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Effects of different squat angles and surface stability on lower limb muscle activation: A surface electromyography study

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ABSTRACT

Background: The squat is a fundamental lower-body exercise that activates key muscles, including the rectus femoris, vastus medialis oblique, biceps femoris, and semitendinosus. Variations in angle and stability may influence muscle activation, though evidence on their combined effects remains limited. Surface electromyography (sEMG) is a reliable method for assessing these responses for training and injury prevention. **Objectives:** This study aimed to investigate the effect of squat angle and the use of a balance dome on lower limb muscle activation using sEMG. **Methods:** A within-subject experimental design with 10 participants examined lower limb muscle activation using surface electromyography (sEMG) during squats at 90° and 120° under stable and unstable conditions. Signals were processed via RMS and MVC normalisation. A two-way repeated-measures ANOVA assessed main and interaction effects, reporting F-values, degrees of freedom (df), and effect sizes (η^2p). Bonferroni-adjusted post hoc tests were applied, with $p < 0.05$ considered significant. **Results:** A repeated-measures design revealed muscle-specific differences in activation across conditions. Quadriceps activation was higher at 90°, while hamstrings were more responsive to instability. Significant effects were observed for VMO ($F(1,9) = 41.201$, $p < 0.01$, $\eta^2p = 0.370$) and biceps femoris ($F(1,9) = 36.720$, $p < 0.01$, $\eta^2 = 0.517$). Overall, squat angle had a stronger influence than stability. **Conclusion:** Preliminary findings indicate squat muscle activation is muscle-specific and condition-dependent. Quadriceps respond to angle and stability, while hamstrings act as stabilisers. Instability alters neuromuscular strategy. Findings should be interpreted cautiously due to the small sample size and limitations of the EMG.

Keywords: Biomechanics; sport; performance; physiotherapy; surface electromyography

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INTRODUCTION

The squat is a fundamental multi-joint exercise widely utilised in biomechanics, involving coordinated movements of the hip, knee, and ankle that produce substantial activation of lower limb muscles and contribute to functional movement performance (Straub & Powers, 2024). Recent evidence indicates that squat exercises effectively recruit major muscle groups such as the quadriceps, hamstrings, and gluteus maximus, with activation patterns influenced by variations in movement execution and loading condition (Yavuz & Erdag, 2017). Moreover, squat training plays a critical role in enhancing athletic performance and functional capacity and is widely applied in rehabilitation to improve joint stability and neuromuscular control (Gene-Morales et al., 2020). However, emerging studies indicate that neuromuscular responses during squat exercises are highly sensitive to variations in technique and external conditions, underscoring the need for more precise investigation of muscle activation across different squat parameters (Chagas et al., 2024).

Surface electromyography (sEMG) has become a widely adopted method for assessing neuromuscular activity during dynamic exercises, providing objective insights into muscle activation patterns under varying movement conditions (Farina et al., 2016). In the context of squat exercises, variations in knee angle have been shown to significantly influence muscle recruitment, with deeper squat positions generally eliciting greater activation of the gluteus maximus and quadriceps due to increased mechanical demand and joint loading (Kubo et al., 2019). Additionally, performing squats on unstable surfaces, such as balance dome devices, introduces greater neuromuscular challenges by requiring enhanced postural control and joint stabilisation, which may alter muscle activation strategies compared to stable conditions (Aslam et al., 2025). However, despite growing interest in these variables, the combined effects of squat angle and surface instability on lower limb muscle activation remain insufficiently understood, particularly when examined simultaneously using sEMG.

Although numerous studies have examined muscle activation during squat exercises, most have focused on isolated variables, such as squat depth or surface instability, rather than investigating their combined effects (Aslam et al., 2025; Kubo et al., 2019). This fragmented approach limits a comprehensive understanding of how multiple biomechanical and neuromuscular factors interact during functional movements. Furthermore, existing findings remain inconclusive regarding the relative contributions of key muscle groups, particularly the hamstrings and quadriceps, across varying squat conditions, with some studies reporting greater quadriceps dominance and others suggesting increased posterior chain involvement depending on technique and external demands (Yavuz & Erdag, 2017). Consequently, there is a clear need for integrated investigations that simultaneously examine squat angle and surface stability to better understand their combined influence on lower limb muscle activation patterns.

Given these limitations, the present study aims to investigate the combined effects of different squat angles and surface stability on lower-limb muscle activation using surface electromyography (sEMG). Specifically, this study examines neuromuscular responses of key muscle groups, including the quadriceps and hamstrings, under stable and unstable conditions at varying knee angles. Unlike previous studies, which primarily examined squat depth or surface instability as separate variables (Aslam et al., 2025; Kubo et al., 2019; Yavuz & Erdag, 2017), only a limited number of studies have investigated the combined effects of both on lower limb muscle activation within a single experimental framework. In particular, the interaction between knee angle and surface stability using sEMG remains under-explored. Therefore, this study adopts an integrated approach to analyse how biomechanical (knee angle) and environmental (surface stability) factors interact within a controlled repeated-measure design.

METHOD

Participants

The sample size (n = 10 participants) was determined based on both practical considerations and methodological justification. In surface electromyography (sEMG) studies employing repeated-measures designs, relatively small sample sizes are commonly accepted due to reduced inter-subject variability and increased statistical power within subjects (Cappellini et al., 2020). Previous EMG-based squat studies have also utilised similar sample sizes ranging from 8 to 10 participants while still detecting significant differences in muscle activation (Marchetti et al., 2016; Yavuz & Erdag, 2017).

An a priori power analysis was conducted using a two-way repeated-measures ANOVA, a commonly recommended approach for sample size determination in biomechanics research McCrum et al. (2022) for sample size justifications in gait & posture. Previous EMG-based squat studies have also used a priori power analysis to determine adequate sample sizes in within-subject designs van den Tillaar and Hope (2023) for EMG and squat repetition studies. A moderate effect size (f = 0.25) was assumed based on conventional benchmarks for behavioural and experimental research Lakens (2022) with an alpha level of 0.05 and a desired statistical power of 0.80. The analysis indicated that 10 participants would be sufficient. The resulting degrees of freedom were $df_1 = 1$ and $df_2 = 9$, with an actual power of 0.81.

The participants consisted of 10 males, with an average age of 19.2 ± 1.03 years, height of 169 ± 4.69 centimetres, body weight of 58.7 ± 4.11 kilograms, and a body mass index of 20.60 ± 1.96 (normal weight category). Inclusion criteria were healthy young adults, physically active, with no history of lower limb injury or musculoskeletal disorders in the past six months. Exclusion criteria included: no presence of neuromuscular disorders, current pain or injury, and the ability to perform squat movements properly. All participants were in good health condition at the time of testing.

The health research ethics committee of Semarang State University approved the research protocol. It was guided by operational standards and guidelines for ethical reviews of human participant research from WHO (2011) and international ethical guidelines for health-related research involving humans from CIOMS and WHO (2016), with ethical clearance number 218/KEPK/EC/2021.

Instrument

The instruments used in this study were a surface electromyography system and a goniometer. Muscle activity was recorded using a wireless surface electromyography system (Noraxon Ultium EMG System; Noraxon Inc., Scottsdale, AZ, USA). Disposable Ag/AgCl surface electrodes were placed on the skin over the target muscles following the Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) guidelines. Prior to electrode placement, the skin was shaved, lightly abraded, and cleaned with alcohol to reduce skin impedance.

Figure 1. Noraxon Ultium EMG System; Noraxon Inc., Scottsdale, AZ, USA & Ag/AgCl Surface Electrodes

Figure 2. Participants Performed Squat Trials Under Four Conditions : 90º Stable (A), 90º Unstable (B), 120º Stable (C), and 120º Unstable (D). Each Trial was Conducted Across Increasing Force Levels (20–100%), with A 1-Minute Rest Between Conditions and No External Feedback Provided.

The EMG signals were sampled at 1500 Hz and processed using Noraxon MyoResearch software. Raw EMG signals were filtered using a band-pass filter (20-450 Hz) to remove movement artefacts and high-frequency noise. The root-mean-square (RMS) values were then calculated to quantify muscle activation. A 3600 ISOM goniometer was used to measure the knee joint angle to ensure the squat positions at 90° and 120°. Before the measurement session, participants performed a standardised warm-up and were familiarised with the squat movement. Each participant performed three trials of squat contractions lasting 10 seconds for each condition, with a 3-second familiarisation set prior to the trials, following the protocol described by (Marchetti et al., 2016).

The use of Noraxon electromyography (EMG) begins with subject preparation to ensure signal quality, specifically by cleaning the skin of sweat and oil and, if necessary, shaving hair to reduce impedance. Electrodes are then placed on the target muscle using two active electrodes and one ground electrode, aligned with the muscle fibres on the muscle belly at a distance of ± 2 cm. Next, the system is connected to the Noraxon MyoResearch software for subject setup and protocol configuration. Once the sensors are connected, calibration is performed to ensure signal quality and obtain a baseline while the subject is at rest..

EMG data were normalised to the maximum voluntary contraction (% MVC). MVC was obtained through maximal voluntary isometric contraction (MVIC) during knee extension at approximately 60° of knee flexion, as this method provides a reliable and standardised reference for normalisation of quadriceps muscle activity. Participants were instructed to exert maximal effort against resistance for 5 seconds, and the highest RMS value recorded was used as the reference for normalisation.

Experimental Procedure

Participants performed squat trials under four conditions: 90° stable, 90° unstable, 120° stable, and 120° unstable (using a balance dome). Each participant completed three trials per condition, with each trial lasting 10 seconds. A standardised warm-up and familiarisation session was conducted prior to testing. A 3-second pre-contraction phase was included before each trial. A 1-minute rest interval was provided between conditions to minimise fatigue. No external feedback was given during the trials to ensure natural movement execution.

Data Processing

EMG signals were sampled at 1500 Hz and processed using Noraxon MyoResearch software. Raw signals were filtered using a band-pass filter (20-450 Hz) to remove motion artefacts and noise. The signals were then smoothed using a moving-window technique, and muscle activation was quantified using the root mean square (RMS) over a 100 ms window. All EMG data were normalised to the maximum voluntary contraction (% MVC) to allow comparison across participants.

Data Analysis

The RMS values obtained from the sEMG signals were statistically analysed using repeated measures analysis of variance (ANOVA) to determine differences in muscle activation across squat angles (90° and 120°) and surface conditions (with and without a balance dome). When significant effects were identified, paired t-tests were performed as post-hoc analyses to determine specific differences between conditions. Statistical significance was set at $p < 0.05$. The sEMG signals were processed using a band-pass filter (20-450 Hz) to remove movement artefacts and high-frequency noise. The filtered signals were then smoothed using a moving-window technique, and muscle activation was quantified as the root mean square (RMS) over a 100 ms time window. The RMS value was calculated using the following formula:

$$RMS = \sqrt{\frac{\sum_{n-1}^{N} x_n^2}{n}}$$

Where x_n represents the EMG signal amplitude and n represents the number of samples within the analysis window.

RESULTS AND DISCUSSION

Result

The rectus femoris demonstrated greater activation at the 90° squat angle compared to 120°, with a value of 17.07 ± 3.45 (90° stable) and increased to 20.17 ± 2.40 at 90° unstable. Activation then decreased at the 120° angle, namely 13.22 ± 3.08 (stable), and increased slightly in the unstable condition (14.18 ± 4.16).

In the vastus medialis oblique (VMO), a pattern of decreasing activation was observed as the squat angle increased. Activation values at 90° were relatively similar between stable (12.34 ± 3.21) and unstable (12.51 ± 3.14) conditions but decreased at 120° to 7.51 ± 2.04 (stable) and 8.53 ± 2.40 (unstable).

For the biceps femoris, the highest activation was found in the 90° unstable condition (24.27 ± 3.23), compared to the 90° stable condition (19.67 ± 3.93). At a 120° angle, activation decreased in the stable condition (13.95 ± 3.32) but increased again in the unstable condition (18.53 ± 2.56).

Meanwhile, the semitendinosus muscle exhibited a relatively consistent pattern, with greater activation under unstable conditions than under stable conditions at both angles. The recorded activation values were 14.17 ± 3.40 (90° stable) and increased to 17.42 ± 3.35 (90° unstable), as well as 10.49 ± 2.40 (120° stable) and 13.32 ± 2.45 (120° unstable).

Overall, the quadriceps muscles (rectus femoris and VMO) tended to show higher activation at 90°. In contrast, the hamstring muscles (biceps femoris and semitendinosus) showed a more variable response to changes in stability conditions, with a tendency toward increased activation under unstable conditions. Can be seen in **Table 1**.

Table 1. RMS Values (%MVC) Under Various Squat Conditions

Muscle	RMS values in the squat position Mean ± SD			
	90° Stable	90° Unstable	120° Stable	120° Unstable
Rectus Femoris	17.07 ± 3.45	20.17 ± 2.40	13.22 ± 3.08	14.18 ± 4.16
Vastus Medialis Oblique	12.34 ± 3.21	12.51 ± 3.14	7.51 ± 2.04	8.53 ± 2.40
Biceps Femoris	19.67 ± 3.93	24.27 ± 3.23	13.95 ± 3.32	18.53 ± 2.56
Semitendinosus	14.17 ± 3.40	17.42 ± 3.35	10.49 ± 2.40	13.32 ± 2.45

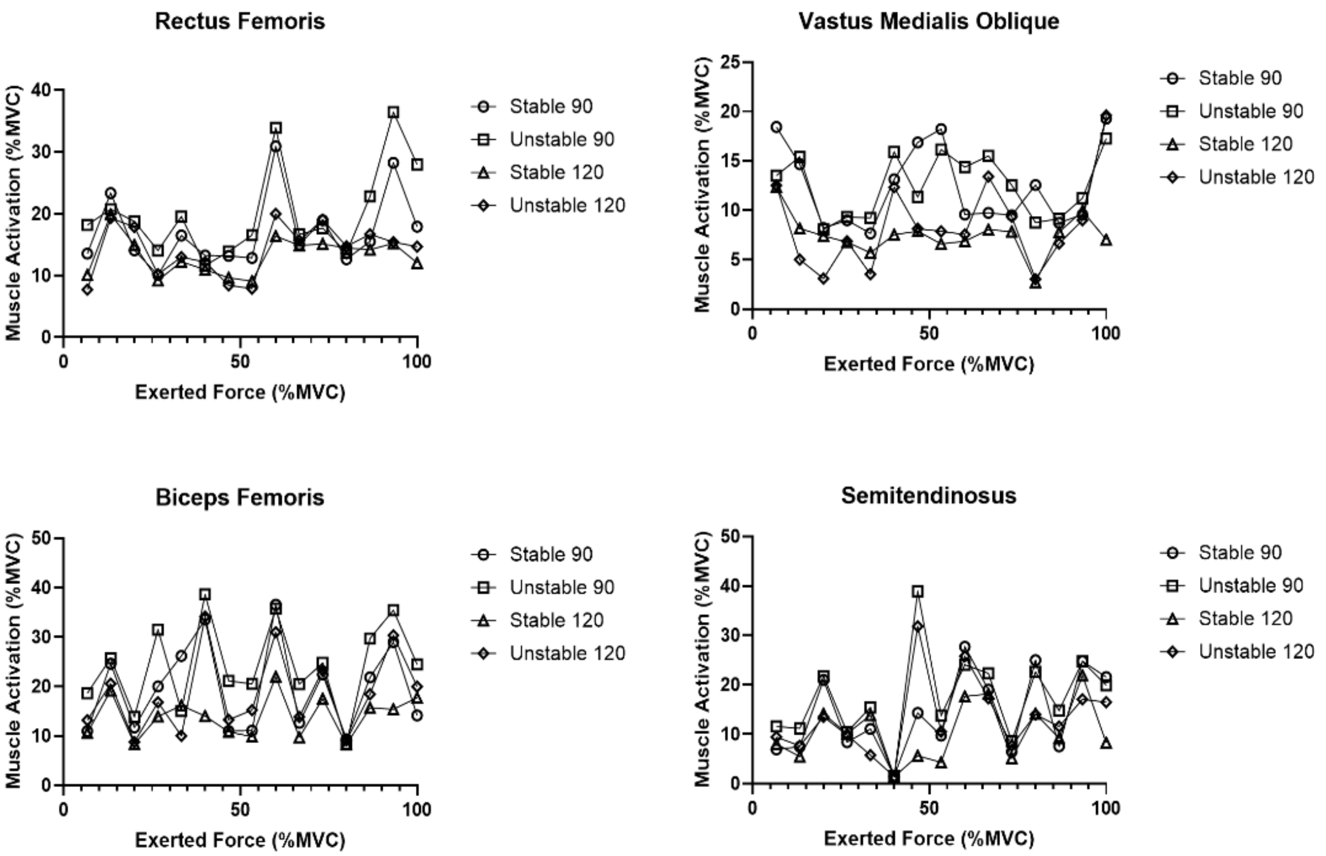

Figure 3. Multi-Panel Line Graphs Showing Muscle Activation (%MVC) Across Varying Force Levels under Different Squat Conditions. Each Subplot Represents a Specific Muscle Group. The X-Axis Indicates Exerted Force Levels (20-100% MVC), And The Y-Axis Represents Muscle Activation Normalized to Maximum Voluntary Contraction (%MVC). Line Styles Distinguish between Stable and Unstable Conditions at 90° and 120° Knee Flexion.

The EMG force relationship demonstrated muscle-specific activation patterns with distinct slopes across conditions. In the rectus femoris, activation increased with exerted force in all conditions, indicating a positive EMG force relationship. However, the slope of increase was moderate and tended to plateau at mid-range force levels (around 60%), particularly under unstable conditions, suggesting a limited sensitivity to higher mechanical demand.

The vastus medialis oblique (VMO) exhibited the steepest EMG force slope among all muscles, indicating a strong and progressive increase in activation with increasing force. This trend was especially pronounced under unstable conditions at higher force levels (80-100%), where activation sharply increased. The steeper slope reflects a greater neuromuscular responsiveness to both increased torque demand and postural instability.

In contrast, the biceps femoris showed a relatively shallow EMG force slope, with only a modest increase in activation as force increased. Activation tended to peak at moderate force levels and to decline slightly at higher intensities, particularly under unstable conditions, indicating a nonlinear response and a reduced contribution to force production.

Similarly, the semitendinosus showed a flat EMG-force relationship, with minimal changes in activation across all force levels and conditions. The low slope indicates a stable activation pattern, suggesting a limited role in adapting to increased mechanical demand.

From a biomechanical perspective, these findings indicate that the quadriceps muscles, particularly the VMO, are highly sensitive to increases in force and instability, reflecting their primary role in producing knee joint torque. Additionally, the altered slopes under unstable conditions suggest a shift in neuromuscular strategy, where the system prioritizes joint stability and postural control over maximal force output.

Table 2. Results of Two-Way ANOVA with Effect Sizes (η^2)

Muscle	Effect	df_1	df_2	F	*Sig. (p)*	η^2
Rectus Femoris	Angle	1	9	13.035	.003***	.482
	Stability	1	9	13.426	.003***	.490
	Interaction	1	9	4.593	.050*	.247
Vastus Medialis Oblique	Angle	1	9	41.201	.001***	.370
	Stability	1	9	20.731	.050*	.207
	Interaction	1	9	10.409	.028**	.333
Biceps Femoris	Angle	1	9	36.720	.002***	.517
	Stability	1	9	12.897	.000***	.344
	Interaction	1	9	22.336	.000***	.289
Semitendinosus	Angle	1	9	21.212	.000***	.221
	Stability	1	9	3.209	.044*	.186
	Interaction	1	9	2.439	.006**	.383

In general, most of the effects showed significant results ($p < 0.05$), indicating that squat angle and surface conditions influence lower-limb muscle activation. In general, it was found that knee angle and surface stability had a significant effect on lower limb muscle activation, both independently and through their interaction. For the rectus femoris muscle, there were significant main effects of angle ($F(1,9) = 13.035$, $p = .003$, $\eta^2 = .482$) and stability ($F(1,9) = 13.426$, $p = .003$, $\eta^2 = .490$), as well as an interaction effect at the borderline of significance ($F(1,9) = 4.593$, $p = .050$, $\eta^2 = .247$), indicating that the influence of surface condition tends to depend on the squat angle.

For the vastus medialis oblique muscle, the angle effect showed a very strong influence ($F(1,9) = 41.201$, $p = .001$, $\eta^2 = .370$), followed by the stability effect ($F(1,9) = 20.731$, $p = .050$, $\eta^2 = .207$) and a significant interaction ($F(1,9) = 10.409$, $p = .028$, $\eta^2 = .333$). This indicates that VMO activation is strongly influenced by changes in knee angle as well as the combination of angle and surface condition.

In the hamstring muscle group, specifically the biceps femoris, significant effects of angle ($F = 36.720$, $p = .002$, $\eta^2 = .517$) and stability ($F = 12.897$, $p < .001$, $\eta^2 = .344$) were found, as well as a significant interaction ($F = 22.336$, $p < .001$, $\eta^2 = .289$). Meanwhile, in the semitendinosus, significant effects of angle ($F = 21.212$, $p < .001$, $\eta^2 = .221$) and stability ($F = 3.209$, $p = .044$, $\eta^2 = .186$) were also significant, with a significant interaction ($F = 2.439$, $p = .006$, $\eta^2 = .383$).

Overall, these results indicate that muscle activation is influenced not only by knee angle or surface conditions individually, but also by their interaction. Squat angle consistently exerts a strong influence on muscle activation, while surface conditions provide an additional effect that varies across muscles. These findings confirm that the neuromuscular response during squats is complex and depends on a combination of biomechanical and stability factors.

Table 3. Bonferroni-Adjusted Paired Comparisons of Normalized Lower Limb Muscle Activation (%MVC) Across Squat Angle and Stability Conditions

Muscle	Comparison	*t*	*df*	*p*	Significance
Rectus Femoris	90° Stable vs 90° Unstable	-3.30	9	.005***	0.0125
	120° Stable vs 120° Unstable	-1.99	9	.066*	
	90° Stable vs 120° Stable	3.27	9	.005***	
	90° Unstable vs 120° Unstable	3.55	9	.003***	
Vastus Medialis Oblique	90° Stable vs 90° Unstable	-.203	9	.842	0.0125
	120° Stable vs 120° Unstable	-.969	9	.349	
	90° Stable vs 120° Stable	4.45	9	.001***	
	90° Unstable vs 120° Unstable	4.96	9	.000***	
Biceps Femoris	90° Stable vs 90° Unstable	-2.98	9	.010***	0.0125
	120° Stable vs 120° Unstable	-2.83	9	.013***	
	90° Stable vs 120° Stable	3.52	9	.003***	
	90° Unstable vs 120° Unstable	6.15	9	.000***	
Semitendinosus	90° Stable vs 90° Unstable	-1.91	9	.076*	0.0125
	120° Stable vs 120° Unstable	-1.41	9	.180	
	90° Stable vs 120° Stable	2.76	9	.015**	

Muscle	Comparison	*t*	*df*	*p*	Significance
	90° Unstable vs 120° Unstable	4.57	9	.000***	

Significance level adjusted using Bonferroni correction (α = 0.0125).

The results of paired comparisons with Bonferroni correction (α = 0.0125) revealed specific patterns of muscle activation differences across squat conditions. In the rectus femoris muscle, there were significant differences between the 90° stable and 90° unstable conditions (t(9) = -3.30, p = .005), as well as between 90° stable and 120° stable (t(9) = 3.27, p = .005) and between the 90° unstable and 120° unstable conditions (t(9) = 3.55, p = .003). However, the comparison between the 120° stable and 120° unstable conditions did not show a significant difference after correction (p = .066).

For the vastus medialis oblique (VMO), no significant differences were found between the stable and unstable conditions at either 90° (p = .842) or 120° (p = .349). Conversely, significant differences were found between squat angles, specifically between 90° stable and 120° stable (t(9) = 4.45, p = .001) and between 90° unstable and 120° unstable (t(9) = 4.96, p < .001), indicating the dominance of angle over stability.

For the biceps femoris, all comparisons showed significant results after Bonferroni correction, including between 90° stable and 90° unstable (t(9) = -2.98, p = .010), 90° stable and 120° stable (t(9) = 3.52, p = .003), and 90° unstable and 120° unstable (t(9) = 6.15, p < .001). Meanwhile, the comparison between 120° stable and 120° unstable (p = .013) was slightly above the corrected significance threshold and was therefore not considered statistically significant.

For the semitendinosus, no significant differences were found between the stable and unstable conditions at either 90° (p = .076) or 120° (p = .180). The difference between the 90° stable and 120° stable conditions (p = .015) also did not meet the criteria for significance after Bonferroni correction. However, the comparison between the 90° unstable and 120° unstable conditions showed a significant difference (t(9) = 4.57, p < .001).

Overall, these results indicate that the effect of squat angle is more consistent in influencing muscle activation compared to stability conditions. Additionally, the hamstring muscles, particularly the biceps femoris, exhibit greater sensitivity to changes in conditions compared to the quadriceps muscles.

Discussion

The findings of this study demonstrate that both knee joint angle and surface stability significantly influence muscle activation during squat exercises. In particular, the quadriceps muscles showed greater activation at 90° compared to 120°, indicating that deeper squat positions increase the mechanical demand on the knee extensors. From a biomechanical perspective, increased knee flexion enlarges the moment arm at the knee joint, thereby requiring greater extensor torque to control the descent and maintain joint stability. This interpretation is consistent with recent evidence showing that squat depth is positively associated with quadriceps activation and knee joint loading (Kubo et al., 2019; Straub & Powers, 2024). More recent analyses also confirm that deeper squat angles increase patellofemoral joint stress and extensor demand, reinforcing the role of quadriceps in load management during functional tasks (Escamilla et al., 2025; Gheidi et al., 2025).

Among the quadriceps, the vastus medialis oblique (VMO) exhibited the most pronounced response to changes in squat angle. The higher activation observed at 90° suggests that the VMO plays a critical role in stabilising the patella and maintaining knee alignment under increased mechanical load. This is supported by contemporary studies indicating that VMO activation is closely linked to knee joint stabilisation and is particularly sensitive to changes in joint angle and loading conditions (Chang et al., 2015; Gene-Morales et al., 2020; Yavuz & Erdag, 2017). Recent EMG-based investigations further highlight that selective activation of the VMO is essential for maintaining medial patellar tracking, especially during high-demand tasks such as deep squats and dynamic movements.

In contrast, the hamstring muscles demonstrated a different activation strategy, particularly under unstable conditions. Both the biceps femoris and semitendinosus showed relatively greater activation when instability was introduced, suggesting an increased role in joint stabilisation rather than force production. This aligns with recent findings showing that unstable surfaces increase neuromuscular demands, leading to enhanced co-contraction around the knee joint to maintain postural control (Aslam et al., 2025; Horsak et al., 2015; Xiao et al., 2026). Additional studies in the past decade have reported that instability training shifts muscle function toward stabilisation by increasing proprioceptive demands and motor unit synchronisation, rather than simply increasing activation magnitude.

The EMG–force relationship observed in this study further supports the presence of muscle-specific neuromuscular strategies. The VMO exhibited a steep activation slope with increasing force levels, reflecting its dominant role in generating knee extensor torque. In contrast, the hamstrings showed a relatively flatter activation profile, indicating a stabilising function across varying force demands. This distinction is consistent with recent neuromuscular control models suggesting that the central nervous system distributes muscle activation based on functional roles within the kinetic chain rather than uniformly scaling activation with force (Nimphius et al., 2019).

Furthermore, the significant interaction between squat angle and surface stability highlights the combined influence of mechanical and postural demands on muscle recruitment. Changes in joint angle primarily affect biomechanical loading, whereas instability introduces additional demands on balance and coordination. Recent integrative studies emphasise that these factors do not operate independently but interact to shape movement strategies, particularly in multi-joint exercises such as the squat (Chagas et al., 2024).

While surface electromyography (sEMG) measurements may be influenced by factors such as electrode placement, signal variability, and movement artefacts, standardised preparation and processing protocols were implemented in accordance with established guidelines to enhance signal reliability. Recent literature indicates that, when properly controlled, sEMG provides valid and reliable estimates of muscle activation during dynamic tasks (Fuentes del Toro & Aranda-Ruiz, 2025). Therefore, the observed activation patterns are likely to reflect meaningful neuromuscular responses rather than methodological artefacts.

CONCLUSION

Preliminary findings from this study suggest that muscle activation during squats is muscle-specific and influenced by task conditions. The quadriceps muscles, particularly the vastus medialis oblique (VMO), tend to be more responsive to changes in knee angle and stability, indicating a key role in force production and knee joint stabilisation. In contrast, the hamstring muscles (biceps femoris and semitendinosus) exhibit a relatively more consistent activation pattern, which may reflect their role in maintaining postural control and balance rather than acting as primary force generators.

Furthermore, unstable conditions do not consistently increase muscle activation; rather, they appear to alter neuromuscular strategies, in which the nervous system may prioritise stability over maximal force production. Overall, these findings suggest that the interaction between mechanical demands and the complexity of neuromuscular control influences muscle activation during squats. However, further research with larger sample sizes is needed to confirm these observations. These preliminary results should be interpreted with caution, given the limited sample size and the inherent variability of surface electromyography (sEMG) measurements, including potential signal noise and device-related limitations.

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