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Muscle Excitation of the Lower Extremity During a Single Leg Rotational Squat in Individuals With and Without a Previous Hamstrings Strain Injury

Claudia M. Simpson
Georgia Southern University

Muscle Excitation of the Lower Extremity During a Single Leg Rotational Squat in Individuals With and Without a Previous Hamstrings Strain Injury

An Honors Thesis submitted in partial fulfillment of the requirements for Honors in Health Sciences and Kinesiology

By Claudia Simpson

Under the Mentorship of Dr. Jessica Mutchler

ABSTRACT

The hamstrings muscles work with quadriceps and gluteal muscles to stabilize the hip and knee during multidirectional movements. The purpose of this study was to determine muscle excitation patterns of the lower extremity during a single leg rotational squat (SLRS) in individuals with and without a previous hamstrings injury. Twenty physically active individuals between 19-23 years old participated in the study, ten with previous injury and ten without. The Hamstring Outcome Score was used to assess participants' perceived physical abilities (Hamstring=89.37+7.2%, Control=96.75+2.83%; $p=0.011$). Participants completed five trials of a SLRS moving through four phases to a 72bpm metronome and reaching to maximum excursion. Wireless electromyography (EMG) was collected on the hamstrings, quadriceps, and gluteal muscles. Mean EMG of each muscle was normalized and reported as %EMG. Between group differences were assessed using one-way ANOVAs for each muscle by phase. Limb differences for the hamstring group were assessed using paired samples t-tests. Significance was set at $p<0.05$. No statistically significant differences were observed between groups ($P>0.05$). A statistical difference was observed within group for the biceps femoris during the down phase ($P=0.023$). The results suggest that individuals with a previous injury perceive a physical deficit, but muscle excitation patterns are similar to their healthy counterpart when performing a SLRS that requires strength and stability. Individuals with previous injury exhibit greater muscle excitation in the biceps femoris of the previously injured limb when moving into a squat position compared to the non-injured leg.

Thesis Mentor:_________________________

Dr. Jessica Mutchler

Honors Director:_________________________

Dr. Steven Engel

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CHAPTER I

INTRODUCTION

The hamstrings’ primary action occurs in the sagittal plane and are also responsible for controlling knee valgus and varus moments (Struminger, et al., 2013). The ratio of the hamstrings muscle strength to the quadriceps muscle strength is a risk factor for lower extremity injury since both muscles are active at the knee (Yamazaki, et al., 2009). Co-activation of muscles around the knee joint assist in maintaining stability and balance, but unbalanced activation may excessively activate the range of the knee joint leading to collapse (Park, Shim, & Choi, 2017). Quadriceps dominant activation increases anterior translation of the tibia magnifying ACL loading, but balanced hamstrings co-activation provides dynamic joint stabilization protecting the knee during sports related tasks (Begalle, et al., 2012). Quadriceps to hamstrings (Q:H) co-activation plays an important role during sagittal, frontal, transverse, and multiplanar movements at the knee to properly reduce the load on the ACL (Begalle, Distefano, Blackburn, & Padua, 2012; Harput, Soylu, Ertan, Ergun, & Mattacola, 2014).

Within sport and recreation activity, a hamstrings strain injury (HSI) is the most prevalent soft tissue injury and has continued to be for decades (Lobacz, Glutting, & Kaminski, 2016). Hamstrings strains occur during demands of rapid knee extension such as sprinting and jumping, and/or demands for maximal lengthening of the muscles as seen in martial arts and dance (Jean-Louis, 2014). The semitendinosus muscle is involved when the mechanism is of the stretching nature, whereas the biceps femoris is more often injured during high-speed activities (Lobacz, et al., 2016). Sex, age, and level of play also have effects on the risk of HSI (Engebretsen, Myklebust, Holme, Engebretsen, & Bahr, (2008). A previous injury is shown to reduce proper joint function, stability, and control due to scar tissue, weakness, and a subtle difference to the length-tension relationship (Engebretsen, et al., (2008). As a result, previous injury alters lower extremity muscle contribution (Shanbehzadeh, et al., 2014). Despite the best prevention and rehabilitation programs hamstrings strain injuries still occur, and have a high re-injury rate ranging from 12-34% (Lobacz, Glutting, & Kaminski, 2016; Schmitt, Tyler, & McHugh, 2012). A preventative examination of lower extremity alignment can be done with a single leg squat (SLS) serving as a tool to identify improper movement patterns at the trunk, pelvis, knee, and ankle (Khuu, et al., 2016).

The purpose of this study was to determine if differences in lower extremity muscle excitation are present in individuals with a previous hamstrings injury, as compared bilaterally and to a matched control, when performing a single leg rotational squat. Our hypothesis was that the previously injured limb will have different muscle excitation patterns compared to the matched control, and the uninjured limb when performing a single leg rotational squat.

CHAPTER II
REVIEW OF LITERATURE

Epidemiology

Within sport and recreation activity, a hamstrings strain injury (HSI) is the most prevalent soft tissue injury and have continued to be for decades (Lobacz, Glutting, & Kaminski, 2016). Hamstrings strains occur during demands of rapid knee extension such as sprinting and jumping, and/or demands for maximal lengthening of the muscles as seen in martial arts and dance (Jean-Louis, 2014). These activities share the passive stretch or eccentric action required to decelerate (Jean-Louis, 2014). Typically, HSI affects the muscle tendon proximally and/or the biceps femoris laterally (Jean-Louis, 2014). The semitendinosus muscle is involved when the mechanism is of the stretching nature, whereas the biceps femoris is affected during high-speeds (Lobacz, et al., 2016). Mendiguchia, Alentorn-Geli, & Brughelli, (2011), found an association between the psoas of the contralateral leg and hamstrings length with the psoas muscle having a greater influence on hamstrings length. Other research suggests that age, sex, and level of play have effects on the risk of hamstrings strain (Engebretsen, Myklebust, Holme, Engebretsen, & Bahr, 2008).

Moreover, hamstrings show the behavior of appearing sensitive to delayed onset muscle soreness (DOMS) after loads of eccentric exercise yet having a high rate of relapse after an initial strain (Jean-Louis, 2014). Most non-contact injuries to the lower extremity involve multiple factors; however, spontaneous movement patterns and inadequate neuromuscular control are contributing factors to injury (Khuu, Foch, & Lewis, 2016). A previous injury is shown to reduce proper joint function, stability, and control due to scar tissue, weakness, and a subtle difference to the length-tension relationship (Engebretsen, et al., 2008). As a result, previous injury alters lower extremity muscle contribution (Shanbehzadeh, et al., 2014). HSI recovery time is long when the musculoteninous junction or muscle belly is involved and becomes even longer if the biceps femoris disturbs the central tendon (Lobacz, et al., 2016). Yet, reinjury, at rates of 12-34%, result in longer recovery times than the initial injury due more severe symptoms (Lobacz, et al., 2016). Compared to other risk factors such as decreased flexibility, fatigue, muscular deficits, lumbar posture, or core stability, previous HSI increases the reinjury rate two to six times. A preventative examination of lower extremity alignment can be done with a single leg squat (SLS) serving as a tool to identify improper movement patterns at the trunk, pelvis, knee, and ankle (Khuu, et al., 2016).

Muscle Excitation Patterns of the Lower Extremity

The hamstrings' primary action occurs in the sagittal plane and are responsible for controlling knee valgus and varus motions (Struminger, et al., 2013). Muscle co-activation is when muscles around a joint act simultaneously and proper muscle co-activation is important for joint stability and efficiency of movement (Harput, Soylu, Ertan, Ergun, & Mattacola, 2014). The ratio of the hamstrings muscle strength to the quadriceps muscle strength is a risk factor for lower extremity injury since both muscles are active at the hip and knee (Yamazaki, et al., 2009). The hamstrings function synergistically with the ACL to prevent anterior translation of the tibia which is caused when the quadriceps contract (Begalle, Distefano, Blackburn, & Padua, 2012). Co-activation of muscles around the knee joint assist in maintaining stability and balance during medial, lateral and anterior, and posterior activation, but unbalanced co-activation may excessively activate the range of the knee joint leading to collapse (Park, Shim, & Choi, 2017). Quadriceps dominant activation increases shear forces anteriorly magnifying ACL loading but balanced hamstrings co-activation provides dynamic joint stabilization protecting the knee during sports related tasks (Begalle, et al., 2012). Decreased hamstrings activation compared to quadriceps poses a potential mechanism for lower extremity injury (Begalle, et al., 2012). Quadriceps to hamstrings (Q:H) co-activation plays an important role during sagittal, frontal, transverse, and multiplanar movements at the knee to properly place the load on the ACL (Begalle, Distefano, Blackburn, & Padua, 2012; Harput, Soylu, Ertan, Ergun, & Mattacola, 2014). Unbalanced co-activation between quadriceps and hamstrings is one of the potential factors that places female athletes at risk for lower extremity injury specifically ACL (Harput, et al., 2014). Quadriceps activation for females is dominant during SLS, running, and jumping compared to males (Harput, et al., 2014). Females activate the lateral quadriceps and hamstrings more than the medial during squat and landing from a jump which increases knee valgus (Harput, et al., 2014). The lateral hamstrings and medial gastrocnemius are activated when the tibia is rotated laterally, whereas the medial hamstrings and lateral gastrocnemius are activated with medial tibia rotation (Park, et al., 2017). Stepping and cutting performed in the frontal plane rather than the sagittal require greater activation from the medial hamstrings and gluteal muscles (Struminger, et al., 2013). Hamstrings activation specifically on the medial side plays a role in limiting knee valgus motion during static and dynamic tasks by controlling the motions of the knee in the frontal plane (Struminger, et al., 2013). High activation of the medial hamstrings may limit knee valgus and ACL loading whereas, high levels of lateral hamstrings activation may reduce anterior tibial translation as well as ACL loading (Struminger, et al., 2013).

Muscles of the hip stabilize the pelvis during weight bearing activities specifically activities involving a forward lean with internal or external rotation of the hip (Webster & Gribble, 2013). If there is dysfunction of the hip due to structural abnormality and/or muscle weakness, maintaining stability especially with an ACL deficiency becomes more difficult due to the multidirectional capabilities of the hip joint (Yamazaki, Muneta, Ju, & Sekiya, 2009). Poor control of hip muscles can lead to improper foot placement predisposing to lower extremity injury (Webster & Gribble, 2013). Moreover, individuals with low back pain, ACL deficiency, pelvic pain, or previous hamstrings injury show increased hamstrings activity while walking specifically when changing from double to single leg stance (Sole, Milosavljevic, & Sullivan, 2012). Altered biomechanics following injury to the lower extremity increase the risk HSI (Sole, et al., 2012). The hamstrings active earlier when going from double leg to single leg stance if previously injured which is indicative of changed proprioception and neuromuscular control after injury (Sole, et al., 2012). Earlier or greater activation of the medial hamstrings during preparatory and loading phases of landing results in less knee valgus motion (Struminger, et al., 2013).

Rehabilitation Protocols

During the acute stage, focus should be placed on protecting the HSI and minimizing range of motion (ROM) and strength deficits (Schmitt, Tyler, & McHugh, 2012). Mild immobilization may be beneficial during this stage to limit muscle proliferation and the creation of lesions (Lobacz, et al., 2016). 48 hours after injury, isometric strengthening at multiple angles can begin to properly align scar tissue (Schmitt, et al., 2012). Once gait is normalized and knee flexion strength at 90 degrees is above 50% compared to the uninjured leg, the next phase can begin (Schmitt, et al., 2012).

In the next phase, strengthening and neuromuscular control are the focus to prepare the hamstrings for sport specific movements (Schmitt, et al., 2012). Concentric and eccentric training can begin at the same time (Schmitt, et al., 2012). Eccentric strengthening is the most promising method to prevent and rehabilitate HSIs (Lobacz, et al., 2016). Elongating the hamstrings muscles with hip flexion are more beneficial to decrease recovery time (Lobacz, et al., 2016). Eccentric training of the hamstrings muscles allows for increased strength with lengthening because there is an adaptive increase in sarcomeres in series (Lobacz, et al., 2016). Therefore, peak torque can occur with a smaller angle of knee flexion, which is a longer muscle length (Lobacz, et al., 2016). Examples of eccentric training include but are not limited to; straight leg deadlift, SLS, and Nordic hamstrings curl (Khuu, Foch, & Lewis, 2016; Schmitt, Tyler, & McHugh, 2012). Muscle activation and demand must be considered in the rehabilitation protocol of a hamstrings strain to promote balanced activation with activity. Before moving onto the next phase, manual muscle testing must be graded 5/5 and jog both forward and backward at a moderate pace with no pain (Schmitt, et al., 2012).

Research has found that the most balanced Q:H co-activation is obtained during a single-leg dead lift (Schmitt, et al., 2012). During the exercise, there is more hamstrings activation than quadriceps activation when compared to other exercises (Begalle, et al., 2012). As for the SLS, it is generally performed by standing on one leg, squatting down to a certain degree or end range of motion, and returning to the initial position (Khuu, Foch, & Lewis, 2016). However, the neuromuscular system can be taxed differently depending on where the non-stance leg is placed Khuu, Foch, & Lewis, 2016). The non-stance leg back is the most taxing for the hamstrings by allowing for greater hip flexion Khuu, Foch, & Lewis, 2016). The SLS can be found in a variety of daily activities and sports specific movements and should be used to examine the lower extremity kinetic chain (Shanbehzadeh, et al., 2014). Q:H muscle co-activation is greater in females than males during the SLS; however, it is imbalanced with the quadriceps being the dominantly activated (Harput, et al., 2014).

In the final phase, sports specific movements and eccentric strengthening in lengthened positions is emphasized (Schmitt, et al., 2012). Plyometrics in addition to sport specific training and advanced balance exercises should begin in this phase (Schmitt, et al., 2012). Lateral and transverse hop-to-balance, as well as lateral band walk exercises effectively promote balanced Q:H co-activation (Begalle, et al., 2012). Balances exercises increase quadriceps and hamstrings muscle strength to improve performance during activities of daily living and benefit neuromuscular reeducation during motion in the frontal plane (Begalle, et al., 2012; Park, et al., 2017). Progressive agility and trunk stabilization programs have been proven to decrease re-injury rate in the first two weeks and one year after return to play (RTP) (Lobacz, et al., 2016). In elite soccer plays, balance training through double and single leg exercises has been observed to prevent HSIs (Lobacz, et al., 2016). Full strength through end range of motion and no limitations with sport specific tasks should be acquired before return to play.

The use of closed kinetic chain (CKC) exercise facilitates co-activation of the leg muscles during stance and movement to stabilize the knee (Begalle, et al., 2012). However, not all CKC exercises elicit the most balance quadriceps to hamstrings (Q:H) co-activation. For instance, a standing squat exercise has a greater amount of hamstrings activation compared to the minimal hamstrings activation required during a seated leg press (Begalle, et al., 2012). On the other hand, open kinetic chain (OKC) exercises facilitate isolated strengthening of select muscle groups (Harput, et al., 2014). Compared to stretching and isolated hamstrings strengthening, recovery time can also be shortened by treating the nervous system (Lobacz, et al., 2016). This can be done through slump stretching, tensioners and sliders to free the nerves from the surrounding soft tissue (Lobacz, et al., 2016).

CHAPTER III

METHODOLOGY

Participants

Participants included two groups of ten recreationally active individuals, those with and those without a history of hamstrings injury (Hamstring: 6 males, 4 females; age = 21.8 ± 1.23 years, ht = 1.77 ± 0.07 m, mass = 78.32 ± 11.44 kg; Control: 6 males, 4 females; age = 22.30 ± 1.70 years, ht = 1.78 ± 0.082 m, mass = 78.35 ± 12.79 kg). All participants participated in physical activity for a minimum of 30 minutes, 3 times per week, and were matched based on sex, age, height, mass and type of preferred activity (running, weightlifting, etc). Participants were included in the hamstrings group if they suffered a hamstrings injury resulting in a limitation of their activities of daily living and/or physical activity. Participants in the hamstrings injury group were excluded if they had a history of complete hamstrings muscle disruption (grade III) or avulsion based on the severity of the muscle injury established by the classification of the National Athletic Injury Reporting System (NAIR), had any lower extremity injury including a hamstrings strain within the past four months, lower extremity surgery, lower extremity nerve entrapment, lower extremity or back pain with the protocol. Participants in the control group were excluded if they had a lower extremity injury at the time of testing, injury within 4 months prior to testing and/or surgery of the lower extremity.

Prior to being considered as a participant for this study all volunteers were given and signed an informed consent form.. The participants were informed of their right to refuse to participate in this study or to pull out at any time. Should the participant choose to withdraw, that decision would not adversely affect the relationship with this institution or cause loss of benefits to which the participant may be otherwise entitled.

Procedures

The screening process occurred on the first day the participant presents for the experiment. The screening process incorporated questions involving the individual's history of hamstrings strain and other previous or current injuries. Upon arrival, participants were asked to complete the Oslo Sports Trauma Hamstrings Injury Screening Questionnaire (HaOS) to confirm their placement in the hamstrings group or the control group. These groups were determined to be grouped appropriately given the difference in HaOS (Hamstring=89.37+7.2%, Control=96.75+2.83%; $p=0.011$). Once eligibility was confirmed, they were asked several demographic questions and their height and weight were taken along with their lower leg and arm length length..

Participants started the test session by performing self-guided stretches of the major hip muscle groups (quadriceps, hamstrings, adductors and external rotators). If they did not know appropriate stretches for these muscle groups, the examiner demonstrated appropriate stretches. Stretches were followed by a 5-minute warm-up of brisk walking on a treadmill.

After warming up, reflective markers and surface electrodes were placed on the participants. Electromyography (EMG) surface electrodes were placed on the rectus femoris (RF), vastus medialis oblique (VMO), biceps femoris(BF), semitendinosus (MH), gluteus medius (GMed), and gluteus maximus (GMax) of both limbs. Cluster and single reflective markers were placed bilaterally on the anterior and posterior superior iliac spines, lateral aspect of the thighs, lateral femoral epicondyles, lateral aspects of the shanks, lateral malleoli, calcanea, and second metatarsal heads. All participants performed the protocol in spandex and standard shoes supplied by the lab. The kinematic data was captured through eight high speed cameras at a sampling frequency of 200Hz. EMG data was captured at a sampling frequency of 2000Hz.

The single-leg rotational squat set-up (Figure 1) was done based on the study by Webster and Gribble (2013). The height from the floor to the participant's lateral femoral condyle determined the height of the excursion marker. The participant's arm length, acromion to distal third phalanx, determined the distance between the pole and the participant. This distance and height were determined to be a comfortable, yet challenging placement and considered "maximum excursion" for this exercise (Webster & Gribble, 2013). The participants were allowed to practice the single leg rotational squat on each limb a maximum of six times. This task familiarization was to ensure more natural biomechanics during the test trials. For the test trials, all participants performed five successful trials of a single leg rotational squat per limb starting with the dominant limb. In 4 beats of a metronome set to 72bpm, each participant was instructed to squat on the involved limb, rotate to reach the marker, return to straight-ahead squat, and return to the start position. This sequence and test set up can be seen in Figure 1. Each trial was followed by a ten second rest. Participants concluded each session with self-stretching to reduce the risk of muscle soreness.

Data Analysis

A custom Visual3D (C-Motion Research Biomechancis) code was used to full-wave rectify and filter the EMG for each trial. Peak EMG for each of the six muscles was determined for each trial. Trial were broken into four phase, the down phase from single leg standing to single leg squat, the rotate towards phase from squat to maximum excursion, the rotate away phase from maximum excursion back to straight ahead squat, and the up phase from single leg squat to standing. The mean EMG value for each muscle during each of the phases was identified and recorded. These values were then normalized to the overall peak EMG of the muscle for the corresponding trial and reported at %EMG. The %EMG values were then averaged. This created the variables of interest, for example RF_Down, RF_Towards, RF_Away, RF_Up for all muscles.

Statistical Analysis

Data was analyzed using SPSS Statistics 25. Between group differences were assessed using one-way ANOVAs for each muscle by phase. Limb differences for the hamstring group were assessed using paired samples t-tests. Statistical significance will be set at <.05 *a priori*. Cohen's *d* was used to calculate effect sizes for any differences observed to be significant.

CHAPTER IV

RESULTS

Mean and standard deviations for %EMG per muscle and phase for the healthy group and hamstring group comparisons are shown in Table 1. There were no statistically significant differences between groups (P>.05).

Mean and standard deviations for %EMG per muscle and phase for the PIL and UL of the hamstring group are shown in Table 2. A statistically significant difference in the biceps femoris %EMG of the down phase was observed between PIL and UL (PIL: 7.63 ± 2.99%; UL: 4.59 ± 1.80%; p=0.23; d = 1.02). There were no additional statistically significant differences between limbs (P>.05).

CHAPTER V

DISCUSSION AND CONCLUSION

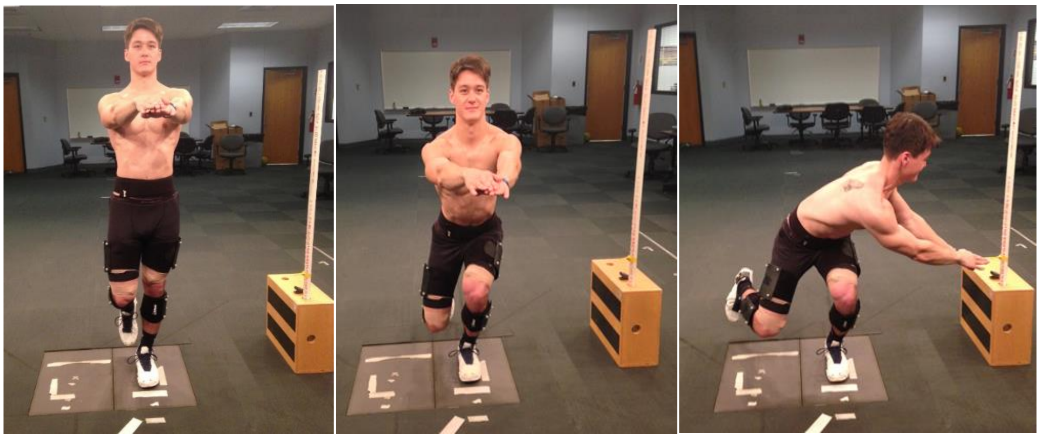
The purpose of this study was to determine if differences in lower extremity muscle excitation are present in individuals with a previous hamstrings injury, as compared bilaterally and to a matched control, when performing a single leg rotational squat. Our hypothesis was that the previously injured limb would have different muscle excitation patterns compared to the matched control, and the uninjured limb when performing a single leg rotational squat. The between group hypothesis was not supported. We observed that there were no significant differences in muscle excitation patterns between the hamstring group and their matched controls. However, the within group hypothesis was supported. We observed a significantly higher percentage of muscle activation of the biceps femoris muscle during the down phase of the SLRS when compared to the uninjured limb.

The between group results suggest that individuals with a previous HSI perform similarly to those without a previous injury even though they do not trust their hamstring 100%. The difference between limbs may explain the continued perception of disability indicated on the HaOS considering that the previously injured hamstring required a higher activation to perform the same task compared to the uninjured limb.

These observations were similar to other research findings which have shown that increased hamstring activation has been clinically observed in patients with hamstring injuries and hamstrings activation patterns changed after injury. This is indicative of alterations in proprioception and neuromuscular control (Sole, et al., 2012). Previous literature has reported that greater hamstring activation is required during single-leg dynamic exercises, which translate to sport specific tasks such as hurdling, cutting, and kicking (Struminger, et al., 2013). Given the results of the current study, this information should be used when creating rehabilitation protocols to decrease risk of reinjury when returning to play. The goal for the final stage of a rehabilitation protocol should be sport specific tasks, eccentric training in lengthened positions, plyometrics, and advanced balance exercises (Schmitt, et al., 2012). Lateral and transverse hop-to-balance, as well as lateral band walk exercises are known to effectively promote balanced Q:H coactivation (Begalle, et al., 2012). Whereas 180º jumps were found to elicit significantly less hamstring activation when compared to single and double leg sagittal hops (Struminger, et al., 2013). In addition, testing for limb symmetry should be a factor when determining return to play since a difference in muscular activation is known. Testing both double and single leg exercises has been observed to prevent hamstring injuries (Lobacz, et al., 2016).

There were several limitations to the study. Some individuals in hamstring group did have a history of bilateral strain, but the other limb's strain was greater than 5 years and a Hamstring Outcome Score similar to the control group was reported. Same size was low given a convenience sample was used, but the difference observed was supported by a large effect size. Another limitation of the study was the assumption that participants gave their best effort.

In conclusion, the results suggest that individuals with a previous injury perceive a physical deficit, but muscle excitation patterns are similar to their healthy counterpart when performing a SLRS that requires strength and stability. Individuals with previous injury exhibit greater muscle excitation in the biceps femoris of the previously injured limb when moving into a squat position compared to the non-injured leg. This is clinically relevant given that a single leg squat is a common exercise and seen within sport specific movements such as kicking and cutting. It may be beneficial to test for limb asymmetries in muscle activation patterns in those with prolonged perceptions of disability following a hamstrings strain.



A. B. C.

Figure 1. Test set-up for the SLRS. Down phase was defined as moving from A to B, Toward phase was defined as moving from B to C, Away phase was defined as moving from C back to B, and Up phase was defined as moving from B back to A.

Table 1. Between Group Means and Standard Deviations of %EMG during SLRS

%EMG	Phase	Healthy	Hamstring Group	p-value
Rectus Femoris	Down	9.63 ± 3.31	7.66 ± 2.78	.166
	Towards	13.43 ± 2.74	14.02 ± 3.53	.683
	Away	10.96 ± 3.08	11.83 ± 3.69	.574
	Up	8.19 ± 3.51	8.29 ± 3.91	.955
Vastus Medialis Oblique	Down	10.64 ± 1.97	10.38 ± 1.87	.758
	Towards	14.28 ± 2.98	14.39 ± 2.15	.928
	Away	13.31 ± 3.63	14.58 ± 3.11	.413
	Up	12.41 ± 3.57	13.94 ± 3.36	.642
Medial Hamstring	Down	7.38 ± 2.52	7.51 ± 2.44	.906
	Towards	8.11 ± 2.90	7.05 ± 2.93	.427
	Away	9.11 ± 3.13	9.47 ± 3.09	.799
	Up	9.87 ± 2.50	11.18 ± 3.28	.328
Biceps Femoris	Down	6.70 ± 3.35	4.59 ± 1.80	.097
	Towards	8.25 ± 3.88	7.71 ± 4.07	.765
	Away	9.27 ± 4.04	8.67 ± 2.69	.700
	Up	11.93 ± 3.34	11.59 ± 3.48	.827
Gluteus Medius	Down	9.21 ± 3.27	7.90 ± 2.53	.329
	Towards	5.17 ± 2.36	4.89 ± 3.35	.827
	Away	7.94 ± 2.54	7.74 ± 3.09	.875
	Up	16.25 ± 5.38	15.71 ± 5.91	.833
Gluteus Maximus	Down	7.27 ± 3.34	6.22 ± 2.08	.408
	Towards	5.30 ± 3.51	4.70 ± 2.93	.682
	Away	11.49 ± 5.73	11.89 ± 3.33	.857
	Up	22.16 ± 2.05	21.89 ± 2.49	.796

Table 2. Within Group Means and Standard Deviations of %EMG during SLRS

Measure	Phase	Previously Injured Limb	Uninjured Limb	*p*-value
Rectus Femoris	Down	7.72 ± 2.03	7.66 ± 2.78	.952
	Towards	12.23 ± 2.99	14.02 ± 3.53	.078
	Away	10.43 ± 1.81	11.83 ± 3.69	.197
	Up	7.20 ± 3.06	8.29 ± 3.91	.510
Vastus Medialis Oblique	Down	11.58 ± 2.87	10.38 ± 1.87	.236
	Towards	14.65 ± 3.52	14.39 ± 2.15	.844
	Away	14.37 ± 2.22	14.58 ± 3.11	.852
	Up	13.60 ± 3.08	13.16 ± 3.46	.717
Medial Hamstring	Down	8.99 ± 2.40	7.52 ± 2.44	.170
	Towards	7.57 ± 2.19	7.05 ± 2.94	.639
	Away	9.58 ± 2.26	9.47 ± 3.09	.924
	Up	12.94 ± 2.16	11.18 ± 3.28	.270
Biceps Femoris	Down	7.63 ± 2.99	4.60 ± 1.80	.023*
	Towards	10.03 ± 3.99	7.71 ± 4.07	.110
	Away	10.78 ± 3.85	8.67 ± 2.69	.127
	Up	14.13 ± 1.75	11.60 ± 3.49	.088
Gluteus Medius	Down	8.40 ± 2.91	7.90 ± 2.53	.600
	Towards	3.82 ± 1.96	4.89 ± 3.35	.366
	Away	5.76 ± 2.88	7.74 ± 3.09	.101
	Up	15.51 ± 3.34	15.71 ± 5.91	.884
Gluteus Maximus	Down	6.93 ± 4.00	6.22 ± 2.08	.480
	Towards	5.05 ± 4.17	4.70 ± 2.93	.707
	Away	9.31 ± 5.96	11.88 ± 3.33	.143
	Up	21.12 ± 2.59	21.89 ± 2.49	.526

* Denotes statistically significant difference at $p<.05$

REFERENCES

Begalle, R. L., Distefano, L. J., Blackburn, T., & Padua, D. A. (2012). Quadriceps and Hamstrings Co-activation During Common Therapeutic Exercises. *Journal of Athletic Training,47*(4), 396-405. doi:10.4085/1062-6050-47.4.01

Engebretsen, A. H., Myklebust, G., Holme, I., Engebretsen, L., & Bahr, R. (2008). Prevention of injuries among male soccer players. *The American Journal of Sports Medicine,36*(6), 1052-1060. doi:10.1177/0363546508314432

Harput, G., Soylu, A. R., Ertan, H., Ergun, N., & Mattacola, C. G. (2014). Effect of gender on the quadriceps-to-hamstrings co-activation ratio during different exercises. *Journal of Sport Rehabilitation,23*(1), 36-43. doi:10.1123/jsr.2012-0120

Jean-Louis, C. (2014). Factors associated with recurrent hamstrings injuries. *Department of Physical Medicine and Rehabilitation, University of Liege, Liege, Belgium,*681-691.

Khuu, A., Foch, E., & Lewis, C. L. (2016). Not all single leg squats are equal: a biomechanical comparison of three variations. *The International Journal of Sports Physical Therapy,11*(2), 201-211.

Lobacz, A. D., Glutting, J., & Kaminski, T. W. (2016). Clinical practice patterns and beliefs in the management of hamstrings strain injuries. *Journal of Athletic Training,51*(2), 162-174. doi:10.4085/1062-6050-51.3.08

Mendiguchia, J., Alentorn-Geli, E., & Brughelli, M. (2011). Hamstrings strain injuries: are we heading in the right direction? *British Journal of Sports Medicine,46*(2), 81-85. doi:10.1136/bjsm.2010.081695

Park, S., Shim, S., & Choi, B. (2017). Comparison of quadriceps, hamstrings, and gastrocnemius muscle co-activation in balance exercises. *Isokinetics and Exercise Science,25*(4), 309-316. doi:10.3233/ies-173154

Schmitt, B., Tyler, T., & McHugh, M. (2012). Hamstrings injury rehabilitation and prevention of re-injury using lengthened state eccentric training: a new concept. *The International Journal of Sports Physical Therapy,7*(3), 333-341.

Shanbehzadeh, S., Amiri, A., Pirali, M., Nassadj, G., Yazdi, H. R., & Jamshidi, A. A. (2014). Relative muscle contribution of lower extremity muscles during isokinetic single leg squat in patients following reconstruction of the anterior cruciate ligament. *Isokinetics and Exercise Science,22*(4), 343-349. doi:10.3233/ies-140556

Sole, G., Milosavljevic, S., & Sullivan, J. (2012). Altered muscle activation following hamstrings injuries. *British Journal of Sports Medicine,46*, 118-123.

Struminger, A. H., Lewek, M. D., Goto, S., Hibberd, E., & Blackburn, J. T. (2013). Comparison of gluteal and hamstrings activation during five commonly used plyometric exercises. *Clinical Biomechanics,28*(7), 783-789. doi:10.1016/j.clinbiomech.2013.06.010

Webster, K. A., & Gribble, P. A. (2013). A comparison of electromyography of gluteus medius and maximus in subjects with and without chronic ankle instability during two functional exercises. *Physical Therapy in Sport,14*(1), 17-22. doi:10.1016/j.ptsp.2012.02.002

Yamazaki, J., Muneta, T., Ju, Y. J., & Sekiya, I. (2009). Differences in kinematics of single leg squatting between anterior cruciate ligament-injured patients and healthy controls. *Knee Surgery, Sports Traumatology, Arthroscopy,18*(1), 56-63. doi:10.