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Kinesiological Analysis of Quadriceps and Hamstring Muscle Activation During the Single-Leg Squat Test in Healthy Non-exercising Individuals

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Abstract

Background: Surface electromyography (sEMG) is a reliable, non-invasive method for evaluating muscle activation during functional tasks. The Single-Leg Squat Test (SLST) is commonly used to assess lower-limb neuromuscular control and knee stability. However, normative electromyographic data for quadriceps and hamstring muscle activation in healthy non-exercising adults are limited. Establishing baseline values is important for comparison with physically active populations such as recreational and elite runners.

Objective: This study aims to analyze the activation patterns of the quadriceps and hamstring muscles during the SLST in healthy, non-exercising adults using sEMG.

Methods: This descriptive cross-sectional study included 22 healthy, non-exercising male adults aged 31-50 years. sEMG using the Delsys Trigno Discover Wireless EMG System was employed to record normalized muscle activation (%MVIC, maximum voluntary isometric contraction) of the quadriceps muscle (VMO (vastus medialis oblique) and VL (vastus lateralis)) and hamstring muscles (BF (biceps femoris) and ST (semitendinosus)) during the lowering and rising phases of the SLST. MVIC was recorded for normalization, and maximum isometric strength of the quadriceps and hamstrings was measured using a Kinvent Push-Pull Dynamometer (Kinvent Biomecanique, Montpellier, France). Descriptive statistics (mean, standard deviation, and median) were used for data analysis.

Results: Quadriceps muscles demonstrated greater activation than hamstring muscles during the SLST. During the lowering phase, the mean normalized activation (%MVIC) was 86.18 ± 32.73 for VMO, 83.05 ± 28.30 for VL, 34.73 ± 24.29 for BF, and 26.09 ± 13.99 for ST. During the rising phase, activation increased to 126.04 ± 50.13 for VMO and 125.00 ± 40.60 for VL, while BF and ST activation decreased to 22.55 ± 11.55 and 18.22 ± 8.05, respectively. The mean maximum isometric strength was 31.68 kg for the quadriceps and 24.09 kg for the hamstrings.

Conclusion: Healthy, non-exercising adults exhibit distinct neuromuscular activation patterns during the SLST, with significantly greater quadriceps activation during the rising phase and relatively greater hamstring activation during the lowering phase. These findings provide normative sEMG reference values that may be useful for comparison with recreational runners, elite runners, and individuals undergoing lower-limb rehabilitation.

Categories: Sports Medicine, Physical Medicine & Rehabilitation, Orthopedics
Keywords: hamstrings, healthy adults, kinesiology, muscle activation, mvic, quadriceps, single-leg squat test, surface electromyography

Introduction

Promoting public health remains a key priority for policymakers [1]. This priority has gained increasing significance in view of the rising prevalence of health conditions associated with sedentary behavior and lifestyle-related factors [2]. Regular engagement in physical activity is an important component of maintaining good health and can help reduce the likelihood of developing chronic health conditions [3]. In India, noncommunicable diseases (NCDs) constitute a major public health concern, and maintaining adequate levels of physical activity may play an important role in reducing the risk of these diseases [4]. Conversely, physical inactivity has emerged as a major global health challenge, placing a considerable burden on healthcare systems and economies. Evidence from various studies indicates that insufficient physical activity is associated with a greater likelihood of developing NCDs. Moreover, low levels of physical activity may negatively influence psychological well-being and diminish overall quality of life [5,6].

Regular aerobic activities, such as running, have demonstrated beneficial effects on multiple physiological systems and may contribute to improved health outcomes by reducing chronic disease burden and cardiometabolic risk [7]. The World Health Organization (WHO) recommends that adults undertake at least 150 minutes of moderate-intensity aerobic activity or 75 minutes of vigorous-intensity aerobic activity per week. Physical activity refers to any movement of the body generated by skeletal muscles that increases energy expenditure beyond resting levels and supports the preservation and enhancement of overall health [5,8,9].

Adequate muscular strength is important for achieving optimal physical performance and may also contribute to lowering the risk of injury [10,11]. Squat-based exercises form an integral component of many knee rehabilitation programs. The squat movement closely resembles several functional activities encountered in daily life, including stair climbing, sitting, standing, running, and hopping. Unilateral closed-kinetic-chain exercises are increasingly being utilized as part of knee rehabilitation programs and conditioning programs because they impose relatively lower shear forces on the knee joint than open-chain exercises while closely replicating weight-bearing functional movements [12]. Therefore, the single-leg squat (SLS) has been incorporated into strength-training programs and clinical practice to provide task-specific training for single-leg, weight-bearing activities [13].

Surface electromyography (sEMG) is a non-invasive method that facilitates the quantitative evaluation of the activation of individual superficial muscles during functional tasks, providing detailed information about muscle recruitment patterns [14,15]. sEMG can measure muscle activation across an entire muscle group as well as within individual muscle bellies, allowing for a more comprehensive evaluation of muscle activity [16]. The authors propose that reduced activity of the quadriceps and hamstrings may affect the function of adjacent muscles, whereas greater muscle activation may contribute to a lower risk of injury [17]. Thus, it is essential to determine the muscle activation and recruitment of the quadriceps and hamstring muscles of non-exercising individuals to evaluate the status of activation of their muscles during a single-leg squat test (SLST), which will be useful as a baseline measure before evaluating physically active individuals, such as recreational runners and elite runners, who are already engaged in regular running and fitness programs and have self-controlled strength and activity of quadriceps and hamstring muscles.

Materials And Methods

Materials

The equipment used in the study included the Delsys Trigno Discover Wireless EMG system (Delsys Inc., Natick, MA, USA), containing Trigno Avanti Wireless EMG Sensors, Trigno Discover Software (version 2.1) Trigno Base Station, adhesive sensor interfaces, and Delsys EMGworks analysis software (version 4.8.1; Delsys Inc., Natick, MA, USA), as shown in Figure *1*.



FIGURE 1: Delsys Trigno Discover Wireless EMG system

A Kinvent Push-Pull Dynamometer (Kinvent Biomecanique, Montpellier, France) was used to record maximum isometric strength (MIS) of quadriceps and hamstring muscles, as shown in Figure *2*.



FIGURE 2: Kinvent Push-Pull Dynamometer

Methodology

A total of 22 non-exercising individuals participated in the study. All participants were males aged 31-50 years, below 90 kg bodyweight, and not undergoing any form of physical exercise. Participants who were unable to maintain a single-leg stance for 30 seconds while keeping the pelvis level and the trunk upright and having a strength of hip abductors < 4/5 were excluded from the study.

Protocol of the Study

Prior to data collection, ethical approval was obtained from the Protocol Review Committee (PRC) and Institutional Ethics Committee (IEC) of Krishna Institute of Medical Sciences (KIMS). Participants were screened according to the predefined inclusion and exclusion criteria. The study procedures were explained to each participant in a language they could understand. Written informed consent was obtained from all participants before enrollment in the study. Baseline demographic characteristics, including age, sex, height, body weight, and body mass index (BMI), were subsequently recorded.

Following completion of the screening procedure, participants were familiarized with the evidence-based SLST protocol. Testing was performed on the dominant lower limb of each participant. Dominancy was assessed by asking the participant to imagine kicking a ball. The limb that was used first to perform the action was considered the dominant limb [18-20]. Participants were individually assessed for their ability to maintain a single-leg stance for 30 seconds while maintaining a level pelvis and a neutral trunk position [20].

Maximum voluntary isometric contraction (MVIC) assessment was conducted for the quadriceps muscle (VMO (vastus medialis oblique) and VL (vastus lateralis)) and hamstring muscle (BF (biceps femoris) and ST (semitendinosus)) using a Delsys Trigno Discover Wireless sEMG system with Trigno Avanti Wireless sensors. Simultaneously, maximal isometric strength of the quadriceps and hamstring muscle groups was determined with a standardized Kinvent Push-Pull Dynamometer (software-based) to obtain reference values of MIS in specified positions. Three trials were taken, and the highest score was used to calculate normalized amplitude percentage (%) using EMGworks Analysis software for both muscles, and peak isometric strength was recorded in kilograms [20-22].

Participants were instructed to perform the SLST protocol for 2-3 minutes until they felt comfortable with it. Before data acquisition, the skin over the designated sEMG electrode sites was shaved and cleansed with an alcohol swab to improve electrode adhesion and facilitate optimal signal conduction. All participants performed a 5-minute warm-up on a stationary bicycle at a self-selected speed before testing [23-25].

sEMG activity was captured using the Trigno Discover Wireless EMG System with Trigno Avanti wireless sensors. The Trigno Avanti sensor placement and acquisition procedures followed the manufacturer's

recommendations and established surface EMG guidelines [20,26,27]. sEMG data were collected at a sampling rate of 1259 Hz and a bandwidth of 20-450 Hz using the Delsys Trigno Discover Wireless EMG Biofeedback System. The EMGworks Analysis Software system facilitated normalization of recorded amplitude against MVIC values of the sampled muscles, calculated as a percentage (%) [27].

Assessment of MVIC

Quadriceps femoris (VMO and VL): The quadriceps femoris muscle MVIC was assessed in a high-sitting position, with the hip positioned at 90° flexion and the knee at 60° flexion. Trigno Avanti Wireless EMG sensors were placed on the VMO and VL muscle belly. The trunk remained upright, while the arms were crossed over the chest to reduce compensatory movements during MVIC assessment. Knee extension was resisted using a Kinvent Push-Pull Dynamometer, with maximal isometric resistance maintained for 5 seconds. Three MVIC trials were conducted, with the highest recorded value used to calculate the normalized amplitude percentage (%) of the quadriceps muscles (VMO and VL) using EMGworks Analysis software. MIS was measured in kilograms, as illustrated in Figure *3* [28,29].



FIGURE 3: MVIC testing of the quadriceps (VMO and VL) muscles along with maximum isometric strength measurement with Kinvent Push-Pull Dynamometer

Trigno Avanti wireless EMG sensors placed on the VMO and VL muscle belly.

Kinvent Push-Pull Dynamometer attached to the distal 1/3rd of the leg for maximum isometric strength testing.

Recording of MVIC of quadriceps (VMO and VL) muscles was done using Trigno Discover Software version 2.1, as shown in Figure *4*.

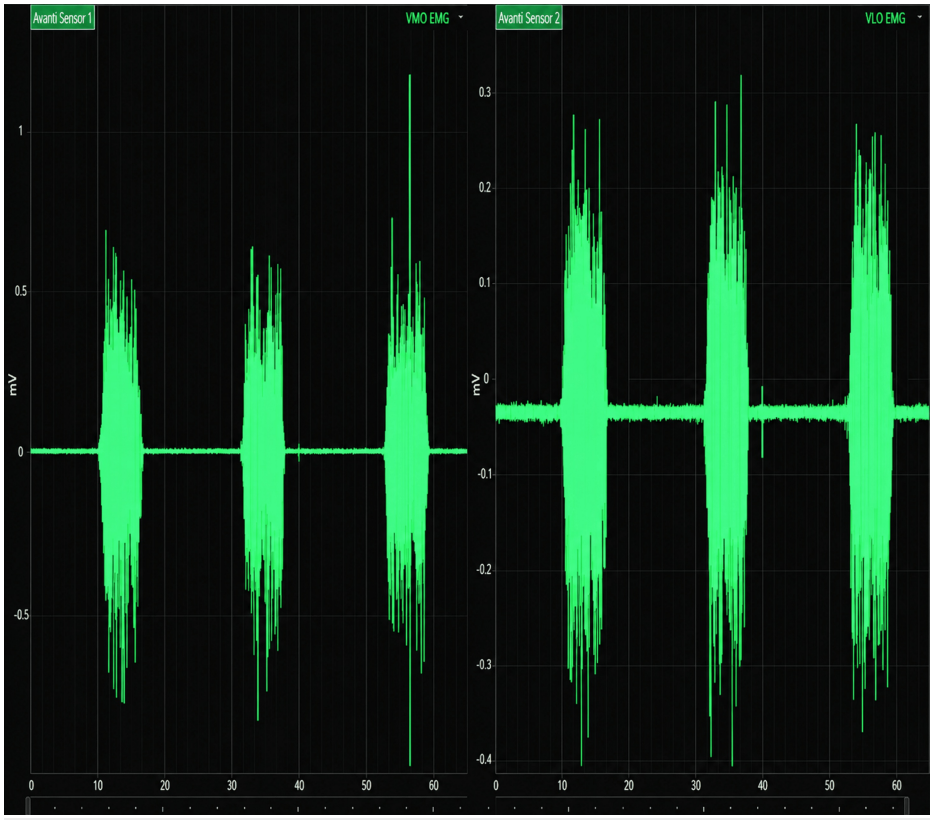


FIGURE 4: MVIC recording of the quadriceps (VMO and VL) muscles

Hamstrings (BF and ST): The hamstring MVIC assessment was performed with the participant positioned prone and the knee maintained at 30° of flexion, with a cushion used to support the limb and maintain the required testing position. Trigno Avanti Wireless EMG sensors were placed on the BF and ST muscle belly. Knee flexion was resisted using a Kinvent push-pull dynamometer with maximum isometric resistance maintained for 5 seconds. Three trials were conducted, and the highest recorded MVIC value was selected to calculate normalized amplitude percentage (%) using EMGworks Analysis software for the hamstring muscles (BF and ST); MIS was recorded in kilograms, as demonstrated in Figure *5* [20,30,31].



FIGURE 5: MVIC testing of hamstring muscles (BF and ST) along with maximum isometric strength measurement with Kinvent Push-Pull Dynamometer

Trigno Avanti Wireless EMG sensors placed on the BF and ST muscle belly.

Kinvent Push-Pull Dynamometer attached to the distal 1/3 of the leg for maximum isometric strength testing.

Recording of MVIC of hamstring (BF and ST) muscles was done using Trigno Discover Software version 2.1, as shown in Figure *6*.

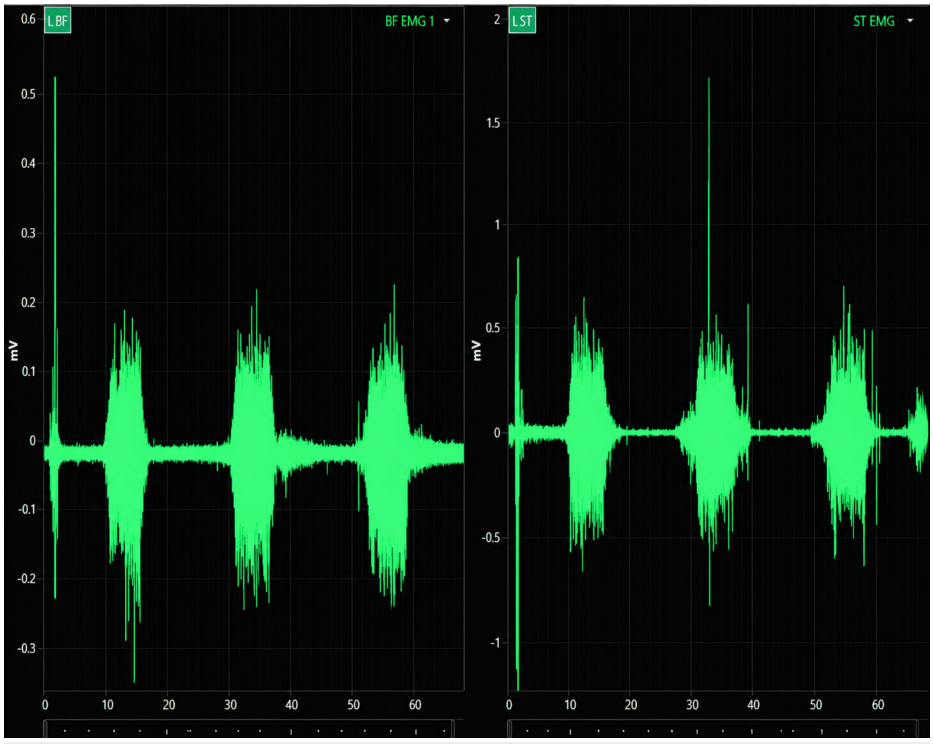


FIGURE 6: MVIC recording of hamstring muscles (BF and ST)

SLST: The procedure requires minimal equipment and preparation time, and visual observation of participant performance has demonstrated good reliability. For the SLST, a "T" configuration measuring 6 inches horizontally and 10 inches vertically was marked on the floor using 1.5-inch-wide zinc oxide tape. Participants performed the test barefoot on the designated limb, standing along the vertical portion of the marking while maintaining the contralateral knee at approximately 90° of flexion. They were instructed to lower their body into a squat until the horizontal marking was no longer visible beyond the toes and then return to the starting upright position. Participants were allowed to practice the SLST until they were adequately familiarized with the test instructions and procedure, as demonstrated in Figures *7*-*9*, respectively [32].



FIGURE 7: SLST starting position anterior view

Trigno Avanti wireless EMG sensors placed on the VMO and VL muscle belly.



FIGURE 8: SLST starting position posterior view

Trigno Avanti Wireless EMG sensors placed on the BF and ST muscle belly.



FIGURE 9: SLST end position

SLST: Single-Leg Squat Test

Recording of the amplitude of sEMG activity of quadriceps (VMO and VL) and hamstrings (BF and ST) muscles was done using Trigno Discover Software version 2.1, as shown in Figure *10*.

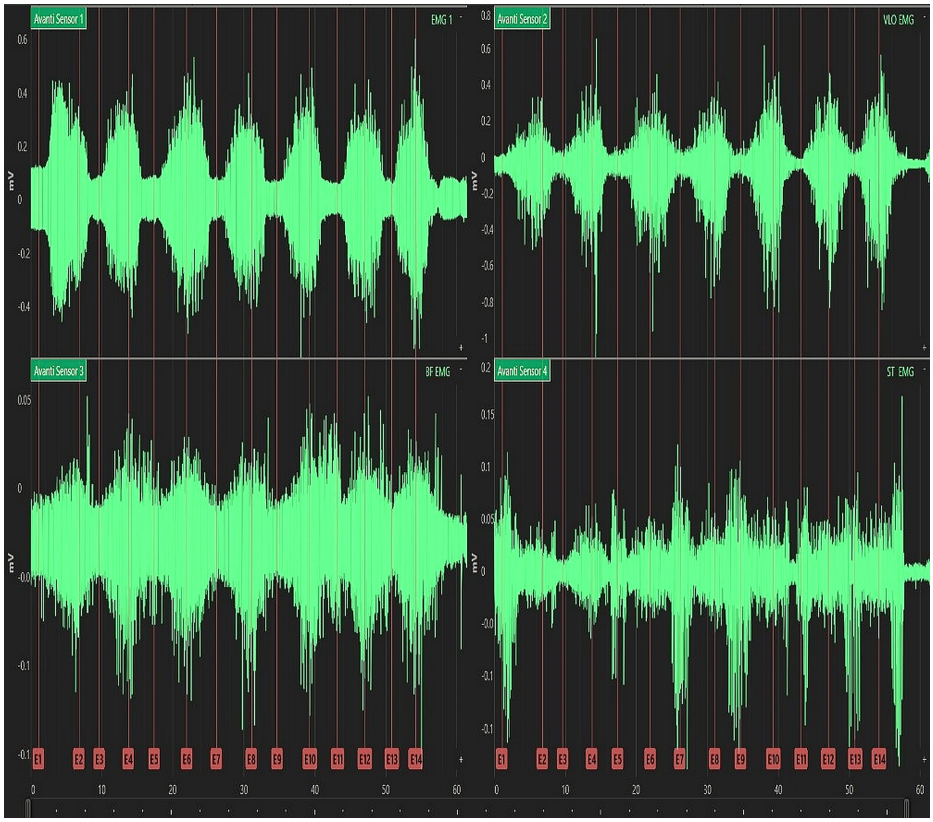


FIGURE 10: Recording of EMG activity of the VMO, VL, BF, and ST muscles with marked lowering and rising phases of SLST

SLST: Single-Leg Squat Test

Analysis of peak amplitude of quadriceps (VMO and VL muscles) using raw sEMG recorded data using Delsys EMGworks analysis software (version 4.8.1), as shown in Figure *11*.

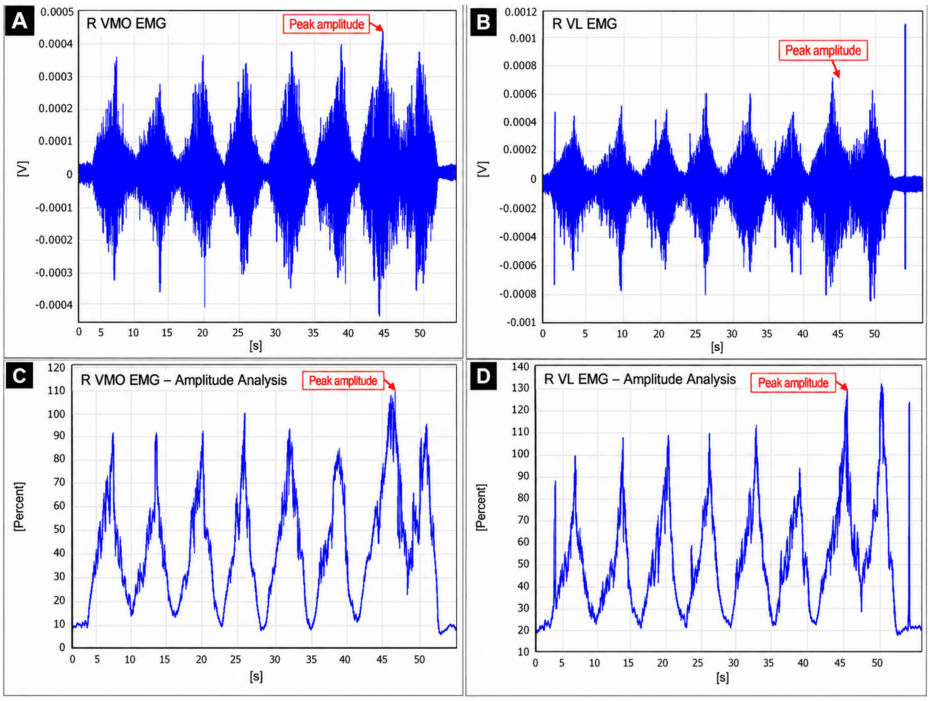


FIGURE 11: Analysis of peak amplitude of VMO and VL muscles during lowering and rising phases of SLST using Delsys EMGworks analysis software

(A) Raw sEMG display of right VMO amplitude; (B) raw sEMG display of right VL amplitude; (C) peak amplitude analysis of right VMO expressed as %MVIC; and (D) peak amplitude analysis of right VLO expressed as %MVIC.

SLST: Single-Leg Squat Test; sEMG: surface electromyography; MVIC: maximum voluntary isometric contraction.

Analysis of peak amplitude of hamstring (BF and ST) muscles using raw sEMG recorded data using Delsys EMGworks analysis software (version 4.8.1), as shown in Figure *12*.

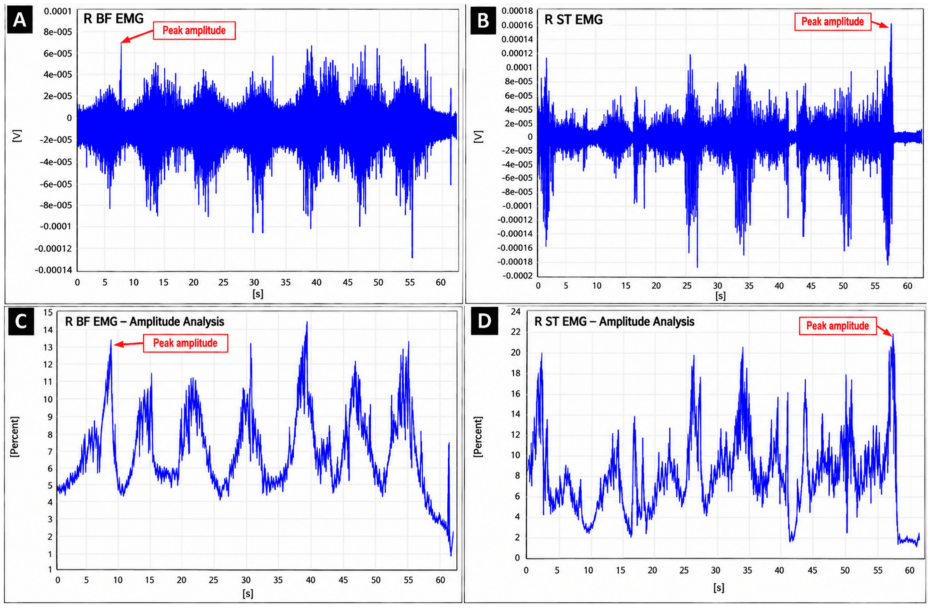


FIGURE 12: Analysis of peak amplitude of BF and ST muscles during lowering and rising phases of SLST using Delsys EMGworks analysis software

(A) Raw sEMG display of right BF amplitude; (B) raw sEMG display of right ST amplitude; (C) peak amplitude analysis of right BF expressed as %MVIC; and (D) peak amplitude analysis of right ST expressed as %MVIC.

SLST: Single-Leg Squat Test; sEMG: surface electromyography; MVIC: maximum voluntary isometric contraction.

Ethical Considerations

It is a simple, noninvasive procedure where each participant was screened and tested for electromyographic activity of quadriceps and hamstring muscles during an SLST in tertiary healthcare under the supervision of a qualified physiotherapy faculty.

Statistical Analysis

Data collected and descriptive statistical calculations done for demographic data viz. age, height, weight, and BMI. Descriptive statistical calculations were also done for the amplitude % of the quadriceps (VMO and VL) and hamstring (BF and ST) muscles using Delsys EMGworks analysis software.

Results

In this descriptive cross-sectional study, a total of 22 healthy, non-exercising male adults aged 31-50 years participated. All participants were not undergoing any form of physical activity. Demographic characteristics of the participants included age, height, weight, and BMI, as shown in Table *1*.

	Age (yrs)	Height (cm)	Weight (kg)	BMI (kg/cm²)
Non-Exercising Individuals	37±4.44	168.5±7.28	71.64±10.2	25.24±3.15

TABLE 1: Mean and Standard Deviation of Demographic Data viz. Age, Height, Weight, and BMI of Non-exercising Healthy Individuals (n=22)

Quadriceps muscles (VMO and VL) demonstrated higher mean normalized sEMG peak amplitude (%MVIC) during the rising phase compared with the lowering phase. In contrast to the quadriceps, hamstring muscles (BF and ST) demonstrated higher mean normalized sEMG peak amplitude (%MVIC) during the lowering phase than during the rising phase. Overall, the table demonstrates a phase-dependent pattern of muscle activation, with greater normalized sEMG amplitude in the quadriceps during the rising phase and greater

hamstring amplitude during the lowering phase of the SLST, as graphically shown in Table 2 and Figure 13.

SLST Quadriceps (Mean±SD)				SLST Hamstrings (Mean±SD)			
VMO Amplitude %		VL Amplitude %		BF Amplitude %		ST Amplitude %	
Lowering	Rising	Lowering	Rising	Lowering	Rising	Lowering	Rising
86.18±32.73	126.04±50.13	83.05±28.30	125±40.60	34.73±24.29	22.55±11.55	26.09±13.99	18.22±8.05

TABLE 2: Mean and Standard Deviation of sEMG Activity, Peak Amplitude (%MVIC) of Quadriceps (VMO and VL) and Hamstrings (BF and ST) (n=22) During Single-Leg Squat Test (SLST)

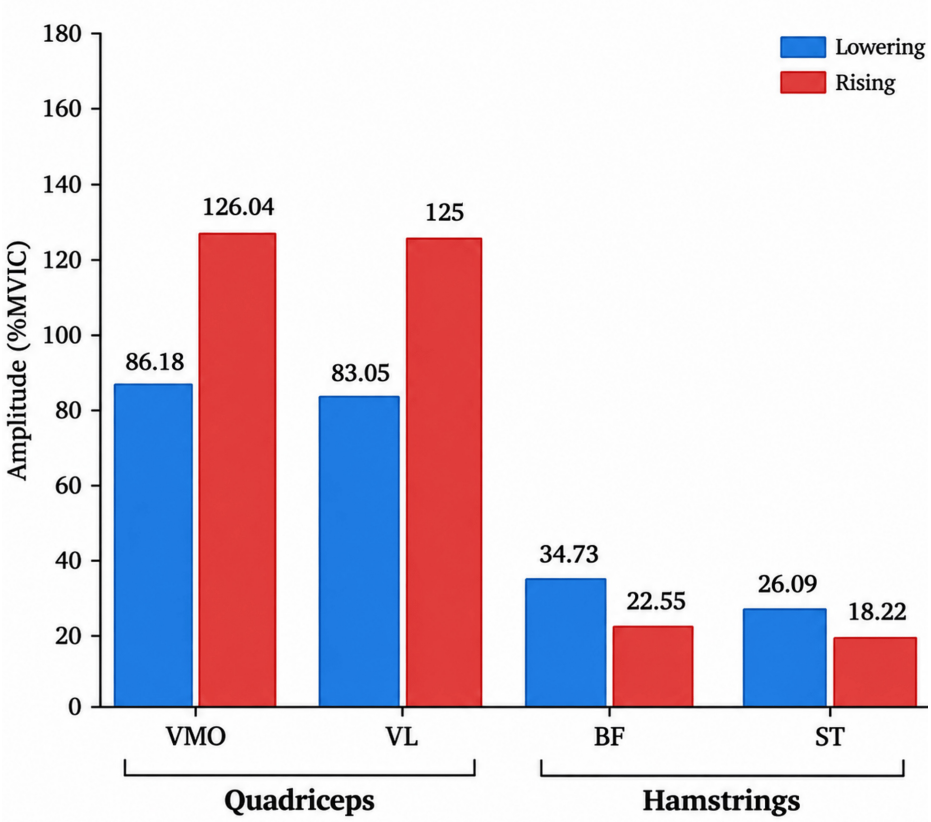


FIGURE 13: Mean of sEMG peak amplitude (%MVIC) of quadriceps (VMO and VL) and hamstring (BF and ST) muscles during lowering and rising phases of SLST

Quadriceps demonstrated a higher mean maximum isometric strength (kg) than the hamstrings in the study participants with greater variability in the quadriceps measurements, as graphically shown in Table 3 and Figure 14.

Maximum Isometric Strength (kg) Mean±SD	
Quadriceps	Hamstrings
34.68 ± 8.46	21.09 ± 4.56

TABLE 3: Mean and Standard Deviation of Maximum Isometric Strength of Quadriceps and Hamstring Muscles

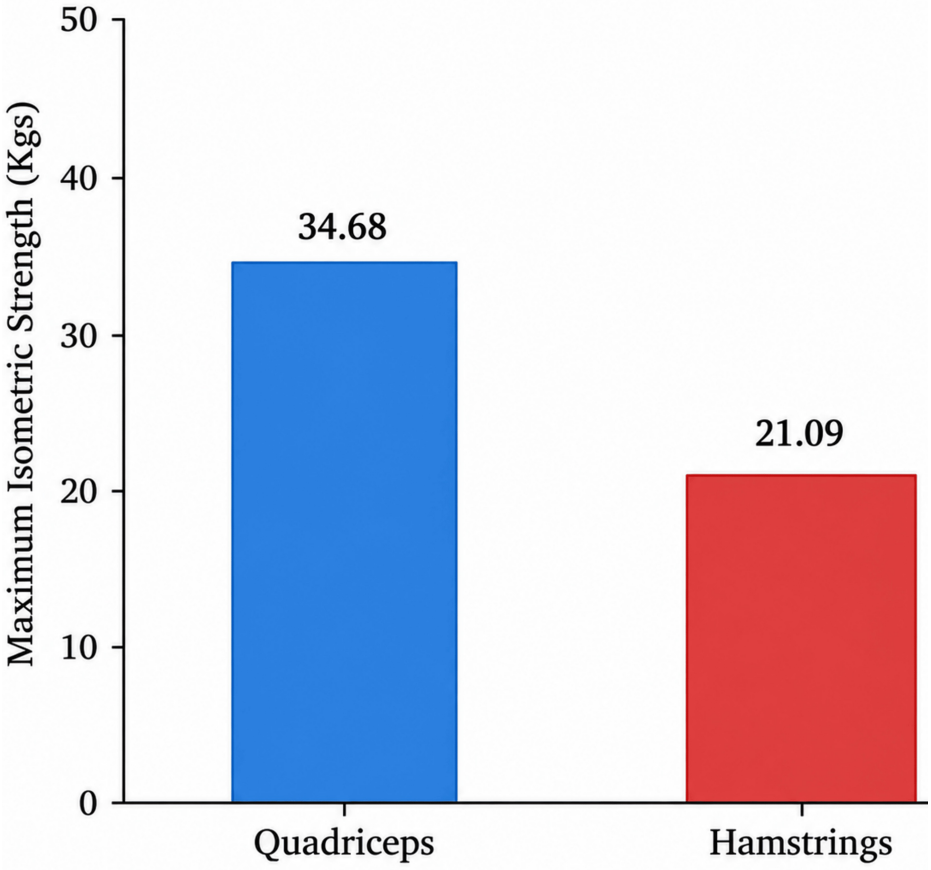


FIGURE 14: Maximum isometric strength of quadriceps and hamstring muscles (kg)

Discussion

This baseline investigation describes the characteristics of healthy, non-exercising individuals. sEMG activity of the quadriceps (VMO and VL) and hamstrings (BF and ST) was evaluated during the SLST, with muscle activation expressed as peak amplitude (%MVIC). MIS was additionally evaluated in both muscle groups. Squat-based exercises are commonly incorporated into knee rehabilitation programs. The movement pattern resembles several functional activities, including stair negotiation, sitting, standing, running, and hopping [12,33].

sEMG has increasingly been employed to evaluate muscle activation patterns in the quadriceps and hamstrings. sEMG provides quantitative information on muscle activation at both the muscle-group and individual muscle-belly levels. The authors propose that reduced quadriceps and hamstrings muscle activity may affect the function of adjacent musculature, whereas increased muscle activation may contribute to a lower risk of injury [16]. The synergistic activation of the quadriceps and hamstrings during coordinated muscle contraction has led to the use of various squat variations, including single- and double-leg squats performed on stable or unstable surfaces, to promote knee stability and potentially reduce excessive valgus and varus movements in athletes [33].

Earlier research conducted by Escamilla et al. and McCurdy et al. reported that single-leg squatting produces substantial lower-limb muscle activation and distinct muscle recruitment patterns during functional tasks [33,34]. Single-leg closed-chain exercises are also used in rehabilitation because they provide weight-bearing training while placing relatively lower shear demands on the knee joint than open-chain exercises. Consequently, the single-leg squat (SLS) has been incorporated into strength-conditioning programs and clinical practice to provide task-specific training for single-leg weight-bearing activities [35,36].

Strength contributes to physical performance and also plays a fundamental role in injury prevention [37]. Furthermore, Distefano et al. identified single-leg squatting as a demanding rehabilitation exercise requiring coordinated lower-extremity muscle activation [38]. The present study demonstrated greater mean VMO and VL activation during the rising phase of the single-leg squat, whereas the BF and ST showed relatively greater activation during the lowering phase. The findings are consistent with the biomechanical characteristics of the movement, where the concentric phase requires greater knee extensor activity, while the eccentric phase involves controlled hamstring muscle activation to stabilize the knee.

Limitations of the Study

The sample size was relatively small. Only healthy, non-exercising males aged 31-50 years were included. Assessment was limited to only the dominant limb and four superficial muscles (VMO, VL, BF, and ST), while other muscles contributing to single-leg squat performance were not evaluated.

Conclusions

The present study demonstrated distinct activation patterns in quadriceps and hamstring muscles during the lowering and rising phases of an SLST in healthy, non-exercising adults. Quadriceps muscles exhibited greater activation than the hamstring muscles, reflecting their primary role in controlling knee motion and maintaining lower-limb stability during functional activities. These findings provide normative electromyographic data that may serve as a reference for future comparisons of the SLST in recreational and elite runners.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Vaibhav S. Dolas, Anandh S.

Acquisition, analysis, or interpretation of data: Vaibhav S. Dolas

Drafting of the manuscript: Vaibhav S. Dolas

Critical review of the manuscript for important intellectual content: Vaibhav S. Dolas, Anandh S.

Supervision: Vaibhav S. Dolas, Anandh S.

Disclosures

Human subjects: Informed consent for treatment and open access publication was obtained or waived by all participants in this study. The Institutional Ethics Committee of Krishna Institute of Medical Sciences (KIMS) issued approval KVV/IEC/08/2024. **Animal subjects:** All authors have confirmed that this study did not involve animal subjects or tissue. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

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