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# Effects of an eight-week neuromuscular training program on balance and reaction speed in collegiate hadang athletes: A controlled trial

**Ida Zubaida[abc,*], Tricahyani Endah Yuniarti[cde], Qory Jumrotul Aqobah[ace], Abdul Al Aziz Ramadhan[be], & Sabrina Zahra Almaas Saniyyah[bce]**

**Universitas Sultan Ageng Tirtayasa, Indonesia**

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**ABSTRACT**

**Background**: Hadang is a traditional Indonesian team sport that demands a high level of whole-body reaction time and unilateral postural control. Various training modalities have been shown to improve key physical components which collectively support performance in fast-paced games like the hadang. However, evidence on the effectiveness of neuromuscular training in this sport is limited. **Objectives**: This study aimed to evaluate the impact of 8 weeks of neuromuscular training on balance and reaction speed in university-level Hadang athletes. **Methods**: A quasi-experimental, controlled pretest–posttest design with two parallel groups was used. Thirty athletes were allocated to either a neuromuscular training group (NTG; n = 15; 3 sessions/week for 8 weeks; ~30–40 minutes/session) or a control training group (CTG; regular training without neuromuscular training). Primary outcomes were unilateral balance and whole-body reaction time. Data were analyzed using 2 × 2 mixed-design ANOVA, with paired t-tests for simple effects. **Findings/Results**: Compared to CTG, NTG demonstrated significant improvements in balance and significant decreases in whole-body reaction time, while changes in CTG were not substantial. **Conclusion**: Eight weeks of structured neuromuscular training effectively improved balance and reaction time in college-level hadang athletes, with moderate effect sizes for balance and large effects for reaction time. Given its simplicity, minimal equipment requirements, and compatibility with standard training microcycles, neuromuscular training is worthy of adoption as a core, evidence-based component of performance periodization for hadang.

**Keywords:** Hadang; traditional sport; neuromuscular training; balance; reaction speed

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**Corresponding Author:** Ida Zubaida, Department of Sport and Science, Faculty of Medicine, Universitas Sultan Ageng Tirtayasa, Banten, Indonesia
ida.zubaida@untirta.ac.id

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**Authors' Contribution**: a – Study Design; b – Data Collection; c – Statistical Analysis; d – Manuscript Preparation; e – Funds Collection

## INTRODUCTION

The sport of hadang is a type of sport that originated and developed in Indonesia and is known as a traditional sport (Rahesti et al., 2023). It consists of successive bouts of running, jumping across lines, and evading opponents, demanding high levels of speed, precision, agility, and tactical decision-making from its players (Muliadi & Jauhar, 2021). In addition to its cultural value, previous work has highlighted the potential of hadang to stimulate physical, cognitive, and physiological development in children and adolescents (Muliadi & Jauhar, 2021; Nurdiansyah, 2018). Our recent research further showed that an organized hadang intervention yielded significant improvements in cardiovascular and respiratory fitness in adolescents, including estimated $VO_2$ max, ventilatory efficiency, and post-activity heart rate recovery, underscoring its potential as a game-based aerobic training modality (Zubaida et al., 2024).

Neuromuscular training has emerged as an evidence-based approach to enhance key physical capacities that underpin performance in fast-paced, multidirectional sports. Interventions that integrate strength, plyometric, balance, and coordination exercises have been shown to improve endurance, agility, muscular strength, and balance in various athletic populations (Akbar et al., 2022; Dhawale et al., 2020; Mainer-Pardos et al., 2024; Wan et al., 2025; Zouhal et al., 2019). Complementary findings from medicine ball–based programs in archery and plyometric-based interventions in futsal and football also suggest that targeted neuromuscular and power-oriented training can yield meaningful gains in balance, muscular endurance, and sport-specific agility (Branquinho et al., 2022; Irawan et al., 2024; Karavelioglu et al., 2016; Neves et al., 2023; Ramirez-campillo et al., 2022; Šišková et al., 2021; Wattimena et al., 2025). A recent systematic review found that a 6–10-week neuromuscular training protocol with a frequency of 2-3 sessions per week consistently improves sprinting, jumping, balance, and agility performance in athletes (Chen et al., 2025). Additionally, other systemic reviews suggested that neuromuscular training focuses on exercises that improve motor skills and influence agility, muscle strength, and balance, which are important for performance (Akbar et al., 2022).

Despite this growing body of evidence, the application of structured neuromuscular training to hadang remains poorly documented. The development of hadang as a competitive sport has lagged behind other disciplines, it is not yet contested at the National Games (PON), and the number of specialized hadang athletes remains limited. Existing conditioning guidelines for hadang are largely extrapolated from other sports and are not derived from empirical trials in hadang players themselves (Muliadi & Jauhar, 2021; Nurdiansyah, 2018; Zubaida et al., 2024). Consequently, there is no consensus regarding the optimal dose, progression, or sport-specific content of neuromuscular training for hadang, which constrains coaches' ability to design low-cost, time-efficient, and field-feasible programs tailored to this traditional game.

From a performance standpoint, hadang requires athletes to repeatedly execute rapid whole-body movements (Muliadi & Jauhar, 2021; Safitri & Rahman, 2023). Evidence from neuromuscular training research indicates that integrative programs can enhance sensorimotor efficiency, improve landing mechanics, reduce sway variability, and modulate feedforward and feedback control pathways, resulting in better static and dynamic balance as well as faster motor responses (Concha-Cisternas et al., 2024; Roso-Moliner et al., 2023). In line with these mechanisms, NMT has been associated with meaningful gains in balance and agility performance, which are closely related to reaction speed and time to action in various field and combat sports (Akbar et al., 2022; Chen et al., 2025). Thus, balance and reaction time represent two critical, yet underexplored, performance variables in hadang for which neuromuscular training may offer substantial benefits.

Therefore, there is a clear need to evaluate whether a structured neuromuscular training program can improvements in key neuromechanical capacities hadang performance. The present study was designed to examine the effects of neuromuscular training on balance and reaction speed in adolescent hadang athletes. By expanding the application of neuromuscular training to this traditional Indonesian sport, this research aims to provide sport-specific, evidence-based guidance for coaches, contribute to performance optimization and potential injury-risk mitigation in hadang, and support the broader scientific recognition and development of indigenous games within the sports science literature.

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## METHOD

### Research Design

This study used a quasi-experimental pretest–posttest design with two parallel groups (neuromuscular training, NTG; usual-practice control, CTG). Allocation was non-random because the athletes were already organized into intact training classes based on the university timetable. These intact classes were assigned as NTG and CTG, and no individual randomization or formal one-to-one matching procedure was performed. The study was conducted from February to July 2025 at the Sports Centre Sultan Ageng Tirtayasa University. The NTG completed an eight-week neuromuscular training intervention consisting of three sessions per week, whereas the CTG continued their usual training regimen without any additional neuromuscular components. Baseline characteristics were compared between groups to verify comparability at the start of the study.

### Participants

The target population comprised collegiate-level Hadang athletes aged 19–21 years. A purposive sampling strategy was used to recruit athletes who met the following inclusion criteria: (i) currently active in Hadang training with a minimum frequency of three sessions per week over the preceding two years, (ii) no self-reported musculoskeletal injury within the past six months, and (iii) willingness and availability to complete the full training program and participate in all testing sessions. Individuals not meeting these criteria were deemed ineligible. The study protocol received ethical clearance from the Research Ethics Committee of Universitas Sultan Ageng Tirtayasa. Before enrollment, participants were informed about study procedures, potential risks, and benefits, and provided written informed consent in accordance with institutional guidelines.

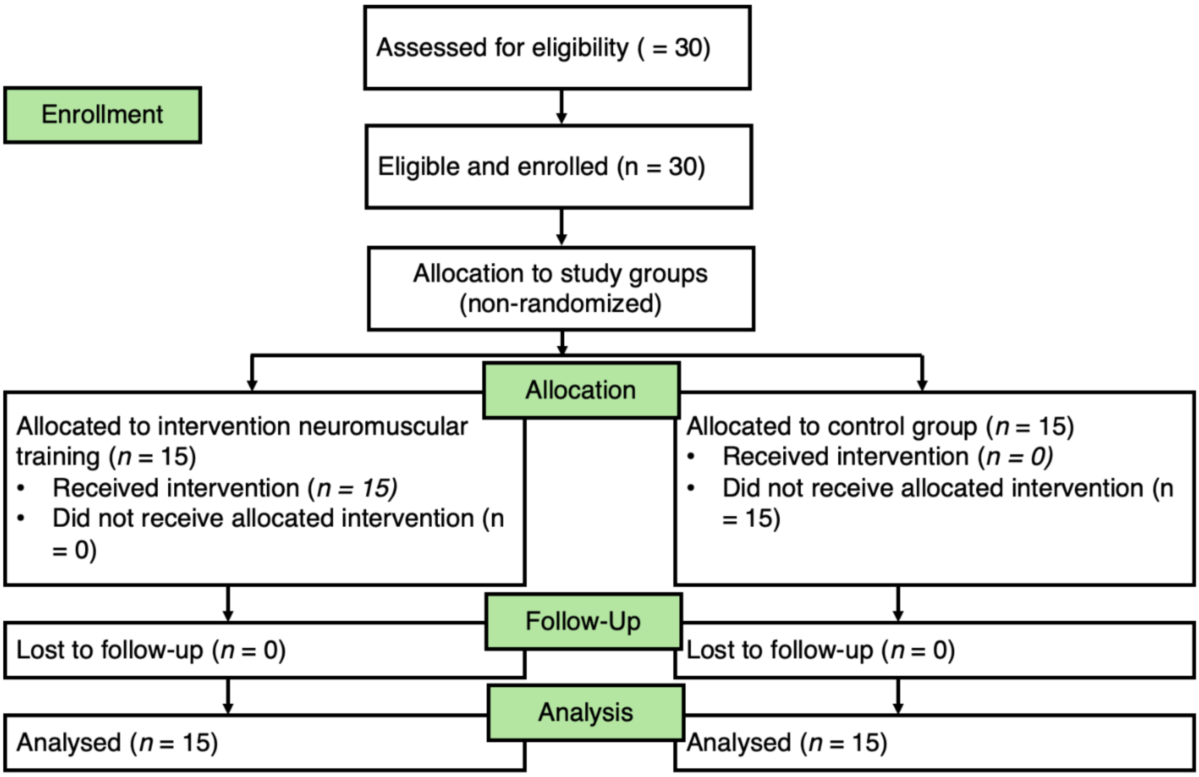


**Figure 1. Study Flow Diagram**

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**Procedure**

The stages undertaken in this study comprised:

1. At the initial stage, participants were allocated to two groups: the NTG (n = 15) and the CTG (n = 15). Prior to data collection, we conducted an a priori power analysis in G*Power (v3.1) for a mixed ANOVA targeting the group × time interaction. The resulting estimate indicated a total sample size of N ≈ 28-32 to achieve 80% power for the interaction; accordingly, we set N = 30 (15 per group) as a compromise between statistical sensitivity and single-site feasibility, while allowing for minimal attrition. Following allocation, all participants completed a standardized anthropometric assessment. Stature was measured to the nearest 0.1 cm using a wall-mounted stadiometer, and body mass was measured to the nearest 0.1 kg using a calibrated digital scale with built-in bioelectrical impedance analysis (Omron Karada Scan; Omron Healthcare, Kyoto, Japan). Body mass index (BMI) was calculated as $kg \cdot m^{-2}$, and body-fat percentage was estimated via the device's impedance algorithm. Measurements were obtained with participants barefoot and in light clothing. After anthropometry measurement, participants underwent balance assessment using the Stork Stand Test. Meanwhile, whole body reaction time was then assessed using a dedicated apparatus (Takei Scientific Instrument Co., Japan). Both the Stork Stand Test and the Takei whole-body reaction task have demonstrated acceptable reliability and validity for evaluating balance and reaction speed in adult and athlete populations. In this study, we employed psychometrically established general fitness assessments as proxy outcome measures, given the current absence of validated, sport-specific instruments tailored in sport of hadang.
2. The second phase comprised the 8-week training intervention. Participants assigned to the Neuromuscular Training Group (NTG) completed a supervised neuromuscular program beginning in week 1 and continuing through week 8. Before the first session, athletes were briefed on study procedures and coached on correct technique to minimize injury risk. Each training session for NTG group began with a 10-minute dynamic warm-up, followed by a structured neuromuscular main set lasting 40 minutes, and concluded with a 10-minute cool-down. Intensity targets were periodized across the eight weeks, starting at moderate levels in the initial microcycles and rising progressively toward the final weeks, with in-session adjustments to task difficulty to maintain athletes within the prescribed intensity band. The control group followed the team's routine microcycle of three sessions per week at approximately 60 minutes per session that included a 10 minute dynamic warm-up, 40 minutes of technical and tactical drills without instability, perturbation, plyometric, or reactive cue content, and 10 minutes of conditioning comprising light-to-moderate aerobic work. Both groups were instructed not to initiate new training routines outside the protocol.
3. Follow-up testing was conducted in week 9 (final phase). To reduce participant burden and because anthropometry was not a primary outcome, no additional anthropometric measurements were obtained at this stage. All athletes completed the same functional assessments as at baseline, under matched conditions. Participants were instructed to refrain from vigorous exercise for 24-48 h. Static balance was evaluated using the Stork Stand Test. Meanwhile, reaction speed was assessed using a dedicated whole-body reaction apparatus (Takei Scientific Instrument Co., Japan).

**Table 1. Design of Neuromuscular Training Program**

| Week | Series | Work /rest (s) | Intensity | Rest (min) | Strength (balance & core) | Agility (whole-body reaction) |
|---|---|---|---|---|---|---|
| 1 | 3 | 30/15 | Low | 3 | Glute bridge, lateral band walk, single-leg stance reach (light star excursion), Pallof press, BOSU plank. | Reactive step grid (4-directions), agility ladder (basic + random call), ball-drop step & catch, jump rope. |
| 2 | 3 | 30/15 | Low | 3 | Single-leg RDL (bodyweight), side plank, mini-squat to balance, dead bug, standing calf raise on foam. | Choice Stepping Reaction Time (CSRT) on floor grid, lateral shuffle + coach call, FITLIGHT stand-and-step touches. |
| 3 | 4 | 40/20 | Low-Moderate | 3 | Medicine-ball chop to single-leg hold, Bulgarian split squat | Unilateral drop jump (DJ) + 3 m reactive sprint, cone coordination |

| Week | Series | Work /rest (s) | Intensity | Rest (min) | Strength (balance & core) | Agility (whole-body reaction) |
|---|---|---|---|---|---|---|
| | | | | | (bodyweight), TRX row with balance, BOSU plank reach. | (color/number call), COD to light cue. |
| 4 | 4 | 40/20 | Moderate | 3 | Single-leg RDL (light DB), anti-rotation press (Pallof), heel-to-toe tandem on foam, abdominal bracing. | Resisted reactive sprints (band) to audio cue, whole-body reaction step (Takei/step plate), randomized shuttle COD. |
| 5 | 4 | 40/20 | Moderate | 3 | Medicine-ball throw to balance, push-ups with shoulder tap, BOSU squat (low depth), glute med wall press. | Agility ladder (in-in-out-out) with random call, single-leg hop & stick to light cue, reaction-ball drop to step. |
| 6 | 4 | 40/20 | Moderate -High | 3 | Split-squat isometric holds, hip airplane (assisted), TRX Y-raise, plank with perturbation (partner tap). | 5 m sprint to light + stop on command, lateral shuffle + step to plate, perturbation stepping (treadmill/plate). |
| 7 | 4 | 40/20 | Moderate -High | 3 | Single-leg squat to box, band anti-rotation walk, BOSU single-leg balance with head turns, Copenhagen plank (easy). | Stroboscopic/occluded-vision catch & step, unilateral DJ + 3 m sprint to random cone, partner mirror-step drill. |
| 8 | 4 | 40/20 | High | 3 | RDL (DB) to knee drive balance, lateral lunge to balance, Pallof press hold walkout, plank reach on foam. | Zig-zag reactive hops, dual-task CSRT (audio + color call), ball-drop step-sprint (10 m), agility circuit (competition). |

### Statistic Analysis

Statistical analysis in this study was conducted in stages. First, the data set was curated by checking for completeness, aligning formats, and filtering for entry errors and extreme outliers. Second, descriptive statistics were calculated to characterize the distribution of the measurements. Third, inferential testing using two-tailed paired-samples t-tests on pre- and posttest scores was conducted in IBM SPSS Statistics. Results are presented in tables and charts for clear interpretation. Finally, pre- and posttest comparisons were interpreted to evaluate whether neuromuscular training resulted in significant changes in whole-body reaction time and balance among the participants, and these findings were used to assess the effectiveness of the intervention and its implications for broader application.

## RESULTS AND DISCUSSION

This study aimed to determine the effectiveness of neuromuscular training in developing balance and reaction speed among collegiate-level hadang athletes. To our knowledge, this is the first investigation to examine the effects of neuromuscular training on both balance and reaction time in this population. The principal finding indicates that a structured neuromuscular training program was effective in improving balance and reaction time in collegiate-level hadang athletes.

**Table 2. Anthropometric Characteristics of Participants**

| Variable | NTG (Mean ± SD) | CTG (Mean ± SD) | *P*-value | Levene F | Levene P |
|---|---|---|---|---|---|
| Age (years) | 19.69 ± 0.70 | 19.50 ± 0.59 | 0.418 | 0.449 | 0.507 |
| Weight | 62.07 ± 10.18 | 64.55 ± 9.32 | 0.491 | 0.079 | 0.780 |
| Weight (kg) | 167.71 ± 5.80 | 166.79 ± 4.61 | 0.636 | 0.268 | 0.608 |
| BMI (kg/m$^2$) | 21.70 ± 3.80 | 23.39 ± 2.30 | 0.152 | 0.930 | 0.343 |

As shown in **Table 3**, both groups demonstrated improvements in balance outcomes, with generally larger changes observed in the experimental group compared with the control group. In contrast, whole-body reaction time showed a marked improvement only in the experimental group. For the left side standing stork, the experimental group increased from 42.99 ± 11.00 at baseline to 54.00 ± 12.01 at post-test, yielding a mean change of +11.01 points. This improvement was statistically significant, $t(14) = 2.24$, $p = 0.042$, and was associated with a moderate within-group effect size (Cohen's $d = 0.58$).

**Table 3. Pre- and Post-Intervention Scores, Within-Group Changes, and Effect Sizes for Left and Right Side Standing Stork and Whole-Body Reaction Time in the Experimental and Control Groups**

| Variable | Groups | Δ (Post – Pre) | t(14) | p-value | Cohen's d (within) | Hedges' g (between) | $\eta^2$ (Group × Time) |
|---|---|---|---|---|---|---|---|
| Left Side Standing Stork | NTG | +11.01 | 2.238 | 0.042 | 0.578 | 0.343 | 0.017 |
| | CTG | +5.01 | 1.321 | 0.208 | 0.341 | | |
| Right Side Standing Stork | NTG | +7.99 | 2.120 | 0.050 | 0.547 | 0.198 | 0.004 |
| | CTG | +5.01 | 1.320 | 0.208 | 0.341 | | |
| Whole-Body Reaction Time (S) | NTG | −0.21 | −5.265 | 0.001 | −1.359 | −0.908 | 0.099 |
| | CTG | −0.04 | −0.748 | 0.467 | −0.193 | | |

The control group improved from 39.99 ± 9.00 to 45.01 ± 10.01 (Δ = +5.01), but this change was not significant, t(14) = 1.32, $p = 0.208$, with a small effect size (d = 0.34). The between-group effect size for the change scores was small (Hedges' g = 0.34), and the Group × Time interaction explained a small proportion of variance ($\eta^2 \approx 0.02$). A similar pattern was observed for the right side standing stork. The experimental group improved from 46.01 ± 10.01 to 54.00 ± 9.00, corresponding to a mean change of +7.99 points, which approached statistical significance, t(14) = 2.12, $p = 0.052$, with a moderate within-group effect size (d = 0.55). The control group increased from 42.99 ± 12.99 to 48.00 ± 10.99 (Δ = +5.01; t(14) = 1.32, $p = 0.208$; d = 0.34). The between-group effect on change was small (Hedges' g = 0.20), and the interaction effect size was trivial ($\eta^2 \approx 0.00$). In contrast, whole-body reaction time showed a clearly differentiated response between groups. The experimental group improved from 0.53 ± 0.09 s at baseline to 0.32 ± 0.11 s at post-test (Δ = −0.21 s), indicating a substantial reduction in reaction time. This change was highly significant, t(14) = −5.27, $p < 0.001$, with a large within-group effect size (Cohen's d = −1.36). The control group exhibited only a small, non-significant reduction from 0.49 ± 0.12 s to 0.45 ± 0.13 s (Δ = −0.04 s; t(14) = −0.75, $p = 0.467$; d = −0.19). The between-group effect for change in whole-body reaction time was large (Hedges' g = −0.91), and the Group × Time interaction accounted for a meaningful proportion of variance ($\eta^2 \approx 0.10$), indicating that the experimental intervention produced substantially greater improvements in reaction speed compared with the control condition.

This study investigated the effects of a neuromuscular training program on developing balance and reaction time in collegiate hadang. Left and right leg balance data showed significant improvements in the NTG group ($p < 0.05$) after 8 weeks of neuromuscular training intervention. Meanwhile, the control group did not experience significant improvements, indicating that no substantial changes in balance and reaction time in collegiate hadang could occur without specific intervention. The greater improvement in reaction time compared to balance in the NMT group reflects the more rapid adaptation of the visuomotor-reactive component. This result aligns with previous research that concluded that neuromuscular training protocols consistently produce significant reductions in reaction time within short intervention cycles (Luo et al., 2025). In contrast, static and dynamic balance relies more on sensory reweighting, requiring longer exposure and highly specific training to the sensory modality, thus tending to result in slower rates of improvement (Ketterer et al., 2024).

The neuromuscular training program in this study enhanced proprioceptive acuity, sensorimotor integration, and feed-forward postural control, mechanisms consistently implicated in balance gains with integrative neuromuscular approaches (Guzmán-Muñoz et al., 2020; Marinkovic et al., 2024). Evidence from a recent study showed that integrative neuromuscular training improves balance performance alongside other physical qualities (Chen et al., 2025; Concha-Cisternas et al., 2023; Rezaeipour & Apanasenko, 2020), aligning with the bilateral static-balance improvements observed in our NTG group. Additionally, a previous systematic review indicates that different types of neuromuscular training benefit athletes, as this training method can effectively enhance reciprocal, static, and dynamic balance ability in athletes (Gao et al., 2024).

Meanwhile, in non-athlete adults, randomized trials of neuromuscular training programs further demonstrate superior improvements in standing postural control and core muscle contractility versus conventional exercise, supporting a mechanistic link between trunk neuromuscular function and whole-body balance (Chmielewski et al., 2024; Huang et al., 2023; Silva-Moya et al., 2022). The integrative neuromuscular training program systematically improved speed and change-of-direction, two indicators of rapid movement execution that are strong proxies for improved reaction speed when unexpected stimuli appear (Chen et al., 2025). In addition, previous research has shown that the training components in integrative neuromuscular training can improve neuromuscular function, thereby increasing the motor response threshold and faster initiation of corrective steps in training and competition conditions (Luo et al., 2025). These converging findings from athletic and non-athletic populations support the present results showing that neuromuscular training effectively enhances both balance and reaction time in collegiate hadang athletes.

Previous study suggested that neuromuscular training enhances proprioceptive acuity and sensorimotor integration while promoting sensory reweighting, thereby reducing sway variability and enabling more precise postural corrections (Marinkovic et al., 2024). This adaptation is enhanced by a form of neuromuscular training that sharpens standing postural control and core muscle function, providing a mechanistic basis for improved unilateral stability (Zhang et al., 2021). Furthermore, the neuromuscular training component increases the demands on neuromuscular control in unstable environments and has been shown to improve both static and dynamic balance (Guzmán-Muñoz et al., 2020).

The neuromuscular training program used in this study shortened the detect–decide–act chain by enhancing visuomotor integration and optimizing anticipatory and reactive control, thereby reducing initiation latency and improving whole-body reaction time. Evidence from previous studies suggested that advanced neuromuscular training yields measurable gains on visuomotor reaction tests, while integrative neuromuscular training consistently improves speed and agility that underlie faster stimulus to movement execution (Luo et al., 2025). Taken together, these mechanisms provide a coherent explanation for the greater improvements in reaction time and meaningful gains in unilateral balance observed in the NTG compared to the CTG.

The present findings suggest that integrating neuromuscular training into routine hadang preparation can meaningfully enhance two key performance-related components: unilateral balance and whole-body reaction speed. Both capacities are critical in hadang, where athletes must repeatedly decelerate, change direction, evade opponents, and maintain postural stability while responding rapidly to dynamic tactical situations. Coaches and strength-and-conditioning practitioners working with hadang athletes can feasibly adopt an NMT protocol similar to the one implemented in this study: 8 weeks in duration, 3 sessions per week, and approximately 40 minutes per session, with at least 24 hours between sessions to allow recovery and minimize excessive fatigue.

Several limitations should be acknowledged when interpreting these findings. first, First, the sample size was relatively small and drawn from a single university cohort, which may reduce statistical power and limit the generalizability of the results to other competitive levels, age groups, or institutions. Second, although the study employed a controlled pretest-posttest design, allocation to groups was non-random, and no formal matching procedure was applied. As such, residual confounding cannot be fully excluded, and causal inferences should be made with caution. Furthermore, the use of a general physical fitness assessment to evaluate balance and reaction speed is also a limitation of this study. Although this instrument has been extensively validated to assess basic physical attributes in several high-performance sports, it may not fully capture the specific demands of hadang. Therefore, future research is recommended to incorporate more specific assessment methods for hadang performance.

Future studies should aim to replicate and extend these findings using larger and more diverse samples, including athletes from different competitive levels and age categories. Randomized controlled trials with stratified or matched allocation would strengthen causal inference and help to better isolate the independent effects of NMT from other training influences. Longer intervention and follow-up periods are also warranted to determine the durability of neuromuscular adaptations and to assess whether continued or periodic NMT is required to maintain gains in balance and reaction time. In addition, incorporating hadang-specific performance tests would provide a clearer understanding of how neuromuscular improvements transfer to sport-specific outcomes. Investigations that combine NMT with other modalities, such as plyometric or sprint training, and that systematically manipulate training volume and intensity could help to establish optimal periodization strategies. Finally, including injury surveillance and biomechanical analyses (e.g., jump-landing mechanics or cutting kinematics) would clarify whether NMT not only enhances performance but also contributes to injury risk reduction in hadang athletes.

## CONCLUSION

This study demonstrates that 8 weeks of neuromuscular training effectively improves balance and reaction speed in collegiate hadang athletes, with statistically significant pre–post gains and meaningful effect sizes. In the neuromuscular training group, left-leg and right-leg balance increased by +11.01 s and +7.99 s, respectively, with significant or borderline significant improvements ($t(14) = 2.24$, $p = 0.042$, Cohen's $d = 0.58$; $t(14) = 2.12$, $p = 0.050$, Cohen's $d = 0.55$) and small between-group effects (Hedges' $g = 0.34$ and $0.20$; $\eta^2 = 0.017$ and $0.004$). Whole-body reaction time decreased by 0.21 s ($t(14) = -5.27$, $p = 0.001$), accompanied by a large within-group effect (Cohen's $d = 1.36$), a large between-group effect (Hedges' $g = 0.91$), and a moderate group × time interaction effect ($\eta^2 = 0.099$).

Given these statistically significant and practically relevant effects, together with the simplicity of the exercise structure, minimal equipment requirements, and compatibility with standard court-based practice, neuromuscular training represents a safe, cost-effective, and evidence-based component of performance preparation rather than merely an "easily integrated" option. In practical terms, coaches are encouraged to implement a 8-week neuromuscular training block, delivered 3 times per week for approximately 40 minutes per session within regular training microcycles to systematically enhance balance and reaction speed in hadang athletes.

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## CONFLICT OF INTEREST

The author declares that there is no conflict of interest in this research.

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