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The Impact of Crossramp Angle and Elliptical Path Trajectory on Lower Extremity Muscle Activation

Matthew M. Thorsen
matthewthorsen7@gmail.com

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By

Matt Thorsen

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Kathleen Kitto, Dean of the Graduate School

ADVISORY COMMITTEE

Chair, Dr. Dave Suprak

Dr. Jun San Juan

Dr. Lorrie Brilla

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Abstract

The purpose of this study was to examine the effects of linear path and converging path ellipticals at three varying crossramp angles (35°, 25°, and 15°) on mean muscle activation of the gluteus maximus (GMAX), semitendinosus (ST), vastus medialis (VM), lateral gastrocnemius (LG), and vastus lateralis (VL). The study consisted of 25 young adults (15 males and 10 females. All subjects had previous experience with elliptical trainers and had no contraindications preventing them from taking part in the study. The main outcome measure was mean muscle activation, presented at %MVC, for GMAX, ST, VM, LG, and VL. A two-way, repeated measures analysis of variance (ANOVA) was performed to determine significance, with an alpha level of 0.05. The converging path elliptical trainer showed no significant difference in muscle activation for GMAX, ST, VM, or LG, compared to the linear path elliptical, but was significantly higher (p = .006) for VL. Results for the crossramp angle showed that VM and VL had significantly higher muscle activation on the 35° ramp angle, with activation lessening from 25° to 15° (p = .027 and p < .001 respectively). LG showed higher activation on the 15° ramp angle with activation lessening from 25° to 35° (p = .003). Exercising at a higher crossramp angle appears to activate the quadriceps more, while exercising at a lower crossramp angle would activate the LG to a higher degree. Additionally, individuals wanting to focus on VL activation should perform exercise on a converging path elliptical at a higher crossramp angle; however, caution should be exercised to account for over strengthening of the VL.

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Table of Contents

List of Figures

List of Appendices

Chapter I

The Problem and Its Scope

Introduction

In 1995, Precor produced the first commercial elliptical trainer, called the elliptical fitness cross-trainer (EFX) 544 (About Precor: History of Innovation, 2016). The elliptical trainer had some advantages over traditional stationary equipment; it was the first piece of exercise equipment to allow the foot to roll from heel to toe just like in heelstrike running (Chien, Tsai, & Lu, 2007). Also, the smooth ellipse motion allowed for low impact since the foot never leaves contact with the pedal (D'Lima, Steklov, Patil, & Colwell, 2008). Elliptical trainers have mass appeal, due to a lower rate of perceived exertion, at a higher heartrate, and low impact, which is why ellipticals are used in a variety of settings, in health clubs, at homes, and in physical therapy clinics (D'Lima, Steklov, Patil, & Colwell, 2008; Brown, Cook, Krueger, & Heelan, 2010). One issue with some current elliptical trainers is that, while designed to mimic normal gait, lower extremity kinematics indicate results that differ from normal walking or running patterns; therefore, utilization of an elliptical trainer for the optimization of human gait may not be effective (Knutzen, McLaughlin, Row, Martin, & Lawson, 2008). The fixed path of an elliptical trainer may lead to injuries of the lower extremities (Lu, Chien, & Chen, 2007). Therefore, an elliptical trainer designed to more accurately reproduce natural gait would still have the benefits of the current ellipticals but may be safer, more biomechanically grounded, and more transferable to everyday life.

Purpose of the Study

The purpose of this study was to examine the differences between a standard linear path elliptical and a converging path elliptical, determine the advantages or disadvantages, for muscle activation, of the converging path elliptical, and draw conclusions about target populations. A secondary purpose of the study is to determine if the converging path elliptical more closely replicates lower extremity muscle activation patterns of walking and running.

Hypothesis

The hypothesis of this study is that the prototype converging path elliptical will exhibit significant differences compared to the traditional linear path elliptical in regard to lower extremity EMG muscle activation.

Significance of the Study

Movement improvements gained on an elliptical trainer may not always directly correlate to improvements in walking and/or running (Burnfield, Shu, Buster, & Taylor, 2010). It is important to develop new elliptical trainers that have general mass appeal and can be used by many people in a variety of different scenarios yet is also more beneficial and closely linked to normal human gait. As Hewett, Torg, and Boden (2009) showed, excessive knee valgus measures and hip abduction forces can lead to increased risk of ACL tears among other injuries. Thus, it is important that new pieces of exercise equipment take these factors into account and ensure safety. This study examined a new prototype elliptical, its differences and advantages in muscle activation and joint angles compared to the current Precor EFX 800 model elliptical trainer.

Limitations

- The limitations of this study include that the study population will be comprised of young, apparently healthy adults from a Kinesiology program. Therefore, this population is more inclined to be physically active and data for these subjects may differ from data of a more diverse population.
- Another limitation could be multiple treatment interference. The 5-minute time frame given between conditions may not be adequate for the subject to recover and exert the same amount of effort for the second condition. However, due to randomization of the condition order this limitation should be mitigated.
- The subjects were instrumented with many pieces of data collection hardware and although this is to remain steady for both conditions it may skew performance if comparing subject data with a greater population. The conditions and variables within the conditions were completely randomized. The instrumentation of the subjects was always done by the same individual to ensure accuracy. Testing was completed in one session so there was very little risk of experimental mortality or maturation.

Definition of terms

Flight phase: The flight phase refers to the point in a running gait where neither limb is in contact with the ground or platform (Cappellini, 2006).

Initial contact: Initial contact refers to the point of contact on a forward moving limb (Novacheck, 1998).

Converging: To approach the same point from different directions. Converging refers to the path of an elliptical starting wide at the base and moving more midline at the top of the ramp (Morris, 1980).

Electromyography: A method utilizing either surface electrodes or fine wire/needle electrodes to detect the action potentials of muscles and provide an electronic readout of the contraction intensity and duration (Floyd, 2012).

Extension: Straightening movement resulting in an increase of the angle in a joint by moving bones apart (Floyd, 2012).

Flexion: Movement of the bones toward each other at a joint by decreasing the angle (Floyd, 2012).

Gait cycle: A gait cycle is the duration from one-foot strike (initial contact) to next foot strike (initial contact) (Guo et al., 2006).

Kinematics: Kinematics are descriptions of movement that do not consider forces that cause said movement (Novacheck, 1998).

Linear Motion: Motion along a line. Linear motion refers to the pedal path of an elliptical adhering to a straight path (Floyd, 2012).

Loading Phase: Loading phase refers to the period of absorption where the absorbing limb accepts weight of the body mass and the center of mass falls from its peak height (Novacheck, 1998).

Midstance: Midstance refers to the point where the braking limb is now under the hip (Novacheck, 1998).

Propulsive phase: Propulsive phase is where the limb in contact with the ground produces force to accelerate the mass center forward (Hamner, Seth, & Delp, 2010).

Swing phase: The swing phase refers to when the propelling limb loses contact with the ground and swings forward towards the Initial contact, often marked by toe off (Novacheck, 1998).

Valgus: Valgus refers to the medial collapse of joint, specifically in regards to the knee (Hollman et al., 2009).

Triceps surae: Consists of both the soleus muscle and both heads of the gastrocnemius (Bobbert, 2001).

Chapter II

Review of Literature

Introduction

Elliptical trainers are used by many for different purposes, be it rehabilitation or simply fitness. Ellipticals are sought after to replicate a normal walking or running gait while minimizing impact forces. Additionally, many ellipticals offer moving arm levers to activate upper body musculature, provide cross ramp selections to adjust height of the movement plane, and allow users to select a level of resistance to meet their needs. Although impact forces are minimized, the fixed movement pattern may have other effects on lower extremity muscle activation, which has yet to be examined adequately in the literature and needs to be examined further to fully understand the advantage and disadvantage of using an elliptical trainer (Knutzen et al., 2008). This review will examine the lower extremity kinematics and EMG muscle activation patterns of walking/running and elliptical trainer use at various inclines and velocities.

Review of Literature

Lower extremity kinematics of normal gait. The gait cycle for running, measuring when one foot contacts the ground and then when that same foot comes back into contact with the ground, is comprised of initial contact (IC), midstance (MS), propulsive phase (PP), and swing phase (SP) (Novacheck, 1998). The lower extremity joints move throughout different angles in each of these phases. During the IC, the hip joint reaches approximately 10° of flexion after which the hip begins to extend as the MS phase approaches reaching 0° of flexion. As the stride reaches the PP, the hip flexion angle reaches its minimum of nearly -20° of flexion. This is to help extend the hip and propel the body forward. The SP is comprised of the hip transitioning from extension, to neutral, to a 10° of flexion position. The knee joint reaches a first peak during IC where the knee flexes to approximately 20° to accept the weight transference. Moving towards the MS and propulsive phases, the knee extends slightly to about 10° of flexion. The second, and larger peak, occurs during the SP where the knee flexes to 60° allowing the limb to swing through the gait cycle, begin to extend, and finally reach neutral flexion/extension just prior to IC. The ankle joint begins to plantar flex in preparation for the IC. Shortly after the ankle dorsiflexes, to -20° of plantar flexion, the stride moves towards MS. The ankle then quickly moves to a plantarflexion peak during the PP, about 17°. The ankle dorsiflexes, -5° of plantarflexion, during the SP to aid in moving the limb through the gait cycle (Winter, 1984). These aforementioned joint angles comprise a pattern of normal, overground running gait at a tempo of 110 strides/min. A study by Riley et al., (2008) examined the differences in joint kinematics between treadmill and overground running. Ultimately, results indicated that aside from knee maximal and minimal knee flexion, which had slight variations, treadmill and overground running are vastly similar. Overground running speed was based on each subjects average 10-Km speed and treadmill speed was based off an average of the overground speeds. Joint kinematics of normal gait running indicate rough values of: hip adduction 12.4°, hip internal rotation 13.7°, hip external rotation 14.1°, knee flexion max 106.5°, knee flexion min 9.3°, ankle eversion 2.2°, and pelvic rotation max 8°. These values provide a framework for lower extremity movement patterns that can be used to compare against other changing factors of running, be it incline or velocity changes.

Kinematics and velocity changes of normal gait. Normal human gait changes when velocity increases. In order to accommodate the increase in speed, factors such as stride length, contact patterns, stride duration, and joint kinematics change. Arendt-Nielsen et al. (1991) noted that when transitioning from slow walking to fast walking, the stride times decreased and frequency of stride increased. However, when examining peak knee joint angle, it was apparent that the change in velocity did not produce a significant change. Therefore, the adaptations would occur in a different variable (i.e. stride frequency or flight time)

According to Novacheck (1998), when transitioning from walking to jogging then to sprinting, the pelvis and trunk tilt anteriorly as velocity increases in order to utilize horizontal impulse for increasing propulsive forces. When examining hip extension, Novacheck found that hip extension values are similar between walking and running; however, the point in which maximum hip extension is attained happens at a different time point in the stride sequence. For walking, maximum hip extension is measured right before toe off at the end of the propulsive phase, while in running, maximum hip extension occurs later, right at toe off. Stride length is also known to increase with increasing speed; this is accomplished by an increased maximum hip flexion in running compared to walking. Similar to Novacheck, another study found that speed increased the hip and ankle maximum joint extension angles in MS phase (Guo et al., 2006). Additionally, Guo et al. (2006) reported that the hip and knee maximum flexion angles were greatly increased, as speed increased, during the swing phase. Hip maximum flexion angles increased from 22.5°, at 2.0 m/s, to 28.9°, at 3.5 m/s. Maximum knee flexion angles increased from 44.3°, at 2.0 m/s, to 61.7°, at 3.5 m/s. Novacheck (1998) found similar data that knee joint angles were also affected by increasing locomotion velocity. When comparing the propulsive phases of running and sprinting, knee flexion is less during sprinting yet knee extension is greater. This allows for greater leg stiffness and shorter contact times during the IC and MS phases. The increased knee extension during PP allows for greater propulsive forces and longer duration to produce force against the ground. A comparison of peak knee flexion values, walking

60°, running 90°, and sprinting 105°, shows that peak knee flexion, occurring at SP, increases at higher velocity. Increasing knee flexion affects the stride frequency by allowing the non-contact limb to quickly move forward more quickly by limiting the lever arm of the lower extremity. Increased velocity walking/running demonstrated an effect on lower extremity kinematics. Additionally, walking and running does not always occur on a level surface and joint angles will change to reflect increases or decreases in surface pitch (Guo et al., 2006).

Kinematics of normal gait on an incline. When an individual is running uphill, contact with the ground happens earlier in the gait cycle and at a position more superiorly than in level-ground running. In order to accommodate the sooner and higher ground contact, the contacting limb will have greater degrees of flexion at the hip, knee, and ankle joints during the contact (initial contact) and the swinging limb must therefore leave the ground earlier in order to ensure the individual does not fall forward beyond the base of support. Guo et al. (2006) measured subject kinematics while running upon surfaces with varying degrees of incline. They found that, as the slope of the treadmill increased, the propulsive foot lost contact with the ground earlier in the gait cycle. Peak hip, knee, and ankle flexion angles were greater during the swing phase when jogging up an incline compared to flat ground (Guo et al., 2006). These two changes mean that stride length and stride duration decreases when running uphill. Similarly, Paradisis and Cooke (2010) found that when comparing uphill, downhill, and flat sprint running, on a custom built ramp, that the stride length was significantly shorter in the uphill condition, 2.0 meters, when compared to flat and downhill running, 2.11 and 2.26 meters, respectively. Additionally, the flight duration of the gait cycle was shortest in uphill running, 124 ms, versus flat and downhill running, 127 ms for both conditions. Parallel with flight duration, flight distance was significantly shorter in uphill sprint running compared to flat and downhill running. Paradisis and

Cooke also measured joint angles, at contact and at takeoff, under the varying inclines and found that at contact the shank angle was significantly more acute than horizontal running, 88° compared to 92°, respectively. Knee and hip joint angles were only marginally smaller for uphill versus flat running at point of contact. When examining joint angles at takeoff, both shank and knee joint angles were significantly different than horizontal running, with the uphill shank angle being 6° less than horizontal and uphill knee being 7° less than horizontal running. These results indicate that, at point of contact, the ground to shank angle was more acute in uphill running, suggesting that contact in uphill running happens earlier in the gait cycle than it does for horizontal/flat running. When examining point of takeoff, both the shank to ground and knee angles were more acute in uphill running, suggesting that the propelling extremity was unable to reach full extension before moment of takeoff, thereby shortening stride length. Lange, Hintermeister, Schlegel, Dillman, & Steadman, (1996) studied the effects of treadmill grade changes (0, 12, and 24° incline) on ankle, knee, and hip joints during points of IC and range of motion throughout. What Lange and his colleagues found was that, for the entire stride length, hip and ankle range of motion was increased while knee range of motion decreased with increasing grade. This was proposed to be due to the near maximal knee extension during level walking and subsequent decreases as incline increased. Examining joint angles, at IC, there was increased flexion at the hip, dorsiflexion of the ankle, and knee flexion. The following joint angles are measured at IC across the varying grades, ankle measures progressed from 5.8° of plantarflexion at 0% grade to 1.1° dorsiflexion at 12% grade and finally 11.2°dorsiflexion at 24% grade, hip angle started at 23.2° during level walking and moved to 39.6° at 12% grade and 45.7° at 24% grade, and lastly, knee joint angle changed from 4.4° flexion at 0% grade to 26° at

12% and 45.7° at 24% grade. Just as walking and running have patterns of kinematics across a variety of scenarios so does the motion of an elliptical trainer.

Gait kinematics on an elliptical trainer. Lu, Chien, and Chen (2007) performed a study on lower extremity joint angles and joint loading while on an elliptical trainer. During the swing phase of the stride the mean peak hip flexion angle was 40.33° and for stance phase of motion the mean peak hip flexion was 28.89°. Mean peak knee joint flexion angle, during swing phase, was 79.4°. Rogatzki et al. (2012) observed subjects on a Precor Adaptive Motion Trainer (AMT), with stride lengths and motion similar to that of an elliptical trainer, and measured mean peak joint angles for the ankle, knee, and hip over a duration of 10 complete cycles. The angles measured were mean peak joint angles, where the anatomical position was at 0°. For the ankle, the peak dorsiflexion was 20.7˚ and the peak plantarflexion was 3.0˚. The knee joint had a peak flexion of 89.0˚ and peak extension of 14.9˚ extension. The hip joint had a peak flexion of 51.2˚ and peak extension of 17.4˚. The resistance was set so that each subject would be at 80% of their individual heart rate reserve with the pace being 120 strides/min. Horvais et al. (2008) performed a similar study using an elliptical trainer where subjects were allowed to freely choose their step frequency and joint kinematics were measured. For this study, the knee and hip were the only lower extremity joints examined with both minimal and maximal angles captured. These joint angles were relative joint angles where the angle between two body segments around a single joint, knee joint angle is the angle between the thigh and shank for example. For the knee, joint mean minimal joint angle was 119.7˚ and mean maximal joint angle was 168.2˚. The hip joint mean minimal joint angle was 145.3˚ and mean maximal joint angle was 170.3˚. The studies by Rogatzki and Horvais vary greatly, possibly because Rogatzki et al. was examining an AMT which is similar to an elliptical trainer but has some differences and Horvais et al. was using a

Performa 190 elliptical trainer. From the results of these two studies, movement on an AMT Precor machine allows for greater knee flexion as compared to the Performa 90 elliptical trainer. However, the data for hip and knee joint angles between Horvais and Lu have similarities. Potentiating that, while the AMT is a different training device and elicits different joint angles, two different ellipticals demonstrate similar movement pattern in joint kinematics. Contrasting these knee joint angles with walking/running, a greater knee flexion measurement does not necessarily correspond with similar gait patters. Comparing elliptical patterns and bipedal locomotor patterns will be discussed further in the next section.

Kinematics of elliptical trainer vs. walking/running. Elliptical trainers, while designed to mimic low impact overground locomotor gait, exhibit differences in lower extremity joint kinematics. Buster, Ginoza, and Burnfield (2006) conducted a study to examine the similarities and differences between overground and treadmill walking with elliptical trainer gait. They found that, at the ankle, there was reduced plantar flexion during the loading response, one degree for elliptical trainer versus six and seven degrees for treadmill (TM) and overground (OG) walking, respectively. The elliptical demonstrated greater values of dorsiflexion at the end of the PP, 20° compared to that of TM and OG walking, 15° and 14° respectively. Lastly, elliptical movement possessed significantly greater dorsiflexion during the MS, 19° compared to two degrees for both TM and OG walking. When examining the knee joint, the elliptical data showed 32° of flexion at IC, 32° of flexion during LR, and 26° of flexion during PP. Compared to OG with values of 4° of extension, 11° of flexion, and 1° of extension, for IC, LR, and PP. TM walking demonstrated similar values to OG knee values at IC, LR, and PP with 3° of extension, 15° of flexion, and 1° of extension respectively. The elliptical trainer demonstrated hip values 42° of flexion compared to the OG 31° and TM 33°. For the swing phase the elliptical measured 51° of hip flexion while OG showed 34° of flexion and TM had 35° of flexion. During PP elliptical hip flexion measured 4°, OG measured 10° of hip extension, and TM measured 9° of hip extension. This study indicates that, for lower extremity joints, there is a trend towards greater range of motion on an elliptical trainer compared to OG and TM walking, except in regard to hip extension, where OG and TM walking allowed for greater hip extension at the end of PP. A study by Burnfield et al. (2010) found that when examining walking gait kinematics to those of a SportsArt elliptical trainer for hip, knee, and ankle at various periods in the gait cycle, that the elliptical trainer had significantly higher joint angles for all lower extremity joints except ankle at the loading response, end of PP, and MS positions (figure 6). These data agree with the previously mentioned study by Buster et al. and indicate that, on average, an elliptical trainer will elicit greater joint angles than those of merely walking overground or on a treadmill. Greater joint angles could increase difficulty of the workout, aid in joint mobility, and change degree of muscle activation (Chumanov, Wille, Michalski, & Heiderscheit, 2012).

Muscle activation during normal gait. In normal gait, the lower extremity follows a typical pattern, which includes initial contact (IC), midstance (MS), swing phase (SP), and propulsive phase (PP) (Novacheck, 1998). The lower extremity muscle groups activate in a corresponding manner to these specific phases. According to Gazendam and Hof (2007), the quadriceps muscle group activates slightly before IC and ceases activation at the end of PP, with a maximum activation roughly at the onset of the IC. The hamstring group has a two-peak pattern, with one peak in the second half of SP and a twin peak during the IC. The gluteal group also has two peaks in the gait cycle, with one peak occurring during IC and the other during SP. The triceps surae group showed a single peak pattern of activation just before IC and ceasing at the end of PP. Similarly, Arendt-Nielson, Sinkjaer, Kallesoe, and Nielson (1991), Kyrolainen, Avela, and Komi (2007), and Hamner, Seth, and Delp (2010) found that the gluteus maximus and bicep femoris reached their peak activation in the late SP in order to slow the forward movement of the swinging leg (Lieberman, 2007).

The vastus lateralis, bicep femoris, and gluteus maximus (the weight-accepting muscles) have a majority of their activation occurring at IC, thereby accepting weight, resisting downward force, and providing stability for the body to pivot, about the foot, to continue forward motion. The gastrocnemius reached its peak activation at push off, end of PP, which provides propulsive force. The tibialis anterior reached a first peak during IC and a second peak in the early stages of the SP, to dorsiflex the foot (Burnfield, Shu, Buster, & Taylor, 2010). Additionally, Bartlett, Sumner, Kram, and Ellis (2014) note that the gluteus maximus contributes to vertical support after IC, contributes horizontal propulsion and braking, and aids in deceleration of the swinging leg in the SP. Human gait is not always performed at a set speed and, therefore, patterns of activations may change as a result.

Muscle activation and velocity changes of normal gait. As the velocity of movement increases, so does the work required to move the body at the increased speed; therefore, an increase in speed should require increased muscle activity from the lower extremity muscle groups. In general, the locomotor gait pattern of activation for the lower limb muscles did not differ in shape or form when jogging on an indoor track at increasing speeds. The main changes that occurred were increases in amplitude or a shift in when the peaks appeared, but not their general shape (Kyrolainen et al., 2007; Gazendam & Hof, 2007; Arendt-Nielson et al., 1991; Bartlett et al., 2014; Lieberman, 2006). Vastus lateralis and rectus femoris increased in amplitude of activation with an increase in velocity as well as surpassing the maximum voluntary contraction (MVC) taken pretest (Kyrolainen et al., 2007; Gazendam et al., 2007). Additionally, vastus medialis did not increase in muscle activation amplitude due to increasing gait speed (Gazendam & Hof, 2007). Semitendinosus exhibited an increase to both peaks of activation due to an increase in speed, while bicep femoris displayed an increase in activation in the SP and IC accompanying the increase in velocity. Furthermore, the semimembranosis activation amplitude remained constant between a walking and running speed (Gazendam & Hof, 2007; Kyrolainen et al., 2007). The gastrocnemius showed a 40% increase in peak muscle activation due to faster speeds while the soleus observed no changes. The gluteus maximus is known to have increased muscle activity due to increasing movement speed (Kyrolainen et al., 2007; Gazendam & Hof, 2007; Arendt-Nielson et al., 1991; Bartlett et al., 2014; Lieberman, 2006). The increases of the gluteus maximus activation are most likely due to the increased trunk pitch in a running gait. This indicates that as individual leans forward the degree of glueteal activation increases. Additionally, the gluteus maximus activation increase is seen during the flight phase of running in the swing leg, which may aid in deceleration of the swinging leg, trunk flexion control, and/or leg extension (Lieberman, 2006). Just as increasing velocity changed the kinetics and kinematics of the lower extremity, so might increase or decreases in the inclination of the movement platform.

Muscle activation and incline changes of normal gait. Important to note are the changes that occur when comparing level running/walking to uphill running/walking as the muscles that are activated and their degree of activation can change significantly. Yokozawa, Fujii, & Ae (2007) observed that, of the lower extremity muscles (gluteus maximum, semimembranosus, semitendinosus, bicep femoris, iliacus, iliopsoas, adductor longus, adductor brevis, adductor magnus, rectus femoris, vastus medialis, vastus intermedius, vastus lateralis, gastrocnemius, soleus, and tibialis anterior), there were no significant differences between level running and uphill running at slow and medium speeds. However, at high speeds there were greater levels of activation in uphill running than level running. This is most likely attributable to step length and frequency, as these were near identical in slow and medium uphill running as they were in level running. Arendt-Nielsen, Sinkjær, Nielsen, & Kallesøe (1991), found that when observing level and incline walking that the greatest change in lower extremity muscle activation occurred at the tibialis anterior and sartorius, a 420% and 410% increase respectively; however, these results were insignificant as the variability was too great. The increase in these muscles is most likely due to the need for a shorter stride length and earlier contact where the ankle must be dorsiflexed and the knee and hip flexed to meet the surface sooner (Guo et al., 2006). Lieberman (2006) observed that gluteus maximus activation levels for walking on an incline were only slightly higher than level walking and much lower than level running. Additionally, the researchers observed that, unlike level running, gluteus maximus activation during uphill running did not increase with an increase in speed. However, Lieberman (2006) only measured at a 12° incline and speculates that the gluteus maximus may be activated more in much higher incline conditions. Aside from locomotion on an incline, many people also utilize elliptical trainers, thus, examining the patterns of an elliptical trainer can provide insights into efficacy and biomechanical soundness.

Muscle activation on an elliptical trainer. Horvais, Samozino, Textoris, Hautier, and Hintzy (2008) observed that subjects on an elliptical had significant activation of the knee and hip extensor muscles (rectus femoris, vastus lateralis, and gluteus maximus) during the downward phase, or PP, of the motion cycle. Additionally, the gastrocnemius was activated at the bottom of the cycle and aided in propelling the foot pedal backwards. The tibialis anterior activated to resist excessive ankle plantar flexion during the PP. The bicep femoris worked to extend the hip in the downward phase. Extensor muscles and other supplemental muscles are activated in the downward phase and not much is mentioned about the upward phase. This is due to the fact that the feet are not strapped into the pedals; therefore, the upward phase of one pedal is produced by the downward phase of the opposite foot. Petrofsky et al. (2013) demonstrated that muscle activation on an elliptical was much higher for the quadriceps group than for the hamstring group, perhaps due to the activation of extensor muscles as noted by Horvais et al. (2008). While walking and running may be second nature to many, a portion of the active population utilize other pieces of equipment; therefore, it is important to analyze muscle activation patterns and compare elliptical trainers to walking/running for biomechanical similarities.

Muscle activation of elliptical trainer vs. walking/running. Patterns of muscle activation for ellipticals show similarities to walking with some differences. Peak gluteus medius and maximus activations happen at roughly the same time for elliptical gait as compared to walking, occurring at 3-5% and 4% of the gait cycle respectively, in the loading phase (LP) (Burnfield, Shu, Buster, & Taylor, 2010). However, activation for the gluteal group lasted longer for the elliptical condition than it did in the walking condition, and the gluteus maximus had a greater peak and mean amplitude on the elliptical trainer. Activation of the gastrocnemius on elliptical occurred in the MS versus right before the SP in walking. Gastrocnemius duration of activation exhibited no significant difference between the two conditions, but the peak and mean activation was higher in walking than on the elliptical, most likely due to the impact seen in walking that is not observed on an elliptical trainer. Burnfield et al. (2010) also observed higher peak and mean values for the vastus lateralis on the elliptical, but lower values for the hamstring groups. Several other authors reported significant findings that muscle activation was generally higher on an elliptical, specifically pertaining to hip extensor groups (Moreside & McGill, 2012) and that peak activation and duration of the quadriceps group was higher on an elliptical compared to walking while activation for the hamstrings was lower on the elliptical (Prosser, Stanley, Norman, Park, & Damiano, 2011). Rogatzki et al. (2012) noted a large difference between elliptical trainer muscle activation and running muscle activation, in that on an elliptical most of the propulsive power comes from the hip and the knee, whereas in running the ankle provides most of the forward propulsive power.

Summary

Normal walking/running gait studies show that muscle activations of the lower extremity muscle groups, in general, have greater peak and mean amplitudes at higher speed compared to lower speed but still maintain a similar pattern of activation (Kyrolainen et al., 2007; Gazendam & Hof, 2007; Arendt-Nielson et al., 1991; Bartlett et al., 2014; Lieberman, 2006). Furthermore, when examining level running versus uphill running, Yokozawa et al. (2007) observed no significant changes in muscle activation in slow to medium speeds and only had significant differences when looking at high speed conditions. Similarly, Lieberman (2006) only detected slight increases in gluteal muscle activation when on a slight incline but postulated that at a steeper incline activation values for gluteal muscles might increase to a greater extent. In regards to lower extremity kinematics, during velocity increases, studies found that stride time decreased while stride frequency increased. Additionally, stride length also increased with increasing velocity (Arendt-Nielsen et al., 1991). When transitioning from walking to running, the trunk and pelvis also tilt more anteriorly and maximum hip extension occurs later in the gait cycle (Novacheck, 1998). When running uphill, compared to level running, there is an increase in hip, knee, and ankle flexion, as well as a decrease in stride length, duration, and flight time (Guo et al., 2006; Paradisis and Cooke, 2010).

Muscle activation on an elliptical as compared to walking demonstrates greater peak and duration values in extensor muscle groups of both the hip and knee (Burnfield et al., 2010; Moreside & McGill, 2012; Prosser et al., 2011). Activation of leg flexors, primarily the hamstring group, had lower levels of activation (Burnfield et al., 2010; Prosser et al., 2011). Activation of the gastrocnemius was lower in amplitude and happened earlier in the motion cycle on the elliptical versus walking on a treadmill (Burnfield et al., 2010 & Sozen, 2010). Burnfield et al. (2014) observed that there were muscle activation changes on an elliptical due to speed increases. They noted that with increased speed there was an increase in activation of key stabilizer muscles: gluteus medius, GMAX, VL, medial gastrocnemius, and soleus. This demonstrates, that similar to walking muscle activation, amplitudes increase with an increase in velocity on an elliptical trainer. Furthermore, Buster, Ginoza, and Burnfield (2010) found that, when comparing elliptical trainer lower extremity joint kinematics to walking/running kinematics, there was a trend towards increased range of motion. For IC, LP, and PP at the knee, there were increased measurements of knee flexion. Concerning the ankle, there were overall decreased levels of plantarflexion but also increased levels of dorsiflexion throughout the gait cycle. Burnfield et al. (2010) found that generally the elliptical recorded higher joint angles than in walking/running, except at the ankle joint during IC, LP, and PP. Having established an understanding of joint kinematics and muscle activation patterns between elliptical trainers and walking/running, examination comparing a linear path elliptical to a converging path elliptical is proposed. This examination may possibly demonstrate the converging path to more closely mimic walking/running gait.

Chapter III

Methods

Introduction

The current study examined the differences between a Precor linear path EFX 800 series (Precor, Woodinville, WA, USA) elliptical trainer with a prototype converging path elliptical trainer, in regards to muscle activation patterns of the lower extremity. Muscle activation patterns included mea activation amplitude of the gluteus maximus (GMAX), vastus lateralis (VL), vastus medialis (VM), semitendinosus (ST), and lateral head of the gastrocnemius (LG). Furthermore, lower extremity kinematic data was used to determine the propulsion phase. Elliptical trainers are widely used exercise equipment for the purpose of fitness or rehabilitation. As this study examines a prototype piece of equipment, few studies have inspected a converging movement path on an elliptical trainer.

Description of Study Sample

The study sample consisted of 25 (15 male and 10 female) college-aged individuals. It is important to note that these 25 subjects were primarily from Western Washington University's Kinesiology undergraduate program and were recreationally active participants. Of the 25 subjects, only data from 23 of the subjects was included due to inaccuracies of the values. The mean age of the group was 22.19 ± 1.77 years old. The mean body mass was 70.84 ± 10.85 kg. The mean height was 1.71 ± 0.09 m. All subjects had previous experience on a linear path elliptical; however, since the converging path elliptical is a prototype, no subjects had prior experience with this elliptical trainer. Human subject approval is shown in Appendix 1 and informed consent documentation is in Appendix 2.

Design of Study

The design of this study was a within subject design where the subjects serve as their own control. Each subject was tested on both the linear path and converging path ellipticals in order to analyze differences in muscle activation between the two conditions.

Data Collection Procedures

Instrumentation. The testing of muscle activation patterns utilized surface electromyography (EMG) to collect and analyze activation patterns. A Noraxon Telemyo DTS unit was used in conjunction with Noraxon MR3.2 (Scottsdale, Arizona) software to collect the data. Data was measured at 1500 Hz with a gain of 500 and CMRR > 100dB. All EMG data was rectified and smoothed using root mean squared (RMS) technique. Each subject was instrumented with five EMG sensors and disposable, Noraxon, self-adhesive Ag/AgCl dual snap surface electrodes, placed using double-sided adhesive tape, on the muscle bellies of the right gluteus maximus (GMAX), vastus lateralis (VL), vastus medialis (VM), semitendinosus (ST), and lateral head of the gastrocnemius (LG) using guidelines by Rainoldi, Melchiorri, & Caruso, (2004). The surface electrodes had an inter-electrode distance of 1.75 centimeters. The GMAX was found by making a line between the anterior superior iliac spine (ASIS) and greater trochanter of the test limb, then asking the subject to contract the gluteals, finding the center of the muscle belly along said line. The VL was found by having the subject contract the quadriceps in both a 90° and 180° angle, finding the center of the muscle belly on the lateral aspect of the quadriceps. Similarly, the VM followed the same procedure as the VL, however, the center of the muscle belly was found on the medial aspect of the quadriceps. The ST was found by having the subject lie prone on a treatment table while flexing their leg to a 90° angle. The researcher then had the subject isometrically contract the hamstrings while providing resistance. The ST muscle belly was found medial to the bicep femoris. The LG was found by having the subject face away from the researcher and plantarflexing the right ankle, the center of the muscle belly was comprised of the lateral portion of the gastrocnemius. All sensors were placed along the direction of the muscle fibers determined by an anatomical model. A Noraxon DTS 2D electronic goniometer (Noraxon, Scottsdale, AZ, USA) was placed on the lateral aspect of the shank and thigh, with the distal-most green bar placed in line with the greater trochanter and lateral epicondyle and the proximal green bar placed in line with the lateral epicondyle and lateral malleoli. The sensor cable of the electronic goniometer spanned the lateral portion of the knee joint and was sure to have no compression or laxity. Knee flexion/extension data from the goniometer was collected within MR3.2 and synced with the EMG timing. A checklist of instrumentation procedures can be seen in Appendix 4.

Measurement techniques and procedures. Each subject was tested in the Biomechanics Laboratory of Western Washington University. All testing was completed in one session. For each subject, the order of presentation of elliptical type (linear vs. converging path) and ramp angle were randomized. Prior to instrumentation, each subject completed a 5-minute warm-up, at a self-selected pace, on the elliptical they were randomly assigned to start with, followed by some brief dynamic stretching movements. After this warm-up period, the subjects were instrumented with the EMG sensors. Before testing began, maximum voluntary isometric contractions (MVIC) of the five muscles were recorded to normalize the EMG amplitude. The MVIC composed of manual muscle tests of the gluteus maximus (hip extension against the wall while hip is at 35° of hip flexion), semitendinosus (examiner is resisting knee flexion with the knee at 90°), vastus lateralis and vastus medialis (examiner resisting knee extension at 90°), and gastrocnemius (subject was asked to lift heel up while standing and the examiner applying a downward force on both shoulders). Maximum voluntary contraction tests were performed following guidelines from Kendall, Provance, and McCreary, (1993). Once subjects were fully instrumented and MVIC's were obtained, they warmed up on the first elliptical for 2 minutes at the lowest ramp angle at a speed that resulted in a stride rate of 120 strides/min. Next, the first, randomized, ramp angle was selected and 1 minute of familiarization was completed. After 1 minute of familiarization, kinematic and EMG data were collected for 15 s. Subjects completed the next 45 seconds on that ramp angle. The next, randomized, ramp angle was selected and followed the same pattern. The third remaining ramp angle was chosen and data collected following the previous pattern. This pattern of data collection resulted in 15 s of data collection at 3 varying cross ramps of 15, 25, or 35° angles. The total time on each elliptical was 8 minutes. The subjects were then given a 5-minute rest to allow for a washout period from the first condition to the last and allow for the transfer of the next elliptical to be moved into the data collection volume. The same steps were then repeated for the second elliptical. The subjects were then deinstrumented and allowed to rest or leave at will. A detailed protocol is listed in Appendix 3 and Study 1 guidelines were followed. Study 2 guidelines were used in a study not examined here.

Data Analysis

Age and body mass were presented using mean and standard deviation calculations. Electromyography (EMG) data was collected with MR3.2, in which the signal was full-wave rectified and smoothed, and exported to a custom National Instrument LabVIEW 16.0 (National Instruments Austin, TX, USA) program to analyze mean activation during the concentric phase. Concentric phase, or propulsive phase, was defined as the point of maximal knee flexion until maximal knee extension. Knee flexion/extension angles from an electronic goniometer were used to determine the concentric phase of the gait cycle. The LabVIEW program then found a peak and trough in the center of the data set, to avoid anomalies in the movement and allow for acclimatization to the ramp angle, and recorded EMG muscle activation from the found peak to the following trough. The mean of the EMG data from the concentric phase of one cycle was used for data analysis.

Statistical Analysis

For analysis of significance a two-way, repeated measures analysis of variance (ANOVA) was performed, using IBM SPSS Statistics 24 (IBM, Armonk, New York, USA). Independent variables included elliptical type (linear vs. converging path) and ramp angle (15° vs. 25° vs. 35°), and the dependent variable was mean EMG signal. The alpha level was set to $p < 0.05$.

Chapter IV

Results and Discussion

Introduction

This study examined the differences between a Precor EFX 800 model elliptical trainer and a prototype converging path elliptical trainer, in regards to muscle activation of the lower extremity, at ramp angles of 15°, 25°, and 35°. Data was collected, for 15 second intervals, during three different ramp angles, and on two different elliptical trainers. Five two-way analysis of variance (ANOVA) were run with an alpha level of 0.05 for data analysis of lower extremity musculature.

Results

Demographics

Age, height, and body mass were recorded on data collection day for all subjects. The final subject count was 22 subjects with mean age of 22.19 ± 1.77 years, mean height 1.71 ± 0.09 meters, and mean body mass of 70.84 ± 10.85 kilograms.

Gluteus Maximus

Mauchly's Test of Sphericity for gluteus maximus (GMAX) activation was significant for the interaction effect between elliptical trainer type and crossramp angle. Therefore, the Greenhouse Geisser correction of degrees of freedom was used to determine significance. The two-way repeated measure ANOVA revealed no significant interaction between elliptical type and crossramp angle for GMAX (F[1.12, 24.46] = .801, p = .392, η^2 = .035). For the main effect of crossramp angle, there was no significant effect (F[1.007, 22.153] = 1.664, p = .210, η^2 = .070).

The main effect of elliptical trainer type was not significant (F[1.00, 22.00] = 1.672, p = .209, η^2 = .071) (Figure 1).

Semitendinosus

Examining semitendinosus (ST) muscle activation Mauchly's Test of Sphericity showed significance for both crossramp angle and the interaction between elliptical type and crossramp angle, thus the Greenhouse Geisser correction was used. The two-way repeated measure ANOVA revealed a non-significant interaction between elliptical type and crossramp angle for ST (F[1.549, 34.080] = 1.004, p = .359, η^2 = .044). For the main effect of crossramp angle, there was no significance (F[1.117, 24.574] = 4.046, p = .051, η^2 = .155). There was also no significant main effect of elliptical trainer type on mean ST activation (F[1.00, 22.00] = .484, p = .494, η^2 = .022) (Figure 2).

Vastus Medialis

Mauchly's Test of Sphericity for mean vastus medialis (VM) muscle activation was significant for both crossramp angle and the interaction between crossramp angle and elliptical type, leading to the use of the Greenhouse Geisser correction of degrees of freedom. The two-way repeated measure ANOVA revealed a non-significant interaction between elliptical type and crossramp angle for VM activation (F[1.279, 28.329] = 4.915, p = .309 , η^2 = .183). For the main effect of crossramp angle, the ANOVA revealed significance (F[1.288, 22.153] = 1.664, p = .039 , η^2 = .070) with the significant difference between crossramp angle 35° and 15°, but not between with 25° and 35° or 25° and 15°. The main effect of elliptical trainer type was not significant (F[1.00, 22.00] = .095, p = .630, η^2 = .004) (Figure 3).

Lateral Gastrocnemius

Mauchly's Test of Sphericity was significant for lateral gastrocnemius (LG) mean activation for crossramp angle and the interaction between crossramp angle and elliptical type, therefore, Greenhouse Geisser correction was again used. The two-way repeated measure ANOVA revealed non-significant interaction between elliptical type and crossramp angle for LG (F[1.560, 34.325] = 1.311, p = .277, η^2 = .056). For the main effect of crossramp angle, the ANOVA revealed significance (F[1.579, 34.747] = 7.668, p = .003, η^2 = .258) with the significant difference between crossramp angle 35° and 15° (p = .026) and 35° and 25° (p = *.002)*. Ramp angle 15° had the higher activation followed by 25° and then 35°. There was no difference between 15° and 25°. The main effect of elliptical trainer type was not significant (F[1.00, 22.00] = 3.920, p = .060, η^2 = .151) (Figure 4).

Vastus Lateralis

As with all other muscle activations, Mauchly's Test of Sphericity was significant for vastus lateralis (VL) activation on crossramp angles and the interaction between crossramp angle and elliptical type so Greenhouse Geisser was used. The two-way repeated measure ANOVA revealed a non-significant interaction effect between elliptical type and crossramp angle on mean VL activation (F[1.334, 29.359] = 2.560, p = .112, η^2 = .104). For the main effect of crossramp angle, the ANOVA revealed significance (F[1.541, 33.894] = 35.469, p < .001, η^2 = .617) with the significant difference between all crossramp angles. The difference between 35° and 25° and between 35° and 15° had a p value of <0.001 while the difference between 25° and 15° had a p value of 0.050. Ramp angle 35° had the highest activation and ramp angle 15° had the lowest. The main effect of elliptical trainer type was significant (F[1.00, 22.00] = 9.256, p = .006, η^2 =

.296) with the converging elliptical causing greater mean activation of the VL (Figure 5). The ANOVA output data is included in appendix 5.

Below, figures 1-5, give graphical representation to mean muscle activation for both linear and converging elliptical trainers across all three crossramp angles.

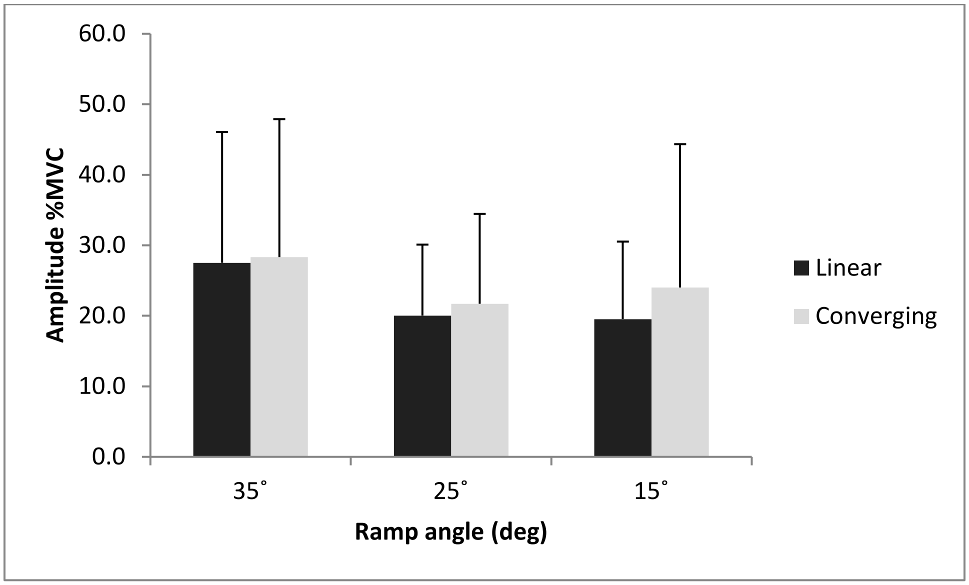

Figure 1. Mean and standard deviation gluteus maximus (GMAX) muscle activation across linear and converging path ellipticals and crossramp angles.

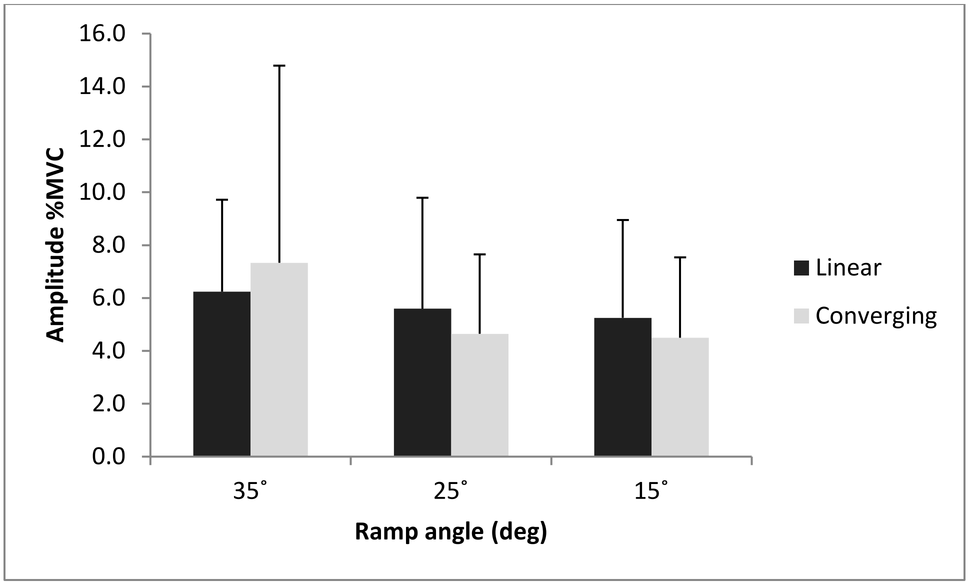

Figure 2. Mean and standard deviation semitendinosus (ST) muscle activation across linear and converging path ellipticals and crossramp angles.

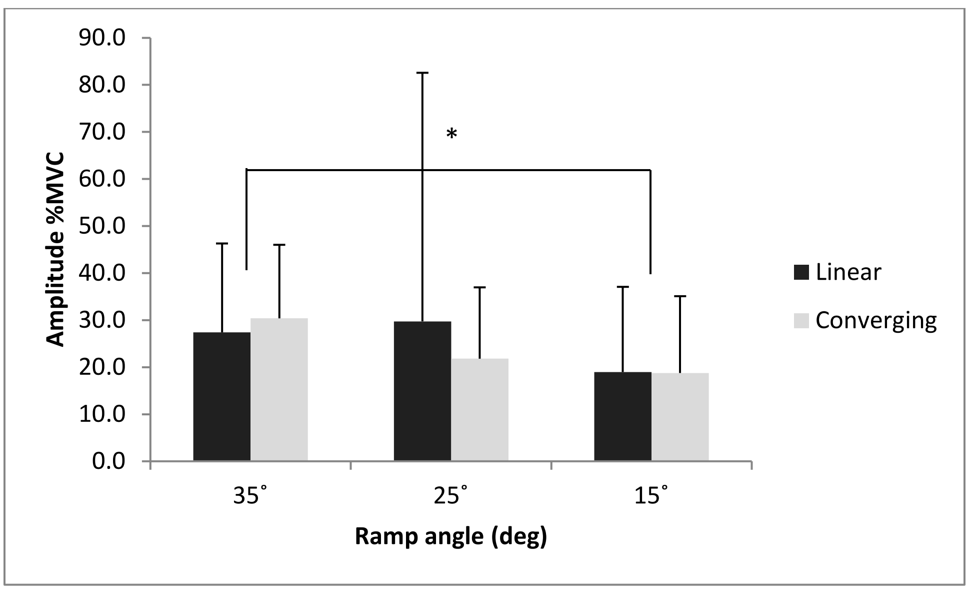

*Figure 3. Mean and standard deviation vastus medialis (VM) muscle activation across linear and converging path ellipticals and crossramp angles. * denotes significance, $p < 0.05$, between crossramp angle.*

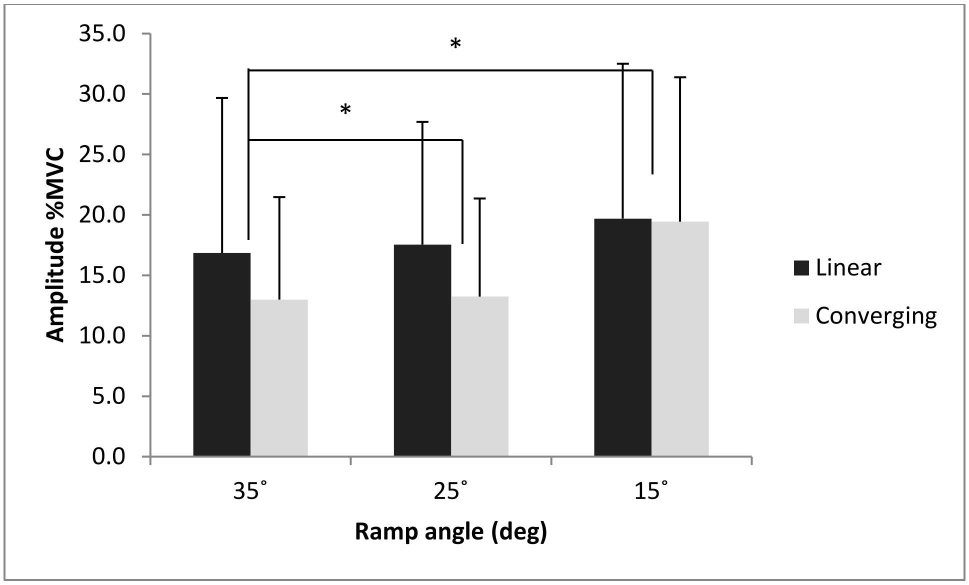

*Figure 4. Mean and standard deviation lateral gastrocnemius (LG) muscle activation across linear and converging path ellipticals and crossramp angles. * denotes significance, p < 0.05, between crossramp angle.*

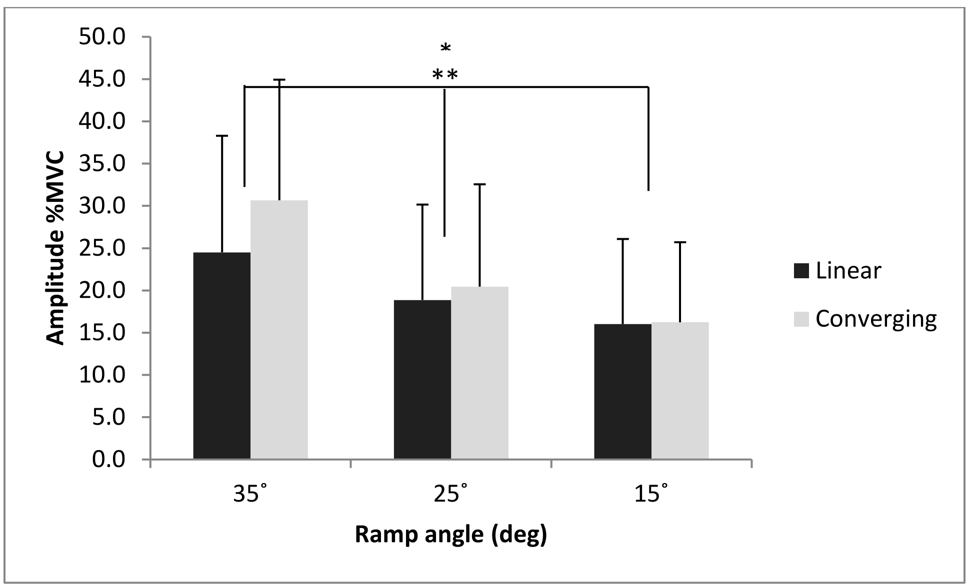

*Figure 5. Mean and standard deviation vastus lateralis (VL) muscle activation across linear and converging path ellipticals and crossramp angles. * denotes significance, p < 0.05, between crossramp angle. ** denotes significance, p < 0.05, between elliptical types.*

Discussion

The purpose of this study was to examine the effects of elliptical trainer type and crossramp angle variations on lower extremity mean muscle activation during the concentric phase, also denoted as the propulsive phase (PP). The experimental hypothesis was that the prototype converging path elliptical will exhibit significant differences, compared to the traditional linear path elliptical in regards to lower extremity EMG muscle activation. The results of this study largely do not support the experimental hypothesis in that only the VL muscle activation demonstrated statistically significant differences (p = .006) between the converging and linear path elliptical trainers. This study examined the concentric phase of the gait cycle and measured mean muscle activation of five lower extremity muscles: GMAX, ST, VM, LG, and VL. Analysis of these five muscles, through a two-way repeated measures ANOVA, indicated that VM, LG, and VL were the only muscles to demonstrate significant differences between the varying crossramp angles and only VL had statistically significant difference between the elliptical trainers. However, ST, while not significant, was very close to the alpha level of significance for ramp angle (p = .051; η^2 = .022) and LG was similarly close to significance for elliptical trainer type (p = .060; η^2 = .151). Generally, the significant differences in crossramp angles were noted between the two extreme angles, 35° and 15°.

Burnfield et al. (2010) performed research comparing ellipticals, of various brands (SportsArt, Life Fitness, Octane, and True), regarding their kinematic and electromyographic (EMG) patterns. They examined the ellipticals with no crossramp inclination and a stride frequency approximately 100 strides per minute. Similar to the present study, they reported findings on gluteus maximus, medial hamstring, vastus lateralis, and lateral gastrocnemius, in addition to several others. Due to the lack of inclination in the study by Burnfield et al., the most direct comparison between the studies would be to examine the appropriate muscles at a 15° incline. Comparing our findings, similarities were shown in muscle activation amplitude (%MVC). Across all four elliptical brands, the mean values described by Burnfield et al., GMAX, medial hamstring, VL, and LG were 19.25, 7, 26.25, and 23.25% MVC, respectively. In the current study, the linear path elliptical GMAX mean activation was 19.5% MVC and 24% MVC for the converging path. ST, which is comparable to medial hamstring, exhibited 5.3% MVC for the linear elliptical and 4.5% MVC for converging path elliptical. VL showed 16% MVC for both elliptical types. Lastly, LG showed 19.7% MVC and 19.4% MVC for the linear and converging ellipticals, respectively. While there are subtle differences, particularly with respect to VL, a majority of the overlapping muscles were within four percentage points of each other. It is important to note that, while the current study examined solely the concentric phase, Burnfield et al. collected values from the entire duration of a gait cycle. However, as much of the swing phase (SP) on an elliptical is passive, measuring only the concentric phase should not have caused large deviations between the two studies. From this comparison, both the linear and converging path ellipticals appear to demonstrate similar EMG patterns to other brand name ellipticals.

These results are in agreement with those of Moreside & McGill (2012). They examined the muscle activation of the GMAX of subjects on an elliptical trainer. The speed used was 80-120 strides per minute and was performed on an elliptical without crossramp inclination. They reported GMAX activation amplitudes of 20.2 and 21.2% MVC, using either handles or bars, respectively. The GMAX activation of the current study for both ellipticals, at 15°, was similar with values of 19.5% MVC for the linear path elliptical and 24% MVC for the converging path. The converging path elliptical demonstrates a greater degree of activation than both the linear path elliptical and the elliptical used by Moreside and McGill. This, again, suggests that the results seen by this study have a measure of validity.

Lin, Tsai, Press, Ren, Chung, and Zhang, (2016) conducted research on lower-limb muscle activation for both a standard elliptical and one that provided adduction force at the foot pedals. The adducting force caused the subjects to exert a counteracting force away from the midline of the body. While the exertion of an abducting force is different than that of the converging elliptical, the movement away from midline is similar to the concentric phase of the converging path elliptical. Lin and colleagues found that GMAX, quadriceps, hamstrings, and LG demonstrated higher amplitudes of muscle activation, expressed as mean %MVC. There were no indications of a crossramp height. The speed was 40-50 rpm or 80-100 strides per minute. The current study, examining the linear path elliptical and converging path elliptical, showed the converging path elliptical had trends of greater activation for GMAX and VL, higher activation for VM and ST at 35° but lower for the other two crossramp angles, and lower activation overall for LG. Comparatively, GMAX and VL are in agreement with the Lin et al., study, however VM, LG, and ST appear to not be. The differences between the two studies could be due to the lateral movements on the converging path being relatively passive, while Lin et al. required 5Nm of active resistance, thereby activating the VM, LG, and ST to a greater degree.

Paquette, Zucker-Levin, DeVita, Hoekstra, and Pearsall (2015) performed research examining lower extremity kinematics and muscle activation across four elliptical variations. The variations included a lateral elliptical, standard elliptical, standard elliptical with toes pointing outward, and standard elliptical with a wide stance. The subjects were required to maintain a 50 strides/min pace and data was gathered for 15 seconds at the fourth minute of exercise. The muscles examined were the GMAX, gluteus medius, bicep femoris, VM, and medial gastrocnemius. The results of the current study are largely in disagreement with those of Paquette et al. A 23.5% MVC mean activation of the VM on the lateral elliptical was the only muscle to parallel with our results of 20-30% MVC. The other muscles measured were of significantly lower amplitude, ~4.9% MVC GMAX activation compared to this study's 20-30% MVC. An explanation of this discrepancy may largely be due to the lower stride rate of 50 strides/min in Paquette's work, which is less than half of that required by the current study. It is possible that the lateral elliptical would have a much greater degree of activation than the linear or converging path elliptical had the pace been comparable.

Precor, the maker of the linear and converging path elliptical, held a patent on adjustable crossramp height on an elliptical for a long duration; therefore, there is a lack of research on the effects of crossramp height concerning muscle activation for other elliptical trainers. Comparisons must then be made to walking, jogging, or running locomotion. Yokozawa, Fufii, and Ae (2007) found that at medium to slow running speeds, 4.2 and 3.3 m/s respectively, there was no significant difference in lower extremity muscle activation between level running and uphill running. However, at the high running speed 5.0 m/s, most muscle groups demonstrated significance muscle activation between level and uphill running ($p < 0.05$.). Three of five muscles from the current study demonstrated significance between crossramp heights. These results, compared with Yokozawa et al., would indicate that 120 strides/min is more comparable to high speed running than slow or medium speed. However, the Yokozawa study had much higher levels of muscle activation during the concentric phase for GMAX and VL, 60% MVC and 100% MVC during high speed running. The differences in these results could be due to the biomechanical differences between running and elliptical-based motion and would need further examination to determine the direct cause.

The current study demonstrated that the linear versus converging path elliptical had no significant effect on mean muscle activation for any muscles except VL; however, LG was close to representing statistical significance. One explanation of this finding is that perhaps the biomechanical differences between the linear and converging path elliptical were too minute to significantly affect the degree of muscle activation. Further results showed that crossramp angle had a significant effect on VM, VL, and LG, as well as nearly significant effect upon VM. Most of the differences existed between the two extreme ramp angles, 35° and 15°. In accordance with previously mentioned references, a 20° difference should elicit a significant change in muscle activation.

While activating the VL to a greater degree may be advantageous to those with atrophied VL’s, or imbalances in that regards, caution should be taken to not over-activate the VL. Sakai, Luo, Rand, and An, (2000) and Reynolds, Levin, Medeiros, Adler, and Hallum, (1983) found that either hyperactivity of the VL, inefficiency of the VM, or a combination of both can lead to patellofemoral pain. Overactivation of the VL may, with long-term use, create imbalances that lead to patellofemoral pain and poor patellar alignment.

There were some limitations to the current study that could have affected the accuracy of the results. EMG, as a research tool has inherent drawbacks and inaccuracies. Hug (2011) outlines several key difficulties with EMG: amplitude cancellation, crosstalk, spatial variability of muscle activity, issues with EMG processing techniques, skin movement artifacts, and neuromuscular fatigue. The current study sought to address many of these issues with proper signal processing and filtering techniques, accurate surface electrode placement, and trial randomization, yet some issues are unavoidable. This study had one researcher perform MVC’s for all subjects. Additionally, one male researcher instrumented all male subjects and one female researcher instrument all female subjects. The hope was to create reliability within the research protocol; however, human error still could have affected placement of surface electrodes and the capture of accurate MVC's. Additionally, subjects may have been more motivated to exercise differently on the different elliptical types. To combat this, the elliptical type order was randomized. For further aid the linear path elliptical could also have been stripped of its housing to ensure no subject knew which elliptical was the prototype and which was a current market product. Lastly, three subjects' data had to be omitted, one due to a mistake by a researcher where the full 15 seconds of data collection was not attained and two subjects' data were discarded due to difficulties collecting accurate MVC data for all muscle groups, thereby creating extreme outliers in mean % MVC muscle activation.

Summary

There was little significant difference between linear and converging path elliptical trainers in regards to mean %MVC muscle activation, except for VL, in which the converging path elliptical elicited greater mean %MVC muscle activation. Utilization of a converging path elliptical may be beneficial for one aiming to focus on VL activation, however, without kinematic data, there appears to be little other biomechanical advantage to exercising on a converging path elliptical with regards to muscle activation. Crossramp angle had a greater effect on muscle activation than did elliptical type, with VL and VM activating to a higher degree during the 35° angle, compared to the 25° and 15°. Therefore, those wishing to activate the quadriceps muscles to a greater extent should seek to exercise at a higher angle incline.

Chapter V

Summary, Conclusions, and Recommendations

Summary

This study examined the effects of two different elliptical types, linear path and converging path, as well as three varying crossramp angles, 35°, 25°, and 15°, on mean muscle activation of the gluteus maximus (GMAX), semitendinosus (ST), vastus medialis (VM), lateral gastrocnemius (LG), and vastus lateralis (VL). Subjects performed two trials each with each subject exercising on both ellipticals and across all three crossramp angles. The order of elliptical type and crossramp angle was randomized. Subjects performed eight minutes of exercise on the first, randomly selected elliptical with 15 seconds of data collection occurring at the 2^{nd}, 4^{th}, and 6^{th} minute, approximately. The subjects were allowed a five-minute rest period between trials. Mean activation was calculated from a concentric phase of the gait cycle approximately 7.5 seconds into the 15 second data collection period. This was done to ensure the subject had adequately acclimatized to the ramp angle as well as prevented any changes the subject might have undergone at the onset of data collection. Results indicated that crossramp angle produced significant differences for VM, LG, and VL muscles while elliptical type only showed a significant effect on VL. The 35° ramp elicited greater activation for both VM and VL, compared to 25° and 15°, while the 15° ramp angle produced the greatest activation in the LG. Between elliptical types the converging path elliptical elicited greater activation for the VL than that of the linear path elliptical.

Conclusions

Varying crossramp angles on an elliptical trainer can be beneficial for targeting greater degrees of activation of key lower extremity muscles. Additionally, a converging path elliptical can significantly increase activation of the vastus lateralis but does not appear to significantly effect GMAX, VM, ST, or LG.

Recommendations

Future Research. Future research should examine the converging path elliptical with varying levels of resistance and pace to determine if elliptical path has a greater effect on lower extremity muscles under varying circumstances. Additionally, future studies should examine the kinematic data of the converging path elliptical. With a combination of EMG and kinematic data, further implications could be drawn as to the efficacy of utilizing a converging versus linear path elliptical. As a point of interest, the converging path elliptical should be compared to adaptive motion devices such as the Precor AMT or Octane Zero Runner to determine differences between a new elliptical type and other similar training modalities.

Practical Applications. The results of this study suggest that training at higher crossramp angles could activate key lower extremity muscles to a greater activation amplitude, possibly leading to a more efficient workout. People wanting to train vastus lateralis specifically should focus on using a converging path elliptical as opposed to a linear path elliptical.

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Appendices

Figure 6 lower extremity joint angle

Joint	Phase	X̄ (SD) Angles (°) for[a]: Walking	SportsArt	Life Fitness	Octane	True
Hip	IC	31.5 (7.2)	43.8 (5.7)[b]	46.1 (4.9)[b]	44.7 (5.4)[b]	45.4 (5.1)[b]
	TSt peak ext	−7.3 (7.6)	4.3 (7.3)[b]	6.7 (8.3)[b]	6.6 (7.7)[b]	5.4 (7.3)[b]
	MSw peak flex	34.4 (4.9)	54.1 (6.7)[b]	56.9 (5.6)[b]	57.6 (6.3)[b]	56.5 (5.4)[b]
Thigh	IC	23.3 (4.2)	32.2 (4.3)[b]	31.9 (3.3)[b]	30.6 (3.0)[b]	31.4 (3.1)[b]
	TSt peak ext	−14.7 (4.4)	−9.5 (5.0)[b]	−8.2 (4.7)[b]	−8.9 (4.4)[b]	−10.0 (5.0)[b]
	MSw peak flex	26.3 (6.4)	40.7 (4.0)[b]	41.9 (2.9)[b]	43.2 (3.1)[b]	41.8 (3.0)[b]
Knee	IC	3.7 (5.6)	34.1 (5.6)[b]	38.7 (5.0)[b]	36.1 (5.4)[b]	36.2 (5.4)[b]
	LR final position	19.3 (6.8)	21.2 (5.6)	23.2 (5.9)	23.0 (6.2)	21.0 (6.2)
	TSt peak ext	6.2 (5.6)	16.2 (5.4)[b]	17.9 (4.6)[b]	18.5 (5.3)[b]	17.8 (5.8)[b]
	ISw peak flex	66.8 (7.1)	72.4 (5.3)[b]	78.2 (5.4)[b]	80.4 (5.9)[b]	82.0 (5.7)[b]
Ankle	IC	3.0 (3.7)	−4.7 (3.4)[b]	5.3 (3.7)	0.8 (4.3)[b]	5.0 (3.4)
	LR peak PF	−2.9 (3.1)	−4.8 (3.8)	4.3 (3.9)[b]	0.7 (4.4)[b]	2.9 (3.8)[b]
	TSt peak DF	14.8 (3.2)	16.6 (5.6)	18.2 (5.5)	16.4 (5.2)	16.9 (4.2)
	MSw final position	3.4 (2.3)	1.3 (3.7)	11.5 (4.3)[b]	7.1 (4.7)	11.8 (4.3)[b]

[a] Positive values indicate flexion of hip, thigh, and knee and dorsiflexion of ankle. Negative values indicate extension of hip, thigh, and knee and plantar flexion of ankle. IC=initial contact, TSt=terminal stance, ext=extension, MSw=mid swing, flex=flexion, LR=loading response, ISw=initial swing, PF=plantar flexion, DF=dorsiflexion.
[b] The value was significantly different from that for walking; the significance level after Bonferroni adjustment was $P<.003$ (0.05/14).

Appendix 1 Human Subjects Approval

WESTERN WASHINGTON UNIVERSITY

HUMAN SUBJECTS REVIEW COMMITTEE

APPROVAL FOR USE OF HUMAN SUBJECTS

TYPE OF REQUEST: ☐ new ☐ continuation ☒ modification

PROTOCOL NUMBER: 14-036

INVESTIGATOR(S): Jun San Juan

DEPARTMENT: PEHR

PROJECT TITLE:

The effects of different ramp angles using an elliptical machine on lower extremities

APPROVAL PERIOD: 3/31/15 – 3/30/16

NUMBER OF SUBJECTS: unknown

APPROVED INFORMED CONSENT FORM ATTACHED: ☐ Yes ☒ No

Approved by ______________________ Date 3/31/2015
Human Subjects Review Committee

Comments:

Note: Approval is for the period specified above. A protocol renewal form will be sent to you prior to the expiration of this approval period. If there are any adverse events or changes in the research procedures affecting the use of human subjects in this project during the current period, the HSRC must be notified immediately.

Appendix 2 Informed Consent Aim 1

Western Washington University
Consent to Take Part in a Research Study
Specific Aim 1: The Effects of Different Ramp Angles Using an Elliptical Exercise Machine on Lower Extremity Kinematics, Kinetics, Muscle Activation and Oxygen Consumption.

You are invited to participate in a research study conducted by Jun San Juan, PhD, ATC, Dave Suprak, PhD, ATC, and Lorrie Brilla, PhD from the department of Physical Education, Health, and Recreation at Western Washington University. The purpose of this investigation is to examine the effects of different inclination angles on an elliptical machine on your lower body motion and oxygen consumption. You were selected as a possible participant in this study because you have no history of lower body injury, and you are 18 years old or over.

If you decide to participate, you understand that the following things will be done to you. You will be asked to fill out a brief form to provide basic information such as age, height and weight and which is your dominant foot. Non-invasive measurements will be made while you are using the elliptical for 40 minutes. To perform motion measurements, small reflective markers will be attached using a double sided tape to several sites around your hip, knee, ankle and foot. To measure muscle activation, small electrodes will be attached to your skin over several sites surrounding your hip and thigh. To measure oxygen consumption, you will be asked to wear a mouthpiece. The entire testing process should take about 60 minutes.

There is no direct benefit to you by participating in this study. However, you understand that information gained in this study may help in understanding the benefits of the different angles of the elliptical machine and may guide decisions made in prescribing strengthening and injury rehabilitation exercise.

Participation in any research study carries with it possible risks. Because multiple trials will be performed, there is a risk of muscle fatigue. However, precautions have been taken to minimize this risk. However, you may discontinue participation at any time during testing.

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission. Subject identities will be kept confidential by coding the data with subject numbers, rather than names.

Your participation is voluntary. Your decision whether to participate will not affect your relationship with Western Washington University. If you decide to participate, you are free to withdraw your consent and discontinue participation at any time without penalty. Additionally, you will be compensated in the amount of $20 for participating in the study.

If you have any questions, please feel free to contact Jun San Juan, (360) 650-2336, Department of Physical Education, Health and Recreation, Western Washington University, Bellingham, WA, 98225. If you have questions regarding your rights as a research subject, please contact Janai Symons in the Office of Research and Sponsored Programs, Western Washington University, Bellingham, WA, 98225, (360) 650-3082. You have been offered a copy of this form to keep.

I have read the above description and agree to participate in this study.

Print Name____________________________________ Date_______________

Signature____________________________________

Note: Please sign both copies of the form and retain the copy circled "Participant Copy"

Research Copy Participant Copy

Appendix 3 Protocol

Precor Protocol

- ✓ SUBJECT FILL OUT: Precor test participation release and confidentiality agreement
- ✓ WARM UP
  - 5 minutes on elliptical
  - Lower extremity stretching
- ✓ INSTRUMENTATION
  - Reflective markers
    - 24 markers
  - EMG sensors (right lower extremity)
    - Glutes
    - Semimembranosus
    - Semitendinosus
    - Vastus lateralis
    - Vastus medialis
    - Gastrocnemius
  - Mouthpiece for O2 consumption
  - Heart rate monitor
- ✓ MVC for EMG normalization

Study 1
ADD LAB EQUIPMENT INFO

- ✓ CURRENT ELLIPTICAL DESIGN
  - Stride rate= 120 strides/minute (with metronome)
  - 2 minutes at:
    - Ramp angle setting 5 Resistance level 10
    - Ramp angle setting 10 Resistance level 10
    - Ramp angle setting 15 Resistance level 10
    - Ramp angle setting 35 Resistance level 10
    - Ramp angle setting 40 Resistance level 10
- ✓ 5 minutes rest
- ✓ NEW ELLIPTICAL DESIGN
  - Stride rate= 120 strides/minute (with metronome)
  - 2 minutes at:
    - Ramp angle setting 5 Resistance level 10
    - Ramp angle setting 10 Resistance level 10
    - Ramp angle setting 15 Resistance level 10
    - Ramp angle setting 35 Resistance level 10
    - Ramp angle setting 40 Resistance level 10

Study 2

- ✓ NEW ELLIPTICAL DESIGN; Forward gait pattern
  - Stride rate= 120 strides/minute (with metronome)
  - 2 minutes at:
    - Ramp angle setting 5 Resistance level 10
    - Ramp angle setting 15 Resistance level 10
    - Ramp angle setting 40 Resistance level 10
- ✓ 5 minutes rest
- ✓ NEW ELLIPTICAL DESIGN; Reverse gait pattern
  - Stride rate= 120 strides/minute (with metronome)
  - 2 minutes at:
    - Ramp angle setting 5 Resistance level 10
    - Ramp angle setting 15 Resistance level 10
    - Ramp angle setting 40 Resistance level 10

- ✓ De-instrument
- ✓ Cool down

Appendix 4 Study 1 Checklist

Precor Study 1

Subject ID:		Date: / /	
Test participation release & confidentiality agreement YES / NO			
Does the subject understand the protocol YES / NO			
Height:	Weight:	Age:	Dom. Leg R / L
Elliptical randomly selected for **first** data collection NEW / OLD			
Old/ New Incline angle order 1st___________ 2nd ___________ 3rd___________			
Old/ New Incline angle order 1st___________ 2nd ___________ 3rd___________			
5 minute warm up on elliptical selected completed YES / NO			
Lower extremity stretching completed YES / NO ☐ Knees to chest ☐ Heel to butt ☐ Heel to opposite hip			
EMG Instrumentation completed YES / NO ☐ R glute max ☐ R semimembranosus ☐ R vastus lateralis ☐ R vastus medialis ☐ R Gastrocnemius			
MVC for EMG normalization completed YES / NO ☐ Glute max ☐ Semimembranosus ☐ Vastus lateralis ☐ Vastus medialis ☐ Gastrocnemius			
Kinematic instrumentation completed YES / NO Qualisys markers ☐ R ASIS ☐ L ASIS ☐ R PSIS ☐ L PSIS ☐ R greater trochanter ☐ L greater trochanter ☐ R thigh cluster (lateral) ☐ R medial epicondyle ☐ R lateral epicondyle ☐ R shank cluster (lateral) ☐ R medial malleolus ☐ R lateral malleolus ☐ R foot cluster ☐ R head of 1st metatarsal Metabolic cart ☐ Mouth piece ☐ Nose plug Heart rate monitor			

Precor Study 1

STUDY 1	
Elliptical randomly selected for **first** data collection (copy from above)	NEW / OLD
Instrumentation and equipment ready for collection ☐ EMG ☐ Met Cart ☐ Qualisys ☐ Heart rate	YES / NO
Elliptical 1 completed 2 minutes @ **Ramp** ______ **/ Resistance 10** 2 minutes @ **Ramp** ______ **/ Resistance 10** 2 minutes @ **Ramp** ______ **/ Resistance 10**	YES / NO
5 minutes rest completed	YES / NO
Elliptical 2 completed 2 minutes @ **Ramp** ______ **/ Resistance 10** 2 minutes @ **Ramp** ______ **/ Resistance 10** 2 minutes @ **Ramp** ______ **/ Resistance 10**	YES / NO
5 minutes rest completed	YES / NO

Notes:

Appendix 5. ANOVA Output

.

Within-Subjects Factors

Measure: GM_activation

Elliptical_Type	Ramp_angle	Dependent Variable
1	1	GM_35_Old
	2	GM_25_Old
	3	GM_15_Old
2	1	GM_35_New
	2	GM_25_New
	3	GM_15_New

Descriptive Statistics

	Mean	Std. Deviation	N
GM_35_Old	56.0969	138.21766	23
GM_25_Old	26.2142	31.19378	23
GM_15_Old	26.4097	34.63789	23
GM_35_New	52.9028	119.38984	23
GM_25_New	38.2619	80.35865	23
GM_15_New	23.7307	19.91103	23

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[c]
Elliptical_Type	Pillai's Trace	.071	1.672[b]	1.000	22.000	.209	.071	1.672	.236
	Wilks' Lambda	.929	1.672[b]	1.000	22.000	.209	.071	1.672	.236
	Hotelling's Trace	.076	1.672[b]	1.000	22.000	.209	.071	1.672	.236
	Roy's Largest Root	.076	1.672[b]	1.000	22.000	.209	.071	1.672	.236
Ramp_angle	Pillai's Trace	.261	3.713[b]	2.000	21.000	.042	.261	7.427	.616
	Wilks' Lambda	.739	3.713[b]	2.000	21.000	.042	.261	7.427	.616
	Hotelling's Trace	.354	3.713[b]	2.000	21.000	.042	.261	7.427	.616
	Roy's Largest Root	.354	3.713[b]	2.000	21.000	.042	.261	7.427	.616
	Pillai's Trace	.058	.651[b]	2.000	21.000	.532	.058	1.301	.144

Elliptical_Type * Ramp_angle	Wilks' Lambda	.942	.651[b]	2.000	21.000	.532	.058	1.301	.144
	Hotelling's Trace	.062	.651[b]	2.000	21.000	.532	.058	1.301	.144
	Roy's Largest Root	.062	.651[b]	2.000	21.000	.532	.058	1.301	.144

a. Design: Intercept
Within Subjects Design: Elliptical_Type + Ramp_angle + Elliptical_Type * Ramp_angle

b. Exact statistic

c. Computed using alpha = .05

Mauchly's Test of Sphericity[a]

Measure: GM_activation

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Elliptical_Type	1.000	.000	0	.	1.000	1.000	1.000
Ramp_angle	.014	89.919	2	.000	.503	.504	.500
Elliptical_Type * Ramp_angle	.201	33.667	2	.000	.556	.564	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept
Within Subjects Design: Elliptical_Type + Ramp_angle + Elliptical_Type * Ramp_angle

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Within-Subjects Effects

Measure: GM_activation

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Elliptical_Type	Sphericity Assumed	146.151	1	146.151	1.672	.209	.071	1.672	.236
	Greenhouse-Geisser	146.151	1.000	146.151	1.672	.209	.071	1.672	.236
	Huynh-Feldt	146.151	1.000	146.151	1.672	.209	.071	1.672	.236
	Lower-bound	146.151	1.000	146.151	1.672	.209	.071	1.672	.236
Error(Elliptical_Type)	Sphericity Assumed	1922.549	22	87.389					
	Greenhouse-Geisser	1922.549	22.000	87.389					
	Huynh-Feldt	1922.549	22.000	87.389					
	Lower-bound	1922.549	22.000	87.389					
Ramp_angle	Sphericity Assumed	21667.104	2	10833.552	1.664	.201	.070	3.329	.332
	Greenhouse-Geisser	21667.104	1.007	21517.414	1.664	.210	.070	1.676	.235
	Huynh-Feldt	21667.104	1.008	21496.142	1.664	.210	.070	1.678	.236
	Lower-bound	21667.104	1.000	21667.104	1.664	.210	.070	1.664	.235
Error(Ramp_angle)	Sphericity Assumed	286412.403	44	6509.373					
	Greenhouse-Geisser	286412.403	22.153	12928.804					
	Huynh-Feldt	286412.403	22.175	12916.023					
	Lower-bound	286412.403	22.000	13018.746					
Elliptical_Type * Ramp_angle	Sphericity Assumed	1722.882	2	861.441	.801	.456	.035	1.601	.178
	Greenhouse-Geisser	1722.882	1.112	1549.517	.801	.392	.035	.890	.142
	Huynh-Feldt	1722.882	1.129	1526.631	.801	.394	.035	.903	.143

	Lower-bound	1722.882	1.000	1722.882	.801	.381	.035	.801	.137
Error(Elliptical_Type*Ramp_angle)	Sphericity Assumed	47348.038	44	1076.092					
	Greenhouse-Geisser	47348.038	24.461	1935.619					
	Huynh-Feldt	47348.038	24.828	1907.031					
	Lower-bound	47348.038	22.000	2152.184					

a. Computed using alpha = .05

Estimated Marginal Means

1. Grand Mean

Measure: GM_activation

Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
37.269	14.020	8.193	66.346

2. Elliptical_Type

Estimates

Measure: GM_activation

Elliptical_Type	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1	36.240	14.082	7.036	65.445
2	38.298	14.004	9.257	67.340

Pairwise Comparisons

Measure: GM_activation

(I) Elliptical_Type	(J) Elliptical_Type	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-2.058	1.592	.209	-5.359	1.242
2	1	2.058	1.592	.209	-1.242	5.359

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Pillai's trace	.071	1.672[a]	1.000	22.000	.209	.071	1.672	.236
Wilks' lambda	.929	1.672[a]	1.000	22.000	.209	.071	1.672	.236
Hotelling's trace	.076	1.672[a]	1.000	22.000	.209	.071	1.672	.236
Roy's largest root	.076	1.672[a]	1.000	22.000	.209	.071	1.672	.236

Each F tests the multivariate effect of Elliptical_Type. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

b. Computed using alpha = .05

3. Ramp_angle

Estimates

Measure: GM_activation

Ramp_angle	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	54.500	26.816	-1.113	110.113
2	32.238	11.565	8.254	56.222
3	25.070	4.458	15.824	34.316

Pairwise Comparisons

Measure: GM_activation

(I) Ramp_angle	(J) Ramp_angle	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	22.262	15.306	.480	-17.399	61.922
	3	29.430	23.390	.665	-31.179	90.039
2	1	-22.262	15.306	.480	-61.922	17.399
	3	7.168	8.227	1.000	-14.149	28.485
3	1	-29.430	23.390	.665	-90.039	31.179
	2	-7.168	8.227	1.000	-28.485	14.149

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Pillai's trace	.261	3.713[a]	2.000	21.000	.042	.261	7.427	.616
Wilks' lambda	.739	3.713[a]	2.000	21.000	.042	.261	7.427	.616
Hotelling's trace	.354	3.713[a]	2.000	21.000	.042	.261	7.427	.616
Roy's largest root	.354	3.713[a]	2.000	21.000	.042	.261	7.427	.616

Each F tests the multivariate effect of Ramp_angle. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

b. Computed using alpha = .05

4. Elliptical_Type * Ramp_angle

Measure: GM_activation

Elliptical_Type	Ramp_angle	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
1	1	56.097	28.820	-3.673	115.867
	2	26.214	6.504	12.725	39.703
	3	26.410	7.222	11.431	41.388
2	1	52.903	24.895	1.275	104.531
	2	38.262	16.756	3.512	73.012
	3	23.731	4.152	15.121	32.341

General Linear Model

Within-Subjects Factors

Measure: ST_activation

Elliptical_Type	Ramp_angle	Dependent Variable
1	1	ST_35_Old
	2	ST_25_Old
	3	ST_15_Old
2	1	ST_35_New
	2	ST_25_New
	3	ST_15_New

Descriptive Statistics

	Mean	Std. Deviation	N
ST_35_Old	6.3841	3.47105	23
ST_25_Old	5.4896	4.13121	23
ST_15_Old	5.2107	3.61869	23
ST_35_New	7.2011	7.31122	23
ST_25_New	4.5738	2.95566	23
ST_15_New	4.4887	2.97134	23

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[c]
Elliptical_Type	Pillai's Trace	.022	.484[b]	1.000	22.000	.494	.022	.484	.102
	Wilks' Lambda	.978	.484[b]	1.000	22.000	.494	.022	.484	.102
	Hotelling's Trace	.022	.484[b]	1.000	22.000	.494	.022	.484	.102
	Roy's Largest Root	.022	.484[b]	1.000	22.000	.494	.022	.484	.102
Ramp_angle	Pillai's Trace	.205	2.706[b]	2.000	21.000	.090	.205	5.412	.477
	Wilks' Lambda	.795	2.706[b]	2.000	21.000	.090	.205	5.412	.477
	Hotelling's Trace	.258	2.706[b]	2.000	21.000	.090	.205	5.412	.477
	Roy's Largest Root	.258	2.706[b]	2.000	21.000	.090	.205	5.412	.477
Elliptical_Type * Ramp_angle	Pillai's Trace	.058	.650[b]	2.000	21.000	.532	.058	1.301	.144
	Wilks' Lambda	.942	.650[b]	2.000	21.000	.532	.058	1.301	.144
	Hotelling's Trace	.062	.650[b]	2.000	21.000	.532	.058	1.301	.144
	Roy's Largest Root	.062	.650[b]	2.000	21.000	.532	.058	1.301	.144

a. Design: Intercept

Within Subjects Design: Elliptical_Type + Ramp_angle + Elliptical_Type * Ramp_angle

b. Exact statistic

c. Computed using alpha = .05

Mauchly's Test of Sphericity[a]

Measure: ST_activation

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Elliptical_Type	1.000	.000	0	.	1.000	1.000	1.000
Ramp_angle	.210	32.823	2	.000	.559	.567	.500
Elliptical_Type * Ramp_angle	.709	7.225	2	.027	.775	.822	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept

Within Subjects Design: Elliptical_Type + Ramp_angle + Elliptical_Type * Ramp_angle

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Within-Subjects Effects

Measure: ST_activation

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Elliptical_Type	Sphericity Assumed	2.582	1	2.582	.484	.494	.022	.484	.102
	Greenhouse-Geisser	2.582	1.000	2.582	.484	.494	.022	.484	.102
	Huynh-Feldt	2.582	1.000	2.582	.484	.494	.022	.484	.102
	Lower-bound	2.582	1.000	2.582	.484	.494	.022	.484	.102
Error(Elliptical_Type)	Sphericity Assumed	117.414	22	5.337					
	Greenhouse-Geisser	117.414	22.000	5.337					
	Huynh-Feldt	117.414	22.000	5.337					
	Lower-bound	117.414	22.000	5.337					
Ramp_angle	Sphericity Assumed	105.930	2	52.965	4.046	.024	.155	8.093	.691
	Greenhouse-Geisser	105.930	1.117	94.834	4.046	.051	.155	4.520	.514

	Huynh-Feldt	105.930	1.134	93.374	4.046	.051	.155	4.591	.519
	Lower-bound	105.930	1.000	105.930	4.046	.057	.155	4.046	.486
Error(Ramp_angle)	Sphericity Assumed	575.943	44	13.090					
	Greenhouse-Geisser	575.943	24.574	23.437					
	Huynh-Feldt	575.943	24.959	23.076					
	Lower-bound	575.943	22.000	26.179					
Elliptical_Type * Ramp_angle	Sphericity Assumed	20.732	2	10.366	1.004	.375	.044	2.008	.214
	Greenhouse-Geisser	20.732	1.549	13.384	1.004	.359	.044	1.555	.191
	Huynh-Feldt	20.732	1.644	12.608	1.004	.363	.044	1.651	.196
	Lower-bound	20.732	1.000	20.732	1.004	.327	.044	1.004	.160
Error(Elliptical_Type*Ramp_angle)	Sphericity Assumed	454.314	44	10.325					
	Greenhouse-Geisser	454.314	34.080	13.331					
	Huynh-Feldt	454.314	36.176	12.558					
	Lower-bound	454.314	22.000	20.651					

a. Computed using alpha = .05

Estimated Marginal Means

1. Grand Mean

Measure: ST_activation

Mean	Std. Error	95% Confidence Interval	
		Lower Bound	Upper Bound
5.558	.665	4.178	6.938

2. Elliptical_Type

Estimates

Measure: ST_activation

Elliptical_Type	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	5.695	.685	4.274	7.115
2	5.421	.702	3.965	6.877

Pairwise Comparisons

Measure: ST_activation

(I) Elliptical_Type	(J) Elliptical_Type	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.274	.393	.494	-.542	1.089
2	1	-.274	.393	.494	-1.089	.542

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Pillai's trace	.022	.484[a]	1.000	22.000	.494	.022	.484	.102
Wilks' lambda	.978	.484[a]	1.000	22.000	.494	.022	.484	.102
Hotelling's trace	.022	.484[a]	1.000	22.000	.494	.022	.484	.102
Roy's largest root	.022	.484[a]	1.000	22.000	.494	.022	.484	.102

Each F tests the multivariate effect of Elliptical_Type. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

b. Computed using alpha = .05

3. Ramp_angle

Estimates

Measure: ST_activation

Ramp_angle	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	6.793	1.074	4.565	9.020
2	5.032	.610	3.766	6.297
3	4.850	.608	3.588	6.112

Pairwise Comparisons

Measure: ST_activation

(I) Ramp_angle	(J) Ramp_angle	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	1.761	.777	.101	-.253	3.774
	3	1.943	.994	.191	-.634	4.520
2	1	-1.761	.777	.101	-3.774	.253
	3	.182	.338	1.000	-.695	1.059
3	1	-1.943	.994	.191	-4.520	.634
	2	-.182	.338	1.000	-1.059	.695

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Pillai's trace	.205	2.706[a]	2.000	21.000	.090	.205	5.412	.477
Wilks' lambda	.795	2.706[a]	2.000	21.000	.090	.205	5.412	.477
Hotelling's trace	.258	2.706[a]	2.000	21.000	.090	.205	5.412	.477
Roy's largest root	.258	2.706[a]	2.000	21.000	.090	.205	5.412	.477

Each F tests the multivariate effect of Ramp_angle. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

b. Computed using alpha = .05

4. Elliptical_Type * Ramp_angle

Measure: ST_activation

Elliptical_Type	Ramp_angle	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
1	1	6.384	.724	4.883	7.885
	2	5.490	.861	3.703	7.276
	3	5.211	.755	3.646	6.776
2	1	7.201	1.524	4.039	10.363
	2	4.574	.616	3.296	5.852
	3	4.489	.620	3.204	5.774

General Linear Model

Within-Subjects Factors

Measure: VM_activation

Elliptical_Type	Ramp_angle	Dependent Variable
1	1	VM_35_Old
	2	VM_25_Old
	3	VM_15_Old
2	1	VM_35_New
	2	VM_25_New
	3	VM_15_New

Descriptive Statistics

	Mean	Std. Deviation	N
VM_35_Old	28.9469	19.90421	23
VM_25_Old	29.7682	51.61478	23
VM_15_Old	19.2793	17.76389	23
VM_35_New	31.9489	17.01063	23
VM_25_New	22.6408	15.35387	23
VM_15_New	20.2371	17.44991	23

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[c]
Elliptical_Type	Pillai's Trace	.004	.095[b]	1.000	22.000	.761	.004	.095	.060
	Wilks' Lambda	.996	.095[b]	1.000	22.000	.761	.004	.095	.060
	Hotelling's Trace	.004	.095[b]	1.000	22.000	.761	.004	.095	.060
	Roy's Largest Root	.004	.095[b]	1.000	22.000	.761	.004	.095	.060
Ramp_angle	Pillai's Trace	.633	18.121[b]	2.000	21.000	.000	.633	36.243	.999
	Wilks' Lambda	.367	18.121[b]	2.000	21.000	.000	.633	36.243	.999
	Hotelling's Trace	1.726	18.121[b]	2.000	21.000	.000	.633	36.243	.999
	Roy's Largest Root	1.726	18.121[b]	2.000	21.000	.000	.633	36.243	.999
Elliptical_Type * Ramp_angle	Pillai's Trace	.074	.834[b]	2.000	21.000	.448	.074	1.668	.174
	Wilks' Lambda	.926	.834[b]	2.000	21.000	.448	.074	1.668	.174
	Hotelling's Trace	.079	.834[b]	2.000	21.000	.448	.074	1.668	.174
	Roy's Largest Root	.079	.834[b]	2.000	21.000	.448	.074	1.668	.174

a. Design: Intercept

Within Subjects Design: Elliptical_Type + Ramp_angle + Elliptical_Type * Ramp_angle

b. Exact statistic

c. Computed using alpha = .05

Mauchly's Test of Sphericity[a]

Measure: VM_activation

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Elliptical_Type	1.000	.000	0	.	1.000	1.000	1.000
Ramp_angle	.447	16.917	2	.000	.644	.667	.500
Elliptical_Type * Ramp_angle	.436	17.439	2	.000	.639	.661	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept

Within Subjects Design: Elliptical_Type + Ramp_angle + Elliptical_Type * Ramp_angle

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Within-Subjects Effects

Measure: VM_activation

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Elliptical_Type	Sphericity Assumed	38.462	1	38.462	.095	.761	.004	.095	.060
	Greenhouse-Geisser	38.462	1.000	38.462	.095	.761	.004	.095	.060
	Huynh-Feldt	38.462	1.000	38.462	.095	.761	.004	.095	.060
	Lower-bound	38.462	1.000	38.462	.095	.761	.004	.095	.060
Error(Elliptical_Type)	Sphericity Assumed	8916.757	22	405.307					
	Greenhouse-Geisser	8916.757	22.000	405.307					
	Huynh-Feldt	8916.757	22.000	405.307					
	Lower-bound	8916.757	22.000	405.307					
Ramp_angle	Sphericity Assumed	2665.428	2	1332.714	4.915	.012	.183	9.830	.779
	Greenhouse-Geisser	2665.428	1.288	2069.941	4.915	.027	.183	6.329	.639

	Huynh-Feldt	2665.428	1.333	1999.051	4.915	.025	.183	6.553	.650
	Lower-bound	2665.428	1.000	2665.428	4.915	.037	.183	4.915	.563
Error(Ramp_angle)	Sphericity Assumed	11930.682	44	271.152					
	Greenhouse-Geisser	11930.682	28.329	421.147					
	Huynh-Feldt	11930.682	29.334	406.724					
	Lower-bound	11930.682	22.000	542.304					
Elliptical_Type * Ramp_angle	Sphericity Assumed	659.923	2	329.962	1.119	.336	.048	2.238	.234
	Greenhouse-Geisser	659.923	1.279	516.105	1.119	.316	.048	1.431	.191
	Huynh-Feldt	659.923	1.323	498.902	1.119	.317	.048	1.480	.194
	Lower-bound	659.923	1.000	659.923	1.119	.302	.048	1.119	.173
Error(Elliptical_Type*Ramp_angle)	Sphericity Assumed	12976.862	44	294.929					
	Greenhouse-Geisser	12976.862	28.131	461.309					
	Huynh-Feldt	12976.862	29.101	445.932					
	Lower-bound	12976.862	22.000	589.857					

a. Computed using alpha = .05

Tests of Within-Subjects Contrasts

Measure: VM_activation

Source	Elliptical_Type	Ramp_angle	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Elliptical_Type	Linear		38.462	1	38.462	.095	.761	.004	.095	.060
Error(Elliptical_Type)	Linear		8916.757	22	405.307					
Ramp_angle		Linear	2628.222	1	2628.222	29.155	.000	.570	29.155	.999
		Quadratic	37.206	1	37.206	.082	.777	.004	.082	.059
Error(Ramp_angle)		Linear	1983.250	22	90.148					
		Quadratic	9947.431	22	452.156					
Elliptical_Type * Ramp_angle	Linear	Linear	24.027	1	24.027	.321	.577	.014	.321	.084
		Quadratic	635.896	1	635.896	1.235	.278	.053	1.235	.186
Error(Elliptical_Type*Ramp_angle)	Linear	Linear	1647.148	22	74.870					
		Quadratic	11329.715	22	514.987					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: VM_activation

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	89524.911	1	89524.911	33.556	.000	.604	33.556	1.000
Error	58694.968	22	2667.953					

a. Computed using alpha = .05

Estimated Marginal Means

1. Grand Mean

Measure: VM_activation

Mean	Std. Error	95% Confidence Interval	
		Lower Bound	Upper Bound
25.470	4.397	16.352	34.589

2. Elliptical_Type

Estimates

Measure: VM_activation

Elliptical_Type	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	25.998	5.831	13.905	38.091
2	24.942	3.247	18.209	31.675

Pairwise Comparisons

Measure: VM_activation

(I) Elliptical_Type	(J) Elliptical_Type	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	1.056	3.428	.761	-6.052	8.164
2	1	-1.056	3.428	.761	-8.164	6.052

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Pillai's trace	.004	.095[a]	1.000	22.000	.761	.004	.095	.060
Wilks' lambda	.996	.095[a]	1.000	22.000	.761	.004	.095	.060
Hotelling's trace	.004	.095[a]	1.000	22.000	.761	.004	.095	.060
Roy's largest root	.004	.095[a]	1.000	22.000	.761	.004	.095	.060

Each F tests the multivariate effect of Elliptical_Type. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

b. Computed using alpha = .05

3. Ramp_angle

Estimates

Measure: VM_activation

Ramp_angle	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	30.448	3.642	22.895	38.000
2	26.205	6.627	12.462	39.948
3	19.758	3.551	12.393	27.123

Pairwise Comparisons

Measure: VM_activation

(I) Ramp_angle	(J) Ramp_angle	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1	2	4.243	4.367	1.000	-7.073	15.560
	3	10.690*	1.980	.000	5.560	15.820
2	1	-4.243	4.367	1.000	-15.560	7.073
	3	6.446	3.518	.241	-2.669	15.562
3	1	-10.690*	1.980	.000	-15.820	-5.560
	2	-6.446	3.518	.241	-15.562	2.669

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Pillai's trace	.633	18.121[a]	2.000	21.000	.000	.633	36.243	.999
Wilks' lambda	.367	18.121[a]	2.000	21.000	.000	.633	36.243	.999
Hotelling's trace	1.726	18.121[a]	2.000	21.000	.000	.633	36.243	.999
Roy's largest root	1.726	18.121[a]	2.000	21.000	.000	.633	36.243	.999

Each F tests the multivariate effect of Ramp_angle. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

b. Computed using alpha = .05

4. Elliptical_Type * Ramp_angle

Measure: VM_activation

Elliptical_Type	Ramp_angle	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1	1	28.947	4.150	20.340	37.554
	2	29.768	10.762	7.448	52.088
	3	19.279	3.704	11.598	26.961
2	1	31.949	3.547	24.593	39.305
	2	22.641	3.202	16.001	29.280
	3	20.237	3.639	12.691	27.783

General Linear Model

Within-Subjects Factors

Measure: LG_activation

Elliptical_Type	Ramp_angle	Dependent Variable
1	1	LG_35_Old
	2	LG_25_Old
	3	LG_15_Old
2	1	LG_35_New
	2	LG_25_New
	3	LG_15_New

Descriptive Statistics

	Mean	Std. Deviation	N
LG_35_Old	16.5371	12.62169	23
LG_25_Old	17.2920	9.99089	23
LG_15_Old	19.5516	12.53344	23
LG_35_New	12.9114	8.29756	23
LG_25_New	12.9353	8.06345	23
LG_15_New	18.9187	11.93910	23

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[c]
Elliptical_Type	Pillai's Trace	.151	3.920[b]	1.000	22.000	.060	.151	3.920	.473
	Wilks' Lambda	.849	3.920[b]	1.000	22.000	.060	.151	3.920	.473
	Hotelling's Trace	.178	3.920[b]	1.000	22.000	.060	.151	3.920	.473
	Roy's Largest Root	.178	3.920[b]	1.000	22.000	.060	.151	3.920	.473
Ramp_angle	Pillai's Trace	.431	7.959[b]	2.000	21.000	.003	.431	15.919	.923
	Wilks' Lambda	.569	7.959[b]	2.000	21.000	.003	.431	15.919	.923
	Hotelling's Trace	.758	7.959[b]	2.000	21.000	.003	.431	15.919	.923
	Roy's Largest Root	.758	7.959[b]	2.000	21.000	.003	.431	15.919	.923
Elliptical_Type * Ramp_angle	Pillai's Trace	.073	.832[b]	2.000	21.000	.449	.073	1.663	.173
	Wilks' Lambda	.927	.832[b]	2.000	21.000	.449	.073	1.663	.173
	Hotelling's Trace	.079	.832[b]	2.000	21.000	.449	.073	1.663	.173
	Roy's Largest Root	.079	.832[b]	2.000	21.000	.449	.073	1.663	.173

a. Design: Intercept

Within Subjects Design: Elliptical_Type + Ramp_angle + Elliptical_Type * Ramp_angle

b. Exact statistic

c. Computed using alpha = .05

Mauchly's Test of Sphericity[a]

Measure: LG_activation

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Elliptical_Type	1.000	.000	0	.	1.000	1.000	1.000
Ramp_angle	.734	6.503	2	.039	.790	.840	.500
Elliptical_Type * Ramp_angle	.718	6.953	2	.031	.780	.829	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept

Within Subjects Design: Elliptical_Type + Ramp_angle + Elliptical_Type * Ramp_angle

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Within-Subjects Effects

Measure: LG_activation

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Elliptical_Type	Sphericity Assumed	284.523	1	284.523	3.920	.060	.151	3.920	.473
	Greenhouse-Geisser	284.523	1.000	284.523	3.920	.060	.151	3.920	.473
	Huynh-Feldt	284.523	1.000	284.523	3.920	.060	.151	3.920	.473
	Lower-bound	284.523	1.000	284.523	3.920	.060	.151	3.920	.473
Error(Elliptical_Type)	Sphericity Assumed	1596.932	22	72.588					
	Greenhouse-Geisser	1596.932	22.000	72.588					
	Huynh-Feldt	1596.932	22.000	72.588					
	Lower-bound	1596.932	22.000	72.588					
Ramp_angle	Sphericity Assumed	574.784	2	287.392	7.668	.001	.258	15.337	.933
	Greenhouse-Geisser	574.784	1.579	363.927	7.668	.003	.258	12.111	.883
	Huynh-Feldt	574.784	1.681	341.940	7.668	.003	.258	12.890	.898
	Lower-bound	574.784	1.000	574.784	7.668	.011	.258	7.668	.754
Error(Ramp_angle)	Sphericity Assumed	1649.003	44	37.477					
	Greenhouse-Geisser	1649.003	34.747	47.458					
	Huynh-Feldt	1649.003	36.981	44.591					
	Lower-bound	1649.003	22.000	74.955					
Elliptical_Type * Ramp_angle	Sphericity Assumed	89.538	2	44.769	1.311	.280	.056	2.622	.269
	Greenhouse-Geisser	89.538	1.560	57.389	1.311	.277	.056	2.045	.238
	Huynh-Feldt	89.538	1.658	54.011	1.311	.278	.056	2.173	.245
	Lower-bound	89.538	1.000	89.538	1.311	.265	.056	1.311	.195

Error(Elliptical_Type*Ramp_angle)	Sphericity Assumed	1502.747	44	34.153					
	Greenhouse-Geisser	1502.747	34.325	43.780					
	Huynh-Feldt	1502.747	36.471	41.204					
	Lower-bound	1502.747	22.000	68.307					

a. Computed using alpha = .05

Tests of Within-Subjects Contrasts

Measure: LG_activation

Source	Elliptical_Type	Ramp_angle	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Elliptical_Type	Linear		284.523	1	284.523	3.920	.060	.151	3.920	.473
Error(Elliptical_Type)	Linear		1596.932	22	72.588					
Ramp_angle		Linear	467.998	1	467.998	8.345	.009	.275	8.345	.788
		Quadratic	106.786	1	106.786	5.658	.026	.205	5.658	.623
Error(Ramp_angle)		Linear	1233.776	22	56.081					
		Quadratic	415.227	22	18.874					
Elliptical_Type * Ramp_angle	Linear	Linear	51.500	1	51.500	1.288	.269	.055	1.288	.192
		Quadratic	38.039	1	38.039	1.343	.259	.058	1.343	.198
Error(Elliptical_Type*Ramp_angle)	Linear	Linear	879.599	22	39.982					
		Quadratic	623.148	22	28.325					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: LG_activation

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	36925.110	1	36925.110	77.448	.000	.779	77.448	1.000
Error	10489.021	22	476.774					

a. Computed using alpha = .05

Estimated Marginal Means

1. Grand Mean

Measure: LG_activation

Mean	Std. Error	95% Confidence Interval	
		Lower Bound	Upper Bound
16.358	1.859	12.503	20.212

2. Elliptical_Type

Estimates

Measure: LG_activation

Elliptical_Type	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	17.794	2.239	13.150	22.437
2	14.922	1.717	11.360	18.483

Pairwise Comparisons

Measure: LG_activation

(I) Elliptical_Type	(J) Elliptical_Type	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	2.872	1.451	.060	-.136	5.880
2	1	-2.872	1.451	.060	-5.880	.136

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Pillai's trace	.151	3.920[a]	1.000	22.000	.060	.151	3.920	.473
Wilks' lambda	.849	3.920[a]	1.000	22.000	.060	.151	3.920	.473
Hotelling's trace	.178	3.920[a]	1.000	22.000	.060	.151	3.920	.473
Roy's largest root	.178	3.920[a]	1.000	22.000	.060	.151	3.920	.473

Each F tests the multivariate effect of Elliptical_Type. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

b. Computed using alpha = .05

3. Ramp_angle

Estimates

Measure: LG_activation

Ramp_angle	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	14.724	2.061	10.449	18.999
2	15.114	1.726	11.535	18.692
3	19.235	2.183	14.707	23.763

Pairwise Comparisons

Measure: LG_activation

(I) Ramp_angle	(J) Ramp_angle	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	Upper Bound
1	2	-.389	1.193	1.000	-3.482	2.703
	3	-4.511*	1.562	.026	-8.557	-.465
2	1	.389	1.193	1.000	-2.703	3.482
	3	-4.121*	1.013	.002	-6.746	-1.497
3	1	4.511*	1.562	.026	.465	8.557
	2	4.121*	1.013	.002	1.497	6.746

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Pillai's trace	.431	7.959[a]	2.000	21.000	.003	.431	15.919	.923
Wilks' lambda	.569	7.959[a]	2.000	21.000	.003	.431	15.919	.923
Hotelling's trace	.758	7.959[a]	2.000	21.000	.003	.431	15.919	.923
Roy's largest root	.758	7.959[a]	2.000	21.000	.003	.431	15.919	.923

Each F tests the multivariate effect of Ramp_angle. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

b. Computed using alpha = .05

4. Elliptical_Type * Ramp_angle

Measure: LG_activation

Elliptical_Type	Ramp_angle	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1	1	16.537	2.632	11.079	21.995
	2	17.292	2.083	12.972	21.612
	3	19.552	2.613	14.132	24.971
2	1	12.911	1.730	9.323	16.500
	2	12.935	1.681	9.448	16.422
	3	18.919	2.489	13.756	24.082

General Linear Model

Within-Subjects Factors

Measure: VL_activation

Elliptical_Type	Ramp_angle	Dependent Variable
1	1	VL_35_Old
	2	VL_25_Old
	3	VL_15_Old
2	1	VL_35_New
	2	VL_25_New
	3	VL_15_New

Descriptive Statistics

	Mean	Std. Deviation	N
VL_35_Old	24.7486	13.52381	23
VL_25_Old	18.9567	11.03397	23
VL_15_Old	15.9646	9.84006	23
VL_35_New	30.6831	13.93824	23
VL_25_New	20.3656	11.83620	23
VL_15_New	16.2076	9.25784	23

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[c]
Elliptical_Type	Pillai's Trace	.296	9.256[b]	1.000	22.000	.006	.296	9.256	.828
	Wilks' Lambda	.704	9.256[b]	1.000	22.000	.006	.296	9.256	.828
	Hotelling's Trace	.421	9.256[b]	1.000	22.000	.006	.296	9.256	.828
	Roy's Largest Root	.421	9.256[b]	1.000	22.000	.006	.296	9.256	.828
Ramp_angle	Pillai's Trace	.749	31.278[b]	2.000	21.000	.000	.749	62.555	1.000
	Wilks' Lambda	.251	31.278[b]	2.000	21.000	.000	.749	62.555	1.000
	Hotelling's Trace	2.979	31.278[b]	2.000	21.000	.000	.749	62.555	1.000
	Roy's Largest Root	2.979	31.278[b]	2.000	21.000	.000	.749	62.555	1.000
Elliptical_Type * Ramp_angle	Pillai's Trace	.254	3.567[b]	2.000	21.000	.046	.254	7.134	.597
	Wilks' Lambda	.746	3.567[b]	2.000	21.000	.046	.254	7.134	.597
	Hotelling's Trace	.340	3.567[b]	2.000	21.000	.046	.254	7.134	.597
	Roy's Largest Root	.340	3.567[b]	2.000	21.000	.046	.254	7.134	.597

a. Design: Intercept

Within Subjects Design: Elliptical_Type + Ramp_angle + Elliptical_Type * Ramp_angle

b. Exact statistic

c. Computed using alpha = .05

Mauchly's Test of Sphericity[a]

Measure: VL_activation

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Elliptical_Type	1.000	.000	0	.	1.000	1.000	1.000
Ramp_angle	.702	7.435	2	.024	.770	.817	.500
Elliptical_Type * Ramp_angle	.501	14.502	2	.001	.667	.694	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept

Within Subjects Design: Elliptical_Type + Ramp_angle + Elliptical_Type * Ramp_angle

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Within-Subjects Effects

Measure: VL_activation

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Elliptical_Type	Sphericity Assumed	220.621	1	220.621	9.256	.006	.296	9.256	.828
	Greenhouse-Geisser	220.621	1.000	220.621	9.256	.006	.296	9.256	.828
	Huynh-Feldt	220.621	1.000	220.621	9.256	.006	.296	9.256	.828
	Lower-bound	220.621	1.000	220.621	9.256	.006	.296	9.256	.828
Error(Elliptical_Type)	Sphericity Assumed	524.372	22	23.835					
	Greenhouse-Geisser	524.372	22.000	23.835					
	Huynh-Feldt	524.372	22.000	23.835					
	Lower-bound	524.372	22.000	23.835					
Ramp_angle	Sphericity Assumed	3264.618	2	1632.309	35.469	.000	.617	70.938	1.000
	Greenhouse-Geisser	3264.618	1.541	2118.998	35.469	.000	.617	54.645	1.000

	Huynh-Feldt	3264.618	1.634	1997.680	35.469	.000	.617	57.964	1.000
	Lower-bound	3264.618	1.000	3264.618	35.469	.000	.617	35.469	1.000
Error(Ramp_angle)	Sphericity Assumed	2024.898	44	46.020					
	Greenhouse-Geisser	2024.898	33.894	59.742					
	Huynh-Feldt	2024.898	35.952	56.321					
	Lower-bound	2024.898	22.000	92.041					
Elliptical_Type * Ramp_angle	Sphericity Assumed	207.893	2	103.947	2.560	.089	.104	5.120	.485
	Greenhouse-Geisser	207.893	1.334	155.785	2.560	.112	.104	3.416	.388
	Huynh-Feldt	207.893	1.388	149.729	2.560	.110	.104	3.555	.397
	Lower-bound	207.893	1.000	207.893	2.560	.124	.104	2.560	.334
Error(Elliptical_Type*Ramp_angle)	Sphericity Assumed	1786.502	44	40.602					
	Greenhouse-Geisser	1786.502	29.359	60.851					
	Huynh-Feldt	1786.502	30.546	58.485					
	Lower-bound	1786.502	22.000	81.205					

a. Computed using alpha = .05

Tests of Within-Subjects Contrasts

Measure: VL_activation

Source	Elliptical_Type	Ramp_angle	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Elliptical_Type	Linear		220.621	1	220.621	9.256	.006	.296	9.256	.828
Error(Elliptical_Type)	Linear		524.372	22	23.835					
Ramp_angle		Linear	3110.769	1	3110.769	45.198	.000	.673	45.198	1.000
		Quadratic	153.849	1	153.849	6.627	.017	.231	6.627	.692
Error(Ramp_angle)		Linear	1514.155	22	68.825					
		Quadratic	510.743	22	23.216					
Elliptical_Type * Ramp_angle	Linear	Linear	186.259	1	186.259	2.847	.106	.115	2.847	.365
		Quadratic	21.634	1	21.634	1.371	.254	.059	1.371	.202
Error(Elliptical_Type*Ramp_angle)	Linear	Linear	1439.358	22	65.425					
		Quadratic	347.144	22	15.779					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: VL_activation

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	61756.015	1	61756.015	98.894	.000	.818	98.894	1.000
Error	13738.253	22	624.466					

a. Computed using alpha = .05

Estimated Marginal Means

1. Grand Mean

Measure: VL_activation

Mean	Std. Error	95% Confidence Interval	
		Lower Bound	Upper Bound
21.154	2.127	16.743	25.566

2. Elliptical_Type

Estimates

Measure: VL_activation

Elliptical_Type	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	19.890	2.073	15.591	24.188
2	22.419	2.258	17.736	27.102

Pairwise Comparisons

Measure: VL_activation

(I) Elliptical_Type	(J) Elliptical_Type	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1	2	-2.529*	.831	.006	-4.253	-.805
2	1	2.529*	.831	.006	.805	4.253

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Pillai's trace	.296	9.256[a]	1.000	22.000	.006	.296	9.256	.828
Wilks' lambda	.704	9.256[a]	1.000	22.000	.006	.296	9.256	.828
Hotelling's trace	.421	9.256[a]	1.000	22.000	.006	.296	9.256	.828
Roy's largest root	.421	9.256[a]	1.000	22.000	.006	.296	9.256	.828

Each F tests the multivariate effect of Elliptical_Type. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

b. Computed using alpha = .05

3. Ramp_angle

Estimates

Measure: VL_activation

Ramp_angle	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1	27.716	2.683	22.152	33.280
2	19.661	2.294	14.904	24.418
3	16.086	1.765	12.425	19.747

Pairwise Comparisons

Measure: VL_activation

(I) Ramp_angle	(J) Ramp_angle	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1	2	8.055*	1.052	.000	5.328	10.782
	3	11.630*	1.730	.000	7.147	16.112
2	1	-8.055*	1.052	.000	-10.782	-5.328
	3	3.575*	1.379	.050	.001	7.149
3	1	-11.630*	1.730	.000	-16.112	-7.147
	2	-3.575*	1.379	.050	-7.149	-.001

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Pillai's trace	.749	31.278[a]	2.000	21.000	.000	.749	62.555	1.000
Wilks' lambda	.251	31.278[a]	2.000	21.000	.000	.749	62.555	1.000
Hotelling's trace	2.979	31.278[a]	2.000	21.000	.000	.749	62.555	1.000
Roy's largest root	2.979	31.278[a]	2.000	21.000	.000	.749	62.555	1.000

Each F tests the multivariate effect of Ramp_angle. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

b. Computed using alpha = .05

4. Elliptical_Type * Ramp_angle

Measure: VL_activation

Elliptical_Type	Ramp_angle	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1	1	24.749	2.820	18.900	30.597
	2	18.957	2.301	14.185	23.728
	3	15.965	2.052	11.709	20.220
2	1	30.683	2.906	24.656	36.710
	2	20.366	2.468	15.247	25.484
	3	16.208	1.930	12.204	20.211