Theraband® CLX gold reduces knee-width index but increases gluteus medius activity during the barbell back squat

By

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Abstract

Squatting with resistance bands around the distal portion of the thighs above the patella have grown in popularity. They have been thought to act as a proprioceptive aid by activating the gluteus muscles and therefore, preventing medial knee collapse. The objectives of this thesis were: 1) to determine how the resistance bands would affect lower body muscle activation and 2) to examine how the kinematics of the squat (i.e., knee width index (KWI) and knee angle) may change with the addition of the resistance bands. Twenty-three resistance trained individuals (twelve males and eleven females) completed one set of three repetitions of the barbell back squat (BBS) at 87% of their 1 repetition maximum (RM). This protocol was completed under four conditions; no band, a red band, black band and gold band in a randomized order. A significant difference in the gluteus medius (GME) was found in the gold band condition compared to all other conditions. The KWI was significantly lower with the gold band in comparison to the no band and red band conditions. Overall, males had significantly higher KWI values in comparison to their female counterparts in the band conditions. While placing a gold band may increase the muscle activation of the GME during the squat, the lower KWI values may lead to an increase in knee injuries.

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List of Symbols, Nomenclature or Abbreviations

ACL: Anterior Cruciate Ligament

BBS: Barbell Back Squat

BF: Biceps Femoris

EMG: Electromyography

ES: Erector Spinae

GMA: Gluteus Maximus

GME: Gluteus Medius

MVC: Maximum Voluntary Contraction

RM: Repetition Maximum

VL: Vastus Lateralis

VM: Vastus Medialis

KWI: Knee Width Index

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Chapter 1: Review of Literature

Introduction

In the field of strength and conditioning, the squat is one of the most frequently used exercises (Schoenfeld, 2010). The squatting movement has biomechanical and neuromuscular similarities to a wide range of athletic movements such as running, jumping and lifting (Schoenfeld, 2010), and is therefore implemented in many sport training programs to enhance performance. The squat can benefit the general population as it can improve performance of everyday tasks by recruiting multiple muscle groups in a single movement. In clinical settings, it has become increasingly popular to implement the squat to strengthen lower-body muscles and connective tissue after a joint-related injury as it strengthens the hip, thigh and back musculature; which are important muscles for walking, sitting and standing, as well as sport specific tasks (Escamilla, 2001).

A common movement error typically observed in novice or untrained individuals when performing a squat is knee valgus (Foley et al., 2017). This movement results from the knee joint moving excessively medial in the frontal plane causing hip adduction and internal rotation (Foley et al., 2017). A valgus knee position during the squatting exercise has been shown to increase the risk of athletes sustaining knee injuries such as an anterior cruciate ligament or medial collateral ligament tear (Hoogenboom et al., 2018). It has been hypothesized in previous research that the utilization of a TheraBand, which is a lightweight elastic band that can wrap around any body part or surface with varying resistance may help to correct or minimize this error by acting as a proprioceptive aid (Gooyers et al., 2012).

Several studies have shown that manipulating certain features of the squat exercise resulted in changes of muscle activity. These manipulations include changes in foot positioning, barbell positioning, stability of the surface, intensity of the load, range of motion, and different equipment (Yavuz et al., 2017). There are many ways the squat movement can be performed; however, this review will focus primarily on the back squat in hopes to expand on current literature examining the TheraBand (Foley et al., 2017; Forman et al., 2018; Gooyers et al., 2012; Hoogenboom et al., 2018; Reece et al., 2020; Spracklin et al., 2017).

The purpose of this review is to examine the current methodologies and results to identify any gaps in the literature. This paper will provide a review of the methods utilized in the area of exercise physiology and sport biomechanics in regard to incorporating resistance bands into the performance of different squat techniques (e.g., the barbell back squat and the overhead barbell squat). It will examine the bands effect on electromyography (EMG) of the lower limb musculature, and kinematics such as knee width index (KWI) and knee angle. There have been few studies conducted in this particular area of research, therefore, this review will include studies that have examined the TheraBand in different positions and studies that have examined the barbell back squat and the overhead barbell back squat without the use of the band loop.

Biomechanical and Muscle Activation Differences Between the Back Squat and Overhead Squat

Because of the limited research in this field, it is important to discuss the difference in squat movement as it pertains to current literature. Forman et al. (2018) and Hoogenboom et al. (2018) examined the overhead squat (OHS), compared to the back squat, noting that the OHS may help to understand the results of these studies in comparison to studies that examined the back squat. The only apparent study comparing the back squat to the OHS was conducted by Aspe and Swinton (2014). They determined both biomechanical and muscle activation differences in the barbell back squat and the OHS. The researchers hypothesized that greater muscle activity would be observed in the back squat as heavier loads could be lifted and result in greater force output in comparison to the OHS (Aspe & Swinton, 2014). In contrast, they also hypothesized that due to the reduced stability of the OHS, greater muscle activity would be observed in the anterior and posterior compartments of the trunk. The participants in this study were all rugby players and were competent in performing the back squat and OHS movements. Participants were instructed to do a 3-repetition maximum (RM) test for the back and OHS in a randomized order. Maximum speed testing, where participants were instructed to control the load until the upper thighs reached parallel with the floor, was also conducted. In this testing, once depth was achieved, they were instructed to lift the load as fast as possible (Aspe & Swinton, 2014). They recorded EMG from eight different muscles; the anterior deltoid, rectus abdominis, external oblique, erector spinae, gluteus maximus, vastus lateralis, biceps femoris, and the lateral gastrocnemius. These muscles were selected in accordance with previous research (Cram, 1998). The results demonstrated that the anterior deltoid exhibited significantly greater muscle activity in the OHS which is to be expected as the barbell is held overhead. Greater values were also obtained during the OHS in the rectus abdominis and the external obliques across all loads (Aspe & Swinton, 2014) whereas EMG activity of the lower body was consistently greater during the back squat in comparison to the OHS. Their results confirmed their hypothesis that heavier loads used with the back squat elicits a greater kinetic stimulus and increased muscular activity in the prime movers (Aspe & Swinton, 2014). As this is the only study to examine the differences between the two movements, further research is warranted to confirm the findings and explore the potential benefits of the OHS.

Factors Affected by Resistance Bands

Electromyography

In the literature, there is little known in regard to muscle activity when a looped resistance band is placed around the outer thighs when performing a back squat and an overhead squat. Of the limited research available in this field, there are conflicting findings. While some studies found an increase in muscle activity with the use of a resistance band (Dai et al., 2014; Foley et al., 2017; Spracklin et al., 2017), others found no change (Forman et al., 2018). The variability in the research may be due to a number of factors, such as the resistance of the elastic band used, the research design and the variables that were controlled for by the research group.

Spracklin et al. (2017) conducted the first study to investigate the effects of a looped band on performance rather than only EMG amplitudes and/or biomechanical alignment. The objective of their study was to examine the effects of placing a looped band around the thigh, on EMG amplitude of the thigh, and on the posterior hip muscle groups during a barbell back squat (BBS) among resistance-trained participants. Their second objective was to explore the effects of the band on BBS performance at two different intensities, five repetitions at 80% of their 1RM and 60% of their 1RM to failure (Spracklin et al., 2017). Surface EMG electrodes were placed on the gluteus maximus (GMA), gluteus medius (GME), vastus lateralis (VL), and biceps femoris (BF). This particular study used a blue TheraBand which provided a resistance of 2.6 kg at 100% elongation. The results of this study were in agreement with previous literature (Dai et al., 2014) in that during the looped-band condition, there was greater EMG activity in the GME. This was to be expected as the hip abductors are required to push against the resistance band to prevent collapsing of the knees. In the study conducted by Dai et al. (2014), the band was placed around the ankles instead of the distal thighs; however, they also found an increase in GME activation. In contrast to these findings, the VL and BF showed no significant changes in muscle activity when the looped band was applied (Spracklin et al., 2017). The researchers concluded that the looped band could be placed around the thighs as a training strategy without negatively affecting performance (Spracklin et al., 2017); however, due to the lack of negative and positive effects in conjunction with increased EMG amplitudes, further investigation of the effects that looped bands have on performance is a worthwhile research avenue.

Similar to Spracklin et al. (2017), Foley et al. (2017) examined the effects of the band loop on lower extremity muscle activity during the barbell back squat, however, they recruited both trained and untrained participants. The researchers utilized the red TheraBand, which provided 2.04 kg of resistance at 100% elongation. They measured bilaterally from the same four muscles as the aforementioned study conducted by Spracklin et al. (2017), however, they implemented a different protocol. Their participants were required to perform a 3-repetition maximum (3RM) followed by a bodyweight (BW) load for maximum repetitions to failure. The results of this study indicated that there was an increase in muscle activity for the majority of the lower extremities in both trained and untrained individuals when utilizing the band in comparison to no band (Foley et al., 2017). A significant finding was that regardless of training status, there was less muscle activity in the left VL when squatting with the band compared to without the band during the squats. Also, the VL consistently demonstrated greater muscle activity for both the 3RM and BW conditions in trained compared to untrained. These results provide novel, conflicting findings. Gooyers et al. (2012) hypothesized that the band loop may in fact increase muscle activity in the VL, however, this was proven to be incorrect in this study, as well as Spracklin et al. (2017), who also found no significant change in the muscle activity of the VL.

More recent literature concluded that the TheraBand has no effect on muscle activation in the lower extremities (Forman et al., 2018). This particular study expanded this area of research by examining the overhead squat amongst trained individuals and incorporating the strongest resistance band offered by TheraBand CLX (6.5kg of resistance at 100% elongation). The researchers measured the muscle activity of the bilateral tibialis anterior (TA), medial gastrocnemius (MG), VM, rectus femoris, VL, GMA and GME. However, across all seven muscles throughout the concentric and eccentric phases, there were no significant differences in average or peak EMG between the 'no band' and 'band' conditions (Forman et al., 2018). These findings conflicts with the results of Foley et al. (2017) and Spracklin et al. (2017). This may be due to the differences in muscle recruitment patterns between the back squat and the overhead squat as previously discussed from Aspe and Swinton (2014). A comparison of the overhead squat and the back squat has shown that the EMG activity of the lower body in the back squat, elicited greater muscle activity. Specifically, the GMA had greater muscle activity throughout the back squat across the whole repetition for all loads (Aspe and Swinton, 2014). To further elaborate, the studies conducted by Foley et al. (2017) and Spracklin et al. (2017) not only examined the back squat, which as previously stated, has been shown to elicit greater muscle activity in the lower body muscles, they also used heavier loads. Foley et al. (2017) had their participants attain a 3RM which was achieved when the participant ended in failure and Spracklin et al. (2017) used 60% and 80% of their participants 1RM. The participants examined in this study only used 25% of their own bodyweight (Forman et al., 2018). As the participants were all resistance trained, the load may not have been heavy enough to evoke a change in muscle activity. Perhaps future research should examine the overhead barbell squat with a heavier load. Another potential explanation of why the muscle activity remained unchanged in the overhead barbell squat with the addition of the band is the change in squat depth. The results demonstrated that knee flexion angle was significantly greater for participants while squatting without the band. With the decrease in range of motion (ROM) with the addition of the band, participants still adhered to the metronome. This would suggest a decrease in movement velocity which may potentially explain the results in this study. As the researchers discussed, since contraction/movement velocity is correlated with muscle activity (Croce et al., 2003; Jakobsen et al., 2013), if the band was affecting the muscle activity during the overhead barbell squat, the results may have been suppressed due to the slower rate of the movement (Forman et al., 2018).

Lastly, the newest addition to this field was a study conducted by Reece et al. (2020). Similar to previous research, the researchers aimed to determine whether the addition of a looped resistance band impacted lower body muscle activation. The participants performed different intensity squats at 40% and 80% of their 1RM with no resistance band, a light Corezone resistance band and an extra heavy Corezone resistance band. The light and extra heavy band had a resistance of 6.8kg-9.1kg and 13.6kg-15.9kg, respectively. Consistent with the aforementioned research, EMG sensors were placed bilaterally over the muscle bellies of the VM, VL, BF, GMA and the right GME. In agreement with previous literature (Spracklin et al., 2017; Foley et al., 2017), the researchers of this study found that when using either a light or extra heavy resistance band, all participants experience a significant increase in GMA activity (Reece et al., 2020). However, in contrast to Spracklin et al. (2017) and Foley et al. (2017), the researchers found no significant difference in GME muscle activity with and without the band. Similarly, there was no significant difference in BF muscle activity with and without the resistance bands. Perhaps this is because GMA and the hamstring muscles are synergists for hip extension (Ebben et al., 2000). The hamstrings may act as the primary hip extensor to compensate if there is weakness of the GMA

(Lee et al., 2018). Since previous research has primarily found an increase in muscle activity of GMA (Spracklin et al., 2017; Foley et al., 2017; Reece et al., 2020), the GMA likely acted as the primary hip extensor which may explain why there was no change in the hamstrings muscle. Lastly, Reece et al. (2020) found no significant changes in either the VL or VM muscle activity. In contrast, Foley et al. (2017) found that there were significant changes in the EMG of the VL as previously mentioned.

The conflicting findings found in previous research in regard to muscle activity encourage future researchers to continue exploring this area. According to the literature, if the activation of the hip muscles increased, the positive short-term effects could be beneficial as injury risk could decrease (Hoogenboom et al., 2018). Since there have been inconsistent findings in this area, continuing to explore the effects that the TheraBand has on muscle activity is a worthwhile avenue in this field as it could provide valuable information to clinicians, coaches and athletes.

Kinematics

It is important to examine the changes in knee movement throughout the squat maneuver due to the array of injuries that could occur over time when the knees collapse medially during squatting. KWI has been the primary measure of medial knee collapse and has been identified as the width of the lateral epicondyles of the knees as a ratio to the width of the lateral malleoli of the ankles (Foley et al., 2017; Forman et al., 2018; Gooyers et al., 2012). It has been hypothesized that placing a resistance band around the thighs will act as an external cue to prevent excessive medial collapse of the knees (Gooyers et al., 2012); however, to date, there has been little benefit shown. Gooyers et al. (2012) aimed to examine the impact of wearing light- and medium-tension resistance bands on the frontal plane knee mechanics during bodyweight squats and jumping exercises. To do this, six rigid bodies were placed on the thigh, shank and feet bilaterally using

Velcro straps and double-sided tape. Ten Vicon MX40 cameras were utilized to capture the motion data as well as two force platforms using Vicon software to collect the ground reaction forces and moments. Previous research examined and identified Vicon as a gold standard kinematic assessment tool (Windolf, 2008) as it is an accurate and reliable tool to capture exercises commonly performed in a strength training environment (Mosey et al., 2018). The researchers found that both resistances of the looped bands were unsuccessful at correcting the medial collapse of the knees (Gooyers et al., 2012). More specifically, the medium-tension band resulted in significantly lower KWI values during the ascent phase of the countermovement jump and the bodyweight squat exercise indicating the medial collapse of the knees was exaggerated. This was found across all participants. The authors reported that their findings were not consistent with the positive outcomes that Cook et al. (1999) identified in a clinical case study. However, with a clinical skill set, verbal instruction and feedback from coaches and clinicians may have influenced the positive outcome in that study more than the band itself. The researchers provided possible explanations as to why their results did not match their hypothesis (Gooyers et al., 2012). While the participants were recreationally active, they were untrained. Therefore, the untrained individuals may have been unable to resist the band tension without a task goal, coaching instruction or performance feedback (Gooyers et al., 2012). Other possible explanations for why the outcome was not as expected is that the band may not have challenged the muscles at the hip as the researchers had hypothesized and, lastly, the exposure to the bands was brief and may not have sufficient to influence the participants movement patterns.

Similar to Gooyers study, Foley et al. (2017) and Forman et al. (2018) aimed to investigate the effects of the TheraBand loop on kinematics of the lower extremities during a standard barbell back squat and overhead barbell back squat, respectively. Instead of Vicon, the 3D kinematics in both studies were collected using three 3D Investigator Active Motion Capture Systems. Custom rigid bodies were placed on the participant's foot, shank, and thigh bilaterally, similar in nature to Gooyers et al. (2012), as well as, the pelvis and thorax (Foley et al., 2017). Foley et al. (2017) found that trained participants in comparison to untrained, had a significantly greater knee flexion angle (squat depth) and were able to lift significantly more weight. The results of this study also indicated that KWI showed no significant differences with the addition of a band regardless of training status. However, during the concentric phase of the squat, there was a main effect of squat type (3RM or BW) with a smaller KWI for the 3RM. The smaller KWI could potentially arise from the heavier load utilized for this particular set, as well as, muscle fatigue cause by the demands of the protocol (Foley et al. 2017). Similar to Gooyers et al. (2012), Foley et al. (2017) suggested that in order to see possible improvements in KWI, longer exposure using the band should be implemented. While Foley et al. (2017) found that KWI was unchanged when the band was added, the study conducted by Forman et al. (2018) found that when participants used the TheraBand, their peak and average KWI was decreased for both the concentric and eccentric phase of the movement, indicating there was exaggerated medial collapse. In addition, participants were unable to squat to the same depth with the band indicating their knee flexion angle was decreased. The contradicting findings presented in these two studies may have occurred due to different TheraBand's used. Foley et al. (2017) utilized a band that provided 2.04 kg resistance at 100% elongation whereas Forman et al. (2018) utilized a band that provided 6.5 kg of resistance at 100% elongation. The band used in the latter study was ~318% stronger which possibly indicates that the band was too strong to provide any functional or practical benefit (Forman et al., 2018). As the authors pointed out, different squat technique between participants will lead to different amounts of resistance due to the variation of elongation. If a participant has a wider stance, they will elongate the band more than a participant with a narrow stance. This is an important consideration for future research. The authors indicate that examining a larger variety of resistance band strengths on squat technique could provide further insight to this area of research.

A recent study conducted by Hoogenboom et al. (2018) provided a unique addition to this field of research. The researchers examined the effects of low-level corrective exercises using TheraBand CLX bands on overhead deep squat (OHDS) performance in subjects with identified stability dysfunction during squatting. The protocol was considerably different from the previously mentioned studies (Foley et al., 2017; Forman et al., 2018; Gooyers et al., 2012). Depending on the participants stability dysfunction, a corrective exercise was assigned using the TheraBand CLX. The protocol included 3 sets of 15 OHDS repetitions using the TheraBand CLX in the assigned exercise condition. The resistance of the band was chosen to maintain a non-fatiguing intervention, therefore, if the participants began to fatigue, they decreased the resistance of the TheraBand. Using 2D motion analysis, this study indicated that at 0°-60° of knee flexion and at full squat depth, the KWI became larger post-intervention, demonstrating less knee valgus. This is potentially due to an increase in hip abductors and external rotators activity; however, muscle activity was not measured in this study (Hoogenboom et al., 2018, Lubahn et al., 2011). While this study implemented a much less onerous protocol, it is one of few to demonstrate a positive outcome with the addition of the TheraBand. It provides insight to the effect of TheraBand's on corrective exercises which could be useful in settings such as training programs and rehabilitation programs.

Lastly, Reece et al. (2020) aimed to examine knee kinematics using resistance bands during the BBS. Differing from previous research explored (Gooyers et al., 2012; Foley et al., 2017; Forman et al., 2018), these researchers were the first to investigate knee valgus angle and tibial rotation value instead of using KWI as the primary measure for medial knee collapse. Reece et al. (2020) noted that when comparing males and females, males may be at a higher risk of knee injury when squatting with or without a band. It was found that females had higher tibial rotation means and lower peak knee valgus. This finding was particularly interesting as women have been shown to elicit more knee valgus during squatting movements in comparison to their male counterparts (Wallace et al., 2008; Russell et al., 2006). For both the low and high intensity squat, peak knee valgus angle was highest in both phases of the squat regardless of sex when the extra heavy band was used (Reece et al., 2020). Significantly greater peak knee valgus angles were also demonstrated in both phases of the squat when the light resistance band was utilized. Tibial rotation values were also significantly higher in both the light and extra heavy resistance bands. Similar to Gooyers et al. (2012) and Forman et al. (2018), the authors suggested that the bands may have been too strong for participants to resist, even when squatting with the light resistance band (Reece et al., 2020). Interestingly, the Corezone bands that were used in this study provided 6.8-9.1 kg (light) and 13.6-15.9 kg (extra heavy) of resistance. The heaviest band used in previous literature was 6.44 kg at 100% elongation. The high amount of resistance provided by the bands in this study may explain the results found. The authors of this study suggest that resistance bands not be used while squatting as the chance for injury may be increased as tibial rotation and peak knee valgus angle were increased with both conditions. These outcomes indicate that resistance bands increase medial knee collapse which in turn, increases the risk of injury to the knee (Geiser et al., 2010; Hewett et al., 2005). As recommended by previous researchers, longer exposure with the bands could allow participants to develop muscle activation patterns required to overcome the resistance of the bands (Gooyers et al., 2012; Reece et al., 2020).

Sex Differences

There have been two studies that have recruited both male and female participants when examining resistance bands and their effect on squatting (Gooyers et al., 2012; Reece et al., 2020). Gooyers et al. (2012) did not have a large enough sample size to explore sex-based statistical comparisons, however, they did mention that upon looking at participant-specific responses, there were no consistent differences from the rest of the group in regard to KWI. More recently, Reece et al. (2020) found that across all muscles measured, there were no differences in EMG between sexes. They did, however, find that females had high tibial rotation and lower peak knee valgus in comparison to males. This suggests that males may be at a higher risk for knee injury when compared to females, regardless of whether the band was used or not. No other studies have examined the sex differences when using resistance bands during the BBS, however, Mehls et al. (2020) examine EMG sex differences during the BBS in resistance trained subjects. Their protocol consisted of 85% of their 1RM for 3 sets of 4 repetitions. Interestingly, the only difference in muscle activity between males and females was that men had significantly higher muscle activity in the BF muscle during the descending phase of the squat.

Resistance Band Differences

To date, no two studies have examined the same strength resistance bands when looking at the BBS. The varying resistances may explain why the results have been conflicting in previous literature. Gooyers et al. (2012), who examined body weight squats and vertical jump movements, utilized a light- and medium tension resistance band with 0.15 N/mm and 0.20 N/mm, respectively. The first study to examine the BBS and the use of resistance bands was Spracklin et al. (2017) who utilized a band with 2.6 kg of resistance at 100% elongation. Foley et al. (2017) and Forman et al. (2018) used a band providing 2.04 kg and 6.44 kg of resistance at 100% elongation, respectively. Lastly, Reece et al. (2020) were the first to examine multiple resistances with the BBS. They utilized a light and extra heavy band providing 6.8-9.1 kg and 13.6-15.9 kg of resistance. Varying outcomes have results from these studies.

Conclusion

Reviewing and critiquing the methodologies in current literature is essential for future research. It provides insight to researchers of the methodological considerations in past studies so that there can be improvement upon the sampling technique, research design and statistical analyses. Examining the TheraBand and its effect on muscle activation, KWI and knee angle during squatting exercises is a relatively new and growing area of research and there are still many avenues to be explored. Therefore, the proposed research study will be one of few to examine a variety of resistance band strengths on the barbell back squat with a heavy load. It may provide insight into muscle activity and kinematic changes as the TheraBand increases in resistance and whether or not band should be implemented in training regimes.

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Chapter 2: Co-authorship Statement

My contribution to this thesis is outlined below:

i) I recruited some participants and analyzed all data collected for this thesis.

ii) With the help of PhD students Garrick Forman, Davis Forman and Robert Kumar, I collected all experimental data for this thesis.

iii) I prepared the manuscript and thesis with the help and guidance of my supervisor, Dr. Duane Button and Post-Doctoral Fellow Dr. Shahab Alizadeh.

iv) Dr. Duane Button provided feedback on the manuscript and thesis.

Chapter 3: Theraband™ CLX gold reduces knee-width index but increases gluteus medius activity during the barbell back squat

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Running Head: Loop bands increase gluteus medius EMG but decrease KWI.

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Abstract

Context: This research examined the effects of the Theraband™ CLX red, black and gold on lower-limb muscle activity and kinematics in resistance trained individuals while performing the barbell back squat. This current research protocol will be the first to examine more than two resistance bands in a single study

Objective: To examine the muscle activation change amongst the vastus lateralis (VL), vastus medialis (VM), gluteus maximus (GMa), gluteus medius (GMe), biceps femoris (BF), and erector spinae (ES) during the barbell back squat (BBS) with and without various resistance bands. A secondary objective was to examine how the kinematics of the BBS with the addition of the resistance bands was affected in regard to knee width index (KWI) and knee angle.

Design: Shapiro-Wilk test was used to assess the normality of the data. A two-way (1×within-subject variables: EMG activity; 2×between-subject variable: sex and phase [descending and ascending]) repeated measures ANOVA was used for statistical analysis. If the assumption of sphericity was violated based on Mauchly's test, the Greenhouse–Geisser correction was used. For data that were not normally distributed the Friedman test was used to compare the results. Bonferroni and Wilcoxon signed-rank test were used as post-hoc tests for parametric and nonparametric data respectively.

Setting: Neuromechanics and Ergonomics Lab at Brock University

Participants: Twenty-three (twelve males, eleven females) resistance-trained individuals (22.6±2.6yrs) participated.

Interventions: Participants attended the laboratory on two occasions interspersed by a minimum of 48 hours. During session one, participants executed their 5-repetition maximum (RM) (~85% of 1RM) back squat as a baseline measure. In the second experimental session, participants performed four sets (no-band, red band, black band, and gold band) of three repetitions of the barbell back squat in a randomized order with their 5-RM weight. A Vicon motion capture system collected three-dimensional kinematics via placement of rigid bodies placed bilaterally on the foot, shank, thigh, pelvis, and thorax. Electromyography (EMG) activity was collected from six muscles of the participants' dominant lower limb. Medial knee collapse was calculated utilizing a knee-width index (KWI) ratio, defined as the ratio of the distance between the lateral epicondyles of the femur and the lateral malleoli.

Main Outcome Measures: EMG of the VL, VM, GMa, GMe, BF, ES and the kinematic data during the four sets of three repetitions with the various conditions.

Results: Results indicated a significant effect for band on gluteus medius EMG [F (1.751,70.045) = 10.167, $p < 0.001$, $p\eta^2 = 0.203$]. The gold band resulted in significantly greater gluteus medius EMG activity compared to all conditions. There was a significant effect for band on KWI [F (2.37,99.525) = 21.906, $p < 0.001$, $p\eta^2 = 0.343$] where the gold band showed significantly lower knee width index (KWI) compared to other conditions.

Conclusion: The gold band has the greatest resistance of the CLX offerings. While the resistance of the gold band increased the muscle activation of the hip abductors, it caused a greater medial knee collapse in comparison to the other band resistance conditions.

Keywords: squat, electromyography, resistance bands, kinematics.

Introduction

The barbell back squat (BBS) is a widely utilized movement and perhaps one of the most useful exercises to incorporate in training programs for athletes (Wallace et al., 2008). This is primarily due to the biomechanical and neuromuscular similarities to a variety of athletic movements (Schoenfeld, 2010). Apart from athletes, the squat exercise has grown in popularity in the general population as well as in clinical settings. During squat performance, it has been estimated that approximately 200 muscles are recruited, including, but not limited to, the quadriceps, hip extensors, hip adductors, and hip abductors (Solomonow et al., 1987; Nisell et al., 1986). Additionally, the abdominals, erector spinae, trapezius, rhomboids, and other supporting muscles act to stabilize the trunk during the dynamic movement (Solomonow et al., 1987).

There have been two common technical issues identified when performing the BBS including the knees moving into a valgus knee position (Barnes et al., 1989) and adduction of the hips, specifically during the concentric phase of the movement (Zeller et al., 2003). Training aids, such as elastic resistance bands and loops, that are thought to help correct the valgus knee position, have grown in popularity and are widely used by coaches and clinicians (Foley et al., 2017). It has been hypothesized that utilizing a looped band around the thighs will act as a proprioceptive aid to reduce medial knee collapse by activating hip abductors and therefore pushing the knees apart, promoting neutral knee alignment (Gooyers et al., 2012). However, to date there has been little benefit shown by incorporating resistance bands during squatting. Previous literature has demonstrated that implementing the band during squatting has either exaggerated medial knee collapse (Gooyers et al., 2012; Forman et al., 2018; Reece et al., 2020) or showed no improvement (Foley et al., 2017). It has been shown that the use of bands can increase the muscle activation of certain lower limb muscles which may help to reduce medial knee collapse (Spracklin et al., 2017; Foley et al., 2017; Reece et al., 2020).

While Gooyers et al. (2012) recruited both males and females, statistical comparisons were not made due to an uneven sample size. Based on previous research (Ford et al., 2003; Quatman & Hewett, 2009), the researchers predicted that females would have more frontal knee motion than males; however, participant-specific responses did not support that hypothesis. To date, only one other study has examined sex differences while incorporating resistance bands during the BBS (Reece et al., 2020). Reece et al. (2020) found that males exhibited significantly more medial knee collapse in comparison to females; however, there were no significant differences between the two sexes in regard to the muscle activity of the lower limb musculature. The present research aims to expand the literature by examining both males and females. This current research protocol will be the first to examine more than two resistance bands in a single study. Additionally, no studies to date have examined the correlation between strength and KWI.

Therefore, the purpose of this study was to examine the effects of various resistances of the TheraBand CLX elastic bands on lower limb EMG and kinematics of the BBS in males and females. Based on previous work completed (Spracklin et al., 2017; Foley et al., 2017; Reece et al., 2020), it was hypothesized that as the resistance of the bands increase, muscle activation of gluteus maximus (GMA) and gluteus medius (GME) will increase. It was also hypothesized that the medial knee collapse will be exaggerated as the bands increase in tension and squat depth will be reduced (Gooyers et al., 2012; Foley et al., 2017; Forman et al., 2018; Reece et al., 2020).

Methodology

Participants

Twenty-three (12 males and 11 females) resistance-trained individuals (defined as individuals with regular engagement in resistance training for at least one year and familiar with the barbell back squat), were recruited via convenience sampling for this experiment. The mean height, mass, and age of male and female participants were 82.2 kg ± 11.9, 65.9 kg ± 10.9, 178.1 cm ± 6.4, 167.2 cm ± 7.6, 22.6 years ± 2.4, and 22.6 years ± 2.9, respectively. Procedures were verbally explained to each participant prior to the beginning of the study. To assess exercise readiness, participants completed the Physical Activity Readiness Questionnaire (PAR-Q+). Procedures were in accordance with the Tri-Council guidelines in Canada and approved by the Interdisciplinary Committee on Ethics in Human Research of Memorial University of Newfoundland (ICEHR #20192643-HK) as well as the Research Ethics Board at Brock University (REB # 18-265).

Experimental Set-up

Participants performed 3 repetitions of the barbell back squat (BBS) for each experimental condition. The experimental conditions included: no resistance band, and the red, black, and gold TheraBand CLX. As all volunteers were resistance trained, each participant self-selected their own foot and hand-grip position. Once their foot placement was chosen, tape was placed on the ground to ensure that the position was consistent throughout the entirety of the session. Participants commenced the protocol using 20.5kg (weight of the barbell) without the resistance band. Weight was added in 5-10 kg increments in accordance with the American College of Sports Medicine (ACSM) warm-up guidelines. Once the participant achieved their 5-repetition maximum (RM) test weight, the conditions were randomized. Participants were instructed to perform the BBS at a controlled tempo of 2-0-2-1 (2 count eccentric descent, 0 hold at the bottom, 2 count concentric rise, 1 count hold at repetition completion) at a metronome cadence of 50 beats per minute (bpm). The resistance bands were placed around the distal quadriceps, just proximal to the patella so there was no interference with knee motion. Instructions were given to each participant prior to the addition of the band. They were instructed to maintain tension within the band throughout the entire repetition to prevent the medial collapse of the knees.

Experimental Protocol

Participants were required to visit the laboratory on two separate occasions. The first session was used to determine the participants 5RM, which is approximately 87% of 1RM (Landers, 1984). As all participants were resistance-trained, the warm-up was specific to the individual. Once the participant was sufficiently warmed up, their 5RM was determined by following ACSM guidelines. No data was collected in this session as the weight determined was used in session two.

At the start of session two, a warm-up, consisting of submaximal contractions, was completed prior to the isometric maximal voluntary contractions (MVC). Following EMG electrode preparation, muscle specific MVCs were performed for each muscle. Participants then completed a warm-up consisting of 5 minutes on a treadmill, dynamic stretching and bodyweight squats. Similar to session one, the warm-up was not standardized as participants were all resistance trained. Following the warm-up, participants began the BBS protocol with weight of the bar and no band. The weight on the barbell was increased based on the ability of the participant and ACSM protocol. Once the participant attained their 5RM weight from session one, the protocol began. Four sets of three repetitions of the BBS were performed for each of the conditions in a randomized order. After each set, 5 minutes rest was given to ensure participants were not fatigued.

TheraBand CLX

TheraBand® CLX Consecutive Loop Bands (The Hygenic Corporation, OH, USA) used were the red, black, and gold band which provided 1.68 kg, 3.31 kg and 6.44 kg resistance, respectively at 100% elongation. After 2-3 participants, new bands were used to ensure consistency between subjects. The CLX bands have a series of loops which were placed around each leg. To ensure that the rigid bodies and EMG wires were avoided when putting on and taking off the bands, two researchers guided the looped band carefully over each of the participants legs.

Kinematics

Three-dimensional motion capture was assessed using a 10-camera Vicon motion capture system. Custom-designed rigid bodies, consisting of at least three reflective markers on each, were secured on the participants bilateral on the dorsum of the feet, shank and thigh as well as the pelvis and thorax. Anatomical landmarks were digitized about each rigid body and tracked throughout the movement. Kinematics were sampled at 50 Hz and synchronized with the EMG data. A global coordinate system was calculated prior to the start of every session with X representing medial/lateral movement, Y representing anterior/posterior movement, and Z representing superior/inferior movement.

Kinematic data was analyzed using Visual3D (C-Motion, Germantown, MD, USA). This data was digitally low-pass Butterworth filtered with a 6 Hz cut-off. Knee joint angle was calculated as the thigh relative to the shank, using an XYZ rotation sequence. The maximum and minimum knee joint angles were used in order to examine the start of the eccentric and concentric phases for each repetition. The maximum knee joint angle was considered maximum knee flexion. The distal joint coordinates (XYZ) were calculated for each segment's rigid bodies, based on the start and end positions. KWI was calculated from the three-dimensional position data from each segment as the ratio of distance between the right and left distal thigh (lateral epicondyles) and shank (lateral malleoli). The different phases of the BBS (eccentric vs. concentric) were examined using maximum, minimum, and average KWI.

Electromyography (EMG)

Skin preparation for all electrodes consisted of hair removal with disposable razors, skin abrasion, and cleansing with an isopropyl alcohol swab. To ensure consistent electrode placement, the same researcher placed the Ag-AgCl disposable electrodes 2cm apart on each muscle belly in-line with muscle fiber orientation, according to previous work (Hermens et al. 2000). A ground electrode was placed on the fibular head. Muscle activity was recorded from the participants dominant vastus medialis (VM), vastus lateralis (VL), biceps femoris (BF), gluteus maximus (GMA), gluteus medius (GME) and erector spinae (ES) using a 16-channel Bortec EMG system (AMT-8, Bortec Biomedical Ltd., Calgary, AB).

EMG data were full wave rectified and Butterworth low pass filtered (3 Hz cut-off, dual pass, 2^{nd} order) and normalized to the EMG collected during the muscle specific MVCs using MATLAB (MathWorks Inc., Natick, MA, USA). The kinematic and EMG data signals were synchronized. The kinematic data indicated the start, bottom, and end of the BBS movement; the maximum and average EMG was calculated during each part of the movement. Maximum EMG was taken as the peak muscle activity for both the eccentric and concentric phases. The average EMG for each muscle was measured for both phases between the start and end times, indicated by the kinematic data of the squat repetition.

Strength

Strength was defined as the five-repetition maximum (5RM) mass squat by each individual relative to their body mass (squat weight/body mass). The barbell mass in addition to the plates' mass were calculated as the total mass squatted.

Statistical Analysis

Shapiro-Wilk test was used to assess the normality of the data. A two-way (1×within-subject variables: EMG activity; 2×between-subject variable: sex and phase [descending and ascending]) repeated measures ANOVA was used for statistical analysis. If the assumption of sphericity was violated based on Mauchly's test, the Greenhouse–Geisser correction was used. Independent t-test was used to compare the difference between male and female strength. For data that were not normally distributed, the Friedman test was used to compare the results. Bonferroni and Wilcoxon signed-rank test were used as post-hoc tests for parametric and nonparametric data respectively. For parametric and non-parametric data, Pearson's correlation and Spearman's correlation was conducted, respectively. Alpha levels were set to 0.05 for all statistical tests. All tests were carried out using IBM SPSS v.25. Cohen (1998) interprets the effect size (*d*) magnitudes as trivial (<0.2), small (0.2-0.49), medium (0.5-0.79) or large (≥0.8) effect sizes. Furthermore, partial eta-squared ($p\eta^2$) measures indicating the magnitude of changes associated with significant main effect were provided and reported as small (<0.01), medium (≥0.06) or large (≥0.14). Additionally, correlation coefficients were reported as trivial (0.1-0.3), moderate (0.-3-0.5), or high (> 0.5) (Cohen, 1998).

Results

The normality test revealed that EMG activity of the GMA, GME, BF, ES, participant's strength, and the knee-width-index value were normally distributed ($p > 0.05$). The EMG activity for VL and VM, maximum knee flexion angle, and KWI at maximum knee flexion were not normally distributed in some of the conditions ($p > 0.05$); therefore, nonparametric tests were used to compare these values.

EMG

The results show that there was a significant effect for band on GMe EMG [$F_{(1.751,70.045)} = 10.167$, $p<0.001$, $p\eta^2=0.203$] with the gold band showing significantly higher GMe EMG activity compared to all other conditions (no band: ↓11.4%, $p= .004$; red band: ↓7.7%, $p= .008$; black band: ↓6.4%, $p= .008$). No significant band × sex ($p=.240$), band × phase ($p= .187$), nor band × sex × phase ($p=.429$) interaction effect was found on GMe EMG activity. There was no significant effect for band ($p= .059$) nor interaction effect (band × sex, $p= .785$; band × phase, $p= .828$; band × sex × phase, $p=.587$) on GMa EMG activity. There was no significant effect for band ($p= .883$) nor interaction effect (band × sex, $p= .109$; band × phase, $p= .621$; band × sex × phase, $p=.908$) on ES EMG activity. There was no significant effect for band, sex, and squat phase nor interaction effect on BF EMG ($p > 0.05$). There was also a significant effect for position on GMe EMG [$F_{(1,20)} = 52.32$, $p<0.001$, $p\eta^2=0.72$] with the EMG activity of the GMe being higher in the ascending phase compared to the descending phase.

The nonparametric results revealed no significant effect for band on VM EMG during the descending phase $\chi^2(3) =5.291$, $p=.152$. However, a significant effect for band on VM EMG was found during the ascending phase $\chi^2_{(3)} =15.655$, $p=.001$. The post-hoc test showed that the black band decreased the VM EMG compared to no band during the ascending phase by 9% ($Z = 3.133$, $p = .002$). Furthermore, the gold band reduced the VM EMG compared to no band during the ascending phase by 8.5% ($Z= 2.321$, $p = .020$). Additionally, the black band had an 8.4% reduction compared to red band in VM EMG during the ascending phase ($Z = 2.062$, $p =.039$). There was no significant effect for the bands on the VL EMG during the descending phase $\chi^2_{(3)}$ =3.457, p=.362 and ascending phase $\chi^2_{(3)}$ =3.545, p=.315 of the squat.

Kinematics

Repeated measures ANOVA test revealed that there was a significant effect for band on KWI [$F_{(3,63)} = 11.94$, $p<0.001$, $p\eta^2=0.36$] with the gold band showing significantly smaller KWI compared to no band and red band. The results also revealed a significant effect for band [$F_{(2.37,99.525)} = 21.906$, $p<0.001$, $p\eta^2=0.343$] and a band × sex interaction effect [$F_{(2.37,99.525)} = 3.017$, $p=0.045$, $p\eta^2=0.067$] on KWI. The post-hoc analysis showed that the gold band had a significant lower KWI compared to other conditions (no band: ↑4%, $p< .001$; red band: ↑3%, $p< .001$; black band: ↑2%, $p= .004$). Additionally, the black band had 2% lower KWI value compared to no band (p=.005). Overall, the males had significantly higher KWI values compared to their female counterparts in their respective condition (band). Different bands had a significant effect on KWI values at maximum knee flexion $\chi^2_{(3)}$ =15.783, p=.001. Post-hoc analysis revealed that the gold band elicited lower KWI values at maximum knee flexion compared to all other conditions (no band: ↑4.5%, Z = 3.285, p=.001; red band: ↑3.7%, Z =3.467, p=.001; black band: ↑2.7%, Z=2.433, p=.015). The results for the maximum knee flexion showed that the bands did not significantly affect maximum squat depth $\chi^2_{(3)}$ =6.704, p=082.

Strength

Male participants (1.18 ± 0.16) demonstrated 28% significantly greater strength compared to females (0.92 ± 0.26) for 5RM squat relative to their body mass [$t_{(44)} = 3.975$, $p < .001$, d = 1.15]. Pearson’s two-tailed correlation analysis showed there was no correlation between the amount of strength and KWI for both the ascending and descending phases for all conditions (p > 0.05). When controlled for sex, female’s strength had a strong correlation with the KWI during the ascending phases for red ($r_{(9)}$ = .612, p=.045) and gold ($r_{(9)}$ = .651, p=.030) bands; and during the descending phase for all conditions (no band: $r_{(9)}$ = .615, p=.044, red: $r_{(9)}$ = .675, p=.023, black: $r_{(9)}$ = .647, p=.031, gold: $r_{(9)}$ = .699, p=.017). However, the male participants did not show any correlation between their relative strength and KWI for all bands during both ascending and descending phases ($p > 0.05$). A significant strong correlation was found between the strength of both sexes and their ES during the descending (no band: $r_{(21)}$ = .593, p=.003, red: $r_{(21)}$ = .675, p<.001, black: $r_{(21)}$ = .590, p=.004, and gold: $r_{(21)}$ = .586, p=.004), and ascending (no band: $r_{(21)}$ = .556, p=.006, red: $r_{(21)}$ = .612, p=.002, black: $r_{(21)}$ = .583, p=.004, and gold: $r_{(21)}$ = .516, p=.014) phases. The BF showed a moderate correlation during the ascending phase for no band ($r_{(21)}$ = .450, p=.031) and black band ($r_{(21)}$ = .438, p=.042) for both male and females. When controlled for sex a significant strong correlation was shown between the female's strength and ES EMG during the ascending phase of the squat for no band ($r_{(9)}$ = .699, p=.017), red band ($r_{(9)}$ = .621, p=.042), and black band ($r_{(9)}$ = .696, p=.017); but not for males. No further correlation was observed between strength and EMG activity ($p > 0.05$).

Discussion

This purpose of this study was to examine if various resistance Therabands had an effect on the muscle activity of the lower limb musculature and kinematics during the BBS. We observed three key findings. First, consistent with the literature, GME muscle activity was greater with the addition of the gold Theraband. Second, the KWI decreased as the resistance of the bands increased. It is speculated that although the gold resistance band increased muscle activity of the GME, the tension of the band was too great and caused an increase in medial knee collapse, therefore increasing the risk of knee injury. Lastly, this is the first study to examine the correlation between KWI and strength. Interestingly, we found that there was no correlation between strength and KWI in males; however, as the barbell weight was increased for women, there was an increase in KWI indicating less knee valgus.

Electromyography

Similar to previous literature (Dai et al., 2014; Foley et al., 2017; Spracklin et al., 2017), the current study found that participants experienced a significant increase in GME activity when using the high resistance gold Theraband. This is in partial agreement with the findings from Spracklin et al. (2017) and Foley et al. (2017) who similarly found an increase in GME; however, they also found an increase in GMA activity while the current study did not. The increase in GME is not unexpected given that its main function is to abduct the hip (Spracklin et al., 2017). Interestingly, researchers have demonstrated that the gluteal muscle activity was only consistently increased when the band was used with the untrained participants (Foley et al., 2017). The researchers suggested that this was because trained participants may already have the required muscle activation patterns to withstand the force of the bands and avoid medial knee collapse. However, Spracklin et al. (2017), Reece et al. (2020), and the current study utilized trained participants and saw an increase in either GME, GMA, or both. Most recent findings from Reece et al. (2020) demonstrated that when using either the light or extra heavy resistance band in the low or high intensity squat condition, there was an increase in GMA activity. The researchers reported that the heavier band produced the largest increase in EMG, allowing them to conclude that as the tension of the resistance bands increase, GMA increases as well (Reece et al., 2020). This differs from the current study because there were no significant differences found in the gluteal muscles when the red or black Theraband was used. It is important to note that the studies that have examined the BBS with the use of elastic resistance bands have all utilized different resistances (Foley et al., 2017; 2.04 kg; Reece et al., 2020; 6.8-9.1 kg and 13.6-15.9 kg; Spracklin et al., 2017; 2.6 kg). The current study utilized 1.68 kg, 3.31 kg and 6.55 kg which may explain the differences in results found throughout the literature.

Lastly, Forman et al. (2018) examined seven different muscles using the gold Theraband during the overhead squat (OHS). The muscle activity of all seven muscles were unchanged between conditions. The authors found a significant difference in squat depth when the resistance band was used, suggesting that the unchanged muscle activity may have been due to a decrease in movement velocity. Participants were squatting with less depth while maintaining the tempo of the metronome. Although the current study found no significant changes in squat depth between conditions, the squat depth between participants may have varied, therefore altering EMG because contraction/movement velocity is correlated with muscle activity (Croce et al., 2003; Forman et al., 2018; Jakobsen et al., 2013). Researchers examining resistance bands during the squat exercise may want to consider controlling for squat depth.

In agreement with previous literature (Spracklin et al., 2017), the current study found that there were no significant differences on the VL EMG. However, results showed that there was a significant decrease in the VM EMG during the eccentric and concentric phase of the squat using the black band and during the concentric phase of the squat using the gold band. This differs from Gooyers et al. (2012) hypothesis that resistance bands may elicit greater muscle activity in the vastus lateralis during the squat. Foley et al. (2017) did not support the hypothesis from Gooyers et al. (2012) as well, finding that the VL has significantly lower EMG activity overall in 3RM and bodyweight conditions with the band compared to no band. Reece et al. (2020) stated that there was a trend in a reduction in quadriceps muscle activity with the band compared to no band. Based on these results, if the quadriceps are the muscles that squatters are targeting, it is not recommended that they use resistance bands (Reece et al., 2020).

Consistent with previous research (Spracklin et al., 2017; Foley et al., 2017; Forman et al., 2018; Reece et al., 2020), there was no difference in the muscle activity of the BF across all conditions. Reece et al. (2020) suggested that the hamstrings would be unlikely to resist the forces produced by the band, supporting the observation of no change in EMG activation.

No other squat study utilizing resistance bands examined the ES. Our study found that there were no significant changes in ES muscle activity across all conditions. This was expected as the ES helps to stabilize the spine during the squatting movement (Schoenfeld, 2010); this suggests that the bands did not alter the squat kinematics in a way that compromised the ES.

Knee Width Index

The primary measure of medial knee collapse in this study was KWI. Our data demonstrated that the gold Theraband CLX resulted in a significantly smaller KWI (more medial knee collapse) compared to all other conditions. Additionally, the gold band elicited more medial knee collapse at maximum knee flexion compared to all other conditions. These findings are in agreement with previous literature. The results from Gooyers et al. (2012) revealed that regardless of sex, the band elicited an exaggerated medial knee collapse. The researchers hypothesized that perhaps the band failed at improving neutral knee alignment because no verbal instructions were given to the participants (Gooyers et al., 2012). Foley et al. (2017) took this hypothesis and examined the effects of an elastic band in trained and untrained individuals. The researchers gave participants verbal instructions to resist the force of the band while squatting. In contrast with Gooyers et al. (2012), they found that KWI was unchanged across all conditions except during the 3RM concentric phase which demonstrated an overall lower KWI. The current study is in partial agreement with the results from Foley et al. (2017). Foley et al. (2017) utilized a band that provided 2.04 kg of resistance when stretched to 100% and the present study used the red and black band, which provided 1.68 kg and 3.31 kg of resistance at 100% elongation, respectively. In their study, KWI was unaffected in the body weight condition or the eccentric portion of the 3RM (Foley et al., 2017) and was similarly unaffected in the present study when the red and black band were used. Also, similar to the current study, Forman et al. (2018) utilized a gold Theraband; however, they examined the OHS. In agreement with our results, they also found that with the addition of the band, there was greater medial knee collapse. Perhaps the gold Theraband provides too much resistance to be overcome and is therefore not a practical training aid. Recent findings examined peak knee valgus angle and internal tibial rotation as their primary measure instead of KWI (Reece et al., 2020). This study further supports the notion that resistance bands do not promote neutral knee alignment when used while squatting. Reece et al. (2020) found that with both the light resistance band and the extra heavy resistance band, peak knee valgus angle and tibial rotation were increased in both the low and high intensity squats. Although different measures were used, this is consistent with the current study and previous research that resistance bands increase medial knee collapse (Gooyers et al., 2012; Foley et al., 2017; Forman et al., 2018). To date, no study has demonstrated an increase in KWI with the addition of the resistance bands. Longer-term interventions with the bands and their effect on KWI have not been explored; perhaps this is the next avenue this field of research should examine.

Squat Depth

The results showed that the resistance bands did not affect participants squat depth. This was in agreement with Foley et al. (2017) who found that there was no significant difference in squat depth between conditions. Foley et al. (2017) examined both trained and untrained participants, finding that the trained participants had a significantly greater squat depth when compared to the untrained participants. As noted previously, Forman et al. (2018) also utilized the gold TheraBand; however, they examined it in the OHS instead of the BBS. It is important to note that the biomechanical aspects between these two movements are very different. Instead of placing the bar across the back and shoulders, the load is held overhead in an OHS, creating a greater mechanical challenge (Aspe et al., 2014). While the results of the current study did not find any significant differences in squat depth, Forman et al. (2018) found that participants were able to squat significantly deeper without the band than with the band. Reece et al. (2020) did not report whether they examined their participants squat depth; however, similar to this study, squat depth was not controlled.

Sex Differences

In regard to EMG, our study found that although females had more medial knee collapse, there were no differences between the two sexes. This was in agreement with Reece et al. (2020), as they found that there were no significant differences between males and females across any of the muscles measured. This is not surprising due to findings of a recent study that compared sex differences during back squat (Mehls et al., 2020). Mehls et al. (2020) found that men activate their BF muscle during the back squat more than females. There were no other differences between males and females across all other muscles collected. Interestingly, our study showed that males had significantly less medial knee collapse than their female counterparts. This was expected as women have been shown to have more knee valgus than men in squatting movements (Wallace et al., 2008). However, the knee kinematic results from Reece et al. (2020) indicated that men may be at a higher risk for knee injury as they found that males actually had higher peak knee valgus angles regardless of whether a band was used or not. The effect that each band had on knee kinematics was very similar between both sexes and was therefore discussed without referring to male and female. The current study and Reece et al. (2020) appear to be the only two studies to examine both males and females using resistance bands while squatting; therefore, further investigation into sex differences may be a worthwhile venture.

Strength

Lastly, this was the first study to examine the correlation between strength and medial knee collapse. It was found that men demonstrated 28% greater strength in the 5RM than their female counterparts. Men did not show any correlation between strength and KWI across all conditions for both the eccentric and concentric phases. However, women had a strong correlation with the KWI during the concentric phase with the red and gold bands, and during the eccentric phase for all conditions. This indicates that as women lifted more weight, there was an increase in KWI, indicating less knee valgus. Our results also demonstrated that for both sexes, as more weight was lifted, there was an increase in ES muscle activation in both the eccentric and concentric phases. This is to be expected as heavier loads lifted in the BBS may require increased muscle activity of the ES to resist trunk flexion (i.e., stabilization) (Aspe & Swinton., 2014).

Methodological Considerations

Knee angle was not controlled in the present study, meaning that squat depth varied between participants while squatting. As previously mentioned by Forman et al. (2018), this could potentially affect the muscle activity due to contraction/movement velocity as all participants were squatting to the metronome yet achieving different squat depths. The force applied by the band differed between participants due to differences in strength and foot position. A narrow stance squatter would not cause as much tension on the band as a squatter who had a wide stance. Perhaps future studies should control for foot positioning. Lastly, a recommendation for future research would be to examine resistance bands used in previous studies. As there have been conflicting findings to date due to the varying resistance bands used, it would be beneficial to implement the aforementioned considerations to future studies and compare the outcomes.

Conclusion

Squatting with resistance bands as part of a training regime or rehabilitation strategy has grown in popularity. As this area of research has been explored in recent years, insight into the advantages and disadvantages of utilizing a resistance band while squatting has become more apparent. Although resistance bands have shown to increase gluteal muscle activity (Spracklin et al., 2017; Foley et al., 2017; Reece et al., 2020), medial knee displacement has either been unchanged or exaggerated (Foley et al., 2017; Forman et al., 2018; Gooyers et al., 2012; Reece et al., 2020). As recommended by other researchers (Gooyers et al., 2012), perhaps prolonged longer exposure to the bands will continue to increase gluteal muscle activity and therefore, resist the force of the bands.

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Table Legend

Table 1. Normalized average (avg) and maximum (max) muscle activity (mean ± SD) for each muscle during the eccentric (ecc) and concentric (con) phase of all conditions (no band, red band, black band, gold band).

Table 1

	VM	VL	BF	GMA	GME	ES
No Band						
Avg. Ecc.	57.33 ± 1.51	52.37 ± 1.89	9.83 ± 0.81	14.86 ± 1.69	16.03 ± 1.21	42.75 ± 1.49
Avg. Con.	80.39 ± 2.36	76.09 ± 3.52	23.55 ± 2.39	40.89 ± 4.68	33.16 ± 2.68	46.77 ± 5.09
Max. Ecc.	116.92 ± 6.07	107.72 ± 7.91	20.09 ± 2.39	29.74 ± 2.96	25.56 ± 2.18	72.41 ± 5.59
Max. Con.	138.09 ± 9.37	128.04 ± 10.01	37.39 ± 4.66	69.43 ± 6.81	54.36 ± 3.78	82.69 ± 5.27
Red Band						
Avg. Ecc.	56.11 ± 1.60	52.97 ± 1.66	10.21 ± 0.41	15.57 ± 1.31	16.38 ± 1.39	42.78 ± 1.52
Avg. Con.	78.85 ± 4.13	77.16 ± 3.64	22.43 ± 2.18	42.26 ± 4.24	34.43 ± 3.03	47.21 ± 3.95
Max. Ecc.	112.06 ± 7.99	108.89 ± 9.85	24.39 ± 3.75	32.21 ± 4.08	26.84 ± 3.55	73.56 ± 3.34
Max. Con.	135.33 ± 8.77	132.71 ± 9.95	37.64 ± 6.10	73.22 ± 6.35	55.68 ± 5.43	85.67 ± 6.49
Black Band						
Avg. Ecc.	53.83 ± 1.16	49.73 ± 0.59	9.67 ± 0.61	16.19 ± 1.54	16.67 ± 1.49	42.75 ± 1.11
Avg. Con.	74.29 ± 1.44	73.75 ± 0.42	22.67 ± 1.74	42.68 ± 3.37	34.13 ± 3.09	46.45 ± 2.99
Max. Ecc.	107.82 ± 3.01	103.49 ± 2.71	18.94 ± 1.87	33.47 ± 2.89	26.15 ± 2.11	74.89 ± 2.84
Max. Con.	130.47 ± 3.94	128.87 ± 1.65	36.96 ± 3.19	74.83 ± 4.36	54.31 ± 4.32	85.18 ± 5.34
Gold Band						
Avg. Ecc.	53.63 ± 1.08	51.67 ± 0.38	9.75 ± 0.67	17.27 ± 0.99	17.69 ± 1.35	43.68 ± 1.32
Avg. Con.	74.89 ± 2.77	73.74 ± 2.12	22.36 ± 1.65	43.61 ±2.92	36.95 ± 2.83	45.27 ± 2.42
Max. Ecc.	114.64 ± 4.12	105.03 ± 2.56	18.78 ± 0.69	35.27 ± 3.09	28.62 ± 2.82	74.76 ± 3.91
Max. Con.	132.68 ± 4.91	126.54 ± 5.56	35.93 ± 0.87	75.03 ± 4.51	60.62 ± 6.23	83.32 ± 5.01

Figure Legends

Figure 1. Experimental Set-Up.

A) **Control for foot stance.** Tape placed at the anterior and lateral aspects of the foot and marked for each individual participant. Foot positioning was self-selected during the warm-up and remained the same throughout the duration of the testing session.

B) **Experimental set-up, lateral view.** Participant in the bottom phase of the squat with band placed around the thighs, EMG connected to the right thigh and rigid bodies placed bilaterally on the foot, shank, thigh, pelvis and thorax and participant in an upright position within the closed squat rack with adjustable safety bars.

C) **Experimental set-up and anatomical reconstruction and Visual 3D model of participant.** Participant during collection, data collection in Vicon, and a post collection biomechanical model in Visual3D.

Figure 2. Normalized EMG of the GME during the concentric phase of the BBS. * denotes a significant difference ($p < 0.05$) between conditions.

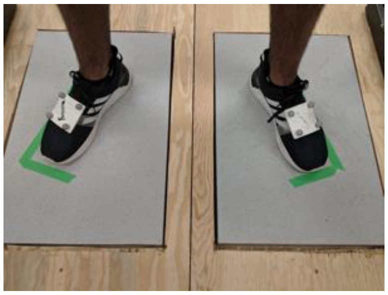
Figure 3. Peak KWI ratio comparison between male and females at maximum knee flexion. # denotes a main effect for sex and * denotes a main effect for band.

Figure 4. Relationship between KWI and relative strength in females during,

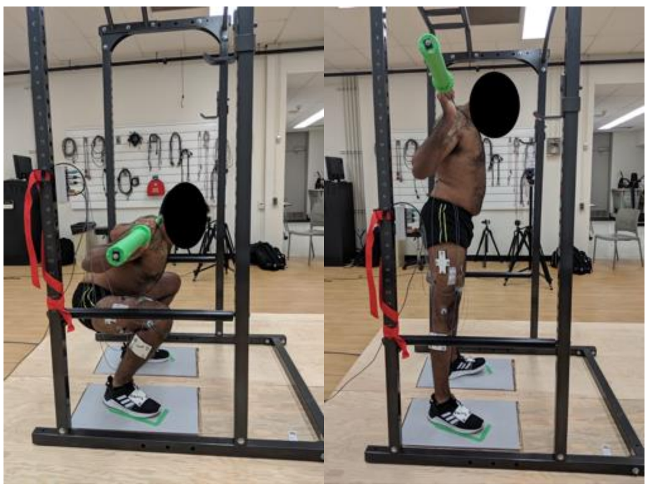
A) Concentric phase of the BBS with the red band

B) Concentric phase of the BBS with the gold band

Figure 1
A)



B)



C)

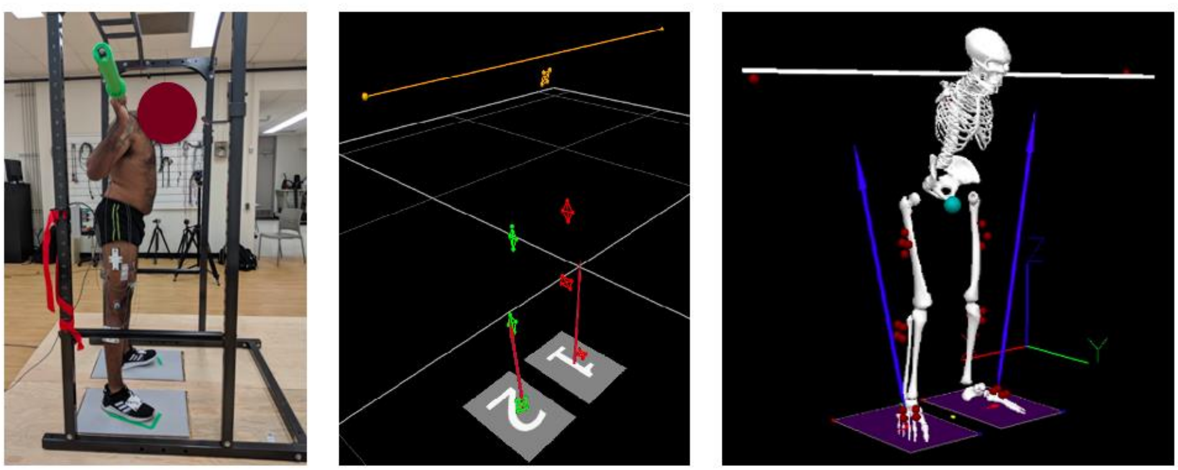


Figure 2

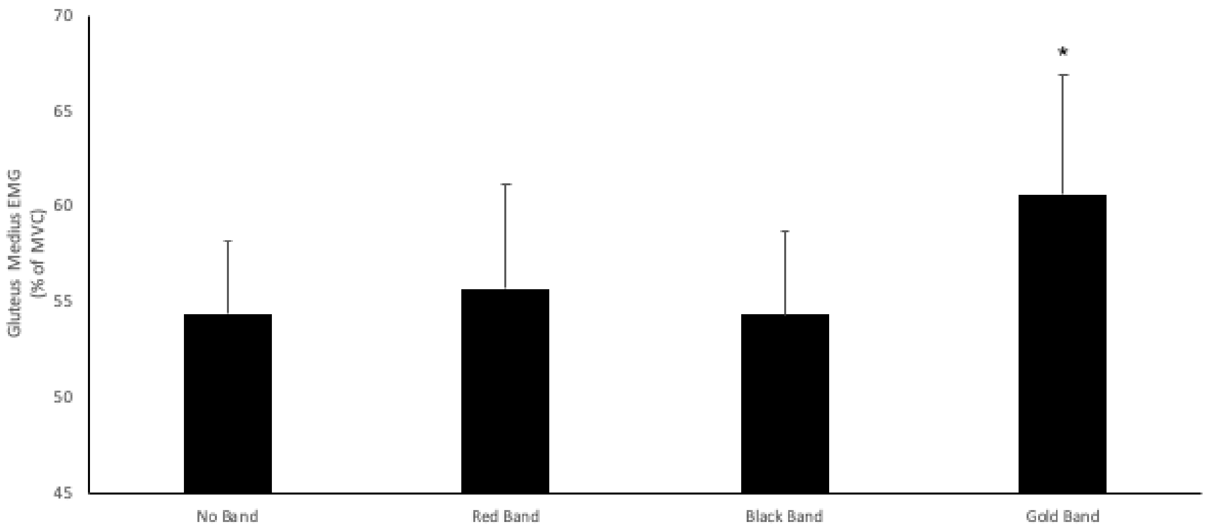
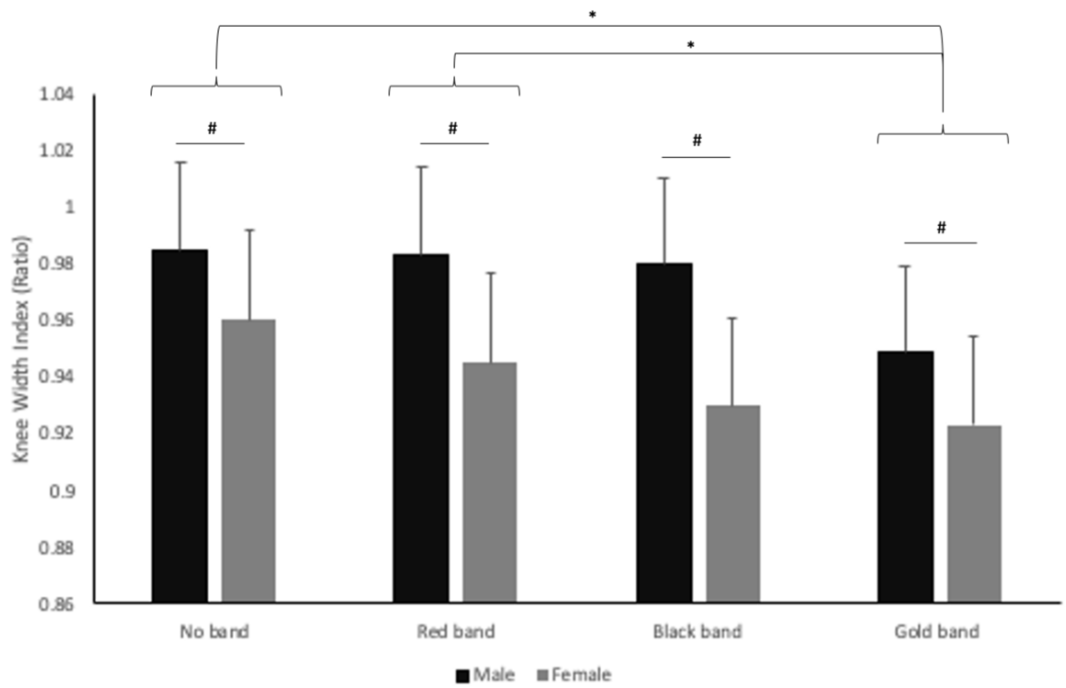

70
65
60
55
50
45
Gluteus Medius EMG
(% of MVC)
*
No Band
Red Band
Black Band
Gold Band

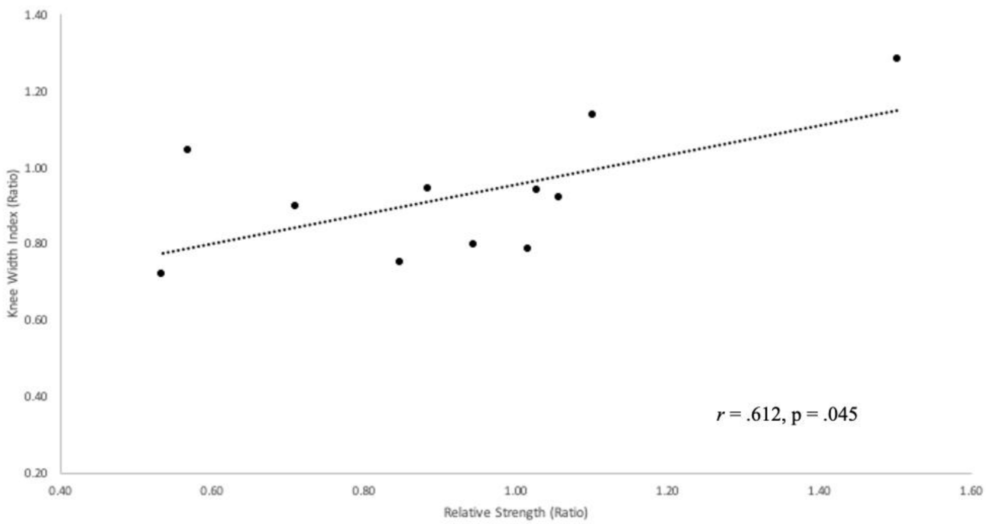
Figure 3



*
*
#
#
#
#
1.04
1.02
1
0.98
0.96
0.94
0.92
0.9
0.88
0.86
Knee Width Index (Ratio)
No band
Red band
Black band
Gold band
Male
Female

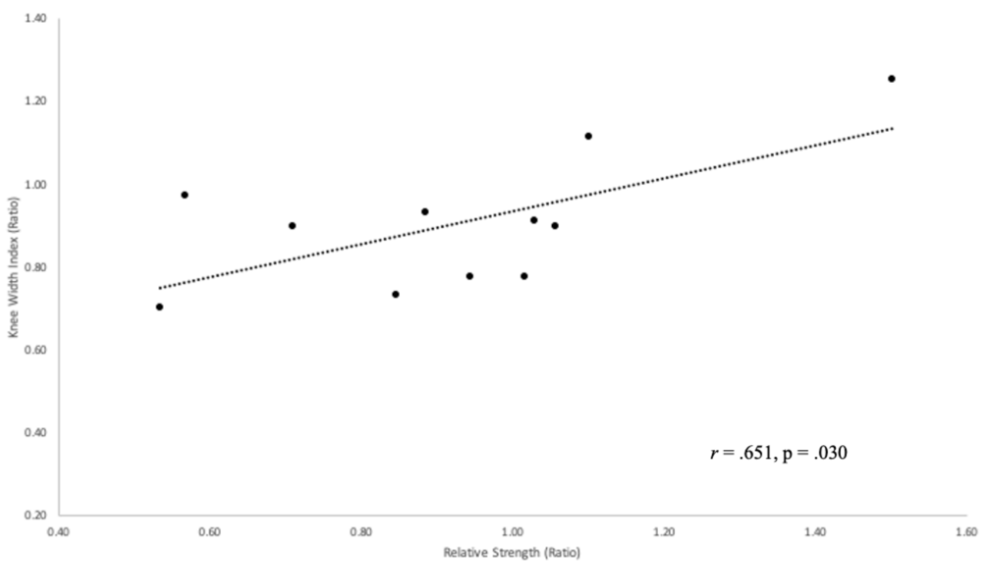
Figure 4

A)



1.40
1.20
1.00
0.80
0.60
0.40
0.20
Knee Width Index (Ratio)
0.40
0.60
0.80
1.00
1.20
1.40
1.60
Relative Strength (Ratio)
r = .612, p = .045

B)



1.40
1.20
1.00
0.80
0.60
0.40
0.20
Knee Width Index (Ratio)
0.40
0.60
0.80
1.00
1.20
1.40
1.60
Relative Strength (Ratio)
r = .651, p = .030

Appendix A: Free and Informed Consent (Memorial University)

Informed Consent Form

Title: A neuromuscular analysis of the barbell back squat and overhead squat in trained individuals using a TheraBand Loop

Researcher: Leah Vardy
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Room PE 2006B
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Co-Supervisor: Dr. Michael Holmes
Department of Kinesiology
Brock University
Email: Michael.holmes@brocku.ca
Phone: 905 688 5550 x4398

You are invited to take part in a research project entitled "*A neuromuscular analysis of the barbell back squat and overhead squat in trained individuals using a TheraBand Loop*"

This form is part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. It also describes your right to withdraw from the study at any time. In order to decide whether you wish to participate in this research study, you should understand enough about its risks and benefits to be able to make an informed decision. This is the informed consent process. Take time to read this carefully and to understand the information given to you. Please contact the researchers, Ms. Leah Vardy or Dr. Michael Holmes, if you have any questions about the study or for more information not included here before you consent.

It is entirely up to you to decide whether to take part in this research. If you choose not to take part in this research or if you decide to withdraw from the research once it has started, there will be no negative consequences for you, now or at any point in the future.

Introduction

This research is being conducted by Ms. Leah Vardy, a Master of Science in Kinesiology student at Memorial University of Newfoundland. As part of my studies, I am conducting research under the supervision of Dr. Duane Button, an associate professor in the School of Human Kinetics and

Recreation at Memorial University of Newfoundland and Dr. Michael Holmes, an assistant professor in the Department of Kinesiology at Brock University.

Purpose of study:

At this time no investigation has been completed which looks at the mechanisms involved which appear to increase the efficiency of the squat. The study hopes to determine these mechanisms and if indeed squatting performance is improved. It is believed, the use of the TheraBand Loop could potentially cause an increase in the activation of the hip musculature, increasing efficiency and range of motion of a trainee's squat. The TheraBand Loop is a lightweight elastic band that can wrap around any body part or surface with varying resistance.

The objectives of this study are to:

1) To determine the difference in muscle activation of the lower back, quadriceps, and hip musculature when conditioned with the TheraBand loop in trained and untrained individuals.
2) To determine the biomechanical difference via kinematic analysis when conditioned with the TheraBand loop in trained individuals.
3) Determine the difference of rate of force development (RDF) and other force discrepancies when conditioned with the TheraBand loop in trained and untrained individuals.

What you will do in this study:

The research study will consist of two testing sessions; 1) Control (~1 hour), and 2) Intervention (~1 hour). There will be at least a period of 48 hours between testing sessions, as this will allocate enough time for you to recover from each bout of exercise. The first occasion will involve familiarizing you with the testing protocol, as well as filling out a simple questionnaire. The experiment will be explained to you, and you will be given the consent form to read. You can ask questions about the study before consenting to taking part. The questionnaire is called the *Physical Activity Readiness Questionnaire for everyone* (*PAR-Q+),* which will assess your physical activity levels.

You will go through the same routine on both testing days.

Upon arriving to the laboratory, you will be prepared for recording muscle activity. This is done using a procedure known as electromyography (EMG). In order to record muscle activity with this technique, small electrodes will be attached to the Quadriceps, Hamstrings and Gluteus musculature. There will be a total of 4 electrodes placed on each muscle. Preparation for the electrode placement will include removal of hair with a razor and the rubbing of an alcohol swab over the shaven skin to clean the surface.

You will then complete a warmup on a stationary bike. The intensity will be low, the exertion will be similar to that of a fast-paced walk.

We will then have to determine the maximum voluntary contraction (MVC) of the 4 muscles. This will mean you will flex and extend the knee and abduct the leg forcefully in order for the researchers to determine the maximum force output of each muscle.

After the prep is complete, you will be asked to complete 2 sets of a 5-repetition goblet squat. The load of the goblet squat will be 10% of the participant's body weight. You will be given verbal and visual feedback as needed when completing the squats to ensure safety and techniques are maintained. You will also be recruited on 2 sessions to complete a 3-repetition max (3RM) and a 100% body weight squat for as many reps as possible. This will be completed using a barbell back squat; other parameters of the above protocol will remain the same. The intervention protocol will follow the same protocol as the control. The intervention itself will be the placement of one resistance band known as the Theraband Loop. This band will be placed around the distal portion of the participants' thighs, ~ 2-3 cm's above the kneecap.

Three-dimensional motion capture will also be assessed. Custom-designed, rigid bodies, consisting of at least three markers will be placed on your foot, lower leg, and thigh so that anatomical landmarks can be digitized.

Withdrawal from the study:
You will be free to withdraw from this study at any time, without explanation. To do so you simply need to inform the researchers and you will be free to leave. Any data collected up to that point will not be used in the study and will be destroyed. In addition, you may request for the removal of your data up to one year later by contacting Leah Vardy at lcv833@mun.ca. If you are a student, your participation in and/or withdrawal from this study will not in any way, now or ever, positively or negatively impact either your grade in a course, performance in a lab, reference letter recommendations and/or thesis evaluation.

You are not eligible to participate in the study:

1. If you have knee and/or back pain/injury
2. If you have a medical condition that prevents you from exercising
3. If you are a student of Dr. Michael Holmes

Possible benefits:

You will not benefit directly from participating in this study. However, the project aims to examine the neuromechanical responses to the squat while using a TheraBand Loop. This information can be used to improve squat performance and if modalities such as the TheraBand loop can be used to increase the efficiency of the squat.

Possible risks:

There are several minor risks associated with participating in this study:

1) You will have electrodes placed on the front and back of your legs and gluteal muscles. These electrodes have an adhesive that has a tendency to leave a red mark on your skin.

This mark is temporary (usually fades within 1-2 days) and is not generally associated with any discomfort or itching.

2) Performing a maximal muscle contraction might lead to slight delayed onset muscle soreness, which is a common occurrence from intense training, it in no way will result in any permanent harm to the muscles.

3) The protocol may seem a little intimidating, and as such, you may experience some nervousness or low-level anxiety. However, each participant will be familiarized to the protocol on Day 1 to ensure they are comfortable with the techniques prior to commencing.

At any time, if you do not wish to take part in the research study you may elect not to participate. If you do experience persistent irritation or discomfort from this study, we recommend that you visit your family doctor or the Campus Wellness Centre.

Confidentiality vs. Anonymity

There is a difference between confidentiality and anonymity: Confidentiality is ensuring that identities of participants are accessible only to those authorized to have access. Anonymity is a result of not disclosing participant's identifying characteristics (such as name or description of physical appearance).

Confidentiality and Storage of Data:

a. Your identity will be guarded by maintaining data in a confidential manner and in protecting anonymity in the presentation of results (see below).

b. All data collected for this study will be kept in a secured location for 5 years, at which time it will be destroyed. Paper based records will be kept in a locked cabinet in the office of Dr. Holmes while computer-based records will be stored on a password protected computer in the office of Dr. Holmes. The only individuals who will access to this data are those directly involved in this study.

c. Data will be retained for a minimum of five years, as per Memorial University policy on Integrity in Scholarly Research after which time it will be destroyed.

d. The data collected as a result of your participation can be withdrawn from the study at your request up until the point at which the results of the study have been accepted for publication (~1 year post study).

Anonymity:

Every reasonable effort will be made to ensure your anonymity in this study. Your participation will not be made known to anyone except researchers who are directly involved in this study. Your identity will not be identified in any reports, conferences or publications without your explicit consent. All data will be represented by a numerical code.

Recording of Data:
There will be no video or audio recordings made during testing.

Reporting of Results:
Results of this study will be reported in written and spoken form (local and national conferences and lectures). Written forms will include my thesis, which will be made accessible to the public following its completion via the QEII Library at Memorial University via http://collections.mun.ca/cdm/search/collection/theses, and will also include a manuscript within a scientific journal. Generally, all results will be presented as group averages. In cases where individual data needs to be communicated it will be done in such a manner that your confidentiality will be protected (i.e. data will be presented as coming from a representative subject).

Sharing of Results with Participants:
Following completion of this study please feel free to ask any specific questions you may have about the activities you were just asked to partake in. Also, if you wish to receive a brief summary of the results then please indicate this when asked at the end of this form.

Questions:
You are welcome to ask questions at any time during your participation in this research. If you would like more information about this study, please contact: Leah Vardy (lcv833@mun.ca) or Dr. Michael Holmes (Michael.holmes@brocku.ca)

The proposal for this research has been reviewed by the Interdisciplinary Committee on Ethics in Human Research and found to be in compliance with Memorial University's ethics policy. If you have ethical concerns about the research (such as the way you have been treated or your rights as a participant), you may contact the Chairperson of the ICEHR at icehr@mun.ca or by telephone at 709-864-2861.

Consent:
Your signature on this form means that:

- You have read the information about the research.
- You have been able to ask questions about this study.
- You are satisfied with the answers to all your questions.
- You understand what the study is about and what you will be doing.
- You understand that you are free to withdraw from the study at any time, without having to give a reason, and that doing so will not affect you now or in the future. If you choose to withdraw, you may request that any data collected from you as the participant be removed from consideration up to 1-year following your participation.
- You understand that if you choose to end participation during data collection, any data collected up until that point will be destroyed.

If you sign this form, you do not give up your legal rights and do not release the researchers from their professional responsibilities.

Your signature: I have read what this study is about and understood the risks and benefits. I have had adequate time to think about this and had the opportunity to ask questions and my questions have been answered.

☐ I agree to participate in the research project understanding the risks and contributions of my participation, that my participation is voluntary, and that I may end my participation.

A copy of this Informed Consent Form has been given to me for my records.

__________________________________ ______________________________

Signature of participant Date

Researcher's Signature:
I have explained this study to the best of my ability. I invited questions and gave answers. I believe that the participant fully understands what is involved in being in the study, any potential risks of the study and that he or she has freely chosen to be in the study.

__________________________________ ______________________________

Signature of Principal Investigator Date

Upon the completion of this study, would you like a brief summary of its results? (Circle Answer)

Yes No

Appendix B: Free and Informed Consent (Brock University)

Michael W.R. Holmes, PhD
Canada Research Chair in Neuromuscular Mechanics and Ergonomics
Assistant Professor
Brock University | Department of Kinesiology
Niagara Region | 1812 Sir Isaac Brock Way | St. Catharines, ON L2S 3A1
brocku.ca | Phone: 905 688 5550 x4398 | Fax: 905 984 4851
Email: michael.holmes@brocku.ca

Date: **March 20, 2019**
Project Title: **A neuromuscular analysis of the barbell back squat and overhead squat in trained individuals using a TheraBand Loop**

Researcher: Leah Vardy
Human Neurophysiology Lab
Room PE 1008
Email: lcv833@mun.ca

Supervisor: Dr. Duane Button
School of Human Kinetics and Recreation
Room PE 2006B
Email: dbutton@mun.ca
Phone: 864-4886

Co-Supervisor: Dr. Michael Holmes
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Principal Student Investigators:
Garrick Forman, PhD Student
Department of Kinesiology
Brock University
gf16sq@brocku.ca

Rob Kumar, MSc. Student
Department of Kinesiology
Brock University
rk12rg@brocku.ca

INVITATION
This form is part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. It also describes your right to withdraw

from the study at any time. In order to decide whether you wish to participate in this research study, you should understand enough about its risks and benefits to be able to make an informed decision. This is the informed consent process. Take time to read this carefully and to understand the information given to you. Please contact the researchers, Ms. Leah Vardy or Dr. Michael Holmes, if you have any questions about the study or for more information not included here before you consent.

It is entirely up to you to decide whether to take part in this research. If you choose not to take part in this research or if you decide to withdraw from the research once it has started, there will be no negative consequences for you, now or at any point in the future.

This research is being conducted by Ms. Leah Vardy, a Master of Science in Kinesiology student at Memorial University of Newfoundland. As part of my studies, I am conducting research under the supervision of Dr. Duane Button, an associate professor in the School of Human Kinetics and Recreation at Memorial University of Newfoundland and Dr. Michael Holmes, an assistant professor in the Department of Kinesiology at Brock University.

WHAT'S INVOLVED

At this time no investigation has been completed which looks at the mechanisms involved which appear to increase the efficiency of the squat. The study hopes to determine these mechanisms and if indeed squatting performance is improved. It is believed, the use of the TheraBand Loop could potentially cause an increase in the activation of the hip musculature, increasing efficiency and range of motion of a trainee's squat. The TheraBand Loop is a lightweight elastic band that can wrap around any body part or surface with varying resistance.

The objectives of this study are to:

1. To determine the difference in muscle activation of the lower back, quadriceps, and hip musculature when conditioned with the TheraBand loop in trained and untrained individuals.
2. To determine the biomechanical difference via kinematic analysis when conditioned with the TheraBand loop in trained individuals.
3. Determine the difference of rate of force development (RDF) and other force discrepancies when conditioned with the TheraBand loop in trained and untrained individuals.

What you will do in this study:

The research study will consist of two testing sessions; 1) Control (~1 hour), and 2) Intervention (~1 hour). There will be at least a period of 48 hours between testing sessions, as this will allocate enough time for you to recover from each bout of exercise. The first occasion will involve familiarizing you with the testing protocol, as well as filling out a simple questionnaire. The experiment will be explained to you, and you will be given the consent form to read. You can ask questions about the study before consenting to taking part. The questionnaire is called the Physical Activity Readiness Questionnaire for everyone (PAR-Q+), which will assess your physical activity levels.

You will go through the same routine on both testing days.

Upon arriving to the laboratory, you will be prepared for recording muscle activity. This is done using a procedure known as electromyography (EMG). In order to record muscle activity with this technique, small electrodes will be attached to the Quadriceps, Hamstrings and Gluteus musculature. There will be a total of 4 electrodes placed on each muscle. Preparation for the electrode placement will include removal of hair with a razor and the rubbing of an alcohol swab over the shaven skin to clean the surface.

You will then complete a warm up on a stationary bike. The intensity will be low, the exertion will be similar to that of a fast-paced walk.

We will then have to determine the maximum voluntary contraction (MVC) of the 4 muscles. This will mean you will flex and extend the knee and abduct the leg forcefully in order for the researchers to determine the maximum force output of each muscle.

After the prep is complete, you will be asked to complete 2 sets of a 5-repetition goblet squat. The load of the goblet squat will be 10% of the participant's body weight. You will be given verbal and visual feedback as needed when completing the squats to ensure safety and techniques are maintained. You will also be recruited on 2 sessions to complete a 3-repetition max (3RM) and a 100% body weight squat for as many reps as possible. This will be completed using a barbell back squat; other parameters of the above protocol will remain the same. The intervention protocol will follow the same protocol as the control. The intervention itself will be the placement of one resistance band known as the Theraband Loop. This band will be placed around the distal portion of the participants' thighs, ~ 2-3 cm's above the kneecap.

Three-dimensional motion capture will also be assessed. Custom-designed, rigid bodies, consisting of at least three markers will be placed on your foot, lower leg, and thigh so that anatomical landmarks can be digitized.

ELIGIBILITY

Males and females are eligible to participate (age range, 17-55 years). We are seeking individuals who have not had lower extremity pain or injury in the past 12 months. If you have any history of chronic pain or neurological impairment we will discuss eligibility with you. Any neurological disorders or chronic injuries reported warrant exclusion from participation in this study.

You are not eligible to participate in the study:

1. If you have knee and/or back pain/injury
2. If you have a medical condition that prevents you from exercising
3. If you are currently enrolled as an undergraduate student in Dr. Michael Holmes class

Timeline: Including instrumentation and experimental setup, it is expected that you will be in the biomechanics laboratory for approximately 3 hours over 2 sessions.

POTENTIAL BENEFITS AND RISKS

You will not benefit directly from participating in this study. However, the project aims to examine the neuromechanical responses to the squat while using a TheraBand Loop. This information can be used to improve squat performance and if modalities such as the TheraBand loop can be used to increase the efficiency of the squat.

There are several minor risks associated with participating in this study:

1. You will have electrodes placed on the front and back of your legs and gluteal muscles. These electrodes have an adhesive that has a tendency to leave a red mark on your skin. This mark is temporary (usually fades within 1-2 days) and is not generally associated with any discomfort or itching.
2. Performing a maximal muscle contraction might lead to slight delayed onset muscle soreness, which is a common occurrence from intense training, it in no way will result in any permanent harm to the muscles.
3. The protocol may seem a little intimidating, and as such, you may experience some nervousness or low-level anxiety. However, each participant will be familiarized to the protocol on Day 1 to ensure they are comfortable with the techniques prior to commencing.

At any time, if you do not wish to take part in the research study you may elect not to participate. If you do experience persistent irritation or discomfort from this study, we recommend that you visit your family doctor or the Campus Wellness Centre.

CONFIDENTIALITY

There is a difference between confidentiality and anonymity: Confidentiality is ensuring that identities of participants are accessible only to those authorized to have access. Anonymity is a result of not disclosing participant's identifying characteristics (such as name or description of physical appearance).

Confidentiality and Storage of Data:

A. Your identity will be guarded by maintaining data in a confidential manner and in protecting anonymity in the presentation of results (see below).
B. All data collected for this study will be kept in a secured location for 5 years, at which time it will be destroyed. Paper based records will be kept in a locked cabinet in the office of Dr. Holmes while computer-based records will be stored on a password protected computer in the office of Dr. Holmes. The only individuals who will access to this data are those directly involved in this study.
C. Data will be retained for a minimum of five years, as per Memorial University policy on Integrity in Scholarly Research after which time it will be destroyed.
D. The data collected as a result of your participation can be withdrawn from the study at your request up until the point at which the results of the study have been accepted for publication (~1 year post study).

Anonymity:

Every reasonable effort will be made to ensure your anonymity in this study. Your participation will not be made known to anyone except researchers who are directly involved in this study. Your identity will not be identified in any reports, conferences or publications without your explicit consent. All data will be represented by a numerical code.

Recording of Data:
There will be no video or audio recordings made during testing.

VOLUNTARY PARTICIPATION
Participation in this study is voluntary. If you wish, you may decline to answer any questions or participate in any component of the study. Further, you may decide to withdraw from this study at any time and may do so without any penalty or loss of benefits to which you are entitled. If you are a Brock student, withdrawing from the study will in no way affect your academic standing. If you wish to withdraw during a study, simply tell the investigator that you no longer wish to participate. Participation, non-participation, or withdrawal from the study will not affect one's standing at Brock University. If you are a student of the PI, recruitment will be handled by a third-party individual to avoid real or perceived coercion that you may feel.

PUBLICATION OF RESULTS
Results of this study may be published in academic journals and presented at conferences. Any images and videos we release publicly will remain confidential by blurring out any identifying factors of any of the participants involved. This includes the blurring of participants faces. Feedback about this study will be available to you by contacting Dr. Holmes at the address at the top of the form. Results should be made available approximately 6 months after your completion of the study. The results will be group data about the main findings of the study. If you wish to know more about individual data, we can arrange to meet.

Reporting of Results:
Results of this study will be reported in written and spoken form (local and national conferences and lectures). Written forms will include my thesis, which will be made accessible to the public following its completion via the QEII Library at Memorial University via http://collections.mun.ca/cdm/search/collection/theses, and will also include a manuscript within a scientific journal. Generally, all results will be presented as group averages. In cases where individual data needs to be communicated it will be done in such a manner that your confidentiality will be protected (i.e. data will be presented as coming from a representative subject).

Sharing of Results with Participants:
Following completion of this study please feel free to ask any specific questions you may have about the activities you were just asked to partake in. Also, if you wish to receive a brief summary of the results then please indicate this when asked at the end of this form.

CONTACT INFORMATION AND ETHICS CLEARANCE
If you have any questions about this study or require further information, please contact Dr. Holmes using the contact information provided above. This study has been reviewed and received ethics clearance through the Research Ethics Board at Brock University (file # 18-265). If you have any comments or concerns about your rights as a research participant, please contact the Research Ethics Office at (905) 688-5550 Ext. 3035, reb@brocku.ca.

You are welcome to ask questions at any time during your participation in this research. If you would like more information about this study, please contact: Leah Vardy (lcv833@mun.ca) or Dr. Michael Holmes (Michael.holmes@brocku.ca).

The proposal for this research has also been reviewed by the Interdisciplinary Committee on Ethics in Human Research and found to be in compliance with Memorial University's ethics policy. If you have ethical concerns about the research (such as the way you have been treated or your rights as a participant), you may contact the Chairperson of the ICEHR at icehr@mun.ca or by telephone at 709-864-2861.

Thank you for your assistance in this project. Please keep a copy of this form for your records.

In signing this consent form, you should understand that:

- You may ask questions at any given time during participation;
- Your participation is voluntary and that refusal to participate will involve no penalty, or loss of benefits to which you are otherwise entitled;
- You can refuse participation at any time during the experiment, and any data collected will not be included in the results of the experiment (unless otherwise stated);
- The researcher might be known to you; however, your identity will be protected by a participant coding system and a secure filing system;
- You will be assigned a code number, and your name will not be associated with the questionnaire or computer collected data;

CONSENT FORM

I agree to participate in this study described above. I have made this decision based on the information I have read in the Information-Consent Letter. I have had the opportunity to receive any additional details I wanted about the study and understand that I may ask questions in the future. I understand that I may withdraw this consent at any time.

____________________	____________________
Name	Date
____________________	
Signature	
____________________	____________________
Witness Name	Date
____________________	
Witness Signature	

Appendix C: Ethics Clearance (Memorial University)

MEMORIAL UNIVERSITY

St. John's, NL Canada A1C 5S7
Tel: 709 864-2561 icehr@mun.ca
www.mun.ca/research/ethics/humans/icehr

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these changes for the Committee's consideration

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Appendix D: Ethics Clearance (Brock University)

Brock University
Research Ethics Office
Tel: 905-688-5550 ext. 3035
Email: reb@brocku.ca

Bioscience Research Ethics Board

Certificate of Ethics Clearance for Human Participant Research

DATE: March 6, 2019 3/26/2019

PRINCIPAL INVESTIGATOR: HOLMES, Michael - Kinesiology

FILE: 18-265 - HOLMES

TYPE: Masters Thesis/Project STUDENT: Leah Vardy
SUPERVISOR: Duane Button

TITLE: A neuromuscular analysis of the barbell back squat and overhead squat in trained individuals using a TheraBand Loop

ETHICS CLEARANCE GRANTED

Type of Clearance: NEW Expiry Date: 3/1/2020

The Brock University Bioscience Research Ethics Board has reviewed the above named research proposal and considers the procedures, as described by the applicant, to conform to the University's ethical standards and the Tri-Council Policy Statement. Clearance granted from **3/26/2019** to **3/1/2020**.

The Tri-Council Policy Statement requires that ongoing research be monitored by, at a minimum, an annual report. Should your project extend beyond the expiry date, you are required to submit a Renewal form before 3/1/2020. Continued clearance is contingent on timely submission of reports.

To comply with the Tri-Council Policy Statement, you must also submit a final report upon completion of your project. All report forms can be found on the Research Ethics web page at http://www.brocku.ca/research/policies-and-forms/research-forms.

In addition, throughout your research, you must report promptly to the REB:

a) Changes increasing the risk to the participant(s) and/or affecting significantly the conduct of the study;
b) All adverse and/or unanticipated experiences or events that may have real or potential unfavourable implications for participants;
c) New information that may adversely affect the safety of the participants or the conduct of the study;
d) Any changes in your source of funding or new funding to a previously unfunded project.

We wish you success with your research.

Approved: Craig Tokuno

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Craig Tokuno, Chair
Bioscience Research Ethics Board

Note: Brock University is accountable for the research carried out in its own jurisdiction or under its auspices and may refuse certain research even though the REB has found it ethically acceptable.

If research participants are in the care of a health facility, at a school, or other institution or community organization, it is the responsibility of the Principal Investigator to ensure that the ethical guidelines and clearance of those facilities or institutions are obtained and filed with the REB prior to the initiation of research at that site.