feuerbacher et al., 2023; Held et al., 2021). Validity among different loads has also been researched, with concern over IMUs reliability and accuracy in measuring velocity among different loads. Arede et al., (2019) used an IMU (Gyko Sport) and linear transducer (SmartCoach) at loads increasing by 10% increments from 40-90% of subjects' 1-RM for the bench press, comparing the IMU to test its validity showing a strong correlation between the two devices (r=0.79; standard error of estimate [SEE]=0.18 m/s). When measuring mean barbell velocity, the IMU was in high agreement with the linear transducer but had slightly higher values when compared to the linear transducer (P=0.103; mean difference 0.075±0.05 m/s). Power, force, velocity, and displacement can all be measured using the Enode Pro IMU. With the use of angular accelerometers, gyroscopes, and magnometers, quantification of these metrics can be realized, previous research has suggested it has high validity and reliability during the traditional back squat when compared linear transducers, 3D motion capture systems, and force plates, which are considered the gold standard of measuring said metrics and human motion (Abott et al., 2020; Clemente et al., 2021; Thompson et al., 2020)

Muscle activation

Closed-kinetic chain (CKC) exercises, like the back squat, often have greater forces on the respective joints being worked, resulting in greater muscle activation. Both Escamilla et al., (1998) and Signorile et al., (1994) compared the back squat (CKCE) and knee extensions (OKCE) noting the differences in muscle activation between the two exercises, showing the superiority of the back squat in terms of muscle activation. Escamilla et al (1998) emphasized the importance of degrees of knee flexion during the exercises, during OKCE peak RF activations occurred at 65 degrees, while during CKCE (squat) peak RF activation occurred between 83-95 degrees of flexion. Similarly, the vasti muscle group (vastus lateralis:VL, vastus intermedius:VI, vastus medialis:VM) experienced peak activation at 45 degrees during OKCE and 55 degrees during CKCE, respectively; this also showed the percentage of involvement that VM and VL activity was 50% greater than RF activity.

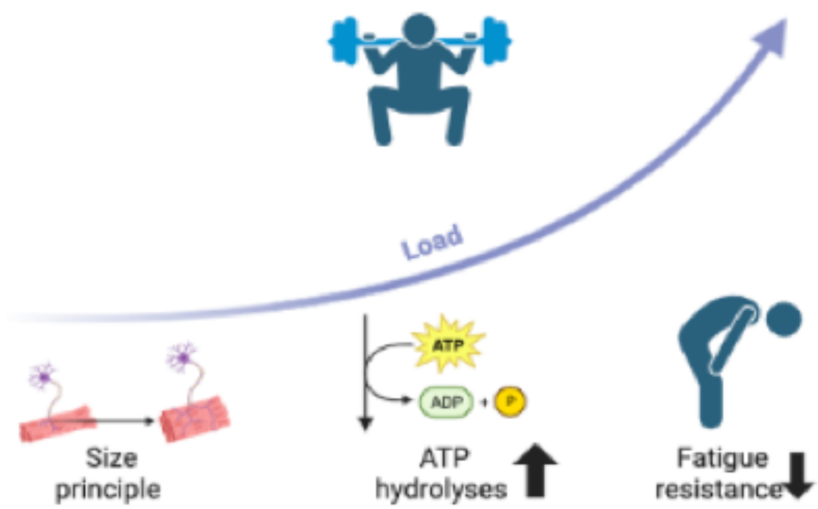
The back squat, a closed kinetic chain, free weight exercise, and compound movement have been researched extensively in both its rehabilitative and performance related qualities. Squatting performance depends heavily on anatomical influences (Myer et al., 2014), individuals are predisposed to different anatomical joint structures that affect the distance, angles, and forces during multi-joint exercises. Hip structure and the ratio of torso-length to leg-length are important in determining the biomechanics of an individual's squat, depending on the depth and angle of the femoral head in the hip joint, as well as the length of the femur will affect an individual's squatting mechanics (Myer et al., 2014; Schoenfeld, 2010). With no two individuals squatting the same, and a large majority of the population being unsure of a proper squat along with the risks associated with poor technique, even more so when weight is added, altering aspects of the squat may benefit more novice-intermediate lifters, improving their performance and avoiding injury (14). Muscle, ligament, and vertebrae can all be affected from poor form. Selhorst et al. (2017), found in 1025 adolescent athletes experiencing lower back pain, 30% were diagnosed with spondylosis, or abnormal wear on the cartilage of the vertebrae as a result of sport participation, likely through repetitive movements where the athlete performed poorly (19). The biomechanical loading of joints will affect how the forces are distributed, for example, pushing through the heels is vital to a safe squat, unwanted heel elevation during a normal BS has shown to create abnormal torques on the entire kinetic chain; this also creates an issue in maintaining a center of gravity as it creates a smaller base of support which may affect the individuals balance and subsequent performance (Myer et al., 2014). Reinforcing proper movement patterns and building up muscle strength through the joints' full range of motion should be emphasized when working with any athletic population, starting with the functional exercises.

There is also evidence to suggest that resistance training experience plays a role in the effects of muscle activation and that alterations in BS may affect these populations differently. Trained participants (Charlton et al.,2017; Monteiro et al., 2022) elicit greater results when there are biomechanical changes, while untrained subjects (Lee et al., 2019) are not affected by biomechanical changes. Lee et al., (2019) found no changes in muscle activation of the knee extensors ($p=0.507$) and no changes in trunk and lumbar spine activation ($p=0.52$). This might suggest the strong neuromuscular component involved in compound movements. Untrained subjects may lack the coordination and muscle fiber recruitment that experienced weightlifters have, while the trained subjects have greater muscular activation and recruitment, making these biomechanical changes, in this case heel elevation, more evident. In a study done on comparing novice to collegiate level athletes, Miletello et al., (2009) found a significant difference in acceleration between novice and collegiate level weightlifters, suggesting novice lifters should focus on building strength before proceeding to more specific athletic traits.

The influence of an external load plays a significant role in muscle activation and fiber recruitment. The different classifications of muscle fibers relate to their activation qualities; contractile speed, myosin heavy chain isoforms (MHC), and energy systems pathways (Plotkin et al., 2021;). They are generally classified as type 1 fibers (slow twitch) which are associated with endurance athletes, involving prolonged muscle involvement, resistance to fatigue, an aerobic respiration, while type 2 fibers (fast twitch) are associated with power athletes. These are short, quick, forceful movements that require significant fiber recruitment and mainly anaerobic glycolysis; the abundance of each fiber type in an individual depends heavily on genetic influence but they are all present in the muscular system (Plotkin et al., 2021). Fibers can be further broken down, specifically, type II fibers are more diverse and used simultaneously or in tandem (type IIa, type IIx, type IIb), type IIa are more associated with muscular endurance using both oxidative and glycolytic properties, while type IIx and IIb use only fast glycolysis to produce energy (Plotkin et al., 2021). Heavier loads require activation of type II fibers, research has suggested that lower movement speed and heavier loads are associated with a combination of type IIa and IIx fibers (Plotkin et al., 2021). Slower movement speeds and heavier loads seem to require both oxidative and glycolytic pathways while a light-moderate load with faster movement speeds uses oxidative pathways. Type II fibers have larger cross-sectional areas being able to produce more absolute force, break down ATP 2-3 times quicker, have greater muscular hypertrophy abilities and subsequently greater post-activation potentiation effects (Hamada et al., 2000; Schoenfeld, 2000; Wilson et al., 2012). Moreover, training type is important in activating specific muscles fibers. Simply put, the higher activation thresholds of type II motor units will not be activated during low-weight, high-repetition training. This is due to the size principle, where motor recruitment is based on demand; increasing intensity to a moderate load (8-10 repetitions) is generally accepted as the highest potential for complete activation (Schoenfeld, 2000). There is also a higher rate of calcium release and the enzyme ATPase that results in a quicker and more forceful contraction (Karp, 2001).

Figure 1

The influence of increasing load on muscles and performance (created using Bio Render)



In heavy compound movements, it can assumed that muscle fiber activation is primarily type II fibers, when performing the back squat at increasing loads (40-90%). Martinez et al., (2022) using a sEMG, found a significant increase between 40% and 90% of 1-RM in muscle activation in females during the ascending phase of a squat in the RF, VL, biceps femoris (BF), and semitendinosus (ST), though there was no significant difference between 80% and 90% 1RM. Two studies done on resistance trained males showed similar findings. van den Tillaar et al., (2019), found increasing loads from 40-100% had a significant effect ($p=0.007$, $n^2>31$) on muscle activity in the RF and a trend in the VM and VL ($0.054<p<0.08$, $n^2>18$), with anything greater than ($n^2>14$) having measured a large effect. Yavuz and Erdag (2017) tested using 80%, 90%, 100% of the individuals 1-RM finding that in 14 healthy males VM activity increased significantly when comparing 80% to 90% and 100% 1-RM loads (56.9 ± 37.1; 67.4 ± 43.5; 73.6 ± 58.6, respectively), all load percentages were normalized to subjects MVIC.

Training history is also a principal factor in muscle activation, Serrano et al., (2019), reported that the VL muscle of elite weightlifters have a significantly different ratio of fiber type, with pure type IIa accounting for 64 ± 13% of muscle fibers compared to the 23 ± 9% from type I fibers. In resistance trained population, Tilaar et al., (2019) assessed resistance trained males (6 ± 3 years of squatting) finding that ranges of loads have similar effects on activation, 40-60%, 70-90%, and 100% all showed different activation but activation within the ranges was similar. Their findings suggest a velocity component, when subjects were able to perform the squat within the desired velocity zones, activation was the same within the ranges, when subjects performed 40-60% of the 1-RM at the desired velocity muscle activation was the same, allowing practitioners to assign velocity zones rather than a load percentage. It is evident that training history, genetic influences, and external forces are important factors in the activation of certain muscle fibers, during heavy resistance training, and more specifically in compound movements, the neuromuscular aspect becomes much more evident. The back squat is a commonly used to assess neuromuscular function through the entire kinetic chain, with the application of a heavy load, the influence increases with more muscular control and strength required and a shift in fiber recruitment to fast-twitch fibers, as well as an increased number of total muscle fibers used (Myer et al., 2005; Myer et al., 2014).

Figure 2

Increasing load effect on muscle fiber type (created with Bio Render)

CHAPTER 3

METHODS

Experimental Approach

Recruited participants met with this investigator on William Paterson's main campus in the Wightman Gym weight room. The study required 4 days of testing with no less than 24 hours between each session. The Day 1 procedures consisted of initial testing, which was finding the participants' one repetition maximum (1-RM) and maximum voluntary isometric contraction (MVC), familiarizing the participants with the procedures, identifying descriptive statistics including age, height, weight, resistance training years, prior injury history, and randomizing the following 3 testing day conditions (heel elevation: 0.0 in., 0.5 in., and 1.0 in.). Day 1 procedures consisted of a muscle specific warm-up which was consistent across all four sessions. Once completed, the participants' MVC was measured consisting of 3 trials of isometric knee extension with 1 minute of rest between each trial. Once completed, participants were asked what their 1RM was based on previous experience, preceding this, the 1RM trials were constructed around this in a controlled manner consisting of about 5-7 sets to achieve the 1RM. Participants then performed a muscle specific cool-down, no less than 24 hours later the participant was permitted for the next day of testing. Sessions 2-4, participants met with the investigator in the same location, William Paterson University main campus Wightman Gym weight room, and consisted of the same muscle-specific warm-up with the addition of a loaded squat warm up to 70% of the individuals' 1-RM (at the predetermined heel height they were randomly assigned). Once the warm-up was completed, EMG sites were prepared, and electrodes were placed at previously measured locations. Sites were located referencing anatomical landmarks in accordance to Surface Electromyography for the Non-Invasive

Assessment of Muscles (SENIAM): patella and anterior superior iliac spine (ASIS), using a tape measure, VM site was at 25% of the total length from ASIS to medial side of patella , RF site 50% from the ASIS to the superior part of the patella, and VL site was at 25% total length between ASIS and lateral side of patella (Figure 3). Participants then performed 3 sets of 10 repetitions at 70% of their 1-RM, 2-5 minutes of rest was given between each set. Once all 3 sets were completed, electrodes were removed, and the participants proceeded with the same muscle specific cool-down. During the 1RM trials and testing trials, participants performed the squats barefoot. Again, participants could return after at least 24 hours post session.

Figure 3

EMG lead site placement in accordance with SENIAM procedures

Participants

This research study has been approved by the William Paterson University IRB. The participation criteria were as follows: 1) between the ages of 18-27 years; 2) At least one year of current resistance training; and 3) No prior musculoskeletal injuries in the last 12 months. Ten participants were recruited and approved for this study (N=8 males, N=2 females aged 23.3 ± 2.79 years, BMI 24.5 ± 2.86 kg/m^2) with no prior injuries in 12 months and current resistance training of at least 1 year (RT years 4.85 ± 2.79). Descriptive statistics can be found in Table 1. Recruitment was done through two methods, advertisement in the Kinesiology Department undergraduate and graduate courses through recruitment flyers and word-of-mouth. Participants were also asked to avoid lower body exercise 24 hours before each session.

Table 1

Participant Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Height (cm)	10	167.6	195.6	177.292	8.1913
Weight (kg)	10	61	91	77.00	9.307
BMI (mg/m2)	10	21.19	29.82	24.5230	2.86188
Age (years)	10	19	27	23.30	2.791
RT years	10	1	8	4.85	2.789
1-RM (lbs)	10	145	325	218.00	55.787

Procedures

Participants met with the principal investigator in the Wightman Gym weight room, located on William Paterson University's main campus. On Day 1, participants were asked to read and sign the informed consent statement, PAR-Q 2023, Health History, and musculoskeletal injury survey as shown in Appendix 1. Participants were then asked to provide height (in), weight (kg), age, sex, and training experience (years) shown in Table 1 descriptive statistics. Once the documents were signed and descriptive statistics were collected, all participants performed the same Day 1 training procedures along with a consistent warm up and cool down across all four sessions, Day 1 was meant to obtain basic and baseline information, as well as familiarize participants with the procedures. Participants were then instructed to perform the warmup. Starting with 5-minutes on a stationary bike, subjects were asked to maintain an RPE from 11 (fairly light) -13 (somewhat hard) (Borg RPE scale; Appendix 1), participants then performed 10 repetitions (on each side) of leg swings side to side and front to back, walking lunge with rotation, lateral band walks (using a TheraBand), bird dogs, and controlled body weight squats to a depth of their preference. Participants were given 30 seconds to 1 minute of recovery based on perceived exertion and 3 minutes of recovery at the end of the warmup.

EMG lead sites were measured and prepared. Following the procedures provided by Noraxon (Scottsdale, AZ), EMG leads sites are prepared prior to testing and on the dominant leg. Sites were prepared, if needed excess hair was removed using a razor, fine sandpaper was lightly rubbed on the skin to remove oils and dead skin until mild erythema is seen to ensure minimal impedance (Konrad, 2006), and leads are placed parallel to the muscle fiber orientation. As previously stated, Day 1 procedures acquired baseline statistics this included; 1RM and mean voluntary contraction (MVC). Preceding the warm-up, three trials of isometric knee extension MVC were recorded using the Noraxon Ultium Surface EMG, the practice of MVC normalization are done under static (isometric) conditions with the intention of calibrating the system to have a unique physiological reference to the movement being performed (Konrad, 2006). In this case, isometric knee extension between 70-90 degrees of knee flexion was performed 3 times, with a 1-minute rest in between trials. Preceding the MVC trials, participants performed the squat 1RM protocol provided by NSCA while also applying force-velocity relationship acquired using the Enode IMU device. Velocity-based methods of 1RM testing relate velocity (m/s) to the load (kg) to assess relative loading intensity (Fritsch et al. 2021). Using the two tools in tandem will allow for a more individualized load based on not only repetitions but load and velocity. IMU placement was placed in the center of the barbell to ensure the most accurate data collection (Fritsch et al., 2021) (Figure 4). Participants then performed a general cool down, starting with 5-minute, light intensity, on the stationary bike, then static stretches consisting of 15 second hold, 3 times on each leg. These were a standing quadricep stretch, standing hamstring holds, piriformis stretch, and gastrocnemius/soleus stretch on the squat wedges.

Figure 4

Enode IMU placement on barbell

Note: IMU should be centered on barbell for most accurate readings

During the next three days of testing, participants are randomly assigned a heel elevation testing order (0.0, 0.5, 1.0 inches). Days 2, 3, and 4 consisted of the same warm-up, cool-down, and testing protocols, with the only changes in heel elevation conditions and warm-up included a loaded barbell squat to the individuals previous 1RM recorded to further potentiate and ready the body for the heavy lift, this was done until 70% of the individuals 1RM was reached. After meeting in the Wightman Gym weight room, participants began with the warm-up protocol previously described. Preceding the warm-up, EMG sites will be prepared by drying the area from any sweat accumulation, removing any excess hair using a razor, and then using fine sandpaper till mild erythema is observed, following this EMG leads were placed in the same locations as identified on day 1 and impedance is constantly measured. Following EMG calibration, participants began testing procedures, performing 3 sets of 10 repetitions, with 2-5 minutes of rest in between sets, squat width was not controlled because of anatomical variability, though a general stance was given, avoiding an extreme wide or narrow stance; and depth was to the participants furthest point of comfort with barbell displacement being measured by the IMU. Following the 3 sets, participants performed the cool-down as previously described. Based on the randomization of testing days, subjects performed trials at 0.0, 0.5, and 1.0 inches of heel elevation in no particular order. Participants were given at least 24 hours of rest between testing days.

Figure 5

1.0 in. heel elevation

Figure 6

0.5 in. heel elevation

Note: Tape is marked on the ramps to provide participants with a visual reference for consistency during testing days.

Figure 7

MVC Pre-testing position

Figure 8

Maximum Voluntary Contraction (MVC) Test (Isometric Knee Extension)

Note: Participants perform maximum effort holds for 3-5 seconds.

EMG/IMU Analyses and Processing:

Prior to and during individual testing, Noraxon EMG and Enode IMU devices were calibrated based on individual physical and physiological references. Height, weight, age, sex was all entered in the EMG and Enode software to familiarize data acquisition relative to the individuals physical and physiological capabilities. With that, MVC trials on day 1 provided an adequate reference to the individual's muscle activation, as shown in Figure 9. Bi-polar raw EMG signals were processed using a sampling frequency of 2000hz, band-pass filtered between 10-450 Hz, signal smoothing using RMS at 50 ms, full-wave rectified, and normalized to percentage of MVC. The MVC trial with the highest value of activation for each of the three muscles was used as the normalization reference. Impedance was measured in real-time, allowing for constant monitoring of impedance, RMS value, and frequency showing a clean signal. EMG data analyzation and processing was done using the MyoResearch 3.21 software. Markers were manually placed after complete repetitions; EMG processes and analyses were done in reference to Noraxon recommendations and similar previous research (Johnston et al., 2017, Lu et al., 2022; Noraxon, 2018). The Enode IMU software samples data at 1000hz and provides real-time feedback, the software using participants height, weight, and individual load (%1RM) to reference data points, which are, barbell displacement (in.), velocity (m/s), power (W), and force (N). Subjects were asked to maintain 0.5 m/s as well as possible in accordance to the movement speed being correlated to the respective load. For reference, Figure 10 shows appropriate velocity ranges and corresponding percentages of 1RM used for velocity-based methods.

Figure 9

MVC normalization with 100% reference (Konrad, 2006)

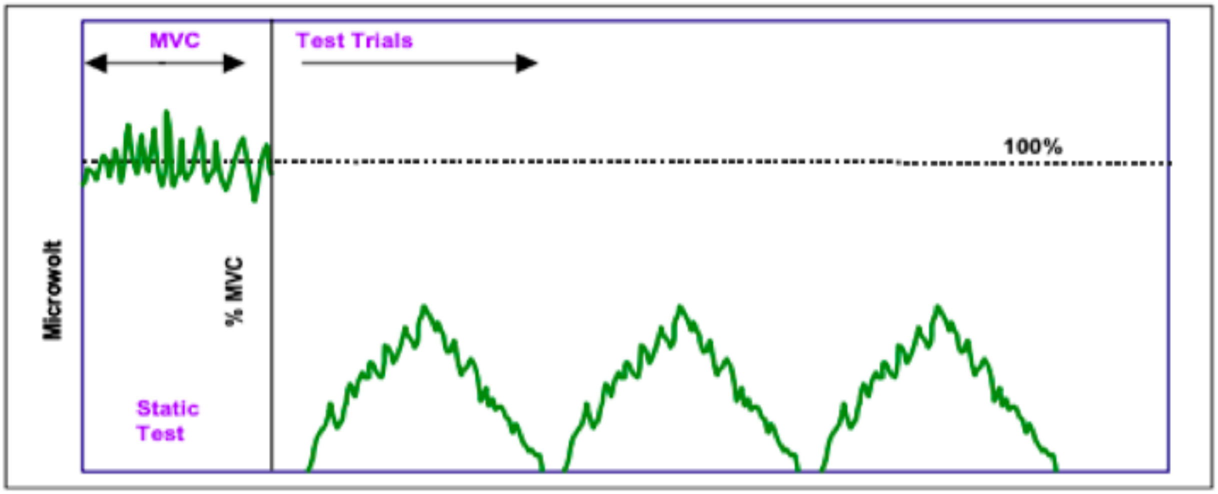
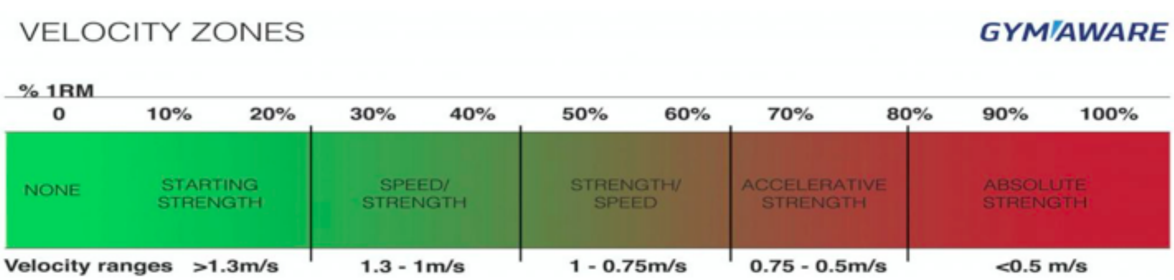


Fig. 40: The concept of MVC normalization. Prior to the test/exercises a static MVC contraction is performed for each muscle. This MVC innervation level serves as reference level (=100%) for all future trials

Figure 10

Velocity-based training zones based on %1RM (GymAware)



Note: Velocity zones are meant as a substitute to the 1-RM method, providing a better understanding of daily-readiness and individual goals.

Statistical Analysis

All data were analyzed in IBM SPSS statistics version 28. Descriptive statistics were obtained from participants with means and standard deviations. Repeated measures ANOVA was used to analyze differences among the barbell metrics at different heel elevations and muscle activity differences between sets 1 and 3. Paired sample t-tests were used to analyze differences in muscle activity using flat footed conditions as the baseline statistic. Alpha was set at 0.05 for both.

CHAPTER 4

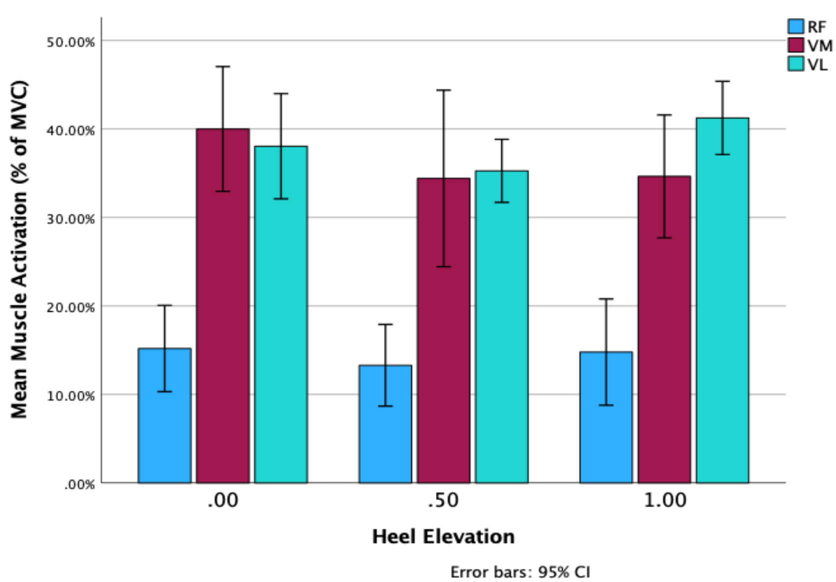
RESULTS

Differences in Muscle Activation Increasing Heel Elevation

A significant decrease in activation was seen in RF and VM activation at increasing heel heights, while there were no significant differences in VL activation. Results displayed in Figure 11 show the means of muscle activation at the different heel elevations showing similar percentages. The significant findings in RF and VM activation were found comparing no heel elevation to 0.5 in. (RF: MD =1.406%; SD =2.166, p = 0.035) (VM: MD = 5.580%; SD = 7.151%; p = 0.018), there was also slight significance in the difference of no heel elevation to 1.0 in. (VM: MD = 5.356; SD = 9.544%; p = 0.055). All other results showed no significant findings among different mean activations (p > 0.05). Repeated measures showed a significant decrease in VM activation between sets 1 and 3 at 1.0 in (MD = 4.115; SE = 1.126; p = 0.001),

Figure 11

Mean muscle activation of entire set at the three different heel heights



IMU Data and Reliability

Movement velocity (m/s), peak power (W), peak force (N), and concentric distance (in.) means were analyzed during all three sessions. Repeated measures pairwise comparisons showed a significant reduction in MV between 0.5 and 1.0 inches of elevation (Figure 13) (MD = 0.027; SEE = 0.008; p = 0.033). All other pairwise comparisons were not significant; heel raised conditions did not provide significant improvements in the analyzed performance metrics.

Mauchly's test was not violated and showed sphericity among all 4 metrics (MV: p = 0.198; PP: p = 0.887; PF: p = 0.659; Dist.: p = 0.708) Reliability of the IMU was strong, with participants 1-RM varying vastly (Min. = 145, Max. = 315, M = 218.0; SD = 55.79) results were relative to load and consistent across all three testing days. Standard error estimates and mean differences of repeated measures for barbell metrics reports strong reliability of means during all three days of testing for all four metrics. Pairwise comparison tables can be seen in table 2.

Figure 12

Mean peak force (PF) and peak power (PP) at the three heel heights

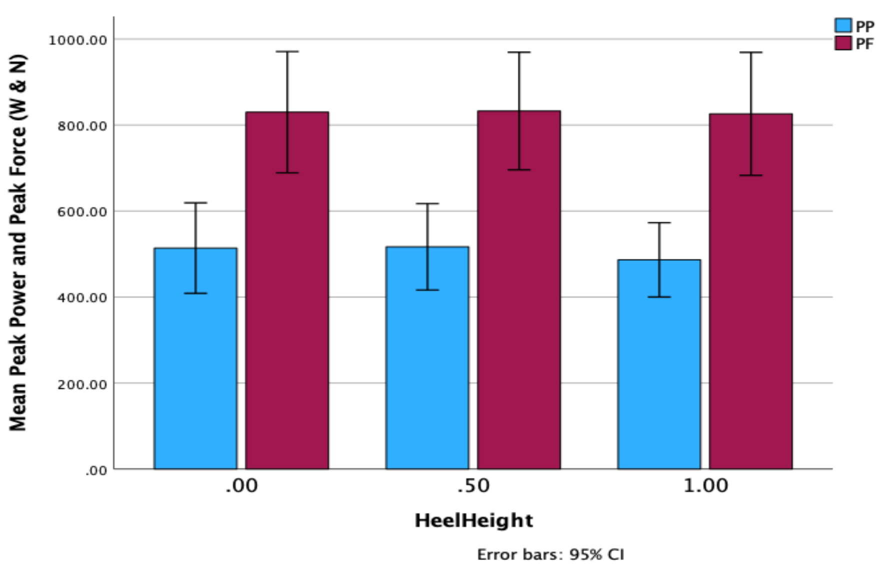


Figure 13

Mean movement velocity (MV) at the three heel heights

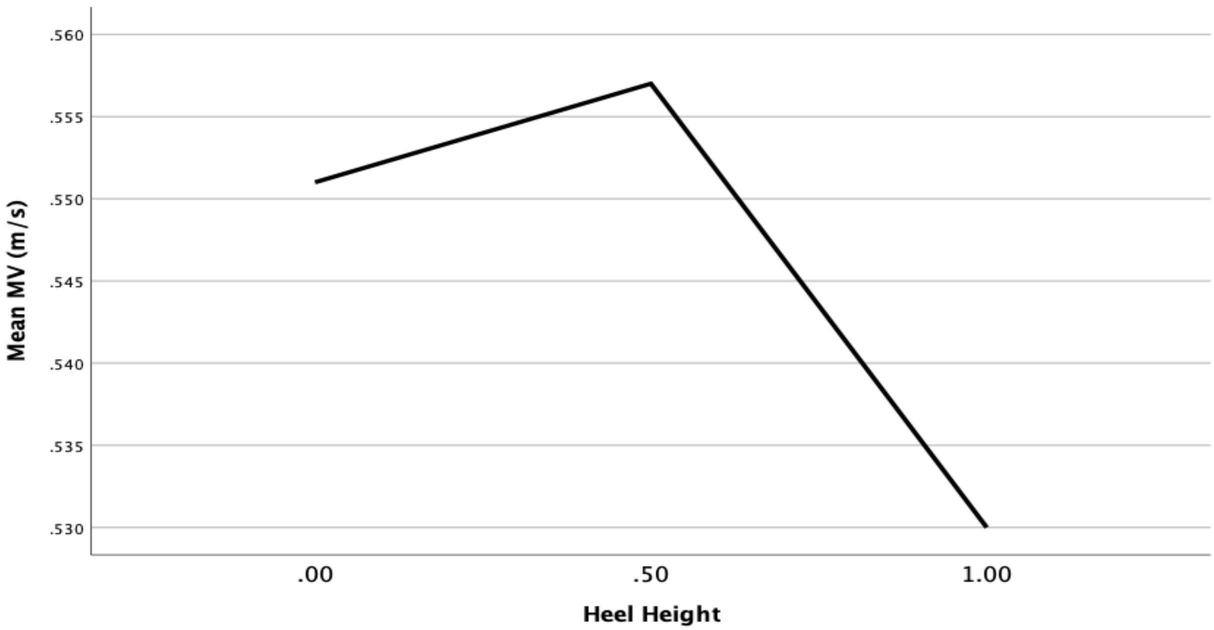


Figure 14

Mean Concentric Barbell Distance (CBD) at the three heel heights

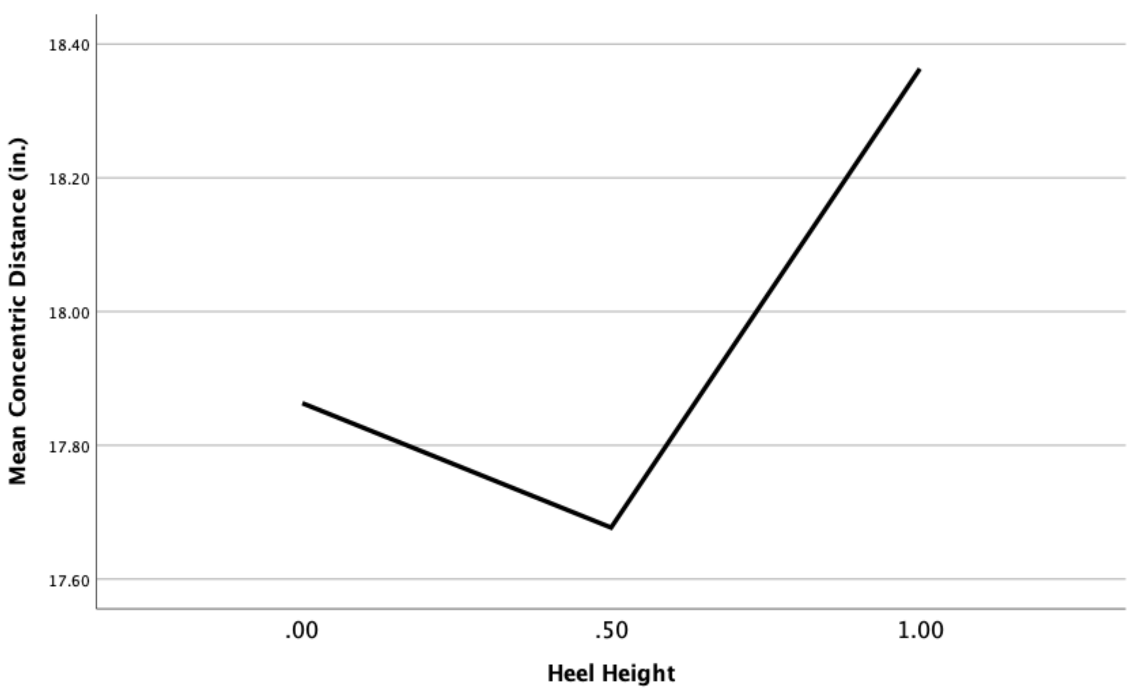


Table 2

Repeated Measures Pairwise Comparisons of Barbell Metrics

Pairwise Comparisons

Measure: Movement Velocity (m/s)

(I) MV	(J) MV	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	Upper Bound
0.0	0.5	-.006	.014	1.000	-.048	.036
	1.0	.021	.015	.580	-.023	.065

Measure: Peak Power (W)

(I) PP	(J) PP	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a] Lower Bound	Upper Bound
0.0	0.5	-2.947	16.746	1.000	-52.068	46.174
	1.0	27.363	16.633	.403	-21.428	76.154

Measure: Peak Force (N)

(I) PF	(J) PF	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a] Lower Bound	Upper Bound
0.0	0.5	-2.727	5.720	1.000	-19.506	14.052
	1.0	3.851	6.157	1.000	-14.208	21.910

Measure: Concentric Distance (in.)

(I) Dist	(J) Dist	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a] Lower Bound	Upper Bound
0.0	0.5	.186	.449	1.000	-1.131	1.503
	1.0	-.500	.460	.915	-1.848	.848

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

CHAPTER V

DISCUSSION

This research study was implemented to analyze the acute effects of heel elevation on back squat (BS) performance and whether these biomechanical changes would elicit enhancements in muscle activation and subsequent performance through the use of surface electromyography (sEMG) and an inertial measurement unit (IMU). At an external load of 70% of the participants 1-RM, performing 3 sets of 10 repetitions, there were observed changes in muscle activation of the vastus, medialis, and lateralis during heel-elevated conditions, while the rectus femoris experienced no statistically significant change in activation, moreover, these changes in activation did not translate to an improvement or reduction in BS performance, with performance metrics peak power (PP), peak force (PF), movement velocity (MV), and concentric barbell displacement (CBD), showing no statistically significant differences among the different conditions.

Outcomes were measured similarly to Charlton et al., (2017), with heel-elevated conditions being compared to flat-footed conditions, examined using paired sampled t-test, due to the within-subject design. Moreover, the results from the present study further reinforce the findings of Charlton et al., (2017) who showed no significant differences in RF activation, Lee et al., (2019) which showed no improvements in the knee extensors with heel elevation Johnston et al., (2017) findings of slight increase in VL and VM activation, though without statistical significance, while the present study found a significant decrease in activity of VM and VL at 0.5 inches of elevation. As for IMU data, to the knowledge of the researchers there are no current studies that examine the effects of heel elevation on acute performance indicators, with that, there is no supporting evidence of the findings in the present study that showed no significant changes in performance during the BS. Through biomechanical changes in exercises, individuals may be able to perform better or achieve a more comfortable movement, though these biomechanical changes may not have a strong enough effect on the neuromuscular system to provide a relevant change in muscle activation and performance.

Effects of Altering Biomechanics on Performance

Heel elevated BS is not a new concept, serving as a rehabilitative technique to compensate for poor ankle mobility which is usually one of the leading causes of improper movement patterns. The state of plantarflexion with heel elevation decreases the activity of the anterior tibialis, which results in significantly less dorsiflexion, normally a limiting factor in the movement, Monteiro et al, (2022) found this to be directly related to increase knee flexion. It is evident that the alteration of the biomechanics of a movement will change the forces acting on the joints and subsequently the amount of muscle involvement.

Research intending to discover the effects of heel elevation on performance has been scarce. Most studies focus on the effects it has on the joints and body in different planes of motion, Charlton et al., (2017) found less trunk inclination and Monteiro et al (2022) showed reduced hip displacement and greater knee displacement. The results of the present study support the findings of Lee et al., (2019), who showed no significant improvement in knee extensor activations. There are many factors that could lead to the amount of contribution that muscles have during an exercise, it has been speculated that a more upright posture creates a greater length tension relationship for the quadriceps muscle, which has been shown to improve with heel elevation (Lee et al., 2019; Schoenfeld, 2010).

With the known effects and speculation of heel elevation, it can be argued that the change offers a safer option in comparison to a flat-footed squat. With a deeper squat generally being easier to achieve with heel elevation, the increased knee flexion could be seen as problematic, though assuming proper form has been taught, deep squats have shown to be more effective in injury prevention (Hartmann et al., 2013). There is also a common misconception of degenerative compressive forces on the patellar tendon as knee flexion continues passed 90 degrees, while research has shown that generally, peak knee flexion does occur at around 90 degrees, the involvement from the supporting ligaments begins to decrease (Hartmann et al., 2013). Assuming that loading and technique are safely implemented, a deeper squat, ideally past the point of the thigh being parallel to the floor, will have greater injury prevention through training the joints full range of motion.

Inertial Measurement Unit (IMU) and Reliability of IMU

The use of IMUs in a sport setting has become a popular method of training and tracking athletes' progression in exercises. There has been shown to be a strong relationship between force and velocity which proves to be a good indicator of fatigue and daily readiness. Of the commercially available IMUs, few have been used to show the efficacy of acute performance changes due to a different stimulus, in this case elevated heels.

The results from the IMU did not show significant improvements when comparing flat footed conditions to heel elevated conditions but the results were reliable and accurate. All participants were limited to 70% of their 1-RM, loads varied significantly (218 ± 55.79 lbs.). The IMU produced accurate data reliable across all three testing days, and relative to the individual's load. Time between testing days also varied but by no less than 24 hours. Though the IMU was not compared to another measuring instrument, the reliability and validity of the present study data is supported by the findings of Feuerbacher et al., (2023) and Cuartero et al., (2022) that showed the Enode IMU, formerly the Vmax Pro, showed good to excellent intraclass correlation coefficient (ICC) for the BS exercise compared to 3D motion capture systems.

Commercially available IMUs also provide a more practical approach to performance testing, with minimal preparation, easy calibration, and user-friendly software. They also provide a cheaper and less complex alternative to analyzing exercise performance. The main mechanism behind the IMU is the external load and the speed of the movement, through a combination of gyroscopes, magnetometers, and accelerometers, an accurate quantification of movement is provided. In this research study, heel elevation did not provide enough biomechanical change to elicit performance differences, mean concentric barbell distance was highest at 1.0 inches of elevation among the participants, but it was not significant. With an accurate IMU identifying biomechanical changes to exercise that elicit greater performance may be attainable, the changes in stimulus during the exercise should be more extreme.

Limitations

This study is not without limitations, notably the sample size was only 10 participants with varying experiences from 1-8 years of resistance training. Stance width, squat depth, and ankle rotation were not controlled, though a general stance was given, to allow participants to assume their most comfortable stance. The load was also restricted to 70% of individuals 1-RM for all three testing days, which could feel different to each individual and therefore have different effects on performance, mean 1RM 218 ± 55.79 and 1RM/BW 1.294 ± 0.146. EMG leads were only used on the superficial quadriceps muscles rectus femoris, vastus medialis, and vastus lateralis which do not provide a complete profile of quadriceps muscle activity. With ankle rotation not controlled, gastrocnemius activity could have influenced the movement. The variability among participants anthropometrics creates difficulty in providing a specific stance width and could elicit different activation patterns.

Similar studies, Charlton et al., (2020) and Lee et al., (2019), studied the effects of heel elevation with 14 and 20 participants, with the former using males between the ages of 18-35, and the latter using healthy individuals between the ages of 18-35, while also controlling stance width and ankle rotation. Both studies recruited subjects with at least one year of resistance training experience and found no significant increases in knee extensor activation. Charlton et al., (2020) used a wide variety of resistance-trained males but noted that only males were recruited to prevent significant anatomic variability among subjects. Furthermore, anatomic variability goes beyond differences in sex and to provide a deeper insight, future studies should aim to recruit participants with similar anthropometric measurements.

Practical Application

The decrease in activity of the RF and VM suggests that the shift in muscle activity is not in the quadriceps. The findings showed no significant improvements in muscle activity and therefore a conclusion could not be drawn on if the effects of muscle activity influence on performance during the BS. There was a slight increase in concentric barbell distance, or the upward phase, though it was not significant. Application of these findings could be to provide the readers with insight on the suggested effects of changes in muscle activity toward a specific population.

This research illustrates that muscle activity in trained subjects may not so easily be altered with minor biomechanical changes. The main concept of heel elevation during a BS is normally to work around limited dorsiflexion, while this is present rather frequently even in healthy populations, the training level may overshadow these limitations. The main contribution of the present study is in the participants used, as there were no significant findings, this presents the argument that the minor biomechanical alteration is not enough to change the neuromuscular connection.

Future Research

With the amount of anatomic variability, it may be difficult to discover the effects of heel elevation as the amount of muscle contribution can be much different, which was present in this study. The effects of heel elevation show conflicting results in research, a larger and more specific sample size would provide a deeper insight on the possible effects. There also may be more beneficial findings in unexperienced weightlifters, with resistance trained individuals the neuromuscular component is strong with a familiar movement, this could cause a slight change of heel elevation to have minimal effect on muscle activation. More heel elevation may also elicit better results, a greater stimulus that forces the body to undergo more significant biomechanical changes.

With no immediate changes in muscle activity, looking at the changes in muscle activity over a much longer period of time could show changes in involvement. Previous research indicated that heel elevation can promote a more upright posture and increased squat depth; studies should examine heel elevated squats implemented into an individual's exercise prescription over several months. Different study designs may show more definitive differences, using this research method with a control and experimental group to see how muscle activity or contribution changes over time.

To fully understand the contributions and activity levels of muscle activity through biomechanical alterations, surface EMG testing should be done on all muscle groups in the lower extremities. With a complete picture of muscle activity, more specific conclusions can be drawn on the possibility of changes in activation. By testing multiple muscle groups, conclusions can be drawn on where activation is increasing or decreasing, and whether it is a result of certain muscle groups becoming more active. Understanding muscle activation and contribution may be a reliable source for measuring performance, while in resistance-trained subjects, to elicit a greater change a more extreme biomechanical alteration should be implemented.

The heel raised BS serves to work around the limitation of ankle dorsiflexion and give the individual a better opportunity to perform a complete squat. Future research should include participants with this limitation and test the activity levels in comparison to healthy subjects. Testing the heel raised squats on subjects with a relevant limitation may provide deeper insight on the appropriate usage of the movement. Finally, it may be beneficial to test subjects that are untrained or with limitations, as in healthy subjects with resistance training experience there simply may not be enough change in stimulus to bring forth significant changes.

CHAPTER VI

CONCLUSION

The results of this study show that heel elevation can alter quadriceps muscle activation. It was hypothesized that muscle activation would increase and subsequently barbell metrics would also increase but the findings showed a significant decrease in RF and VM activity; there were no significant findings in VL activation. There was a slight increase in concentric barbell distance, though not significant. The findings suggest that heel elevation does not have an increasing effect on the superficial quadriceps muscles and as a result barbell metrics were not altered. This could be due to participants' level of training, with many of the participants being well versed in the movement, the slight biomechanical changes could have little effect due to the strong neuromuscular connection. The changes in muscle activity among the participants were similar but the contribution varied significantly, meaning that the level of activity in the quadriceps varied vastly among participants.

Alterations to the biomechanics of a movement provide a unique way to cater to individuals' preferences, variability, or to work around limitations. In the case of heel elevation, most research suggests that heel elevated conditions better support an upright posture, reducing the lumbar shear forces and increasing the activity of the posterior calf muscles along with the quadriceps muscle group (Charlton et al., 2017; Johnston et al., 2017; Sato et al., 2012). Heel elevated squats have proven to be a safer, more effective alternative to the squat movement, though the effects may not be drastic enough to elicit significant changes in muscle activity and movement performance.

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Appendix A

2023 PAR-Q+

The Physical Activity Readiness Questionnaire for Everyone

The health benefits of regular physical activity are clear; more people should engage in physical activity every day of the week. Participating in physical activity is very safe for MOST people. This questionnaire will tell you whether it is necessary for you to seek further advice from your doctor OR a qualified exercise professional before becoming more physically active.

GENERAL HEALTH QUESTIONS

Please read the 7 questions below carefully and answer each one honestly: check YES or NO.	YES	NO
1) Has your doctor ever said that you have a heart condition ☐ **OR** high blood pressure ☐?	☐	☐
2) Do you feel pain in your chest at rest, during your daily activities of living, **OR** when you do physical activity?	☐	☐
3) Do you lose balance because of dizziness **OR** have you lost consciousness in the last 12 months? Please answer **NO** if your dizziness was associated with over-breathing (including during vigorous exercise).	☐	☐
4) Have you ever been diagnosed with another chronic medical condition (other than heart disease or high blood pressure)? **PLEASE LIST CONDITION(S) HERE:** ______	☐	☐
5) Are you currently taking prescribed medications for a chronic medical condition? **PLEASE LIST CONDITION(S) AND MEDICATIONS HERE:** ______	☐	☐
6) Do you currently have (or have had within the past 12 months) a bone, joint, or soft tissue (muscle, ligament, or tendon) problem that could be made worse by becoming more physically active? Please answer **NO** if you had a problem in the past, but it **does not limit your current ability** to be physically active. **PLEASE LIST CONDITION(S) HERE:** ______	☐	☐
7) Has your doctor ever said that you should only do medically supervised physical activity?	☐	☐

If you answered NO to all of the questions above, you are cleared for physical activity.
Please sign the PARTICIPANT DECLARATION. You do not need to complete Pages 2 and 3.

- Start becoming much more physically active – start slowly and build up gradually.
- Follow Global Physical Activity Guidelines for your age (https://www.who.int/publications/i/item/9789240015128).
- You may take part in a health and fitness appraisal.
- If you are over the age of 45 yr and NOT accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.
- If you have any further questions, contact a qualified exercise professional.

PARTICIPANT DECLARATION
If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that the community/fitness center may retain a copy of this form for its records. In these instances, it will maintain the confidentiality of the same, complying with applicable law.

NAME ______ DATE ______

SIGNATURE ______ WITNESS ______

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER ______

If you answered YES to one or more of the questions above, COMPLETE PAGES 2 AND 3.

Delay becoming more active if:

- You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the ePARmed-X+ at www.eparmedx.com before becoming more physically active.
- Your health changes - answer the questions on Pages 2 and 3 of this document and/or talk to your doctor or a qualified exercise professional before continuing with any physical activity program.

01-11-2022

2023 PAR-Q+

FOLLOW-UP QUESTIONS ABOUT YOUR MEDICAL CONDITION(S)

1. Do you have Arthritis, Osteoporosis, or Back Problems?

If the above condition(s) is/are present, answer questions 1a-1c — If **NO** ☐ go to question 2

1a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
1b.	Do you have joint problems causing pain, a recent fracture or fracture caused by osteoporosis or cancer, displaced vertebra (e.g., spondylolisthesis), and/or spondylolysis/pars defect (a crack in the bony ring on the back of the spinal column)?	YES ☐ NO ☐
1c.	Have you had steroid injections or taken steroid tablets regularly for more than 3 months?	YES ☐ NO ☐

2. Do you currently have Cancer of any kind?

If the above condition(s) is/are present, answer questions 2a-2b — If **NO** ☐ go to question 3

2a.	Does your cancer diagnosis include any of the following types: lung/bronchogenic, multiple myeloma (cancer of plasma cells), head, and/or neck?	YES ☐ NO ☐
2b.	Are you currently receiving cancer therapy (such as chemotheraphy or radiotherapy)?	YES ☐ NO ☐

3. Do you have a Heart or Cardiovascular Condition? This includes Coronary Artery Disease, Heart Failure, Diagnosed Abnormality of Heart Rhythm

If the above condition(s) is/are present, answer questions 3a-3d — If **NO** ☐ go to question 4

3a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
3b.	Do you have an irregular heart beat that requires medical management? (e.g., atrial fibrillation, premature ventricular contraction)	YES ☐ NO ☐
3c.	Do you have chronic heart failure?	YES ☐ NO ☐
3d.	Do you have diagnosed coronary artery (cardiovascular) disease and have not participated in regular physical activity in the last 2 months?	YES ☐ NO ☐

4. Do you currently have High Blood Pressure?

If the above condition(s) is/are present, answer questions 4a-4b — If **NO** ☐ go to question 5

4a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
4b.	Do you have a resting blood pressure equal to or greater than 160/90 mmHg with or without medication? (Answer **YES** if you do not know your resting blood pressure)	YES ☐ NO ☐

5. Do you have any Metabolic Conditions? This includes Type 1 Diabetes, Type 2 Diabetes, Pre-Diabetes

If the above condition(s) is/are present, answer questions 5a-5e — If **NO** ☐ go to question 6

5a.	Do you often have difficulty controlling your blood sugar levels with foods, medications, or other physician-prescribed therapies?	YES ☐ NO ☐
5b.	Do you often suffer from signs and symptoms of low blood sugar (hypoglycemia) following exercise and/or during activities of daily living? Signs of hypoglycemia may include shakiness, nervousness, unusual irritability, abnormal sweating, dizziness or light-headedness, mental confusion, difficulty speaking, weakness, or sleepiness.	YES ☐ NO ☐
5c.	Do you have any signs or symptoms of diabetes complications such as heart or vascular disease and/or complications affecting your eyes, kidneys, **OR** the sensation in your toes and feet?	YES ☐ NO ☐
5d.	Do you have other metabolic conditions (such as current pregnancy-related diabetes, chronic kidney disease, or liver problems)?	YES ☐ NO ☐
5e.	Are you planning to engage in what for you is unusually high (or vigorous) intensity exercise in the near future?	YES ☐ NO ☐

2023 PAR-Q+

6.	**Do you have any Mental Health Problems or Learning Difficulties?** This includes Alzheimer's, Dementia, Depression, Anxiety Disorder, Eating Disorder, Psychotic Disorder, Intellectual Disability, Down Syndrome	
	If the above condition(s) is/are present, answer questions 6a-6b	If **NO** ☐ go to question 7
6a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
6b.	Do you have Down Syndrome **AND** back problems affecting nerves or muscles?	YES ☐ NO ☐
7.	**Do you have a Respiratory Disease?** *This includes Chronic Obstructive Pulmonary Disease, Asthma, Pulmonary High Blood Pressure*	
	If the above condition(s) is/are present, answer questions 7a-7d	If **NO** ☐ go to question 8
7a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
7b.	Has your doctor ever said your blood oxygen level is low at rest or during exercise and/or that you require supplemental oxygen therapy?	YES ☐ NO ☐
7c.	If asthmatic, do you currently have symptoms of chest tightness, wheezing, laboured breathing, consistent cough (more than 2 days/week), or have you used your rescue medication more than twice in the last week?	YES ☐ NO ☐
7d.	Has your doctor ever said you have high blood pressure in the blood vessels of your lungs?	YES ☐ NO ☐
8.	**Do you have a Spinal Cord Injury?** *This includes Tetraplegia and Paraplegia*	
	If the above condition(s) is/are present, answer questions 8a-8c	If **NO** ☐ go to question 9
8a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
8b.	Do you commonly exhibit low resting blood pressure significant enough to cause dizziness, light-headedness, and/or fainting?	YES ☐ NO ☐
8c.	Has your physician indicated that you exhibit sudden bouts of high blood pressure (known as Autonomic Dysreflexia)?	YES ☐ NO ☐
9.	**Have you had a Stroke?** *This includes Transient Ischemic Attack (TIA) or Cerebrovascular Event*	
	If the above condition(s) is/are present, answer questions 9a-9c	If **NO** ☐ go to question 10
9a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
9b.	Do you have any impairment in walking or mobility?	YES ☐ NO ☐
9c.	Have you experienced a stroke or impairment in nerves or muscles in the past 6 months?	YES ☐ NO ☐
10.	**Do you have any other medical condition not listed above or do you have two or more medical conditions?**	
	If you have other medical conditions, answer questions 10a-10c	If **NO** ☐ read the Page 4 recommendations
10a.	Have you experienced a blackout, fainted, or lost consciousness as a result of a head injury within the last 12 months **OR** have you had a diagnosed concussion within the last 12 months?	YES ☐ NO ☐
10b.	Do you have a medical condition that is not listed (such as epilepsy, neurological conditions, kidney problems)?	YES ☐ NO ☐
10c.	Do you currently live with two or more medical conditions?	YES ☐ NO ☐

PLEASE LIST YOUR MEDICAL CONDITION(S) AND ANY RELATED MEDICATIONS HERE: ____________________

____

GO to Page 4 for recommendations about your current medical condition(s) and sign the PARTICIPANT DECLARATION.

01-11-2022

2023 PAR-Q+

If you answered NO to all of the FOLLOW-UP questions (pgs. 2-3) about your medical condition, you are ready to become more physically active - sign the PARTICIPANT DECLARATION below:

- It is advised that you consult a qualified exercise professional to help you develop a safe and effective physical activity plan to meet your health needs.
- You are encouraged to start slowly and build up gradually - 20 to 60 minutes of low to moderate intensity exercise, 3-5 days per week including aerobic and muscle strengthening exercises.
- As you progress, you should aim to accumulate 150 minutes or more of moderate intensity physical activity per week.
- If you are over the age of 45 yr and **NOT** accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.

If you answered **YES** to **one or more of the follow-up questions** about your medical condition:
You should seek further information before becoming more physically active or engaging in a fitness appraisal. You should complete the specially designed online screening and exercise recommendations program - the **ePARmed-X+ at www.eparmedx.com** and/or visit a qualified exercise professional to work through the ePARmed-X+ and for further information.

Delay becoming more active if:

- You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the ePARmed-X+ **at www.eparmedx.com** before becoming more physically active.
- Your health changes - talk to your doctor or qualified exercise professional before continuing with any physical activity program.

- You are encouraged to photocopy the PAR-Q+. You must use the entire questionnaire and NO changes are permitted.
- The authors, the PAR-Q+ Collaboration, partner organizations, and their agents assume no liability for persons who undertake physical activity and/or make use of the PAR-Q+ or ePARmed-X+. If in doubt after completing the questionnaire, consult your doctor prior to physical activity.

PARTICIPANT DECLARATION

- All persons who have completed the PAR-Q+ please read and sign the declaration below.
- If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that the community/fitness center may retain a copy of this form for records. In these instances, it will maintain the confidentiality of the same, complying with applicable law.

NAME ______________________ DATE ______________________

SIGNATURE ______________________ WITNESS ______________________

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER ______________________

For more information, please contact
www.eparmedx.com
Email: eparmedx@gmail.com

Citation for PAR-Q+
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The PAR-Q+ was created using the evidence-based AGREE process (1) by the PAR-Q+ Collaboration chaired by Dr. Darren E. R. Warburton with Dr. Norman Gledhill, Dr. Veronica Jamnik, and Dr. Donald C. McKenzie (2). Production of this document has been made possible through financial contributions from the Public Health Agency of Canada and the BC Ministry of Health Services. The views expressed herein do not necessarily represent the views of the Public Health Agency of Canada or the BC Ministry of Health Services.

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Appendix B

Health Status

Musculoskeletal Injuries (Within last 6 months)

Check all that apply and explain injuries

Joint	**No Injury**	**Injury** (Explain)
Neck		
Shoulder		
Back		
Hip		
Knee		
Ankle		
Foot		
Elbow		
Wrist		
Fingers		

Do you knowingly have any allergy or adverse reactions to medical grade adhesive commonly used in, but not limited to: medical bandages, medical electrodes for ECG (stress testing), bandages, taping etc.?

YES____ NO_____

Accepted____ **NOT Accepted____**

Subject Code ____________________ Date_________

P.I. Signature ____________________ Date________

APPENDIX C
Informed Consent

****
William Paterson University

Project Title:	The effects of heel height on back squat performance
Principal Investigator:	Matthew Pierce
Faculty Sponsor:	Dr. Racine R. Emmons Hindelong
Department:	Kinesiology
Course Name and Number:	7800-001
Protocol Approval Date:	

****

Invitation to Participate: I have been asked to volunteer in a research study looking into the effects of heel height on back squat performance. By providing my signature below, I can confirm I have met the inclusion criteria to participate in this study.

Purpose: The goal of this study is to determine the effects of heel raised squats on muscle activation and performance, in comparison to the traditional squat stance, and if they will improve short term muscular performance indicators including, but no limited to, peak power output, velocity, force, rate of force development, and displacement. This study will also utilize velocity-based training methods in determining participants' rating of perceived exertion and fatigue effects when altering heel height, as well as electromyography (EMG) to track muscle activation.

Procedures: Informed consent will be obtained from all participants. The participant will then be asked to complete the Physical Activity Readiness Questionnaire (PAR-Q) and a Health History Survey to determine eligibility for participation in the study
Once the participant is accepted into the study, he/she will be asked to attend four non-consecutive sessions that will be located in the Human Performance Lab, in Grant Hall and in the Wightman Gym weight room; sessions will run for approximately one hour with at least 48 hours between sessions. All four testing days will consist of the same active warm up, in the Wightman Gym involving dynamic stretching and performing a load-based barbell squat warm-up to help further potentiate and ensure readiness of the participant. A cool-down consisting of localized static stretching will be performed after each session before the participant is dismissed. Prior to starting testing during each session, electrode sites (3 total) will be prepared by removing excess hair then applying an alcohol wipe to the area to remove dead skin and oils to minimize EMG impedance and to protect the participant; electrodes will be disposed of after each session and EMG sensors/all other equipment that was in contact with the investigator or participant will be sanitized after each participant session. During the squat exercises, participants will be required to perform without shoes on.

Day 1: initial testing, will consist of obtaining baseline anthropometric measurements, familiarizing the participant with the procedures in the in the Wightman Gym weight room, and finding 70% of the participants estimated1-repetition maximum during the back squat. This will be done by an exercise professional using the NSCA training load chart and the Enode device, adhering to the NSCA repetition guidelines for load while also maintaining a movement speed of 0.5 m/s – 0.75 m/s tracked by the VBT device. There has shown to be a strong relationship between load and velocity, due to everyday fluctuations in individual performance, velocity-based methods may respond better to daily readiness (Zatsiorskii et al., 2021)

Day 2: the participant will meet in the Wightman Gym to perform the same warm-up consisting of dynamic stretching then proceeding with a series of loaded squats based on their previous one repetition maximum intensity and be asked to maintain a movement velocity of at least 0.5 m/s which will be tracked by the Enode device and demonstrated by the researcher. Proceeding the active warm up, the participant will have three EMG leads placed on the superficial muscles of the quadriceps after the sites have been prepared (excess hair removal and site cleaning), participants will then perform three sets of back squats at 70% of their one repetition maximum until they are unable to maintain a movement velocity of 0.5 m/s which will be tracked in real time by the Enode device. Participants will have three minutes of rest in between sets. After a ten-minute cool down of localized static stretching, the participant will be dismissed.

Day 3: participants will again perform the same warm up routine in the Wightman Gym dynamic stretching and the same loaded-squat warm up with the preset weights established in the initial session, now at a 0.5-inch heel incline using squat wedges, while maintaining a movement velocity of at least 0.5 m/s tracked in real time by the Enode device. Three EMG leads will then be placed in the same locations on the quadriceps after the sites have been prepared (excess hair removal and site cleaning), participants will then perform the same squat routine, three sets at 70% of their one repetition maximum with their heels on a 0.5 inch incline, until they are unable to maintain a movement velocity of at least 0.5 m/s, with three minutes of rest between sets. The participant will then perform the same cool down of localized static stretching before being dismissed. Incline heights were based off previous research (Johnston et al. 2017 & Edwards et al. 2008) looking at the effects of heel height on squat performance.

Day 4: participants will begin in the Human Performance lab as before, performing a five-minute walk-jog on the treadmill, dynamic stretching, with 2 minutes of rest before proceeding to the Wightman Gym weight room. The participant will proceed to the Wightman Gym weight to perform the same loaded-squat warm up with the same preset weights established in the initial session, now at a 1.0-inch heel incline, while maintaining a movement velocity of at least 0.5 m/s tracked in real time by the Enode device. Three EMG leads will then be placed in the same locations on the quadriceps after the sites have been prepared (excess hair removal and site cleaning, participants will then perform the same squat routine, three sets at 70% of their one repetition maximum with their heels on a 1.0 inch incline, until they are unable to maintain a movement velocity of 0.5 m/s, with three minutes of rest between sets. The participant will then perform the same cool down of localized static stretching before being dismissed.

Risks: To further avoid potential risks and injuries during the study, participants will be directed to perform a proper warm up and given ample recovery time during and after testing days and be under the constant supervision of a professional for their safety. The inclusion criteria of this study, current resistance training of one year and no physical injury within the last six months, also limit the potential risks for injury. A PAR-Q and Health History Survey will also be utilized to identify any potential risks for exclusion from participation and ensure physical readiness. The potential risks during exercise include an elevated heart rate during exercise and physical injury from exercise. *The potential risks of surface*

EMG are minimal, risk of infection from unsanitary equipment and other minor risks include rash, itching, swelling or redness at the site of electrode placement. To mitigate risk, electrodes will be replaced for each individual after every session to lessen the risk of infection, as well as, proper sanitization of all other equipment that was in contact with the investigator and participant; the removal of excess hair and dead skin is not only important in EMG readings but for the comfort and safety of the participants. Both the warm-up and the cool-down are not only used to potentiate and recover from exercise but to also prevent injury, soreness, and discomfort, their inclusion in this study will continue to enforce that. Additionally, research will be led by a master's Student in Exercise Physiology and Sports Studies under direct supervision of Dr. Racine Emmons, a registered Clinical Exercise Physiologist.
In the event of an injury, the participant will be excluded from the study and be directed to William Paterson's Center for Health and Wellness, located at Overlook South (1^{st} floor), and can be reached at 972-720-2360.
As the participant, I understand that I am not entitled to financial compensation in the event of an injury during the study.

Benefits: The benefits of this study include improving squat performance, range of motion, and decreasing shear forces in the spine when elevating the heels during a squat. The outcomes of this research aim to add to the current body of knowledge on heel-raised squats but also inform athletes and coaches of the benefits, safety, and improvements, helping people prevent injuries, increase strength and subsequently improve performance. This study is entirely voluntary with no form of financial compensation.

Confidentiality and Data Management: I understand that my identity will be protected at all times and that my name will not be used without my separate written permission. I understand that the results of this study will not be reported in a way that would identify individual participants. I understand that by providing consent for this study I am also providing consent for my anonymized responses to be included in datasets that may be used in the future the investigator of this study or other investigators for research related to the purpose of this research study. All hard copies of data will be kept at William Paterson, in the Human Performance lab stored in a locked cabinet, digital data will be stored in a password protected folder that requires multi-factor authentication.
I understand that any data collected as part of this study will be stored in a safe and secure location, and that this data will be destroyed when this research is completed and when/if the research is published.

Participant Rights: I understand my participation in this study is completely voluntary and at any point in the study I may withdraw. If I have questions about this study, I may call or email the investigators. If I have any questions or concerns about this research, my participation, the conduct of the investigators, or my rights as a research subject, I may contact the Institutional Review Board (IRB) at 973-720-2852 or by email to IRBAdministrator@wpunj.edu.

I have read and understand the consent form and I agree to participate in this research study. Upon signing below, I will receive a copy of the consent form.

Name of Participant:

Signature of Participant:

Date:

Name of Investigator: Matthew Pierce

Signature of Investigator:

Date:

THE WILLIAM PATERSON UNIVERSITY OF NEW JERSEY

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College of Arts, Humanities and Social Sciences
Contact: Kate Boschert (BoschertK1@wpunj.edu)
Office of Sponsored Programs

April 21, 2023

To: Matthew Pierce

From: Elizabeth Victor

RE: Protocol #2023-091: *The Effects of Heel Height On Back Squat Performance*

The IRB has APPROVED the above study involving humans as research subjects. This study was approved as: Category: Expedited 45 CFR 46.110(a)(4); special class of subjects: None.

Please note the following extra conditions or requirements that must be met before you may initiate your research:

- *None*

General Conditions and Requirements:

1. The Institutional Review Board expects that your research will be carried out in accordance with your protocol request.

2. Any IRB directed extra conditions or requirements listed above must be approved by your faculty advisor prior to beginning your research.

3. Modifications to the research plan, subject pool, informed consent, survey instruments, or other critical components of your project, must be submitted to the IRB for approval before those changes are implemented.

4. You are required to immediately report any problems that you encounter while using human subjects to your faculty sponsor who will help you report these problems to the Institutional Review Board.

5. This approval of your research is effective for one year from the date of this approval. If your research extends more than one year you must submit an electronic Continuing Review Form to provide an Annual Update to the IRB regarding the progress on your research and to obtain a new approval notice.

Good luck with your research, please contact IRBAdministrator@wpunj.edu if you have any questions.

C: Dr. Emmons

Appendix D

TRAINING LOAD CHART

Max reps (RM)	1	2	3	4	5	6	7	8	9	10	12
% 1RM	100%	95%	93%	90%	87%	85%	83%	80%	77%	75%	70%
Load	10	9.5	9.3	9	8.7	8.5	8.3	8	7.7	7.5	7
	20	19	18.6	18	17.4	17	16.6	16	15.4	15	14
	30	28.5	27.9	27	26.1	25.5	24.9	24	23.1	22.5	21
	40	38	37.2	36	34.8	34	33.2	32	30.8	30	28
	50	47.5	46.5	45	43.5	42.5	41.5	40	38.5	37.5	35
	60	57	55.8	54	52.2	51	49.8	48	46.2	45	42
	70	66.5	65.1	63	60.9	59.5	58.1	56	53.9	52.5	49
	80	76	74.4	72	69.6	68	66.4	64	61.6	60	56
	90	85.5	83.7	81	78.3	76.5	74.7	72	69.3	67.5	63
	100	95	93	90	87	85	83	80	77	75	70
	110	104.5	102.3	99	95.7	93.5	91.3	88	84.7	82.5	77
	120	114	111.6	108	104.4	102	99.6	96	92.4	90	84
	130	123.5	120.9	117	113.1	110.5	107.9	104	100.1	97.5	91
	140	133	130.2	126	121.8	119	116.2	112	107.8	105	98
	150	142.5	139.5	135	130.5	127.5	124.5	120	115.5	112.5	105
	160	152	148.8	144	139.2	136	132.8	128	123.2	120	112
	170	161.5	158.1	153	147.9	144.5	141.1	136	130.9	127.5	119
	180	171	167.4	162	156.6	153	149.4	144	138.6	135	126
	190	180.5	176.7	171	165.3	161.5	157.7	152	146.3	142.5	133
	200	190	186	180	174	170	166	160	154	150	140
	210	199.5	195.3	189	182.7	178.5	174.3	168	161.7	157.5	147
	220	209	204.6	198	191.4	187	182.6	176	169.4	165	154
	230	218.5	213.9	207	200.1	195.5	190.9	184	177.1	172.5	161
	240	228	223.2	216	208.8	204	199.2	192	184.8	180	168
	250	237.5	232.5	225	217.5	212.5	207.5	200	192.5	187.5	175
	260	247	241.8	234	226.2	221	215.8	208	200.2	195	182
	270	256.5	251.1	243	234.9	229.5	224.1	216	207.9	202.5	189
	280	266	260.4	252	243.6	238	232.4	224	215.6	210	196
	290	275.5	269.7	261	252.3	246.5	240.7	232	223.3	217.5	203
	300	285	279	270	261	255	249	240	231	225	210
	310	294.5	288.3	279	269.7	263.5	257.3	248	238.7	232.5	217
	320	304	297.6	288	278.4	272	265.6	256	246.4	240	224
	330	313.5	306.9	297	287.1	280.5	273.9	264	254.1	247.5	231
	340	323	316.2	306	295.8	289	282.2	272	261.8	255	238
	350	332.5	325.5	315	304.5	297.5	290.5	280	269.5	262.5	245
	360	342	334.8	324	313.2	306	298.8	288	277.2	270	252
	370	351.5	344.1	333	321.9	314.5	307.1	296	284.9	277.5	259
	380	361	353.4	342	330.6	323	315.4	304	292.6	285	266
	390	370.5	362.7	351	339.3	331.5	323.7	312	300.3	292.5	273
	400	380	372	360	348	340	332	320	308	300	280
	410	389.5	381.3	369	356.7	348.5	340.3	328	315.7	307.5	287
	420	399	390.6	378	365.4	357	348.6	336	323.4	315	294
	430	408.5	399.9	387	374.1	365.5	356.9	344	331.1	322.5	301
	440	418	409.2	396	382.8	374	365.2	352	338.8	330	308
	450	427.5	418.5	405	391.5	382.5	373.5	360	346.5	337.5	315
	460	437	427.8	414	400.2	391	381.8	368	354.2	345	322
	470	446.5	437.1	423	408.9	399.5	390.1	376	361.9	352.5	329
	480	456	446.4	432	417.6	408	398.4	384	369.6	360	336
	490	465.5	455.7	441	426.3	416.5	406.7	392	377.3	367.5	343
	500	475	465	450	435	425	415	400	385	375	350

- Training load chart can be used to calculate estimated 1-repetion maximum (1RM) values from multiple repetitions completed
  - For example, if an athlete completes 8 repetitions of the squat at 160 lbs, the estimated 1RM would be 200 lbs.
- Training load chart can also be used to assign intensity percentages for program design
  - For examaple, if an athlete's 1RM for the squat is 200 lbs, he/she should be able to successfully complete 10 repetitions of 150 lbs, or 75% max intensity.

Adapted from Landers, J. Maximum based on reps. *NSCA J* 6(6):60-61, 1984.

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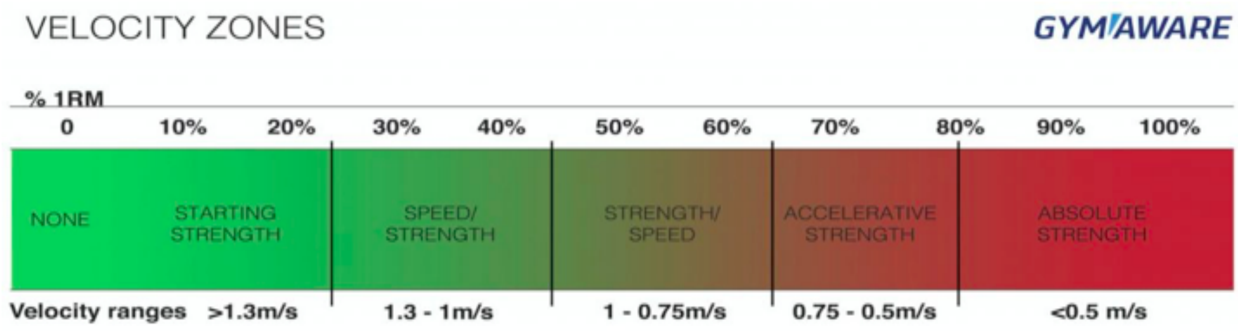
VELOCITY ZONES
GYM/AWARE
% 1RM
0
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
NONE
STARTING STRENGTH
SPEED/ STRENGTH
STRENGTH/ SPEED
ACCELERATIVE STRENGTH
ABSOLUTE STRENGTH
Velocity ranges
>1.3m/s
1.3 - 1m/s
1 - 0.75m/s
0.75 - 0.5m/s
<0.5 m/s