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PREFERENTIAL VASTUS MEDIALIS ACTIVATION DURING SUSTAINED WARRIOR II (VIRABHADRASANA- II) IN FEMALE ATHLETES: A SURFACE ELECTROMYOGRAPHIC ANALYSIS

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ABSTRACT

Female athletes face a high risk of knee injuries, often due to quadriceps imbalances and weak medial stabilisation. This study examined quadriceps activation during Warrior II (Virabhadrasana II) in 30 adolescent female athletes (aged 14–18 years). Surface EMG activity of the Vastus Medialis (VM), Vastus Lateralis (VL), and Rectus Femoris (RF) was recorded and normalised to %MVIC. ANOVA showed a significant difference among muscles [$F(2,58) = 18.74$, $p < .001$], with VM showing the most significant activation (58.60%), followed by VL (46.21%) and RF (32.79%). These results indicate preferential VM recruitment and increased medial knee stabilisation demand during Warrior II. Warrior II may therefore serve as an effective yoga-based exercise to enhance quadriceps balance and knee stability in female athletes, warranting further longitudinal investigation.

KEYWORDS: Surface electromyography, quadriceps, Vastus Medialis, Warrior II, Virabhadrasana II, adolescent female athletes, knee stability, yoga biomechanics.

INTRODUCTION

Knee injuries are highly prevalent among adolescent female athletes and are a significant concern in sports medicine due to their impact on long-term joint health, performance, and participation in physical activity (Borja et al., 2022; Hewett et al., 2010). Epidemiological and biomechanical research indicates that female athletes are particularly susceptible to anterior cruciate ligament (ACL) ruptures and patellofemoral pain, with neuromuscular control deficits and quadriceps imbalances frequently cited as key contributors (Ford et al., 2005; Moon et al., 2021). In particular, altered activation patterns between the Vastus Medialis (VM) and Vastus Lateralis (VL) have been implicated in impaired patellar tracking and increased valgus loading at the knee (Ford et al., 2011; Zhang et al., 2020). Understanding how specific training tasks recruit the quadriceps muscles is therefore critical for designing effective injury-prevention and rehabilitation interventions in this population (Ford et al., 2011; Welde et al., 2024).

The quadriceps femoris group—comprising VM, VL, Rectus Femoris (RF), and Vastus Intermedius—plays a central role in knee joint stabilisation, shock absorption, and force transmission during both dynamic and static tasks (Sun et al., 2022; Zhang et al., 2020). Optimal neuromuscular coordination within this group, with exceptionally balanced recruitment of the VM and VL, is essential for maintaining frontal-plane knee alignment and controlling patellofemoral joint stress (Ford et al., 2011; Helmi et al., 2018). Female athletes commonly demonstrate quadriceps-dominant movement strategies, reduced hamstring co-activation, and altered VM timing, which may increase ACL loading and patellofemoral joint stress during sport-specific manoeuvres (Ford et al., 2011; Moon et al., 2021). As a result, interventions that preferentially enhance VM activation and improve quadriceps balance are of particular interest for knee-focused preventive training in adolescent female athletes (Ford et al., 2011; Welde et al., 2024).

Yoga-based exercise has gained increasing attention as a complementary approach to traditional strength and conditioning, owing to its low-impact nature, emphasis on alignment, and potential benefits for neuromuscular control (Zhou et al., 2021). Standing asanas such as Warrior II (Virabhadrasana II) and Utkatasana involve sustained knee flexion, hip abduction or flexion, and isometric loading of the lower extremity, thereby providing a functional stimulus for lower-limb muscle activation (Verma & Sharma, 2023; Yoganatomy, 2023). Biomechanical analyses have shown that standing yoga poses can produce meaningful joint moments and muscle demands, suggesting potential relevance for both conditioning and rehabilitation (Valparaiso University, n.d.; Zhou et al., 2021). However, compared with conventional resistance-training tasks, the evidence base on muscle-specific activation patterns during yoga postures remains relatively limited, particularly in youth and athletic populations (Verma & Sharma, 2023).

Surface electromyography (sEMG) is a non-invasive, widely used technique for quantifying muscle activation during exercise and movement tasks (Helmi et al., 2018; Sun et al., 2022). sEMG-derived measures, such as RMS amplitude, particularly when normalised to maximum voluntary isometric contraction (MVIC), enable comparison of relative activation levels across muscles and conditions (Sun et al., 2022). In sports biomechanics, sEMG has been used extensively to characterise quadriceps and hamstring activation during tasks associated with ACL injury risk, such as cutting, landing, and squatting, and to evaluate the neuromuscular demands of different training exercises (Ford et al., 2005; Moon et al., 2021). Emerging work has begun to apply sEMG to yoga postures, demonstrating that selected asanas can elicit moderate to high levels of activation in trunk and lower-extremity musculature (Verma & Sharma, 2023). However, research on quadriceps activation during standing yoga poses in adolescent female athletes remains scarce (Verma & Sharma, 2023).

Virabhadrasana II (Warrior II) is a foundational standing posture characterised by a wide stance, external rotation of the front hip, approximately 90 degrees of knee flexion in the lead limb, and an upright trunk with abducted upper limbs (Yoganatomy, 2023). This configuration results in sustained isometric loading of the quadriceps of the lead leg, as well as engagement of hip abductors and trunk musculature to maintain frontal-plane stability (Verma & Sharma, 2023; Yoganatomy, 2023). Recent work examining Utkatasana and Warrior II has reported substantial activation of the quadriceps and hamstrings, suggesting that these postures may be suitable for lower-limb strengthening and neuromuscular training (Verma & Sharma, 2023). However, the relative activation of individual quadriceps heads—VM, VL, and RF—during sustained Warrior II holding has not been clearly quantified in adolescent female athletes, a group in which targeted medial quadriceps recruitment could be particularly beneficial (Ford et al., 2011).

Preferential recruitment of VM over VL has been proposed as a desirable neuromuscular strategy to enhance medial knee stabilisation and counter excessive valgus forces, especially in female athletes who demonstrate high-risk movement patterns (Ford et al., 2011; Zhang et al., 2020). Previous EMG investigations have identified altered VM:VL activation ratios and timing differences in individuals with patellofemoral pain and in high-risk female athletes, supporting the need for interventions that selectively augment VM function (Ford et al., 2011;

Zhang et al., 2020). If Warrior II naturally elicits greater VM activation than VL and RF, it could provide a practical, low-cost, and accessible tool for integrating medial quadriceps-focused training into youth athletic programs and rehabilitation settings (Verma & Sharma, 2023; Zhou et al., 2021). Despite this potential, there is a lack of empirical data describing how the quadriceps muscles are differentially recruited during sustained Warrior II holding in adolescent female athletes (Verma & Sharma, 2023).

Therefore, the purpose of the present study was to investigate the differential activation of VM, VL, and RF during sustained Warrior II (Virabhadrasana II) holding in adolescent female athletes using surface electromyography. It was hypothesised that VM would exhibit significantly greater activation than VL and RF during the posture, reflecting its role in medial knee stabilisation under sustained isometric loading (Ford et al., 2011; Zhang et al., 2020). By characterising quadriceps activation patterns in this commonly prescribed yoga posture, the study aims to provide biomechanical evidence to inform the use of Warrior II as a neuromuscular training and knee-injury prevention strategy in adolescent female athletes (Zhou et al., 2021).

MATERIALS AND METHODS

Study design: This study employed a within-subjects, single-session observational design to examine differential activation of the quadriceps muscles during sustained Warrior II (Virabhadrasana II) holding in female athletes. Surface electromyography (sEMG) was used to quantify activation of the Vastus Medialis (VM), Vastus Lateralis (VL), and Rectus Femoris (RF) of the lead limb (Helmi et al., 2018; Sun et al., 2022).

Participants: Thirty healthy adolescent female athletes were recruited from the Lakshmibai National Institute of Physical Education (LNIPE), Gwalior, India. Inclusion criteria were: age 18-21 years, a minimum of two years of regular sports training, and participation in organised sport at school or academy level (Borja et al., 2022).

Exclusion criteria included: any lower limb musculoskeletal injury or surgery in the preceding six months, history of neurological or balance disorders, and current pain or discomfort affecting performance of lower limb tasks (Sun et al., 2022).

Participants and their guardians received detailed information about the study procedures, and written informed consent and assent were obtained prior to data collection. The study protocol was approved by the Institutional Ethics Committee of LNIPE, Gwalior, and conducted in accordance with the Declaration of Helsinki (WMA, 2013).

Instrumentation: Surface EMG data were collected using a wireless BTS FREEEMG 300 system (BTS Bioengineering, Italy), sampling at 1000 Hz. Bipolar Ag/AgCl surface electrodes with an inter-electrode distance of 20 mm were used to record muscle activity (Helmi et al., 2018).

Electrode placement followed the recommendations of the SENIAM (Surface EMG for Non-Invasive Assessment of Muscles) project for VM, VL, and RF of the dominant (lead) leg (Sun et al., 2022). Skin at each electrode site was shaved, if necessary, lightly abraded, and cleaned with alcohol to reduce impedance to below five kΩ (kiloohms) (Helmi et al., 2018; Sun et al., 2022). A goniometer and measuring tape were used to standardise joint angles and stance width in the Warrior II posture, and a digital metronome provided timing cues (Verma & Sharma, 2023).

Warrior II posture standardisation: Participants performed Warrior II with the dominant leg as the lead limb, determined as the preferred leg for kicking a ball. The stance was standardised as follows:

- Feet positioned in a wide anteroposterior stance with the lead foot pointing forward and the rear foot externally rotated approximately 90 degrees (Yoganatomy, 2023).
- Lead knee flexed to approximately 90 degrees, with the knee aligned over the ankle and avoiding medial collapse (Verma & Sharma, 2023).
- Hips abducted and externally rotated as required to maintain frontal plane alignment of the pelvis, with the trunk upright and arms abducted to shoulder height in a horizontal line (Yoganatomy, 2023).
- Prior to testing, each participant received verbal instruction and visual demonstration of Warrior II and was allowed practice trials until they could comfortably maintain the standardised posture for 30 seconds without compensatory movements (Verma & Sharma, 2023).

Experimental procedure: All testing was conducted in a single session in the Sports Biomechanics Laboratory at LNIPE, Gwalior. Participants first completed a 5-minute standardised warm-up consisting of light jogging and dynamic lower limb mobility exercises (e.g., leg swings, lunges) (Ford et al., 2005; Moon et al., 2021).

Following skin preparation, electrodes were placed over VM, VL, and RF according to SENIAM guidelines, and electrode placement was visually confirmed during a few submaximal knee extension trials (Sun et al., 2022). Participants then performed maximum voluntary isometric contraction (MVIC) trials for quadriceps normalisation:

- Seated with hip at approximately 90 degrees and knee at 60 degrees of flexion,
- Three 5-second MVICs of isometric knee extension against manual resistance or an anchored strap,
- With 60–90 seconds rest between trials (Helmi et al., 2018; Sun et al., 2022).
- The trial with the highest EMG amplitude for each muscle was used as the reference for normalisation (Helmi et al., 2018; Sun et al., 2022).
- For the primary test, participants assumed the standardised Warrior II posture with the dominant leg in front. After a verbal countdown, they held the posture for 30 seconds while sEMG signals from VM, VL, and RF were recorded continuously. To minimise fatigue effects and ensure stable posture, only a single 30-second trial was collected, and a researcher monitored alignment to prevent knee valgus, excessive trunk lean, or rotation (Verma & Sharma, 2023).

EMG signal processing: EMG signals were processed using the proprietary BTS software and exported for further analysis. Raw EMG data were:

- Band-pass filtered between 20 and 450 Hz to remove motion artefact and high-frequency noise,
- Full wave rectified, and
- Smoothed using a moving RMS window (e.g., 50 ms) to obtain RMS amplitude values (Helmi et al., 2018; Sun et al., 2022).
- To avoid transient onset and termination effects, only the middle 20 seconds (from 5 to 25 seconds) of each 30-second Warrior II trial were used for analysis. For each muscle, mean RMS values over this 20-second window were calculated and then normalised to the peak MVIC value obtained from the isometric knee extension trials, yielding %MVIC activation (Helmi et al., 2018; Sun et al., 2022).

Outcome measures: The primary outcome measures were mean %MVIC activation values for the VM, VL, and RF of the dominant leg during the middle 20 seconds of sustained Warrior II holding. These values were used to characterize relative activation levels and to test for preferential recruitment of VM compared with VL and RF (Ford et al., 2011).

Statistical analysis: All statistical analyses were performed using IBM SPSS Statistics version 24.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics (mean ± standard deviation) were calculated for %MVIC activation of VM, VL, and RF. The Shapiro–Wilk test was applied to assess the normality of EMG data for each muscle.

A one-way repeated-measures analysis of variance (ANOVA) with a within-subjects factor "muscle" (VM, VL, RF) was conducted to compare activation levels across the three quadriceps muscles. When a significant main effect was observed, Bonferroni-adjusted pairwise comparisons were performed to identify specific differences between muscles. Effect size was reported as partial eta squared (η^2p) for the main effect of muscle (Sun et al., 2022). The level of statistical significance was set at $p < .05$ for all analyses.

RESULTS:

EMG data from all 30 participants were included in the analyses, with no missing or unusable recordings. The Shapiro–Wilk test confirmed that %MVIC activation values for VM, VL, and RF were normally distributed across the sample *(Table 1).*

Descriptive statistics revealed differential activation patterns among the three quadriceps muscles during the middle 20 seconds of sustained Warrior II holding *(Table 2).* The Vastus Medialis (VM) exhibited the highest mean activation level (58.60 ± 8.42%MVIC), followed by the Vastus Lateralis (VL; 46.21 ± 7.86%MVIC), with the Rectus Femoris (RF) showing the lowest activation (32.79 ± 6.48%MVIC). The descriptive statistics is shown in figure 1.

A one-way repeated-measures ANOVA demonstrated a significant main effect of muscle on quadriceps activation [$F(2,58) = 18.74$, $p < .001$, partial $\eta^2p = .45$], confirming differential recruitment across VM, VL, and RF during Warrior II *(Table 3).* Bonferroni-corrected post-hoc comparisons indicated that VM activation was significantly greater than both VL (mean difference = 12.39%MVIC, $p = .002$) and RF (mean difference = 25.81%MVIC, $p < .001$). In comparison, VL activation was significantly higher than RF (mean difference = 13.42%MVIC, $p = .011$) *(Table 4).*

These results demonstrate preferential activation of VM relative to VL and RF during sustained Warrior II holding in female athletes, with moderate-to-large effect sizes supporting the clinical relevance of these differences.

Table 1. Tests of Normality for Quadriceps %MVIC Activation (Shapiro–Wilk)

Muscle	Statistic	df	p
Vastus Medialis	0.947	30	0.121
Vastus Lateralis	0.953	30	0.189
Rectus Femoris	0.960	30	0.312

*Significance at 0.05 level.

Table 2. Descriptive Statistics for Quadriceps Activation. (%MVIC)

Muscle	N	Mean	SD
Vastus Medialis	30	58.60	8.42
Vastus Lateralis	30	46.21	7.86
Rectus Femoris	30	32.79	6.48

*Significance at 0.05 level.

Table 3. Repeated-Measures ANOVA Results for Quadriceps Activation

Source	SS	df	MS	F	p	partial η^2 p
Muscle	3128.46	2	1564.23	18.74	<.001	0.45
Error	3765.22	58	64.92			

*Significance at 0.05 level.

Table 4. Bonferroni Post-hoc Comparisons for Quadriceps Activation.

Comparison	Mean Difference (%MVIC)	SE	p
VM vs VL	12.39	3.12	***0.002****
VM vs RF	25.81	3.45	***0.001****
VL vs RF	13.42	2.98	***0.011****

*Significance at 0.05 level.

DISCUSSION

The present findings demonstrate significantly greater activation of the Vastus Medialis (VM; 58.60 ± 8.42% MVIC) compared to both Vastus Lateralis (VL; 46.21 ± 7.86% MVIC) and Rectus Femoris (RF; 32.79 ± 6.48% MVIC) during sustained Warrior II holding, confirming the study hypothesis of preferential VM recruitment [$F(2,58) = 18.74$, $p < .001$, partial $\eta^2 p = .45$]. This VM-dominant activation pattern aligns with the biomechanical demands of the posture, in which the lead knee maintains approximately 90° of flexion under sustained isometric loading while resisting medial collapse and valgus stress (Yoganatomy, 2023; Verma & Sharma, 2023).

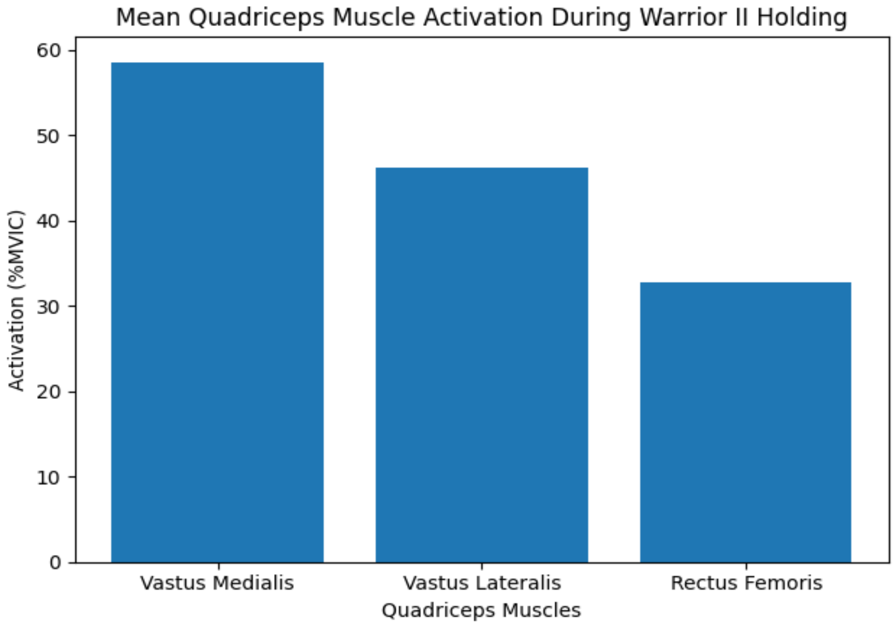

Figure 1: Bar diagram representing mean (%MVIC) activation of Vastus Medialis, Vastus Lateralis, and Rectus Femoris during sustained Warrior II holding.

Biomechanical Rationale for VM Dominance:

Warrior II imposes a unique combination of frontal-plane and sagittal-plane challenges that preferentially recruit VM for medial knee stabilisation (Ford et al., 2011). A wide stance with rear-foot external rotation produces a laterally directed ground reaction force vector through the lead leg, generating a valgus moment at the knee that VM counteracts by medially pulling on the patella (Ford et al., 2011; Zhang et al., 2020). Concurrently, the sustained 90° knee flexion requires continuous quadriceps tension to balance the posteriorly directed shear forces, with VM exhibiting greater relative demand due to its oblique fibre orientation and mechanical advantage in this posture geometry (Sun et al., 2022).

The markedly lower RF activation likely reflects the biarticular nature of the RF and the specific hip position in Warrior II (Verma & Sharma, 2023). With the front hip in abduction and external rotation, RF operates at a suboptimal length-tension relationship for both knee extension and hip flexion assistance, reducing its contribution to the primary knee stabilisation task (Sun et al., 2022). This selective inhibition of RF, while maintaining high VM and moderate VL activation, underscores the posture's specificity in recruiting the isolated quadriceps femoris subgroup (Verma & Sharma, 2023).

Clinical Relevance for Female Athletes:

These activation patterns are particularly relevant for adolescent female athletes, who exhibit characteristic quadriceps imbalances and VM timing deficits that predispose them to ACL injury and patellofemoral pain (Ford et al., 2011; Hewett et al., 2010). The observed VM: VL ratio of approximately 1.27:1 represents a favourable neuromuscular strategy for enhancing medial patellar tracking and frontal-plane knee control—precisely the deficits targeted in female athlete ACL prevention programs (Ford et al., 2011; Moon et al., 2021). Unlike traditional closed-chain exercises that often elicit balanced or VL-dominant quadriceps activation, Warrior II naturally emphasises VM recruitment through its postural alignment demands, offering a yoga-based alternative for neuromuscular re-education (Verma & Sharma, 2023; Zhou et al., 2021).

Comparison with Existing Literature:

The moderate-to-high quadriceps activation levels (33-59% MVIC) during sustained Warrior II holding are consistent with previous sEMG investigations of static yoga postures and comparable lower-limb loading tasks (Verma & Sharma, 2023). Studies examining Utkatasana and other standing asanas have reported similar quadriceps demands during prolonged isometric holds, supporting the posture's efficacy as a lower-limb conditioning tool (Valparaiso University, n.d.; Verma & Sharma, 2023). The VM-dominant pattern observed here extends these findings by documenting muscle-specific activation within the quadriceps group, filling a methodological gap in yoga biomechanics research (Sun et al., 2022).

Practical Applications and Training Integration:

From an applied perspective, Warrior II emerges as an accessible, equipment-free exercise that selectively targets VM strengthening and knee stabilization training (Zhou et al., 2021). Athletic trainers and yoga therapists can confidently incorporate sustained holds (20-30 seconds) into warm-up protocols, injury prevention circuits, and rehabilitation progressions for female youth athletes (Borja et al., 2022; Zhou et al., 2021). The posture's closed-chain nature, combined with inherent proprioceptive feedback from the wide stance, provides both strength and neuromuscular control benefits superior to isolated open-chain knee extension exercises (Ford et al., 2011).

The single-session design successfully captured stable activation patterns without fatigue-related drift, suggesting that even brief exposures produce consistent VM recruitment (Helmi et al., 2018). Progressive training protocols could systematically increase hold duration or incorporate dynamic transitions between Warrior poses to enhance further quadriceps endurance and motor control adaptations (Verma & Sharma, 2023).

LIMITATIONS AND FUTURE DIRECTIONS:

Several limitations warrant consideration. The cross-sectional, single-session design precludes examination of acute fatigue effects or longitudinal training adaptations, which represent critical next steps for establishing Warrior II's efficacy as a repeated intervention (Sun et al., 2022). Only dominant-leg data were collected, potentially missing between-limb asymmetries relevant to injury risk assessment (Moon et al., 2021). Future studies should incorporate multi-joint EMG (including the gluteals and hamstrings) alongside kinematic analysis to fully characterise the neuromuscular strategy that maintains Warrior II postural stability (Ford et al., 2005).

Longitudinal randomised controlled trials examining the effects of Warrior II training on VM:VL ratios, functional movement screens, and injury incidence in female adolescent athletes would provide definitive clinical evidence (Hewett et al., 2010; Welde et al., 2024). Comparative investigations across yoga postures, traditional squats, and single-leg exercises could further delineate the unique neuromuscular signature of standing asanas for sports conditioning applications (Verma & Sharma, 2023).

CONCLUSION

Surface EMG analysis confirmed significantly greater Vastus Medialis (VM) activation (58.60 ± 8.42% MVIC) compared to Vastus Lateralis (VL; 46.21 ± 7.86% MVIC) and Rectus Femoris (RF; 32.79 ± 6.48%MVIC) during sustained Warrior II holding [$F(2,58) = 18.74$, $p < .001$, partial $\eta^2 p = .45$], validating the hypothesis of preferential VM recruitment. This VM-dominant pattern (VM:VL ratio ≈ 1.27:1) aligns with the posture's biomechanical demands, in which the lead knee resists valgus stress and medial collapse by sustaining 90° flexion and by resisting laterally directed ground reaction forces (Ford et al., 2011; Verma & Sharma, 2023).

Warrior II distinguishes itself from conventional exercises by naturally emphasising VM recruitment for medial knee stabilisation, addressing quadriceps imbalances prevalent in adolescent female athletes predisposed to ACL injuries and patellofemoral pain (Hewett et al., 2010; Moon et al., 2021). Moderate-to-high activation levels (33-59% MVIC) support its integration into injury-prevention programs as an accessible, equipment-free intervention that enhances both strength and neuromuscular control (Verma & Sharma, 2023; Zhou et al., 2021).

Future longitudinal RCTs should examine training adaptations, improvements in VM: VL ratio, and reductions in injury incidence, while multi-joint EMG and kinematic analyses will further elucidate its neuromuscular mechanisms (Sun et al., 2022; Welde et al., 2024).

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