Original Article

# Comparative Effects of Different Focus Methods on Muscular Activation During Single-Leg-Squat Exercise

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**Abstract**

**Background:** Single-leg squats are frequently featured in training and rehabilitation programs. The use of focus during exercise changes the state of concentration during exercise. This causes changes in muscular activity. No study has been found comparing focusing methods' effectiveness during single-leg squat movement. **Aim:** This study aims to compare the changes in lower extremity muscular activations in cases of external focus, internal focus, and absence of focus. **Methods:** The muscular activities (Gluteus Medius, Vastus Lateralis, Vastus Medialis, Rectus Femoris, Biceps Femoris, and Semitendinosus) of the healthy participants included in the study were measured with the surface electromyography (EMG) device. External focus, internal focus and without-focus positions were used. **Results:** Seventeen recreationally active participants were included in this study. The muscular activities of the participants, which occurred in three different situations, were measured with the surface electromyography (EMG) device. While the quadriceps were more active in the descent phase, the hamstring muscle group was more active in the ascent phase. The external focus provided more muscular activation than the other two focal conditions. **Conclusion:** According to the results of this study, the use of focus during single-leg squat training and rehabilitation may change the muscular response obtained.

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## Introduction

Considering the complex nature of sports injuries, it can be observed that many risk factors cause injury.[1] Knee injuries in both males and females of all age groups constitute a significant burden in terms of both clinical and public health.[2] Reducing the risk of knee injuries can be achieved through the correct axial relationship of the lower extremity.[3] Excessive valgus angulation of the knee increases the risk of injury, especially during descent.[4,5] A decrease in the knee and hip flexion angle, an increase in the hamstring/quadriceps ratio, and a decrease in gluteus maximus muscle activation are among the factors associated with dynamic knee valgus.[6]

Tests such as single-leg landing and single-leg squat are used in the evaluation of dynamic knee valgus, which is a risk factor for lower extremity injuries.[7,8] The hip abductor muscles, which have movement patterns of abduction and rotation in the hip joint and provide pelvic elevation during walking, reduce the risk of valgus that may occur in the knee by stabilizing the femur, especially during single-leg squats.[8,9] In a study by Crossley *et al.*[10] single-leg squat tests were found to be reliable assessment methods to determine the functioning of the hip muscles. Stickler *et al.*[11]

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evaluated 40 healthy females and emphasized that the relationship between hip strength and single-leg squat mechanics is clinically important and that hip strength should be considered when evaluating single-leg squat kinematics.

It can be observed that different focusing methods are used in single-leg squat assessment and exercise training.[12,13] Previous studies have found that in comparisons of evaluations made with and without focus instructions, the activation of the muscle was increased when a focusing instruction was given.[13,14] When internal and external focusing methods are considered, the external focus seems to be more effective in creating safe movement and improving skill acquisition more successfully than the internal focus.[12]

This study aimed to investigate the effect of different focusing methods on the activity of the knee and hip muscles during a single-leg squat.

## Materials and Methods

### Participants

The study was approved by the University of Health Sciences Gulhane Scientific Research Ethics Committee (Committee No: 2021-388) on 25/11/21 and was carried out under the ethical principles of the Declaration of Helsinki of The World Medical Association. The study has a prospective clinical trial record (Clinical trial no: NCT0518588). All participants who agreed to participate in the study signed a written informed consent form. Using R package "pwr" software, the sample size required for two within-factor repeated measures design was calculated from the pilot study data set as 16 participants with 50% power, 5% type I error, and high effect size (ES) (>0.60 for muscles except for VM).[15,21] Participants who were physically active and met the criteria were included in the study. To protect the privacy of the participants, their names and identity information were kept confidential. A total of 17 participants (9 males, 8 females) were evaluated in the Gulhane Faculty of Physical Therapy and Rehabilitation between 03/01/22 and 24/02/22. The demographic information of the participants was recorded. The inclusion criteria have an age restriction of 18-25 years and a body mass restriction of 18.5-24.9. Exclusion criteria were trauma/surgery involving the lower extremity in the last 6 months or any disorder affecting hip and knee muscle function, Foot Posture Index score not being between 0 and +5, hamstring flexibility – Sit and Reach Test score being greater than +5 cm, limited ankle dorsiflexion angle (expected to be at least 5° more than neutral), hip abductor strength less than 40 Newton Meters (Nm).[16]

### Evaluation protocol

The hip abduction muscle strength assessment was made using a manual dynamometer following the protocol specified by DiMattia *et al*.[17] Three measurements were made for each leg, and the average was recorded.

Hamstring flexibility was assessed using a sit-and-reach test box (Baseline®) according to the protocol described by Baltaci *et al*.[18]

### Single-leg-squat protocol

The participants were instructed to cross their arms across their chests and squat slowly and in a controlled manner while maintaining balance. The knee angle was fixed at 60°. This angle was adjusted with an inclinometer integrated into the EMG device. A metronome was used to control the squatting speed. The participants were asked to come to the squat position within 3 beats of the metronome, to hold the squat position for 3 beats, and to return to the starting position during 3 beats.

The single-leg-squat protocol was performed in three different ways without any focus (A), with an internal focus (B), and with an external focus (C). To ensure randomization, the measurements were taken as A-B-C, C-B-A, B-C-A, and A-C-B, in a different order for each patient. A 60-second rest interval was given between each squat protocol. In the external focus, the subject was asked to stimulate and control the movement with a sign placed at the distance that the patella would contact when the knee angle was 60°. The external focus SLS position is shown in Figure 1.

Figure 1: Single-Leg Squat External Focus Position

In the internal focus, the subject was instructed to stand upright with the knees and hips at or near full extension, feet approximately shoulder-width apart, then lower the body until the thighs are at least parallel to the floor or lower, and keep the back straight throughout the squat. Both knees must be bent to squat, and the knees should not cross the toes when bent. Internal focus and without-focus SLS positions are shown in Figure 2.

Figure 2: Single-Leg-Squat Internal Focus and Without Focus Position

All the participants were allowed at least three application attempts. During the single-leg-squat trials, each subject was digitally videotaped with a video camera placed about 3 meters in front of them on a tripod at the height of the pelvis. To assist decision-making during the evaluation, reflective markers were placed on the projection of the lateral acromial process, trochanter major, lateral femoral condyle, lateral malleolus, lateral heel, 5th metatarsal base, medial malleolus on the anterior surface of the ankle, and spina iliaca anterior superior. The digital images were transferred to the computer for evaluation.

### Measurement of maximal voluntary isometric contraction (MVIC)

For the non-invasive evaluation of the muscles, the skin was cleaned according to the criteria determined by the Surface Electromyography for The Non-Invasive Assessment of Muscles/(SENIAM) before the electrode placement.[19] When the skin surface turned light red, considering the appropriate skin impedance environment, electrodes were placed on the Rectus Femoris (RF), Vastus Lateralis (VL), Vastus Medialis (VM), Biceps Femoris (BF), and semitendinosus, Gluteus Medius (GM) muscles. Care was taken not to exceed 2 centimeters between the centers of the electrodes.

Electrode placements according to the SENIAM criteria are as follows: for the RF muscle, to the midpoint of the line between spina iliaca anterior superior and superior patella; for the VM muscle, one-fifth of the distance between the spina iliaca, anterior superior, and knee joint space; for the VL muscle, two-thirds of the distance between the spina iliaca anterior superior and lateral of the patella; for the BF muscle, half of the distance between the ischial tuberosity and the lateral condyle of the tibia; for the semitendinosus muscle, half of the distance between the ischial tuberosity and the medial condyle of the tibia; for the GM, half of the distance between the crista iliac and greater trochanter. The amplifiers were placed on the skin with double-sided tape and fixed with an elastic band so as not to create tension in the cables.

Before starting the measurement, the participants were asked to lie in the resting position without moving for 15 seconds to evaluate whether the electrodes recorded noise. When noise was detected, the electrodes were repositioned, and the same procedures were repeated. The MVIC levels of each muscle were recorded to normalize the muscle activation levels during the exercises. The measurements were taken three times for each muscle. Each repetition lasted 5 seconds, with a 1-minute rest between measurements. After the MVIC measurement, the participants were given a rest period of 5 minutes. Each exercise was taught to the participants and allowed to be repeated for a maximum of three repetitions. To minimize the effect of fatigue, a 2-minute rest period was given between the exercises.

### EMG analysis

The Noraxon myoRESEARCH® (Noraxon, Scottsdale, USA) program was used for EMG analysis. A 20 Hz high pass filter was used to clear the EMG signals from motion artifacts. The raw data was rectified first, then the root mean squares (RMS) were taken at a time interval of 100 milliseconds, and the signals were smoothed. The maximum of three repeated MVIC signals was obtained, and muscle activation during the exercises was normalized by dividing by the MVIC values. A video camera (50 fps, Logitech Web Camera C500, Morges, Switzerland) was used to determine the phases of the exercises (descent, waiting, and ascent). By examining the video camera images made simultaneously with the EMG recording, the descent, waiting and ascent phases of the exercises were marked. The mean muscle activations of each phase were used as %MVIC for statistical analysis. The hamstring muscle activation level was obtained as the total of the BF and ST muscle activation levels during the exercises, and the QF muscle activation level as the total of the VM and VL muscle activation levels during exercises. These obtained values were used to calculate the Hamstring/QF (H/QF) and medial hamstring/lateral hamstring muscle activation ratios.

### Statistical analysis

The normality of variables was evaluated with the Shapiro-Wilk test. Variables were stated as mean± standard deviation (minimum; maximum) values, or frequency (n) and percentage (%). The intra-rater reliability (IRR) of the (%) MVIC measurements was evaluated with the intraclass correlation coefficient (ICC, two-way mixed effects, the mean of multiple measurements, absolute agreement) and the standard error of measurements (SEM). An ICC value >0.90 was accepted as excellent reliability.[20]

Two-way repeated measures ANOVA was used to understand whether there was an interaction between two factors (phase and focusing) on the %MVIC. The simple main effects were calculated when the interaction effect was statistically significant, and the main effects were examined in other cases. The Bonferroni adjusted *P* values were interpreted for all multiple comparisons. The effect size (f) was interpreted as follows: ≥0.40: large, 0.25-0.39: medium, 0.10-0.24: small ES.[22]

The statistical analysis was conducted with R language (R Core Team)[22] in R Studio 2022.02.3. The following R packages were used: “rel”[23], “ggplot2”[24] and “ggpubr”.[25]

## Results

The evaluation was made of 17 participants, comprising 9 (52.95%) males and 8 (47.05%) females with a mean age of 22.18 ± 0.88 years (min:21, max:24 years), and mean BMI of 21.71 ± 2.08 kg/m2 (min:17.63, max:

24.76 kg/m2). Right-leg dominance was determined in 15 (88.8%) individuals. The IRR results of the MVIC and %MVIC values obtained in different phases and focusing conditions are summarized in Table 1. The perfect consistency was determined for all measurements (ICC >0.90).

**Figure 1:** Single-leg squat external focus position

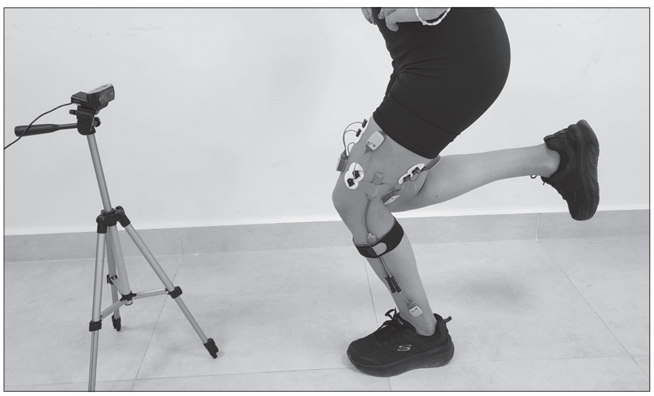

**Figure 2:** Single-leg-squat internal focus and without focus position

Table 1: The intra-rater reliability of measurements (ICC and SEM)

The scatter plot with the mean values, the ES for the interaction, and the main effects for each muscle are presented in Figure 1 (a-f). The phase*focusing interaction effect for VL, GM, and ST was determined to be statistically significant ($P < 0.001$, $P = 0.004$, and $P < 0.001$; respectively). While the interaction effects for RF ($P = 0.197$), VM ($P = 0.393$), and BF ($P = 0.063$) were not significant, the main effects for phase and focusing were statistically significant ($P < 0.001$). The simple main effect comparison for the VL, GM, and ST muscles where the interaction effect is significant and for the RF, VM, and BF muscles with significant main effects, and the results of phase and focusing comparisons are given in Table 2.

Considering the interaction effect, the greatest difference was obtained for VL and ST with an ES of 9.95. Similarly, the ES for the interaction effect, which was also significant for GM, was high (f: 0.65). In the simple main effect analysis for VL, GM, and ST, all pairwise comparisons were significant in both the descending and ascending phases ($P < 0.05$). When the mean differences were examined, it was determined that the %MVIC values obtained with W were lower than those obtained with EF (W-EF<0).

**Table 1: The intra-rater reliability of measurements (ICC and SEM)**

| Muscle | MVIC | % MVIC | | | | | |
|---|---|---|---|---|---|---|---|
| | | Descending | | | Ascending | | |
| | | SLS_D | SLS-DIF | SLS-DEF | SLS_A | SLS-AIF | SLS-AEF |
| RF | 0.998 | 0.989 | 0.995 | 0.995 | 0.981 | 0.995 | 0.992 |
| | 2.13 | 1.72 | 1.26 | 1.31 | 1.54 | 1.06 | 1.20 |
| VM | 0.998 | 0.992 | 0.994 | 0.997 | 0.992 | 0.99 | 0.995 |
| | 1.39 | 1.86 | 1.76 | 1.43 | 1.78 | 1.73 | 1.43 |
| VL | 0.998 | 0.991 | 0.995 | 0.996 | 0.987 | 0.995 | 0.993 |
| | 1.48 | 1.44 | 1.18 | 1.02 | 1.44 | 1.18 | 1.04 |
| GM | 0.996 | 0.993 | 0.993 | 0.995 | 0.988 | 0.992 | 0.997 |
| | 1.98 | 1.78 | 1.73 | 1.43 | 1.86 | 1.76 | 1.43 |
| ST | 0.999 | 0.987 | 0.993 | 0.991 | 0.986 | 0.988 | 0.988 |
| | 1.52 | 1.48 | 1.07 | 1.22 | 1.48 | 1.07 | 1.22 |
| BF | 0.998 | 0.988 | 0.994 | 0.993 | 0.987 | 0.994 | 0.994 |
| | 1.53 | 1.54 | 1.06 | 1.20 | 1.72 | 1.26 | 1.23 |

RF: Rectus Femoris, VM: Vastus Medialis, VL: Vastus Lateralis, GM: Gluteus Medius, ST: Semitendinosus, BF: Biceps Femoris, (%) MVIC: (the percentage of) Maximal voluntary isometric contraction. SLS_D: Single-leg-squat task without any focusing in a descending phase, SLS_DIF: Single-leg-squat task with internal focusing in a descending phase, SLS_DEF: Single-leg-squat task with external focusing in a descending phase, SLS_A: Single-leg-squat task without any focusing in an ascending phase, SLS_AIF: Single-leg-squat task with internal focusing in an ascending phase, SLS_AEF: Single-leg-squat task with external focusing in an ascending phase. $ICC_{3,k}$: Intra-class correlation coefficient (two-way mixed effects, the mean of multiple measurements, absolute agreement, >0.90 was accepted as excellent agreement), SEM: the standard error of measurements

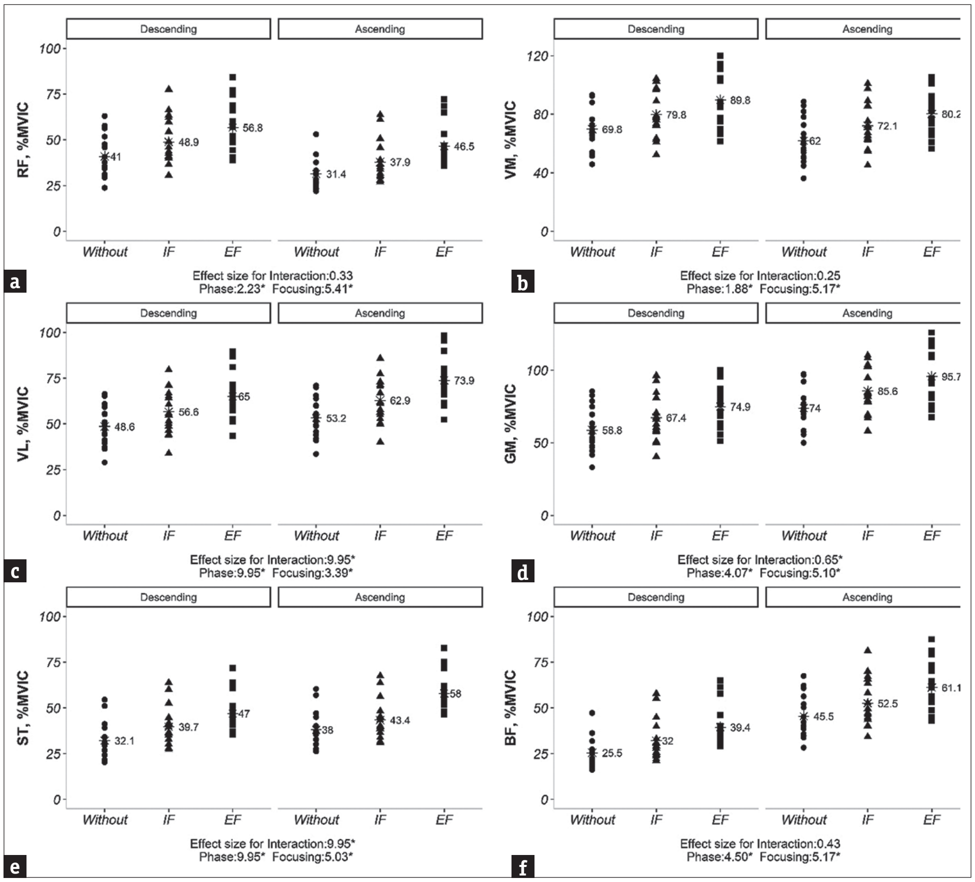


**Figure 3:** (a-f): The values of muscle activity during the SLS without any focusing, internal (IF), and external (EF) focusing in the descending and ascending phases

**Table 2: The mean difference for multiple comparisons of %MVIC***

| | | | | | | |
|---|---|---|---|---|---|---|
| **The multiple comparisons from the simple main effects for the measurements where the interaction effect was significant.** | | | | | | |
| | **In Descending Phase** | | | **In Ascending Phase** | | |
| | **W – IF** | **W – EF** | **IF – EF** | **W – IF** | **W – EF** | **IF – EF** |
| VL | -8.0 | -16.5 | -8.4 | -9.7 | -20.7 | -11.0 |
| GM | -8.6 | -16.2 | -7.7 | -12.0 | -21.7 | -10.0 |
| ST | -7.6 | -14.8 | -7.3 | -5.3 | -19.9 | -14.6 |
| **The multiple comparisons from the main effects for the measurements where the interaction effect was not significant.** | | | | | | |
| | **Focusing** | | | **Phase** | | |
| | **W – IF** | **W – EF** | **IF – EF** | **D – A** | | |
| RF | -7.3 | -15.5 | -8.2 | 10.3 | | |
| VM | -10.1 | -19.1 | -9.0 | 8.4 | | |
| BF | -6.8 | -14.8 | -8.0 | -20.7 | | |

VL: Vastus Lateralis, GM: Gluteus Medius, ST: Semitendinosus, RF: Rectus Femoris, VM: Vastus Medialis, BF: Biceps Femoris, %MVIC: the percentage of maximal voluntary isometric contraction, W: without any focusing, IF: internal focusing, EF: external focusing, D: descending phase, A: ascending phase. *All multiple comparison results based on the Bonferroni adjustment were statistically significant at the 0.05 level

In the RF and VM muscles with significant main effects, the values obtained in the descending phase were higher (D-A >0), and the opposite was true for BF. In the pairwise comparisons made in terms of focusing on the main effect, the greatest difference was obtained in the W-EF comparison. This was followed by the difference between IF-EF for the RF and BF muscles, while the comparison of W-IF for the VM muscle was the second major difference.

Figure 3: (a-f): The values of muscle activity during the SLS without any focusing, internal (IF), and external (EF) focusing in the descending and ascending phases

Table 2: The mean difference for multiple comparisons of %MVIC*

The values of QH muscle activity during the SLS without any focusing, internal (IF), and external (EF) focusing in a descending and ascending phase are summarized in Figure 4. The ES for the interaction effect was found to be 0.60, and statistically significant ($P$ = 0.007). The simple main effect comparison among focusing conditions in a descending phase and an ascending phase was obtained as statistically significant. The mean difference between without focusing and internal focusing (-0.14), without any focusing and

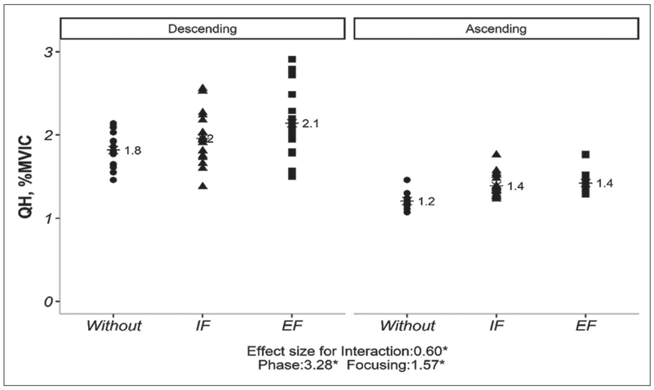


**Figure 4:** The values of QH muscle activity during the SLS without any focusing, internal (IF), and external (EF) focusing in a descending and ascending phase

external focusing (-0.32), and internal and external focusing (-0.18) was significant at the level of 0.05 in a descending phase. In the ascending phase, the difference between internal and external focusing conditions was not significant ($P = 0.272$), and the difference between without and the other two conditions was significant ($P < 0.05$).

Figure 4: The values of QH muscle activity during the SLS without any focusing, internal (IF), and external (EF) focusing in a descending and ascending phase

## Discussion

In this study, six muscle activation values were examined in three different focus models that occur during single-leg squat (SLS) activity. It was also investigated whether this muscular activity differs between the descending and ascending phases of the SLS. According to the results of this study, the external focus approach revealed more muscular activity than both the internal focus and without focus. In addition, significant differences were detected in terms of muscles in the ascending and descending phases of the focus exercises.

Among the three SLS tasks tested, the greatest number of differences in muscle activation levels occurred in external focusing during both the descent and ascent phases. These results are in line with previous studies. For example, Neumann concluded that using an external focus in weight training is more effective than using an internal focus or without focus.[26] Schutts *et al*.[27] showed that the external focus used during the weight-lifting snatch movement was more effective than the internal focus. Benjaminse *et al*.[12] also stated that the external focus is more effective in terms of transferring motor learning abilities to sporting activities. Furthermore, in a study investigating the changes in cortical activity during single-leg balance applications of internal focus and two different external focus applications, the external focus was found to be more effective than the internal focus.[28] The use of external focus is more effective because it creates a more prominent point in terms of visual alignment, focusing, and an effort to make the movement correct with visual perception rather than feedback from the proprioceptive system. In addition, more effort is required to adapt to the external focus, which may increase muscular activity.

In contrast to the present study, Paz *et al*.[29] stated that the use of laser biofeedback and external focus during four different exercises decreased the muscular activity in the forward lunge movement compared to the control group, while there was no difference in the other three movements. Furthermore, Coratella *et al*.[30] stated that the internal focus method used during the back squat movement creates more muscular activity than the external focus. However, although a plethora of literature is available, a clear consensus has still not been achieved. Therefore, this study can be considered to make an important contribution to the literature.

In the current study, the VL, ST, and GM activation levels during both the descent and ascent phases were found to be greater with external focusing than with internal focusing or without focusing. In theory, the demand for the activation of the lower leg muscles could rise due to the increasing overload. Moreover, related posture modifications might potentially have an impact on the increased muscle activity seen during the SLS. The enormous relative mass of the trunk may be able to shift the center of the body's weight forward, resulting in increased hip and knee loading and higher muscle activation during unilateral squats. However, given that the body functions as an inverted pendulum, with the center of gravity constantly shifted and the trunk muscles working to maintain balance, the trunk displacement could potentially increase as the weight-bearing support is decreased during the SLS.[31] When the hip muscles are not strong enough to withstand the increased overload, the degree of trunk displacement, which is related to core stability, will be emphasized.[32] Therefore, one of the causes of the increased muscle activation during the SLS may be the decreased support and concurrent increase in trunk motion.

In the present study, the gluteus medius was found to be more active than other muscles in focusing approaches during both the descent and ascent phases. The gluteus medius is a crucial muscle for walking, jogging, and single-leg weight-bearing because it keeps the opposing side of the pelvis from falling when doing these activities.[33] Knoll *et al*.[34] reported that while the activity of knee extensor muscles increased in traditional split squats, gluteus medius activity increased in a single-leg squat. This finding may suggest that the SLS with focusing is an appropriate variation for an individual with knee pain.

According to the current research, the percentage of MVIC values recorded during the descending phase was higher in the RF and VM muscles during the three SLS tasks. However, the issue is the opposite for BF muscle. The quadriceps group was seen to be more active in the descending phase, and the two groups co-contract and raise the body together in the ascending phase. Similar to the present study, Richards *et al*.[35] stated that EMG activity increased as the knee descent angle increased. One possible mechanism for this situation is that most muscles work eccentrically during the descent phase, while the hamstrings contribute to this increase in rectus femoris activity through co-contraction in the ascent phase.

Quadriceps to hamstrings (Q: H) co-activation is crucial for reducing the pressure on the ACL during sagittal, frontal, transverse, and multiplanar movements of the knee.[36,37] Medial hamstring and quadriceps co-activation decreased knee rotation, abduction, and translation, according to research by Serpell *et al*.[38] Therefore, using the SLS would be recommended to improve stability in the frontal plane and potentially prevent ACL injury. In the research, the SLS with external focusing used a greater Q: H coactivation ratio than the internal focusing and without any focusing. The SLS with external focusing exercise demonstrated 2.1 times greater quadriceps than hamstring activation in the descending phase. In the ascending phase, internal and external focusing SLS exercises had similar Q: H coactivation ratios. The SLS with focusing exercises may be advantageous when prescribing exercises that demand greater quadriceps activation than hamstring activation for quadriceps strengthening because the Q: H ratio was higher than 1.0 for these exercises.

The findings of this study suggested that the three SLS tasks have various muscle-activation profiles and can be utilized separately or in combination as part of a rehabilitation program. The focusing strategy could be changed depending on the muscle activations that are being avoided or targeted.

This study had some limitations. First, the sample consisted of young, healthy adults who were pain-free. This sample was selected so that the effects of changing the focusing patterns on the activation of the hip and thigh muscles could be studied without pain interfering with the findings. Consequently, care should be exercised when interpreting these findings for patient populations. A second limitation was that no gender comparison was made, so it is not known whether the differences in muscle activation levels between the SLS tasks were due only to focusing or gender differences.

## Conclusion

This study quantified the muscle activity level of selected hip and thigh muscles during SLS with three different focuses. The most variations in muscle-activation levels were observed with external focus during both the ascent and descent phases of the three SLS exercises assessed. In the descending phase of the SLS with external focusing, the quadriceps were activated 2.1 times more than the hamstrings. However, the Q: H coactivation ratios during the ascending phase were similar in both internal and external focusing SLS exercises. These results confirmed that the focusing approach is a crucial factor to consider when using the SLS for assessment or rehabilitation. These findings can provide clinicians, researchers, and the general public with information to facilitate the selection of the appropriate SLS variation for individual strengthening and rehabilitation goals.

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### Conflicts of interest

There are no conflicts of interest.

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