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Neuromuscular Responses to Short-Duration Percussive Massage: Effects on Muscle Activation and Lower-Limb Explosive Power in University Teqball Athletes

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ABSTRACT

Background & objective: Percussive massage therapy has emerged as a popular pre-exercise intervention; however, its acute effects on neuromuscular function in hybrid precision sports remain inadequately characterized. This study investigated the acute effects of a 10-minute percussive massage intervention on quadriceps and hamstring muscle activation and lower-limb extensor power in university Teqball athletes.

Materials and methods: A single-blind randomized controlled pretest-posttest design was employed involving 20 Teqball athletes (16 males, 4 females; mean age 21.35 ± 1.89 years). Participants were randomly allocated to either a massage intervention group ($n = 10$) or a passive control group ($n = 10$). The intervention consisted of bilateral quadriceps and hamstring percussive massage (40–60 Hz, 10 minutes total). Primary outcomes included muscle activation of the vastus lateralis and biceps femoris measured via surface electromyography (sEMG; root mean square amplitude, μV), and lower-limb explosive power assessed through countermovement jump (CMJ) height. Data were analyzed using repeated-measures ANOVA with Bonferroni post-hoc corrections ($\alpha = 0.05$).

Results: Significant improvements were observed in the massage group for vastus lateralis activation (+28.4%, $p = 0.002$, Cohen's $d = 1.89$), biceps femoris activation (+24.7%, $p = 0.008$, $d = 1.67$), and CMJ height (+12.6%, $p = 0.001$, $d = 1.42$). No significant changes were observed in the control group (all $p > 0.05$). Significant Time $\times$ Group interaction effects were identified for all outcome measures (all $p < 0.01$).

Conclusions: A 10-minute percussive massage intervention significantly enhances neuromuscular activation and lower-limb explosive power in Teqball athletes, demonstrating large practical effect sizes. These findings support the integration of percussive massage as an effective, non-fatiguing pre-competition warm-up modality in hybrid precision sports.

Keywords

percussive massage; neuromuscular activation; surface electromyography; countermovement jump; post-activation potentiation; Teqball; sports performance.

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INTRODUCTION

Global and Theoretical Context

Teqball is an emerging hybrid sport that combines football-based technical skills with play on a specially curved table, requiring players to coordinate ball control, rapid repositioning, balance, and precise execution within a constrained competitive environment (Balić et al., 2022). The international development of Teqball has accelerated in recent years, including its integration into major multisport events, indicating an expanding competitive environment in which evidence-based approaches to athlete preparation are increasingly relevant (Fédération Internationale de Teqball [FITEQ], 2026). The characteristics of Teqball require athletes to repeatedly generate and control lower-limb forces while maintaining postural stability and technical precision. Consequently, the functional readiness of the quadriceps and hamstring musculature is likely to be important for actions involving kicking, lunging, rapid repositioning, and jumping. Evidence from related football-based populations indicates that lower-limb strength is closely associated with sprint and vertical-jump performance,

reinforcing the importance of neuromuscular function for explosive sport actions (Mandrourkas et al., 2023; Wisløff et al., 2004).

Pre-exercise warm-up is commonly used to enhance physiological and neuromuscular readiness before physical performance. Typical strategies include low-intensity aerobic activity, dynamic stretching, mobility, and sport-specific movements. A systematic review and network meta-analysis of 35 studies found that dynamic and combined static-dynamic stretching can acutely improve countermovement-jump height, although effects vary with intervention duration, age, and population (Li et al., 2023). Thus, warm-up efficacy appears dependent on the type, intensity, duration, and timing of the preparation.

Percussive massage therapy (PMT), usually delivered through handheld devices that generate repeated mechanical oscillations, has become increasingly incorporated into athletic preparation and recovery routines. Compared with conventional massage, PMT offers a standardized mechanical stimulus that

can be applied for a defined duration and frequency. Reviews of massage-gun and percussive-therapy research indicate potential short-term effects on flexibility and tissue characteristics, but the evidence for improvements in strength and explosive performance remains inconsistent (Dakić et al., 2023; Ferreira et al., 2023; Sams et al., 2023). Mechanical stimulation has been proposed to alter local tissue properties and sensory input and may consequently influence the readiness of the neuromuscular system before subsequent voluntary movement (Weerapong et al., 2005). These effects may conceptually overlap with the objective of post-activation potentiation (PAP), in which preceding stimulation can enhance subsequent explosive performance; however, percussive massage should not be assumed to operate through the same physiological pathway as resistance-based PAP (Seitz & Haff, 2016; Tillin & Bishop, 2009).

Critical Review of Existing Evidence

The current evidence base on acute PMT is characterized by substantial methodological heterogeneity. A systematic review of massage-gun studies identified only 11 eligible investigations and reported that most had moderate risk of bias, with considerable variation in treatment duration, target muscles, devices, and outcome measures. The review concluded that massage guns may improve short-term flexibility and some recovery-related outcomes, whereas evidence for strength, acceleration, agility, and explosive performance remains inconsistent (Ferreira et al., 2023). A broader systematic review of massage therapy similarly concluded that performance-related effects are not consistently observed and that the mechanisms linking massage to athletic performance remain incompletely established (Dakić et al., 2023).

Experimental studies illustrate these inconsistencies. In Austria, Konrad et al. (2020) examined 16 healthy male participants who received a 5-minute Hypervolt treatment to the plantar-flexor muscles. The intervention improved ankle range of motion, but did not significantly improve plantar-flexor maximum voluntary contraction, suggesting that an acute mechanical response does not necessarily translate into greater force production. Szymczyk et al. (2022) studied 11 physically active participants following 60 seconds of percussive treatment to each Achilles tendon and reported alterations in tendon stiffness without a clear improvement in post-intervention drop-jump height. These findings indicate that effects may depend on the anatomical structure treated and on the performance task used to quantify the response.

Evidence from the United States provides a similar pattern. Alvarado et al. (2022) studied 26 recreationally active college participants and found improvements in passive range of motion after percussive treatment but no meaningful enhancement across the principal jump-performance outcomes. Ahmed et al. (2024) compared PMT, foam rolling, and hamstring stretching among 39 junior athletes. All three interventions produced within-group improvements in several flexibility and vertical-jump measures, but between-group differences were relatively limited, suggesting that improvements following PMT may partly reflect responses shared by several warm-up modalities rather than a unique effect of percussion itself.

More recent studies have further challenged the assumption that PMT produces a consistently positive ergogenic response. Ormeno and Driller (2025) investigated 16 trained athletes in Australia using a randomized crossover design and found that adding massage-gun treatment to a dynamic warm-up was associated with lower CMJ height and reactive strength

compared with dynamic warm-up alone, while sprint performance was also impaired under the massage-gun condition. Conversely, Eken et al. (2026) reported favorable changes in several jump and kinetic outcomes following different percussive-massage intensities in trained male football players, with responses varying across morning and evening sessions. These contrasting findings suggest that frequency, intensity, timing, preceding warm-up, training status, and circadian conditions may moderate the acute response.

Evidence on neuromuscular activation remains mixed. Hank et al. (2025) reported reduced medial gastrocnemius EMG activity during a standing heel-raise task following brief percussion, indicating that percussive stimulation does not consistently increase EMG amplitude. Therefore, neuromuscular effects should be evaluated using muscle-specific measurements and standardized contraction tasks before definitive conclusions are drawn.

Methodological heterogeneity may partly explain these inconsistent findings. Previous studies have differed in sample characteristics, training status, treatment duration, frequency, pressure, attachment type, target muscle, comparator, and post-intervention testing interval. Moreover, many investigations have focused on flexibility, soreness, or tissue stiffness rather than simultaneously assessing neuromuscular activation and explosive performance (Dakić et al., 2023; Ferreira et al., 2023; Sams et al., 2023). This variability limits direct comparison and leaves the conditions under which PMT may enhance performance insufficiently established.

Research Gap, Novelty, and International Contribution

Although previous research indicates that percussive massage therapy (PMT) can acutely influence flexibility, tissue characteristics, perceived recovery, and selected performance outcomes, evidence remains limited regarding whether a standardized short-duration bilateral protocol can concurrently modify lower-limb neuromuscular activation and explosive performance in Teqball athletes. Existing studies have predominantly involved recreationally active adults, university students, junior athletes, or participants from conventional sports, with direct evidence in Teqball still scarce. Moreover, few randomized controlled studies have simultaneously examined muscle electrical activity and a functional measure of explosive performance, leaving the relationship between acute neuromuscular responses and performance outcomes insufficiently characterized.

The present study addresses this gap by evaluating a standardized 10-minute bilateral PMT protocol applied to the quadriceps and hamstrings in university-level Teqball athletes. Lower-limb neuromuscular activation was quantified using surface electromyography (sEMG) of the vastus lateralis and biceps femoris, while explosive performance was assessed using countermovement-jump (CMJ) height. This integrated design links a muscle-level physiological measure with a functional performance outcome within a randomized controlled framework. Standardization of treatment parameters and blinded outcome assessment further enhances methodological consistency, reproducibility, and measurement validity.

Beyond its sport-specific contribution, the study provides evidence relevant to the broader interpretation of acute PMT responses. Rather than assuming a uniformly beneficial effect, the study examines the response to a defined mechanical stimulus within a specific combination of athlete characteristics, target musculature, intervention dose, and post-treatment assessment. The findings may therefore help clarify whether

inconsistencies in the international literature reflect genuine variability in treatment effects or differences in protocol and experimental context. In this respect, the study contributes sport-specific evidence to the emerging literature on percussive massage and acute neuromuscular performance.

Objectives and Hypotheses

The primary objective of this study was to examine whether a standardized 10-minute bilateral percussive-massage intervention induces greater acute changes in lower-limb neuromuscular activation and explosive performance than passive rest in university-level Teqball athletes. Neuromuscular activation was assessed using sEMG RMS amplitude of the vastus lateralis and biceps femoris, whereas explosive

performance was evaluated using countermovement-jump (CMJ) height. A secondary objective was to quantify the magnitude of pre-to-post changes using standardized effect sizes and to determine whether the pattern of change differed between the intervention and control conditions.

Based on the proposed effects of mechanical stimulation on acute neuromuscular readiness and previous empirical evidence, we hypothesized that, relative to passive rest, the percussive-massage intervention would result in greater pre-to-post increases in sEMG RMS amplitude of the vastus lateralis and biceps femoris (H1) and CMJ height (H2). Accordingly, significant Group $\times$ Time interactions were expected for both neuromuscular activation and explosive-performance outcomes.

MATERIALS AND METHODS

Participants

Twenty university-level Teqball athletes (16 males, 4 females) were recruited from the Universitas Tadulako Teqball team through convenience sampling. Inclusion criteria comprised: (1) age between 18 and 30 years; (2) minimum three months of regular Teqball training (≥ 3 sessions per week); (3) absence of lower-limb musculoskeletal injury within the preceding six months; and (4) no contraindications to massage therapy. Exclusion criteria included: (1) current use of medications affecting neuromuscular function; (2) presence of dermatological conditions precluding electrode placement; and (3) participation in strenuous exercise within 48 hours prior to testing. All participants provided written informed consent following comprehensive explanation of experimental procedures, potential risks, and withdrawal rights. Participant characteristics are presented in Table 1.

Table 1. Participant Characteristics and Eligibility Criteria

Category	Description
Sample Size	20 university-level Teqball athletes
Sex Distribution	16 males, 4 females
Recruitment Method	Convenience sampling from the Universitas Tadulako Teqball team
Age Range	18–30 years
Training Background	Minimum ≥ 3 months of regular Teqball training (≥ 3 sessions/week)

Sample Size Determination

A priori power analysis was conducted using G*Power software (version 3.1.9.7; Heinrich Heine University, Düsseldorf, Germany) based on previous massage intervention studies reporting effect sizes of $d = 1.2$ – 1.5 for neuromuscular outcomes (Cruz-Montecinos et al., 2020). Assuming $\alpha = 0.05$, statistical power $(1 - \beta) = 0.80$, and anticipated effect size $d = 1.2$, a minimum of 9 participants per group was required. To account for potential dropout and data loss, 10 participants were allocated to each experimental condition.

Study Design

This investigation employed a single-blind randomized controlled pretest-posttest experimental design. The study was conducted at the Sport Science Laboratory, Faculty of Teacher Training and Education, Universitas Tadulako, Palu, Indonesia, during January 2025. All experimental procedures were performed between 08:00 and 12:00 hours to minimize circadian variation effects on neuromuscular performance.

Outcome Measures

Table 2. Summary of Outcome Measures and Assessment Protocols

Outcome Domain	Measurement Tool / System	Protocol Description	Key Parameters	Data Processing / Outcome
Muscle Activation (sEMG)	Wireless surface electromyography system (Delsys Trigno; Delsys)	Bipolar surface electrodes were placed over the vastus lateralis and biceps femoris according to SENIAM guidelines following standard skin	Sampling rate: 2,000 Hz; inter-electrode distance:	Raw EMG signals were bandpass filtered and rectified. Root mean square (RMS; μV) was calculated over

Experimental Procedures

All participants completed a standardized familiarization session 48 hours prior to experimental testing, during which they practiced maximal voluntary isometric contractions (MVIC) and countermovement jump technique. On the experimental day, participants arrived at the laboratory having refrained from caffeine (≥ 12 hours), alcohol (≥ 24 hours), and strenuous exercise (≥ 48 hours). Following anthropometric measurements, participants completed a standardized 5-minute cycling warm-up at 50 W on a cycle ergometer (Monark 828E; Monark Exercise AB, Vansbro, Sweden) to establish consistent baseline physiological status. The experimental protocol proceeded as follows: (1) baseline sEMG assessment during MVIC (three 5-second trials with 60-second rest intervals); (2) baseline CMJ assessment (three trials with 30-second rest intervals); (3) intervention period (10 minutes of percussive massage or passive supine rest); (4) immediate post-intervention sEMG assessment; and (5) immediate post-intervention CMJ assessment. Total elapsed time from intervention completion to post-test initiation was standardized at 2 minutes.

Percussive Massage Intervention

The massage intervention was administered using a commercial percussive therapy device (Theragun PRO; Therabody Inc., Los Angeles, CA, USA) operated by a certified sports massage therapist with five years of clinical experience. Participants assumed a supine position on a padded treatment table for quadriceps treatment, followed by prone positioning for hamstring treatment. The intervention protocol targeted bilateral vastus lateralis, rectus femoris, vastus medialis, biceps femoris, and semitendinosus muscles.

Treatment parameters were standardized as follows: percussion frequency of 40–53 Hz (2,400–3,180 percussions per minute), amplitude of 16 mm, and applied pressure of 40–60 mmHg maintained through consistent therapist technique. Each muscle group received 2 minutes of treatment (1 minute per limb), with systematic longitudinal strokes moving from proximal to distal along the muscle belly. The soft-ball attachment head was utilized for all treatments. Total intervention duration was 10 minutes (5 minutes quadriceps, 5 minutes hamstrings). The control group remained in supine position on the treatment table for 10 minutes without intervention.

	Inc., Natick, MA, USA)	preparation (shaving, abrasion, and alcohol cleaning). A reference electrode was positioned over the ipsilateral tibial tuberosity.	20 mm; bandpass filter: 20–450 Hz	the middle 3 s of each MVIC. The mean RMS across three trials was used for analysis.
MVIC Procedure	Custom-built isometric dynamometer	Participants performed three maximal voluntary isometric contractions (5 s each) with standardized verbal encouragement and a 60-s rest interval between trials.	Knee position: 60° flexion for quadriceps; 30° flexion for hamstrings	RMS amplitude (μV) was extracted as an index of neuromuscular activation.
Lower-Limb Explosive Power (CMJ)	Optical measurement system (Optojump Next; Microgate, Bolzano, Italy)	Participants performed maximal countermovement jumps with feet shoulder-width apart and hands on hips (akimbo), with arm swing restricted. Three trials were performed.	Rest interval: 30 s; gravity constant: $g = 9.81 \text{ m/s}^2$	Jump height was calculated from flight time using $h = g \times t^2 / 8$. The highest value was retained for analysis.
CMJ Reliability	—	System validity was supported by prior literature.	ICC = 0.97–0.98	Indicates high test–retest reliability of jump-height measurement.

Statistical Analysis

Statistical analyses were conducted using SPSS version 27.0 (IBM Corp., Armonk, NY, USA). Data are presented as mean $\pm$ standard deviation (SD). Normality and homogeneity were assessed using the Shapiro–Wilk and Levene's tests, respectively, with baseline comparisons performed using independent-samples t-tests. The primary analysis used a 2×2 repeated-measures ANOVA with group (massage vs. control) and time (pre- vs. post-intervention) as between- and within-subject factors, respectively. Significant Group $\times$ Time interactions were followed by Bonferroni-adjusted pairwise

comparisons. Within-group changes were examined using paired-samples t-tests. Effect sizes were expressed as Cohen's d and interpreted as trivial (<0.20), small (0.20 – 0.49), moderate (0.50 – 0.79), or large (≥ 0.80) (Cohen, 1988). Statistical significance was set at $\alpha = 0.05$ (two-tailed).

Ethical Considerations

The study protocol was prospectively registered and received ethical approval from the Institutional Ethics Committee of Universitas Muhammadiyah Palu (Approval Number: 021/KEPK-UMP/2025). All procedures were conducted in accordance with the Declaration of Helsinki (2013).

RESULTS

Participant Characteristics

All 20 enrolled participants completed the experimental protocol without adverse events. Baseline demographic and anthropometric characteristics are presented in Table 1. Independent samples t-tests confirmed no significant between-group differences for age, body mass, height, or training experience (all $p > 0.05$), indicating successful randomization.

Table 3. Baseline Characteristics of Participants by Group Allocation

Variable	Massage Group (n = 10)	Control Group (n = 10)	p-value
Age (years)	21.40 $\pm$ 1.95	21.30 $\pm$ 1.89	0.91
Body mass (kg)	64.8 $\pm$ 9.2	63.6 $\pm$ 8.7	0.76
Height (cm)	169.4 $\pm$ 7.5	168.8 $\pm$ 7.2	0.85
Sex (male/female)	8/2	8/2	1.00
Training experience (months)	8.2 $\pm$ 3.1	7.8 $\pm$ 2.9	0.77

Note. Data are presented as mean $\pm$ SD or n. Statistical comparisons performed using independent samples t-tests or Fisher's exact test.

Muscle Activation

Repeated-measures ANOVA revealed significant Time $\times$ Group interaction effects for both vastus lateralis ($F(1,18) = 28.47$, $p < 0.001$, $\eta^2 = 0.61$) and biceps femoris ($F(1,18) = 21.36$, $p < 0.001$, $\eta^2 = 0.54$) muscle activation. Post-hoc analyses indicated that the massage group demonstrated significant pre-to-post increases in RMS amplitude for both the vastus lateralis (+28.4%, $p = 0.002$) and biceps femoris (+24.7%, $p = 0.008$), with large effect sizes (Table 4). Conversely, the control group exhibited no significant changes in muscle activation for either muscle ($p > 0.05$).

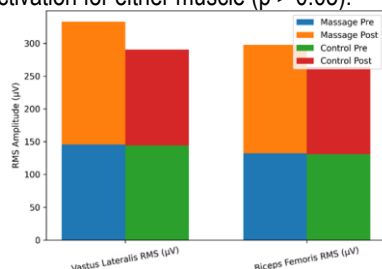


Figure 1. Changes in sEMG RMS Amplitude Pre–Post Intervention

Table 4. Surface Electromyography Root Mean Square Amplitude (μV) Pre- and Post-Intervention

Muscle	Group	Pre-test	Post-test	% Change	Cohen's d
Vastus lateralis	Massage	145.7 $\pm$ 18.3	187.2 $\pm$ 22.1*	+28.4	1.89
	Control	144.3 $\pm$ 19.1	145.8 $\pm$ 18.9	+1.0	0.08
Biceps femoris	Massage	132.4 $\pm$ 16.7	165.1 $\pm$ 20.4*	+24.7	1.67
	Control	131.2 $\pm$ 17.3	132.4 $\pm$ 16.8	+0.9	0.07

Note. Data are presented as mean $\pm$ SD. * $p < 0.01$ compared with pre-test (within-group).

Lower-Limb Explosive Power

For CMJ height, repeated-measures ANOVA demonstrated a significant Time $\times$ Group interaction effect ($F(1,18) = 19.82$, $p < 0.001$, $\eta^2 = 0.52$). The massage group exhibited a significant 12.6% improvement in CMJ height from baseline (41.2 ± 5.8 cm to 46.4 ± 6.7 cm; $p = 0.001$), corresponding to a large effect size ($d = 1.42$). The control group demonstrated no significant change in CMJ performance (41.1 ± 6.1 cm to 41.5 ± 6.0 cm; $p = 0.72$, $d = 0.06$). Results are summarized in Table 5.

Table 5. Countermovement Jump Height (cm) Pre- and Post-Intervention

Group	Pre-test	Post-test	% Change	Cohen's d
Massage (n = 10)	41.2 $\pm$ 5.8	46.4 $\pm$ 6.7**	+12.6	1.42
Control (n = 10)	41.1 $\pm$ 6.1	41.5 $\pm$ 6.0	+1.0	0.06

Note. Data are presented as mean $\pm$ SD. ** $p < 0.001$ compared with pre-test (within-group).

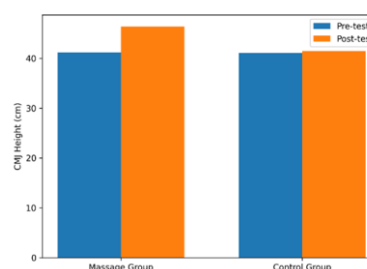


Figure 2. Changes in CMJ Height Following Percussive Massage

DISCUSSION

Acute Effects on Neuromuscular Activation and Explosive Performance

The present randomized controlled study demonstrated significant Group $\times$ Time interactions for vastus lateralis activation, biceps femoris activation, and countermovement jump (CMJ) height following a standardized 10-minute bilateral percussive massage protocol. The substantial interaction effects (partial $\eta^2 = 0.52\text{--}0.61$) indicate that changes over time differed meaningfully between the percussive-massage and passive-rest conditions. The concurrent increase in sEMG RMS amplitude and CMJ height suggests that the intervention was associated with both altered lower-limb myoelectric activity and improved explosive performance under the specific experimental conditions. However, these findings should be interpreted as acute, protocol-specific responses rather than evidence of a universal ergogenic effect. Because the study included only 20 participants, the magnitude and precision of the treatment effects require confirmation in larger samples.

Comparison with International Evidence

The present findings contribute to an international literature characterized by heterogeneous responses to percussive massage. Sams et al. (2023) reported potential acute benefits for strength, explosive performance, and flexibility but highlighted substantial methodological heterogeneity. Konrad et al. (2020); Alvarado et al. (2022) and Szymczyk et al. (2022) reported limited or task-specific performance effects, suggesting that treatment duration, target musculature, application strategy, and outcome selection may influence the response. More recent evidence reinforces this context dependence: Ormeno and Driller (2025) observed reduced CMJ and sprint performance following massage-gun use within a warm-up, whereas Eken et al. (2026) reported improvements in CMJ and selected kinetic variables at specific frequencies and times of day. Hank et al. (2025) likewise found reduced EMG activity following brief percussion, contrasting with the increased sEMG RMS observed in the present study. Recovery studies by Ye et al. (2025) and Roberts et al. (2024) have also reported limited or outcome-specific effects. Collectively, these findings suggest that acute responses to percussive massage are dependent on dose, target muscle, task, athlete characteristics, and intervention timing rather than being uniformly beneficial.

Potential Mechanisms Underlying the Acute Response

The concurrent increase in sEMG RMS and CMJ height is consistent with an acute alteration in neuromuscular readiness; however, the present measurements do not establish the underlying mechanism. sEMG RMS reflects muscle electrical activity but does not directly quantify motor-unit recruitment, firing rate, reflex excitability, or post-activation potentiation. Potential contributions from mechanical stimulation, tissue compliance, blood flow, temperature, mechanoreceptor activation, and neural modulation therefore remain plausible but unconfirmed. Weerapong et al. (2005) proposed multiple biomechanical, circulatory, neurological, physiological, and psychological pathways through which massage may influence performance, while Behm and Wilke (2019) emphasized the

potential contribution of mechanical, circulatory, and neural responses. Accordingly, the present findings support an acute neuromuscular-response interpretation but do not establish a specific PAP-like, reflex-mediated, or other singular mechanism.

Methodological Strengths, Limitations, and Practical Implications

Several methodological features strengthen the internal validity of the study, including sex-stratified block randomization, allocation concealment, blinded outcome assessment, standardized intervention parameters, and complete outcome data. The use of standardized sEMG procedures and CMJ assessment also enabled simultaneous evaluation of neuromuscular activity and functional explosive performance. Nevertheless, interpretation is constrained by the small convenience sample ($n = 20$) from a single university Teqball team, the inability to blind participants and therapists, the use of a passive-rest control, and the absence of delayed post-intervention measurements. Expectancy and nonspecific effects related to attention, physical contact, or sensory stimulation therefore cannot be excluded. In addition, multiple outcomes were analyzed, while the mechanistic interpretation is limited by the absence of motor-unit decomposition, H-reflex, evoked responses, muscle-tendon stiffness, tissue temperature, and local blood-flow measures. The findings consequently remain most applicable to university-level Teqball athletes under controlled laboratory conditions. From a practical perspective, the results suggest that a standardized 10-minute protocol can be incorporated into pre-performance preparation, but the present evidence does not establish superiority over dynamic warm-up, sport-specific activation, foam rolling, manual massage, or post-activation potentiation strategies.

Future Research and Overall Interpretation

Future research should employ larger multisite randomized or crossover designs involving athletes across competitive levels and with broader sex representation. Comparative trials and dose-response studies should examine treatment duration, pressure, frequency, target musculature, and timing relative to performance. Longer follow-up and multimodal physiological measures, including sEMG, motor-unit analysis, reflex or evoked responses, muscle-tendon stiffness, tissue temperature, and local blood flow, are needed to clarify the duration and mechanisms of acute responses. Teqball-specific outcomes, such as kicking velocity, reactive agility, change-of-direction speed, repeated-jump performance, ball-control accuracy, and simulated match sequences, would further improve ecological validity. Overall, the present study extends the international literature by showing that a standardized 10-minute bilateral percussive-massage protocol is associated with acute changes in lower-limb myoelectric activity and CMJ performance in university-level Teqball athletes. However, the heterogeneous findings across populations and protocols indicate that these responses are context dependent and may vary according to treatment dose, target musculature, athlete characteristics, testing procedures, and intervention timing.

CONCLUSION

This randomized controlled study indicates that a standardized 10-minute bilateral percussive massage intervention was associated with greater acute pre-to-post improvements in lower-limb neuromuscular activation, reflected

by surface electromyography RMS amplitude of the vastus lateralis and biceps femoris, and in countermovement-jump height compared with passive rest in university-level Teqball athletes. The findings provide controlled empirical evidence that

short-duration percussive massage may influence both a muscle-level neuromuscular measure and an explosive-performance outcome within this specific sporting context. The study extends the emerging international evidence on percussive massage by providing evidence from Teqball, an underrepresented hybrid sport, and by examining neuromuscular activation and explosive performance concurrently. However, the findings should be generalized

cautiously because the study involved only 20 university-level athletes recruited from a single team and assessed only immediate responses following one intervention session. Accordingly, the results support the potential usefulness of this specific protocol under comparable conditions but do not establish its effectiveness across elite athletes, other sports, different populations, or longer-term training and competition settings.

DECLARATIONS

Ethical Approval

The study protocol received ethical approval from the Institutional Ethics Committee of Universitas Muhammadiyah Palu, Indonesia (Approval No. 021/KEPK-UMP/2025). All experimental procedures were conducted in accordance with the ethical principles of the Declaration of Helsinki (2013).

Consent to Participate

All participants provided written informed consent before participation. They were informed of the study procedures, potential risks, experimental requirements, and their right to withdraw at any time without penalty.

Consent for Publication

Consent for publication was not applicable because the study reports only aggregated and anonymized data and contains no personally identifiable information, individual clinical information, or identifiable participant images.

Author Contributions (CRediT)

Erwin Zainuddin: Conceptualization; Methodology; Investigation; Data curation; Formal analysis; Writing—original draft; Writing—review and editing; Funding acquisition.

Anugrah Riski Tritama: Data curation; Investigation; Formal analysis; Writing—original draft.

Zahra Zetira: Formal analysis; Writing—review and editing.

Zalikal Ilham: Investigation; Data curation; Writing—review and editing.

Muh Arif: Investigation; Data curation; Writing—review and editing.

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Conflict of Interest

The authors declare that they have no conflicts of interest that could have influenced the design, conduct, analysis, interpretation, or reporting of this study.

Data Availability

The datasets generated and/or analyzed in this study are available from the corresponding author upon reasonable request, subject to applicable ethical and institutional restrictions.

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Generative AI Disclosure

The authors declare that no generative artificial intelligence (AI) tools were used to generate, analyze, interpret, or substantively revise the scientific content of this manuscript.

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