Changes in Muscle Activation During Wall Slides and Squat-Machine Exercise

Peter R. Blanpied

Closed kinetic chain exercises are commonly used in strengthening and rehabilitation programs. Altering positions of body segments and supports might affect the way these exercises are performed. The purpose of this study was to compare gluteal, quadriceps, hamstring, and plantar flexor muscle activations during wall-slide (WS) vs. squat-machine (SM) exercise. In addition, the effects of support location and foot position were investigated. Twenty women performed 8 exercises, to 60° of knee flexion. Results indicated that placing the foot forward caused an increase in all muscle activations except in the plantar flexors, which showed an increase with the foot placed in line with the hip. This effect was exaggerated during WS for the plantar flexors and quadriceps and during SM for the hamstrings. When the support was located at the scapular level, hamstring and gluteal activations were greater, and quadriceps activity was less during SM than during WS. These results could be used to target specific muscle groups during strengthening exercise.

Key Words: knee, rehabilitation, EMG

Closed kinetic chain exercises are currently being advocated and used in the rehabilitation of lower extremity musculoskeletal pathology. It has been claimed that these exercises, which usually entail multijoint movements and weight bearing through the involved extremity, increase joint stability, muscle coactivation, and proprioception and more closely simulate functional activities. In the knee, closed kinetic chain exercises such as the single-leg squat have been shown to decrease anterior shear force (6) and displacement of the tibia (16), as well as decrease patellofemoral contact stress (11, 13) and increase joint position sense (1, 3). Because of the dynamic, multijoint nature of these exercises, knee joint forces and torques can be affected by muscles of the hip and ankle (10). For example, during a squat, the hip extensors and plantar flexors are active to control motion at the hip and ankle, respectively, but because of the closed kinetic chain nature of

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the squat, the hip extensors and ankle plantar flexors also contribute to forces and torques occurring at the knee.

One commonly used closed kinetic chain exercise is a wall slide (WS). During this simple exercise the individual rests his or her back against a wall, sliding up and down as knee bends are performed to various depths. Because WSs are extremely limited in the variation of applied resistance (body weight + any handheld weights), hack squat machines have been devised to allow counterbalancing for reduction of resistance below or addition of resistance above body weight. Unfortunately, in both the wall slide and the squat-machine (SM) exercise, little is known about how participant positioning affects the contribution of the muscles performing the exercise. It has been postulated that differences would exist with different body positions (15), and a study has shown different forces in a knee ligament with different foot positions in a cadaver-simulated squat (7), but the literature is inadequate in terms of muscle activation in intact humans.

Although changing the axial rotation of the lower extremity apparently has little effect on muscle activation patterns during the squat (8), two modifications of the WS and the SM exercise may have potential to change the contribution of the muscles performing the exercise: (a) changing the anterior/posterior location of the foot and (b) changing the superior/inferior location of the back support. Both the WS and the SM exercise can be performed with the foot in line with the hip or the foot placed forward. Placing the foot forward changes the application point of the ground reaction force relative to the body and may therefore change the required activation of the muscles. Typically, the WS is performed with the participant’s back against the wall, the contact extending caudally as far as the sacrum. The support location on the squat machine depends on the size of the sled, but with a long sled the support can also be extended as far caudally as the sacrum. A simple modification of having the participant contact the wall or sled only at the scapular level changes the position of the support force and may also change the required contribution of the muscles to the exercise.

The purpose of this study was to determine the differences in gluteal, hamstring, quadriceps, and plantar flexor electromyographic (EMG) activity during WS and SM exercise with the foot placed forward vs. in line with the hip, and with the support force located at the hip vs. the scapular level.

Methods

Participants

Twenty asymptomatic women (age = 31.3 ± 6.9 years, height = 160.9 ± 4.1 cm, mass = 58.1 ± 8.7 kg) served as participants in this study. Prior to testing, participants signed an informed consent approved by the University of Rhode Island Institutional Review Board. Because of the size limitation of the squat machine, only participants who were 170 cm tall or less were tested.
Procedures

The participants’ right legs were tested. After preparing the skin with a propanol scrub, surface EMG electrodes (Therapeutics Unlimited, Iowa City, IA) were placed over the muscle bellies and aligned approximately with the muscle fibers of the gluteus maximus, hamstring group, vastus lateralis, and soleus muscles. Specifically, the gluteus electrode was located 6 cm caudal to a point at one third of the distance between the posterior superior iliac spine and the greater trochanter. The hamstring electrode was placed halfway between the ischial tuberosity and the midposterior knee crease. The quadriceps electrode was placed at one third of the distance between the anterior superior iliac spine and the fibular head. The plantar flexor electrode was placed on the midline of the posterior calf at a level just caudal to the medial gastrocnemius muscle belly with the ankle in neutral dorsiflexion. A reference electrode was placed over the medial malleolus.

The raw EMG signals were displayed on an oscilloscope (Model 2232, Tektronix, Inc., Beaverton, OR) to check for noise and artifact; processed signals (RMS method, 55-ms time constant) were recorded. An electrogoniometer (Therapeutics Unlimited) was placed on the lateral surface of the participant’s knee, aligning the axis of rotation to the lateral condyle of the femur. The signal from the electrogoniometer (ELGON) was used to provide knee position feedback to the participant during performance of the exercise, as well as to delineate repetitions of the exercise during later data analysis. EMG and ELGON signals were sent to a microcomputer (CompUtopia 286, CompUtopia, Warwick, RI), where they were sampled at 1 kHz (RC Electronics, Goleta, CA) and stored.

EMG noise levels were recorded with the participant at rest. Reference contractions of the quadriceps, then the hamstrings, were recorded during a maximal volitional isometric exertion while the participant was sitting and stabilized on a Kin-Com (Chattecx Corp., Chattanooga, TN) isokinetic dynamometer with the knee in 60° of flexion. The reference contraction for the gluteals was recorded during a manually resisted maximal volitional isometric hip extension contraction in prone with the hip in neutral extension and the knee in 90° of flexion. The reference contraction of the plantar flexors was recorded during an isometric hold of a single-leg heel raise, the heel clearing the floor by approximately 3 cm. Noise and all reference contractions were 5 s in duration.

The participants were taught, and were allowed to briefly practice, the one-legged WS and the SM (Life Extension Systems, Kalamazoo, MI) exercise. Participants adopted a position of tibial rotation that was comfortable for them (8, 12); hip and knee motion were required to approximate the sagittal plane. After a 1-min rest period, the participants performed a series of five repetitions in each of four positions on the SM or WS. The factors that made the positions different were foot position and support location. Foot position was with either (a) the stance foot located so that the metatarsal heads of the foot were 50 cm anterior to a line passing through the participant’s trunk and hip (foot forward, or FF) or (b) the stance foot located so that the ankle was aligned with a line passing through the participant’s
trunk and hip (foot in line with the hip, or I-L). The posterior support location was either (a) at the level of the hip (HIP) or (b) at the level of the scapula (SCAP). Different combinations of these two factors were used, resulting in the four conditions tested—HIP:FF, HIP:I-L, SCAP:FF, and SCAP:I-L.

The resistance of the exercises was provided by body weight, with no additional weights added, and the exercises were performed to a four-count beat of a metronome set at 80 beats/min. The participants performed the exercises to a depth of 60° of knee flexion by matching the ELGON trace to a target on the oscilloscope. The participants had at least a 1-min rest period between conditions, and the performance order of the conditions and the exercises was randomized. The last three repetitions of each exercise were recorded and stored for later analysis.

**Results**

Means of each muscle's activities over the three recorded repetitions were determined. The effects of exercise (WS and SM), foot position (foot forward and foot inline with the hip), and support location (hip level and scapular level) were tested by a three-factor repeated-measures analysis of variance (SigmaStat, Jandel Scientific, San Rafael, CA). Post hoc multiple comparisons were performed using paired t tests with Bonferroni's correction.

Means and standard deviations of the muscle activities during the conditions of each exercise are expressed in Table 1 as percentages of the reference contraction. Several significant double and triple interactions were identified in the analysis as will

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Means (±SD, N = 20) of Muscular Activity During Exercise</th>
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<tbody>
<tr>
<td></td>
<td>EMG</td>
</tr>
<tr>
<td></td>
<td>Gluteal</td>
</tr>
<tr>
<td>SM:HIP:FF</td>
<td>28.0 ± 10.3</td>
</tr>
<tr>
<td>SM:HIP:I-L</td>
<td>30.5 ± 9.3</td>
</tr>
<tr>
<td>SM:SCAP:FF</td>
<td>30.5 ± 9.3</td>
</tr>
<tr>
<td>WS:HIP:FF</td>
<td>27.0 ± 12.1</td>
</tr>
<tr>
<td>WS:SCAP:FF</td>
<td>30.5 ± 9.3</td>
</tr>
<tr>
<td>WS:SCAP:I-L</td>
<td>26.3 ± 9.8</td>
</tr>
</tbody>
</table>

*Note. All values are expressed as percentages of the reference contractions. SM = squat-machine exercise; WS = wall-slide exercise. Hip = support located at the hip level; SCAP = support located at the scapular level. I-L = foot positioned in line with the hip; FF = foot positioned 50 cm anterior to the hip line.*
be described. In an effort to protect against Types I and II errors, only comparisons of interest were tested in the post hoc analysis. This process resulted in 12 post hoc dependent *t* tests (with a significant *p* value adjusted to .004) following the triple interactions, and four dependent *t* tests following each double-interaction finding (also with appropriate adjustment of the critical *p*).

**Gluteal Activity.** Analysis of the gluteal EMGs resulted in a significant triple interaction, *p* < .002. Relative to the difference between devices, post hoc tests indicated that, for the support located at SCAP, the SM exercise resulted in greater gluteal EMG for both foot positions, I-L *p* < .0001, FF *p* < .0007. For support location, EMGs were greater with SCAP than with HIP, *p* < .0001, for the SM exercise, foot I-L only. Foot position of FF always caused a greater gluteal EMG, *p* < .0003. Comparison of the gluteal EMG means is illustrated in Figure 1.

**Hamstring Activity.** Analysis of hamstring EMGs revealed three significant double interactions: exercise by support location, exercise by foot position, and support location by foot position (all were *p* < .0005). Post hoc tests indicated that the SM exercise resulted in greater hamstring activity with the support at SCAP (collapsed across foot position, *p* < .0001) or with foot position FF (collapsed across support location, *p* < .0001). Scapular support caused increased hamstring activity during the SM exercise (collapsed across foot position, *p* < .0001) but not during the

![Figure 1 — Gluteal EMG as a percentage of isometric maximum. FF = foot-forward position; I-L = foot in line with hip. HIP = posterior back support at hip level; SCAP = posterior back support at scapular level.](image-url)
WS, \( p = .023 \). Foot position FF also always caused greater hamstring EMG, \( p < .0001 \). Comparison of the hamstring EMG means is illustrated in Figure 2.

**Quadriceps Activity.** Analysis of quadriceps EMGs revealed two significant double interactions: exercise by support location, \( p = .010 \), and exercise by foot position, \( p = .004 \). Post hoc tests indicated that the WS resulted in greater quadriceps activity with the support location at either HIP, \( p = .003 \), or SCAP, \( p = .0002 \), when the data were collapsed across foot position. When collapsed across support location, the WS resulted in greater quadriceps activity with foot position FF, \( p = .0003 \), but not with position I-L, \( p = .104 \). HIP support caused greater quadriceps activity than SCAP support did (collapsed across foot position) during the SM exercise, \( p = .001 \), but not during the WS, \( p = .295 \). The FF position caused greater quadriceps activity during the WS, \( p = .002 \), but not during the SM exercise, \( p = .931 \). Comparison of the quadriceps EMG means is illustrated in Figure 3.

**Plantar Flexor Activity.** Analysis of plantar flexor EMGs revealed another significant triple interaction, \( p = .003 \). There was greater plantar flexor activity during the WS with foot position I-L and support at HIP, \( p < .0003 \), or at SCAP, \( p < .0001 \). The support location caused no statistically significant difference in the relevant tests (all \( p \) values were equal to or greater than the adjusted critical \( p \)). The I-L foot position

![Figure 2 — Hamstring EMG as a percentage of isometric maximum. FF = foot-forward position; I-L = foot in line with hip. HIP = posterior back support at hip level; SCAP = posterior back support at scapular level.](image-url)
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Figure 3 — Quadriceps EMG as a percentage of isometric maximum. FF = foot-forward position; I-L = foot in line with hip. HIP = posterior back support at hip level; SCAP = posterior back support at scapular level.

always caused greater plantar flexor activity than the FF position did, \( p < .003 \). Comparison of the plantar flexor EMG means is illustrated in Figure 4.

**Discussion**

Although statistically significant interaction terms often make interpretation of results difficult, biomechanical analysis of the exercise conditions offers an explanation of the results. Generally, a support force located at the scapular level tended to increase activation of the hip extensors (gluteus and hamstring muscle groups); when support was located at the hip level, the quadriceps activity was increased. The SM exercise (using SCAP support location) caused increased activity in the hip extensors, and the WS caused increased activity in the quadriceps muscles. Using a rationale modeled after Palmitier, An, Scott, and Chao (9), Figure 5 shows that the increased moment arm of the ground reaction force and the influence of gravity during each condition can explain these results. Moving the support location from HIP (Figure 5[A]) to SCAP (Figure 5[B]) lengthens the moment arm of the ground reaction force relative to the hip but shortens it relative to the knee. Thus, hip extensors are required to be more highly active to produce and control the movement with a support at SCAP, and the knee extensors are required to be more highly active with a support at
Comparing the WS (Figure 5[B]) with a similarly configured SM exercise (Figure 5[C]) indicates that reclining the participant back changed her orientation to gravity and caused the moment arm of the ground reaction force to be increased even more at the hip and lessened even more at the knee.

The same rationale can be applied to the results of foot position. With the I-L foot position, the ground reaction force is assumed to be located more toward the toes than it is with the FF foot position (Figure 6). Additionally, the torque caused by gravity and the ground reaction force about the ankle is greater with the I-L foot position (Figure 6[A]). Figure 6(B) also shows the increased moment arm of the ground reaction force about the hip for foot position FF, which could explain the increased hip extensor activity (gluteal and hamstring muscles) for that foot position. These results are similar to those of Escamilla, Fleisig, and Barrentine (as cited in Wilk, Zheng, Fleisig, Andrews, and Clancy [15]), who found increased hamstring activation during the leg press when a high foot position was used.

The finding that the quadriceps had greater activity in the WS for the FF condition can be explained by the change in segment orientation relative to gravity. As approximated in Figure 6, the moment arm of the ground reaction force about the knee seems similar for both foot positions, but the knee torque caused by gravity could be quite different. Also, during the WS, friction between the
participant’s posterior thorax and the wall could contribute to the resistance of the exercise, especially during the concentric, or raising, phase. Performance of the WS with the FF foot position (Figure 6[B]) causes the participant to push against the wall with greater force than with foot position I-L (Figure 6[A]), also increasing the friction force. The friction that must be overcome by the muscles during the concentric phase would therefore be greater than with foot position I-L. It should also be noted that the muscular activity required during the lowering, or eccentric, phase would decrease, but not necessarily at the same magnitude. Using a similar rationale, Wilk et al. (15) postulated that the knee extension torque required would be greater during the WS (with the foot placed forward) than during a free-standing squat (with the foot in line with the hip).

Several comments should be made regarding the magnitude of the values shown in Table 1. First, the magnitude of the EMG seems to be much higher for the normalized plantar flexor than for the other three muscle groups tested. This finding is most likely caused by the difference in reference contractions used for the plantar flexors compared with the other muscle groups. For the plantar flexors, the reference contraction was an isometric hold of the body weight against gravity, certainly less than the maximal isometric exertion asked for during the reference contractions of the other muscle groups. Although participants had different body weights and therefore different resistance applied during the recording of this refer-
Figure 6 — Participant positioning during wall-slide exercise with scapular support showing support force (Fs), body weight (W), ground reaction force (GRF), and moment arms of GRF around the hip (MAhip), knee (MAknee), and ankle (MAankle). (A) Foot placed in line with hip. (B) Foot placed forward.

ence, the analyses used in this study were all within participant-repeated measures, so different body weights had little effect on the conclusions that could be made. The rationale for choosing this alternative reference contraction was that adequate stabilization of the lower leg is extremely difficult during maximal isometric testing of plantar flexion, especially with the knee in less than 60° of flexion.

Second, the activity magnitudes of the other muscles are comparable to findings of others (5, 8) and are quite low, certainly below what should be used if strengthening were a goal in these asymptomatic participants. One reason for such low activities was the use of only body weight to provide resistance. If strengthening were indeed a goal, these data suggest that additional weight should be carried by the participants, either by using handheld weights during the wall slide or by adding weights to the squat machine to increase the resistance offered by the sled. Another reason for the low activities is that the values were expressed as an average over the repetitions of the exercise, from 0 to 60 to 0° of knee flexion. Because the resistance moment arms change as a result of limb position, the resistance torques offered to the muscles during the beginning and the end of the repetition were much less than the resistance offered at 60°, thereby lowering the average measured over the entire repetition.

Finally, the activity magnitude of the hamstrings was very low (~11% of isometric maximum). These data do not support the rationale for using either a WS or an
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SM exercise for the purpose of coactivating the hamstrings and quadriceps muscles, as would be desirable in rehabilitation following anterior cruciate ligament injury or repair (11). Similar low hamstring activations have also been found to occur in asymptomatic participants during a leg press and a free-standing squat (14) and during an Olympic squat (8), as well as in a free-standing squat following anterior cruciate ligament repair (2, 4).

Conclusions

Within the limitations of this study, the following generalizations can be made:

- Gluteal and hamstring muscle group activations are maximized in a position of scapular support and with the foot placed forward. The squat machine was better than the wall slide in causing activation of these muscle groups.
- The quadriceps was better facilitated by using hip support and placing the foot forward. The wall slide was better than the squat-machine exercise for activating the quadriceps in this experiment, using body weight only.
- The plantar flexors exhibited more activity with the foot in line with the hip than with the foot placed forward. The wall slide was better than the squat-machine exercise for producing plantar flexor activity.

References


