Original Research

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EMG Analysis of the Vastus Medialis/Vastus Lateralis Muscles Utilizing the Unloaded Narrow- and Wide-Stance Squats

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The purpose of this study was to see if vastus medialis oblique/vastus lateralis (VMO:VL) ratios could be increased by widening the squat stance and if the VMO activity increases with deeper ranges of knee flexion. Fifteen healthy subjects performed unloaded narrow and wide stance squats through three ranges of knee flexion: 30°, 60°, and 90°. The two squat stances were compared using a 2 × 3 ANOVA to see if the wide-stance squat had any significant difference in EMG activity for VMO:VL ratios compared to the narrow-stance squat. The difference in EMG activity of the VMO between the various angles for both squat stances was also compared. The ANOVA revealed no significant differences between the squat stances for VMO:VL ratios but did show the VMO:VL ratios to be significantly higher with increasing knee flexion angles. These findings suggest that the VMO is active throughout the 90° range and that increasing knee flexion angles can elicit greater activity of the VMO relative to the VL.

Key Words: knee, closed kinetic chain, quadriceps

A concern with many types of knee rehabilitation programs is establishing a balance between the strength of the vastus medialis, particularly the oblique portion, and the vastus lateralis muscles of the quadriceps. Both of these muscles attach to the patella and exert forces that ultimately keep the patella in proper alignment. Compared to the vastus lateralis muscle, the vastus medialis muscles are quick to atrophy, which can cause them to exert less force on the patella (2, 3, 8, 11, 13). In an attempt to target the vastus medialis oblique, exercises must be performed that activate the vastus medialis oblique more significantly than the other quadriceps muscles (4). This selectivity may be described as targeting and has been used in strength training practices. However, research concerning the clinical

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existence of targeting is not conclusive, and we feel this project is an important attempt to provide more information on this subject.

Biomechanically, both the vastus medialis oblique and vastus lateralis contribute to the pull on the patella and assist in patellar tracking. However, the fibers of the vastus medialis oblique align at an angle of 40–55° relative to the patella, while the fibers of the vastus lateralis align at an angle of 12–15° relative to the patella (1, 6, 8, 15). In other words, the fibers of the vastus lateralis run more parallel to the femoral shaft than do the vastus medialis oblique fibers, which may create biomechanical differences in the force applied to the patella. In particular, if the vastus medialis oblique has atrophied, the vastus lateralis may have a resulting mechanical advantage over the vastus medialis oblique. This advantage may create unequal biomechanical force components resulting in improper patellar tracking. However, it is important to note that the vastus medialis oblique originates off of the tendons of the adductor longus and magnus (4). We postulated that widening the stance of a squat movement would stretch the adductor tendons and muscles, which could facilitate and increase the activity level of the vastus medialis oblique. Also, the wider stance might position the vastus medialis oblique fibers in a more direct alignment with the adductors, which could help increase the activity of the vastus medialis oblique since these two muscles have a direct connection. If these postulates are true, then the increased activity of the vastus medialis oblique could help keep the patella in proper alignment.

The intention of this study was to determine if modifying foot placement during the squat movement would significantly alter surface EMG recordings of the vastus medialis oblique muscle when compared to the vastus lateralis muscle. By modifying foot placement, one of three possibilities could result. One, there could be no relative change in vastus medialis oblique/vastus lateralis (VMO:VL) ratio; two, the VMO:VL ratio could decrease; or three, this ratio could increase. If the ratio does increase, this could indicate the possibility for targeting the vastus medialis oblique muscle, since the vastus medialis oblique activity would have to increase relative to the vastus lateralis. Thus, we feel an investigation into foot placement during a squat movement is warranted and may benefit sport rehabilitation programs.

Materials and Methods

Subjects

A sample of convenience was taken from physical therapy students attending Nova Southeastern University, with $N = 15$, average age = 28.6 ± 4.66 years, average height = 68.7 ± 3.52 in. (175 cm ± 8.94 cm), and average weight = 168.2 ± 38.1 lb (76.5 kg ± 17.3 kg). All subjects were screened to eliminate participants with any prior impairments of the hips, knees, and ankles. Also, the subjects had full range of motion of these joints. Documented informed consent was required of each subject in order to participate in the study.

Instrumentation and Procedures

Electromyography (EMG) was used in this study with superficial bipolar electrodes placed over the vastus medialis oblique and vastus lateralis muscles of the subjects' right legs. Electrode placement for the vastus medialis oblique was determined by palpating the superior border of the patella and moving approximately 2 in. medial and 2 in. proximal of the top of the patella for placement of the bottom electrode. The electrode placement for the vastus lateralis muscle was determined by measuring the distance between the greater trochanter and superior portion of the patella with the knee in full extension. This measured distance was multiplied by one-third and the resulting product was used as the distance from the patella for the bottom electrode placement. For both muscles, the upper electrode placement was such that the interelectrode distance was also 1 in. and the two electrodes were in series with the direction of the muscle fibers.

A common reference electrode was placed on the anterior, proximal tibia. Prior to electrode placement, the sites were prepared by shaving and cleansing with alcohol to reduce impedance at the electrode/skin interface. Silver–silver chloride surface electrodes were used for the EMG recordings along with the Therapist System software and Myodata 1200 hardware from Noraxon. Solderberg and Cook found that silver–silver chloride is the best material for superficial muscle testing using the EMG (14). The unit of measurement with the EMG recordings was microvolts.

Maximum voluntary isometric contractions (MVIC) for the vastus muscles were obtained by performing isometric knee extensions with the knees in full extension. These contractions were monitored using the EMG with above-mentioned software and hardware, and the data were stored for normalization purposes. The technique for providing resistance to the subjects was similar to a leg extension manual muscle test. The subjects were seated with 90° of hip flexion and then instructed to completely extend the right knee. The tester stabilized the right knee with one hand and applied force in the direction of knee flexion on the anterior portion of the tibia immediately proximal to the ankle. Each contraction was held for 5 s.

For the squats, a demonstration of the proper technique was provided to all subjects immediately prior to participation in the study. Subjects were permitted as many practice repetitions as needed until proper form was demonstrated and the subjects felt comfortable with the movement. All subjects learned the movements very quickly and did not demonstrate or mention fatigue. The subjects were verbally instructed to perform the movements at their own pace but in a constant, dynamic fashion and were reminded to not unload or rest at the ends of the ranges of the movements. This individual rate of movement is supported in the study by Wilk et al., who analyzed the squat utilizing the preferred pace (16).

All subjects were instructed to forward flex arms to 90° for balance purposes. The subjects' feet were to remain flat on the floor throughout all squat movements such that the heels did not rise off the floor. The narrow-stance squats were performed first, with knee flexion angles first in the 30° range followed by the 60° and 90° ranges. The wide-stance squats were performed second with the knee flexion angles performed in the same order. Subjects performed one set of three consecutive repetitions for each squat and the three ranges. A rest period of at least 90 s was permitted between each set; Kramer and Fleck found that this rest period is needed to restore muscle adenosine triphosphate/creatine phosphate stores (7).

All subjects removed their shoes prior to testing; the surface was a hard tile floor. For both squat stances, we instructed subjects to find their natural, self-selected foot rotation by rocking back on their heels two times.

Each subject's hip width was measured with a flexible tape measure from the right anterior superior iliac spine (ASIS) to the left ASIS. With the narrow-stance squat, the subject's feet were placed hip-width apart. For each exercise, once the foot position was determined, the subject was then adjusted for knee flexion angles. A chair was placed under the subject's buttocks at a height that permitted the desired angle of knee flexion. If the stool was not sufficient to regulate the height, pillows were added to the seat.

Procedures were similar for the wide-stance squat except the feet were placed a distance apart equal to twice the subject's hip width. The two squat exercises were then analyzed along with knee flexion angles to determine which combination elicited any significant differences of EMG activity for the vastus medialis oblique muscle compared to the vastus lateralis muscle as well as any significant differences between the ranges within each squat.

Statistical Analysis

The Therapist System software and Myosystem 1200 hardware from Noraxon were used for the surface EMG recordings. The Noraxon EMG amplifier is designed to cover a bandwidth (highest and lowest frequencies amplified) of 16–500 Hz (–3 db) with a gain (ability to amplify signal) of 1000. The EMG signal was processed using a full-wave rectified linear envelope with a 15-ms moving average. The signal envelope was quantified by determining the area under the curve that results from envelope processing (14). The process signal was analyzed in the asymmetry, average peaks, and normalized (relative contribution) modes.

The data were normalized by taking the value of the EMG recording represented by the area under the curve and dividing it by the MVIC recording. The ratios were established by dividing the normalized data of the vastus lateralis muscle into the normalized data of the vastus medialis oblique muscle. Percentage MVIC values were established by dividing the average peak value of the MVIC into the average peak value of the movement. The average peak value was set to monitor the 10 highest EMG recordings within each three-repetition squatting movement.

The Statistical Package for the Social Sciences (SPSS), Version 7.5, was used to analyze the data. A 2 (stance; wide, narrow) × 3 (degree; 30°, 60°, 90°) repeated-measures analysis of variance (ANOVA) was used to determine the differential effects that foot placement and knee flexion angles had on the ranges of each squat for the EMG activity levels of the vasti muscles. Since this study is exploratory, alpha was set at the .10 level for the ANOVA. Six a priori, post hoc *t* tests were then used to determine which ranges of the narrow-stance squat (30° vs. 60°, 30° vs. 90°, 60° vs. 90°) and which ranges of the wide-stance squat (30° vs. 60°, 30° vs. 90°, 60° vs. 90°) were significantly different. Alpha was set at the .05 level for each of the six *t* tests to control for family-wise alpha inflation.

Results

Table 1 presents the mean normalized data for the wide-stance squat and narrow-stance squat. This table demonstrates that there was a slight increase in mean normalized VMO:VL ratios for the 30° and 60° ranges when comparing the wide-stance squat to the narrow-stance squat. However, for the 90° range, the narrow-stance squat had a higher mean normalized value than the wide-stance squat.

A 2 × 3 repeated-measures ANOVA was performed to compare the mean normalized VMO:VL ratios across the three ranges of the narrow-stance squat and across the three ranges of the wide-stance squat within all subjects. Significant within-subject differences were found across all ranges of the narrow- and wide-stance squats ($F = 4.039$, $p < .030$).

Due to the significant differences found with the 2 × 3 ANOVA, further analysis was needed to indicate which ranges were significantly different across the narrow- and wide-stance squats. Subsequently, *t* tests were performed and the results are demonstrated in Table 2. For the narrow-stance squats, a significant difference was found between the 30° and 90° movements ($t = 2.934$, $p < .011$). For the wide-stance squats, significant difference was found between 30° and 60° ($t = 3.755$, $p < .002$) as well as 30° and 90° ($t = 2.972$, $p < .010$).

Paired *t* tests were performed to provide comparisons between the narrow-stance squats and wide-stance squats for the three ranges of knee flexion. That is, the narrow-stance squats for 30°, 60°, and 90° were respectively compared to the

Table 1 Mean Normalized Data

Squat movement	Average	*SD*	Minimum	Maximum
NSS 30	0.797	0.333	0.237	1.310
NSS 60	0.928	0.313	0.426	1.690
NSS 90	1.065	0.358	0.636	1.830
WSS 30	0.803	0.292	0.291	1.310
WSS 60	0.969	0.323	0.538	1.750
WSS 90	0.988	0.323	0.596	1.630

Note. NSS = narrow-stance squat; WSS = wide-stance squat.

Table 2 *t* Tests for Specifying Which Ranges Were Significant Within the NSS and WSS

Squats	*SD*	*t*	*p*	Means	Mean difference
NSS30–NSS60	0.327	–1.548	0.144	0.797, 0.928	0.131
NSS30–NSS90	0.352	–2.934	0.011	0.797, 1.060	0.263
NSS60–NSS90	0.262	–2.016	0.063	0.928, 1.060	0.132
WSS30–WSS60	0.171	–3.760	0.002	0.803, 0.967	0.164
WSS30–WSS90	0.242	–2.970	0.010	0.803, 0.988	0.185
WSS60–WSS90	0.115	–0.660	0.520	0.969, 0.988	0.019

Note. NSS = narrow-stance squat; WSS = wide-stance squat.

Table 3 Paired *t* Tests for Comparison of the Three Ranges for NSS and WSS

Squats	*SD*	*t*	*p*	Means	Mean difference
NSS30–WSS30	0.200	–1.060	0.917	0.797, 0.803	0.006
NSS60–WSS60	0.184	–0.857	0.406	0.928, 0.968	0.040
NSS90–WSS90	0.167	1.770	0.098	1.06, 0.988	0.072

Note. NSS = narrow-stance squat; WSS = wide-stance squat.

wide-stance squats for 30°, 60°, and 90°. Mean normalized VMO:VL ratios for the three ranges were used, and no statistical significance was found. The results of these paired *t* tests are presented in Table 3.

Discussion

The purpose of this study was twofold. First, we wanted to see if VMO:VL ratios could be increased by widening the squat stance, and, second, we wanted to see if the vastus medialis oblique activity increases with deeper ranges of knee flexion during a closed kinetic chain activity.

We found no significant differences when comparing the respective ranges of the narrow-stance squat with the wide-stance squat. This may have occurred because the wider stance did not position the vastus medialis oblique muscle in a biomechanically advantageous position relative to the vastus lateralis muscle. It was previously postulated that by widening the stance, the adductors and the vastus medialis oblique would be in a straighter or more direct alignment, creating a biomechanical advantage, and/or the adductors would be stretched, which could further improve alignment of the vastus medialis oblique. Neither of these postulates was found to be true in this study.

Pertaining to the second purpose, significant differences were found. A comparison of the ranges of the squat movements with the two stances revealed significant differences for the 30° versus 90° comparison for the narrow-stance squat and for the 30° versus 60° as well as the 30° versus 90° comparisons for the wide-stance squat. These findings suggest that the vastus medialis oblique may be active throughout the 90° range of knee flexion during the squat. A possible explanation for this can be found in the study by Isear et al. (5), whose data revealed the rectus femoris and hamstring muscles to be more active with deeper ranges during the squat. Biomechanically, the rectus femoris may have a superior lateral pull on the patella as its origin is off of the anterior inferior iliac spine and the superior margin of the acetabulum. Thus, when this muscle becomes more active during the deeper squats, the vastus medialis oblique has to oblige with a concurrent increase in activity to keep the patella in proper alignment. Also, with increased activity of the hamstrings during deeper squats, the thigh extension phase may activate the adductor magnus to assist with thigh extension and subsequently force the vastus medialis oblique to further activate due to their connection.

Figures 1 and 2 are bar representations of the mean EMG activity level of all 15 subjects for the narrow- and wide-stance squats. These figures demonstrate that the VMO:VL ratios do in fact increase with increasing knee flexion angles.

It appears that a common method among therapists and trainers when attempting to strengthen the vastus medialis oblique is to focus on terminal knee

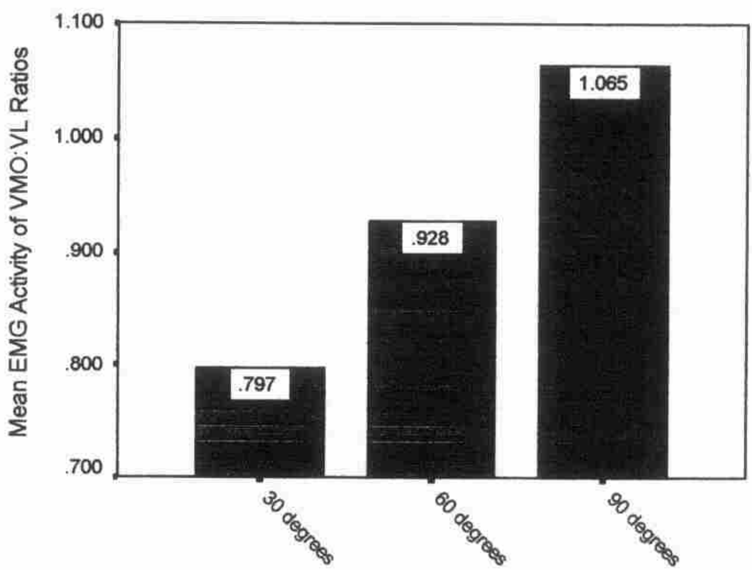

Figure 1 — Bar representation of narrow stance.

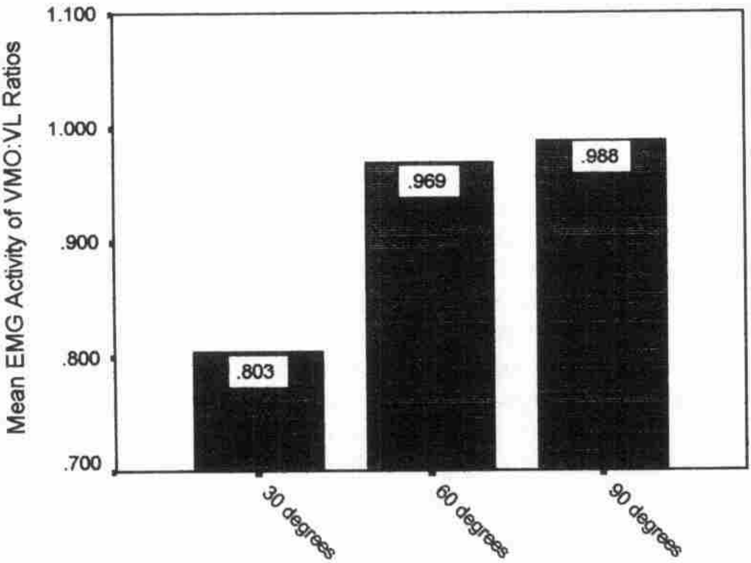

Figure 2 — Bar representation of wide stance.

extension exercises. However, if the vastus medialis oblique is actually more active with increasing knee flexion angles, it makes sense to attempt to strengthen the vastus medialis oblique throughout the increasing knee flexion angles.

The implications of not finding a significantly different VMO:VL ratio with the wide-stance squat will now be discussed. Since we found that the width of the stance during the squat does not alter VMO:VL ratios, then when closed kinetic chain exercises are prescribed, the width of the stance may be determined by the comfort of the patient. That is, it may not make a difference how wide or narrow the stance is for this exercise. However, more research is needed before a generalization of this magnitude can be made. Because this study was performed on healthy, asymptomatic subjects, generalizing the findings to a symptomatic population may be difficult. But, at least for otherwise healthy patients with knee ailments, the width of the stance does not seem to alter the activity of the vastus medialis oblique and vastus lateralis muscles.

The results of this study can have implications for the causes and treatments of knee injuries. For example, Miller et al. used closed kinetic chain exercises with subjects presenting patellofemoral pain syndrome (9). This syndrome is fairly common within physical therapy clinics and can be associated with deficiencies in the balance of the vastus medialis and vastus lateralis muscles. Due to the findings of this study, and other current studies that have found the vastus medialis oblique to be active throughout the range of knee flexion, evaluation and treatment of common knee injuries such as patellofemoral pain syndrome should consider the full range of knee flexion. In other words, since the vastus medialis oblique is reported to be most active at greater ranges, maybe the greater ranges should be targeted for rehabilitation purposes. Of course, other factors such as range of motion and patellofemoral and/or tibiofemoral joint stresses need to be considered.

Comparing this study to current research is difficult, since, to the best of our knowledge, no research has been performed on the relationship of foot width placement during closed chain exercises. Thus, there is no existing literature with which to compare our results. This fact pertains to the first purpose of whether there is a relationship between foot width placement and VMO:VL ratios during closed kinetic chain exercises. However, research has been conducted on the relationship between closed kinetic chain exercises and foot rotation. Although internally, neutrally, or externally rotating the feet may not result in the exact same biomechanical changes as widening or narrowing the foot position during squatting movements, inclusion of foot rotation research is warranted in this discussion, because widening the stance theoretically places tension on the vastus medialis oblique similar to the tension theoretically placed on the vastus medialis oblique with external rotation of the tibia. The second purpose of this study concerns the activity of the vastus medialis oblique during the 90° range of knee flexion during closed kinetic chain exercises, and literature does exist relative to this theory.

Ninos et al. found no significant change in muscle activity levels for the main effect of lower extremity rotation (10). If, in theory, biomechanical similarities do exist between wide-stance squats and externally rotated squats, then our insignificant results are supported by these authors. In terms of the vastus medialis oblique being active throughout the range of knee flexion, we are in concordance. Ninos et al. analyzed squats and described the EMG muscle activity of the vastus medialis oblique and vastus lateralis as percentages relative to the maximum voluntary isometric contraction. The activity of the vastus medialis oblique was approximately 15% at 30° and 25% at 60° of knee flexion, exclusive of foot position. Thus, the activity of the vastus medialis oblique increased with increased knee flexion angles.

Signorile et al. found no significant differences among foot positions for any of the superficial quadriceps during barbell squats (12), just as we found no significant differences with foot width placement and the vasti muscles with the unloaded squat. Of interest, though, was that even though our results were not significant, our data as well as those of Signorile et al. indicated a trend for the vastus medialis oblique to be more active with external rotation or the wide-stance squat. Signorile et al. found higher results for the externally rotated squat, and we found higher results for the wide-stance squat for 30° and 60°. However, Signorile et al. concluded that laterally rotated foot positions did not significantly activate the vastus medialis oblique over the vastus lateralis since no statistically significant differences occurred, but the trend cannot be ignored. In regard to activation of the vastus medialis oblique, it appeared that Signorile et al. did find the vastus medialis oblique to be active throughout the range of motion.

Isear et al. were able to split their squat movements into eccentric and concentric activity and found the vastus medialis oblique to be active throughout the range

(5). Signorile et al. did not modify the squat movement during their study, because they were investigating the concept of hamstring and quadriceps co-contraction during closed kinetic chain activities.

Miller et al. performed closed kinetic chain studies with the lateral step-up and wall slide exercises (9). The degree of knee flexion/extension during the step-ups was not measured but the wall slides were performed from 0° to 75° to 0° of knee flexion. However, mean VMO:VL ratios were presented for only the 0–75° range; thus we were not able to compare our data with these authors' data in reference to vastus medialis oblique and vastus lateralis muscle activity throughout separate ranges. Regardless, further discussion of Miller et al.'s study is warranted.

Although the difference was not significant, Miller et al. did find an increased VMO:VL ratio with the externally rotated positions for the wall slide when compared to the neutral and internally rotated positions. These findings were for the symptomatic group with patellofemoral pain syndrome. The asymptomatic group showed a significant decrease in mean VMO:VL. Two items pertaining to this study are of interest. First, even though the symptomatic group had a nonsignificant increase in VMO:VL ratios, they still had an increase. Second, isometric adduction against a pillow was permitted for the neutral and internally rotated positions but not for the externally rotated position. If isometric adduction had been permitted, the VMO:VL ratio may have been significant. The asymptomatic group showed a decreased VMO:VL ratio with the externally rotated position. However, it is not certain whether this significant decrease would have occurred if isometric adduction had been included with the externally rotated positions. Hanten and Schulthies (4) demonstrated that isometric adduction can increase the VMO:VL ratios with an open kinetic chain exercise, and this phenomenon could possibly occur with closed kinetic chain exercises. Back to the symptomatic group, if isometric adduction had been included and a significant difference resulted, this brings up the possibility that modifications in closed kinetic chain activities may be advantageous only for symptomatic subjects. Thus, future research may be warranted for wide-stance versus narrow-stance squatting movements with patellofemoral pain syndrome subjects.

Hanten and Schulthies found a significant difference between the group means of the vastus medialis oblique and vastus lateralis muscles with the inclusion of hip adduction during isometric open kinetic chain terminal leg extension (4). The authors concluded that "the vastus medialis oblique may be selectively strengthened by performing hip adduction exercises" (4). With the present study, we attempted to see if widening the stance during the squat would increase activity of the vastus medialis. Our results did not support this notion. However, the Hanten and Schulthies study indicates that including an isometric hip adduction contraction rather than just a static stretch may be necessary to further activate the vastus medialis oblique over the vastus lateralis; this is an issue that needs to be investigated.

With this study we did not use stringent controls, as we attempted to modify the squat movement in a simple, functional, and easily reproducible manner. For instance, the amount or angle of dorsiflexion, hip flexion, and leg rotation was not controlled due to our intent to provide a simple and functional exercise that each subject could easily perform. Also, the order of the squat movements was not randomized. All subjects started with the narrow-stance squat and progressed from 30° to 60° and 90° of knee flexion and then proceeded to the wide-stance squat with the same progression of increasing knee flexion angles. The decision to not randomize was made as follows. We felt the primary reason randomization might have been considered necessary was to control for fatigue. We believe that with adequate rest periods between each set and the fact that these movements were easily learned and not physically demanding, random order was not necessary since the subjects were not becoming fatigued. Last, self-selected rotation of the subjects' legs was used in this study. We felt that by permitting the subjects to obtain their natural position of leg rotation, we would be consistent with our intent of analyzing a simple, functional, and easily reproducible movement. We did not want to place the subjects in a forced or unnatural position that could have resulted in a forced or controlled level of leg rotation.

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