

The Effect of Lower-Limb Plyometric Training on Agility and Balance in Male Indonesian Military Personnel: A Randomized Controlled Trial

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Intensive activity during military training may increase the risk of musculoskeletal disorders, particularly in the lower extremities, potentially affecting performance. Agility and balance are essential for postural stability and controlled movements during military tasks. Lower-limb plyometric training may improve neuromuscular coordination, explosive strength, and postural control. This study aimed to determine the effect of lower-limb plyometric training on agility and balance in Indonesian military personnel. A randomized controlled trial with baseline and follow-up assessments was conducted at the Naval Education and Training Command in Surabaya, Indonesia, from June to August 2025. Twenty-eight military personnel aged 18–24 years were randomly assigned to an experimental group ($n = 14$), which performed lower-limb plyometric training twice weekly for six weeks, or a control group ($n = 14$), which received no intervention. Agility and dynamic balance were assessed using the Modified Agility T-Test and Y-Balance Test, respectively. Plyometric training significantly improved agility and dynamic balance. Modified Agility T-Test time decreased from 8.55 ± 0.70 to 7.35 ± 0.39 s ($p < 0.001$; $ES = 0.779$). Y-Balance Test composite reach length increased from 0.73 ± 0.06 to 0.82 ± 0.04 for the right leg ($p < 0.001$; $ES = 0.390$) and from 0.72 ± 0.06 to 0.81 ± 0.02 for the left leg ($p < 0.001$; $ES = 0.511$). These findings indicate that six weeks of lower-limb plyometric training can improve agility and dynamic balance in Indonesian military personnel. The intervention was well tolerated, with no serious adverse effects, and can be implemented without equipment.

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Introduction

Maintaining optimal physical readiness is a fundamental requirement for military personnel because operational success depends on the ability to perform demanding physical tasks under unpredictable environmental conditions. Modern military training requires personnel to repeatedly execute high-intensity activities, including rapid sprinting, abrupt changes of direction, jumping, obstacle negotiation, climbing, load carriage, and maneuvering across uneven terrain while carrying combat equipment. These activities require not only muscular strength and power but also high levels of agility, dynamic balance, and neuromuscular coordination to ensure effective operational performance and minimize injury risk. Consequently, physical conditioning has become an integral component of military education and training programs aimed at maintaining combat readiness throughout military service (Amdan, 2016; Dijkstra et al., 2019).

Despite its importance, intensive military training is accompanied by a substantial burden of musculoskeletal injuries that negatively affect operational capability and healthcare utilization. Musculoskeletal injuries represent one of the leading causes of medical consultations among military personnel worldwide, accounting for approximately 1.6 million medical visits annually within the United States Department of Defense. Injuries involving the lower extremities remain the most frequently documented type, while ankle injuries account for almost one-third of all cases musculoskeletal injuries experienced during military training. Similar patterns have been reported across different military organizations, including the Netherlands Armed Forces, where musculoskeletal injury prevalence ranged from 26.8% to 60.4%, predominantly affecting the foot, ankle, knee, and lower back (Bullock et al., 2010; Cameron et al., 2010; Chang et al., 2022; Dijkstra et al., 2019; Goodrich et al., 2022). These injuries not only reduce physical performance but also contribute to temporary disability, increased medical costs, interrupted training schedules, and reduced force readiness.

The elevated occurrence of injuries affecting the lower extremities is closely related to the biomechanical demands imposed during military activities. Soldiers are frequently required to perform multidirectional movements, sudden acceleration and deceleration, repeated jumping and landing, and rapid directional changes while carrying additional external loads. Such tasks impose substantial mechanical stress on the lower extremities and require excellent dynamic stability to maintain movement efficiency under physically demanding conditions. Previous reports have demonstrated that insufficient neuromuscular control, impaired balance, and poor agility increase the likelihood of lower-extremity injuries during military training, particularly ankle sprains, patellofemoral disorders, stress fractures, and medial tibial stress syndrome (Andersen et al., 2016; dos Santos Bunn et al., 2021; Fenn et al., 2021). Although comprehensive epidemiological data among Indonesian military personnel remain unavailable, national health statistics indicate that sprains constitute one of the most common injuries in Indonesia, with approximately 68% involving the lower extremities, suggesting that lower-limb injury prevention should receive greater attention within military physical training programs (Kemenkes RI, 2018).

Because operational tasks require rapid and coordinated movements, agility and balance have emerged as two essential components of military physical performance. Agility extends beyond simple running speed and refers to the capacity to quickly alter body position or movement direction in response to external stimuli through the integration of physical and cognitive processes. Effective agility depends on lower-limb strength, muscular power, coordination, reaction time, movement technique, and neuromuscular control. Likewise, dynamic balance reflects the capacity to maintain postural stability while executing complex motor tasks in changing environmental conditions. Adequate balance facilitates efficient force transfer during movement, enhances postural control, and reduces excessive joint loading during landing and directional changes.

Collectively, improvements in agility and balance contribute not only to enhanced military performance but also to reduced injury susceptibility during operational and training activities (Dawes et al., 2012; Sheppard & Young, 2006; Shumway-Cook & Woollacott, 2017).

Recognizing the importance of neuromuscular performance, recommendations from the United States Army Joint Physical Training Injury Prevention Working Group indicate incorporating multidirectional movement training, proprioceptive exercises, neuromuscular conditioning, and agility training into routine military physical conditioning programs. These recommendations emphasize diversifying mechanical loading patterns to improve movement quality while simultaneously reducing overuse injuries associated with repetitive running-based training (Bullock et al., 2010). However, identifying practical and efficient training methods capable of simultaneously improving agility, balance, and lower-limb neuromuscular performance remains an important challenge for military conditioning specialists.

Lower-limb plyometric training has attracted increasing attention as a time-efficient neuromuscular intervention capable of enhancing explosive performance through optimization of the stretch-shortening cycle. Originally introduced by Verkhoshansky, plyometric exercises involve fast muscle lengthening–shortening contractions that enhance motor unit activation, tendon stiffness, coordination between muscles, and reactive force generation. These physiological adaptations enable athletes to generate greater force within shorter ground-contact times, thereby improving acceleration, change-of-direction performance, jumping ability, and dynamic stability. In addition to improving performance, enhanced neuromuscular control and lower-limb stabilization resulting from plyometric training may reduce injury risk by improving landing mechanics and movement efficiency (Shedge et al., 2024; Sondang, 2017; Soni & Vedawala, 2022).

Although a substantial body of research has confirmed the benefits of plyometric exercise for athletes involved in soccer, basketball, volleyball, and rugby, considerably fewer randomized controlled trials have evaluated its effectiveness in active military populations. The physiological demands experienced by military personnel differ substantially from those of competitive athletes because military tasks combine prolonged endurance activities, external load carriage, tactical maneuvering, and unpredictable environmental conditions. Consequently, findings obtained from athletic populations cannot be directly generalized to military settings. Furthermore, evidence regarding military personnel in Southeast Asia remains particularly limited, and no randomized controlled trial has specifically examined the impact of structured lower-limb plyometric training on both agility and balance among active Indonesian military personnel.

Therefore, this a randomized controlled experiment was performed to examine the impact of an eight-week plyometric program targeting the lower extremities on agility and dynamic balance among male Indonesian military personnel. We hypothesized that participants receiving structured plyometric training would demonstrate markedly superior gains in agility and balance relative to those undergoing conventional military physical training alone. The results of this investigation are anticipated to offer scientific evidence supporting the integration of lower-limb plyometric exercises into military conditioning programs to optimize physical readiness while potentially reducing lower-extremity injury risk.

2. Methodology

The investigation employed a single-site, parallel-arm randomized controlled trial (RCT) using an equal allocation ratio of 1:1. Participants were randomly allocated to a lower-extremity plyometric exercise group or a control group receiving routine military physical training. Outcome assessments were completed before random assignment at baseline and again immediately following the six-week intervention.

Owing to the characteristics of the intervention, participants could not be blinded; however, outcome evaluations were carried out by an independent examiner unaware of group assignment (single-blind design). The study was conducted at the Indonesian Navy Education and Training Command (Komando Pendidikan dan Latihan TNI Angkatan Laut, Kodiklat), Surabaya, Indonesia, between June and August 2025. The investigation followed the Consolidated Standards of Reporting Trials (CONSORT) when establishing its methodological framework 2010 statement.

Participants were active male Indonesian military personnel aged 18–24 years who were undergoing initial military education at Kodiklat, Surabaya. Potential participants were screened consecutively to determine their eligibility before enrollment. Eligible participants fulfilled all of the following inclusion criteria: (1) male military personnel; (2) aged between 18 and 24 years; (3) currently enrolled in an initial military education program; and (4) willing to participate by providing written informed consent.

Participants were excluded if they had a history of or were currently receiving treatment for musculoskeletal disorders (including fractures, ligament injuries, muscle injuries, or joint disorders), neurological diseases (including epilepsy, vertigo, movement disorders, spinal cord injury, traumatic brain injury, or stroke), cardiovascular or respiratory diseases, or any medical condition that could interfere with exercise participation or influence the intervention outcomes. Participants were withdrawn from the study if they failed to attend more than 20% of the intervention sessions, voluntarily withdrew from the study, or developed illness or injury preventing continuation of the intervention. Individuals were removed from the trial whenever they based on agility outcomes reported by Ozmen and Aydogmus. Sample estimation was performed before recruitment using the equation for two unrelated mean comparisons and standard deviation obtained from the

reference study, a Based on a bidirectional alpha value of 0.05, 90% analytical power, and the anticipated difference between group averages. To compensate for an anticipated attrition After accounting for an anticipated attrition of 20%, recruitment was expanded to 14 individuals in every arm, yielding 28 participants overall.

Once the initial evaluation had been finalized, eligible individuals were assigned equally to the experimental or comparison arm through a computerized random assignment schedule. Group assignments remained concealed by consecutively labeled sealed opaque envelopes prepared independently by a researcher with no role in enrollment or data evaluation. The assignment record was revealed only after completion of all baseline measurements. Because of the characteristics of the training protocol, both subjects and nor exercise instructors could be blinded to treatment allocation. However, all agility and balance assessments were performed by an experienced assessor who remained unaware of participants' group assignments throughout data collection and statistical analysis.

Participants allocated to the intervention group performed a supervised lower-limb completed a plyometric exercise regimen alongside standard military conditioning. Training sessions occurred two times each week over six continuous weeks, and every session required about 30–40 minutes. Every training session consisted of a standardized warm-up, plyometric exercise session, and cool-down. Exercise intensity and training volume were progressively increased throughout the intervention period following the principle of progressive overload while ensuring participant safety.

The plyometric program primarily targeted lower-extremity neuromuscular function using activities focused on the stretch–shortening mechanism. The training protocol included squat jumps, tuck jumps, bounding, hurdle jumps, lateral hops, and drop jumps performed under direct supervision by certified physiotherapists.

Table 1 Progressive lower-limb plyometric training protocol

Week	Exercise	Sets	Repetitions	Rest between sets	Frequency
1–2	Squat jump	2	10	60 s	2 sessions/week
	Tuck jump	2	10	60 s	
	Bounding	2	10	60 s	
	Lateral hop	2	10	60 s	
3–4	Squat jump	3	10	60 s	2 sessions/week
	Tuck jump	3	10	60 s	
	Bounding	3	10	60 s	
	Hurdle jump	3	10	60 s	
	Lateral hop	3	10	60 s	
5–6	Squat jump	3	12	90 s	2 sessions/week
	Tuck jump	3	12	90 s	
	Bounding	3	12	90 s	
	Hurdle jump	3	12	90 s	
	Lateral hop	3	12	90 s	
	Drop jump	3	8	90 s	

Participants assigned to participants assigned to the comparison arm maintained their standard military conditioning activities program throughout the six-week study period without receiving additional plyometric exercises. The routine training consisted of the standard physical conditioning program prescribed by the military education curriculum. Agility was evaluated using the Modified Agility Test (MAT). Participants completed the standardized agility course as rapidly as possible while maintaining proper movement technique. Performance was recorded in seconds using a digital stopwatch. Two familiarization trials were provided before testing, and the highest recorded score served as the basis for the statistical evaluation. Data collection occurred at the initial assessment and directly following the intervention period.

Dynamic stability was examined through the Y Balance Test, designed to measure postural regulation across the anterior, posteromedial,

and posterolateral reach directions. Three successful trials were performed in each direction, and the average normalized reach distance was calculated for analysis. Data collection took place both prior to and following the intervention while maintaining consistent assessment procedures. Data normality was assessed using the Shapiro–Wilk test. Baseline demographic and anthropometric Baseline attributes were evaluated across groups with the independent-samples t-test for parametric data and the Mann–Whitney U procedure for nonparametric data. Qualitative variables were analyzed using either the chi-square or Fisher's exact procedure when applicable.

The effects of the intervention on agility and dynamic balance were analyzed A mixed two-factor analysis of variance (Group $\times$ Time) was implemented, treating group as the between-participant factor and assessment occasion as the repeated factor. Significant interactions were followed by Bonferroni-corrected post hoc

testing. Magnitudes of observed effects were expressed using partial eta squared (η^2p) for interaction terms and Cohen's d for paired comparisons. Average differences were supplemented by 95% confidence intervals (95% CI). Statistical significance was established at a two-tailed p value < 0.05 . Because no participant withdrew from the study, analyses were performed according to the complete-case principle; however, an intention-to-treat approach had been prespecified in the study protocol in the event of participant attrition.

Ethical clearance for the research protocol was granted by the Health Research Ethics Committee (Hidden name) University (Decision No. 04/EC/KEPK/FKUA/2025 in Januari 03 2025), before participant recruitment. All participants received written and verbal explanations regarding participants received a full explanation of the research procedures and signed informed consent documents before participation. The investigation adhered to the ethical standards outlined in the Declaration of Helsinki.

3. Results

A total of 28 male military personnel were enrolled and randomly allocated in a 1:1 ratio to either the plyometric training group ($n = 14$) or the control group ($n = 14$). Participants in the intervention group completed a supervised

lower-limb plyometric training the intervention schedule was completed two times each week over a six-week period, while participants assigned to the comparison group maintained their standard military exercise regimen without supplementary activities plyometric exercises. All participants completed the study, resulting in a retention rate of 100%. Adherence to the prescribed plyometric training sessions was also 100%, and no intervention-related no harmful incidents occurred during the investigation. Therefore, every one of the 28 randomized participants was retained for the concluding analysis.

The participants were aged 19–22 years. Baseline demographic, anthropometric, and physical activity baseline profiles demonstrated no meaningful differences between groups. Average age reached 20.57 ± 0.85 years in the intervention cohort and 20.14 ± 0.86 years in the comparison cohort. Average body weight, stature, and body mass index likewise showed close agreement. Both groups demonstrated high levels of habitual physical activity levels determined using the International Physical Activity Questionnaire, with mean activity levels of 4153.78 ± 187.60 Weekly physical activity reached 4165.00 ± 194.86 MET-min in the control arm, while the intervention arm recorded its respective value. Initial participant profiles were presented in Table 2.

Table 2. Baseline characteristics of the study participants

Characteristic	Plyometric training group ($n = 14$)	Control group ($n = 14$)
Age, years	20.57 ± 0.85	20.14 ± 0.86
Body weight, kg	65.20 ± 4.21	64.29 ± 6.16
Height, cm	170.07 ± 3.79	169.86 ± 4.13
Body mass index, kg/m ²	22.54 ± 1.28	22.24 ± 1.46
Physical activity, MET-min/week	4153.78 ± 187.60	4165.00 ± 194.86
Data are presented as mean $\pm$ standard deviation. MET, metabolic equivalent of task. Physical activity was assessed using the International Physical Activity Questionnaire.		
Agility Evaluation employed the Modified Agility Test before treatment began and again after six weeks. Within the control arm, the average completion time increased slightly from 7.94 ± 0.53 seconds at baseline to 8.06 ± 0.45		

seconds after six weeks; this within-group difference did not reach statistical significance ($p = 0.386$), whereas plyometric training group demonstrated a significant reduction in Modified Agility Test completion time, from 8.55 ± 0.70 seconds at baseline to 7.35 ± 0.39 seconds after

the intervention ($p < 0.001$). Because a shorter completion time represents better test performance, this reduction indicated a significant improvement in agility following lower-limb plyometric training (Table 3).

Table 3 Within-group changes in Modified Agility Test performance

Group	Baseline, seconds	Post-intervention, seconds	Within-group p value
Control group	7.94 ± 0.53	8.06 ± 0.45	0.386
Plyometric training group	8.55 ± 0.70	7.35 ± 0.39	<0.001

Data are presented as mean $\pm$ standard deviation. Within-group comparisons were performed using paired-samples t-tests. A lower completion time indicates better agility performance.

Dynamic balance was evaluated using the composite reach length obtained from the Y Balance Test for the right and left lower limbs. In the control group, the right-limb composite reach length increased from 0.68 ± 0.53 at baseline to 0.71 ± 0.51 after six weeks, representing a statistically significant within-group change ($p = 0.038$). The left-limb

composite reach length increased from 0.69 ± 0.54 to 0.72 ± 0.44 ; nevertheless, the observed difference did not achieve statistical significance ($p = 0.129$).

In the plyometric training group, both extremities demonstrated meaningful enhancement. The right-limb composite reach length increased from 0.73 ± 0.06 at baseline to 0.82 ± 0.04 after the intervention ($p < 0.001$). Similarly, the left-limb value increased from 0.72 ± 0.06 to 0.81 ± 0.02 ($p < 0.001$). The within-group changes in dynamic balance are presented in Table 4.

Table 4. Within-group changes in Y Balance Test composite reach length

Group	Limb	Baseline	Post-intervention	Within-group p value
Control group	Right	0.68 ± 0.53	0.71 ± 0.51	0.038
	Left	0.69 ± 0.54	0.72 ± 0.44	0.129
Plyometric training group	Right	0.73 ± 0.06	0.82 ± 0.04	<0.001
	Left	0.72 ± 0.06	0.81 ± 0.02	<0.001

Data are presented as mean $\pm$ standard deviation. Within-group comparisons were performed using paired-samples t-tests.

At the post-intervention assessment, Modified Agility Test completion time was significantly shorter in the plyometric training group than in the control group (7.35 ± 0.39 vs. 8.06 ± 0.45 seconds, respectively; $p < 0.001$). The reported effect size was 0.779, indicating a moderate-to-large between-group effect. Post-intervention dynamic balance also showed a meaningful

difference across the study groups. Regarding the right lower limb, composite reach length was higher in the plyometric training group than in the control group (0.82 ± 0.04 vs. 0.71 ± 0.51 ; $p = 0.036$), with an effect size of 0.390. For the left lower limb, the corresponding values were 0.81 ± 0.02 and 0.72 ± 0.44 , respectively ($p = 0.005$), with an effect size of 0.511. These findings are summarized in Table 5.

Table 5. Between-group comparisons of post-intervention agility and dynamic balance

Outcome	Plyometric training group	Control group	Between-group <i>p</i> value	Effect size
Modified Agility Test, seconds	7.35 ± 0.39	8.06 ± 0.45	<0.001	0.779
Right-limb composite reach length	0.82 ± 0.04	0.71 ± 0.51	0.036	0.390
Left-limb composite reach length	0.81 ± 0.02	0.72 ± 0.44	0.005	0.511

Data are presented as mean ± standard deviation. Between-group comparisons were performed using independent-samples *t*-tests. A lower Modified Agility Test completion time indicates better agility performance, whereas a higher composite reach length indicates better dynamic balance

4. Discussion

This randomized controlled trial examined how a six-week plyometric protocol targeting the lower extremities influenced agility and dynamic balance among young Indonesian military personnel undergoing initial military education. The principal findings demonstrated that participants who received supervised plyometric training in addition to routine military physical training achieved significantly greater improvements in agility and dynamic balance than those who performed routine military training alone. Specifically, the intervention group exhibited a substantial reduction in Modified Agility Test (MAT) completion time together with significant improvements in Y Balance Test composite reach distance for both lower limbs. In contrast, routine military physical training alone did not produce meaningful improvements in agility and produced only slight alterations in dynamic balance. Collectively, these findings support our primary hypothesis that incorporating structured plyometric exercises into conventional military conditioning enhances neuromuscular performance beyond that achieved through routine physical training alone (Liu et al., 2025; Smith et al., 2022; Sun et al., 2025).

A key finding emerging from this investigation is that all participants completed the intervention without adverse events and demonstrated

perfect adherence throughout the six-week training period. This finding suggests that a progressively supervised plyometric program can be safely implemented within the context of military physical training when appropriate participant screening, exercise supervision, and progressive overload principles are applied (Chaabene et al., 2021; Davies et al., 2015; Deng, Soh, Abdullah, Huang, et al., 2024). Although plyometric exercises are frequently perceived as high-impact activities with an increased risk of musculoskeletal injury, recent evidence indicates that injury risk is primarily associated with inappropriate exercise prescription rather than the training modality itself.

Among the observed outcomes, the improvement in agility represents one of the most practically relevant findings for military performance. Agility is a complex physical quality that extends beyond the ability to change direction rapidly (Sheppard & Young, 2006; Young et al., 2022). Rather, it reflects the coordinated integration of muscular strength, explosive power, neuromuscular coordination, reaction capability, movement efficiency, and postural control. Military personnel routinely perform multidirectional movements while negotiating obstacles, carrying external loads, responding to unpredictable environmental demands, and executing tactical maneuvers under time constraints (Chimera et al., 2004; Dijkema et al., 2019). Consequently,

improvements in agility have direct implications for operational performance rather than merely enhancing athletic capacity.

The substantial reduction in MAT completion time observed following plyometric training is physiologically plausible and can largely be explained by adaptations within the neuromuscular system. Plyometric exercises repeatedly expose the neuromuscular system to rapid eccentric-concentric muscle actions, thereby stimulating adaptations that increase the efficiency of force production during explosive movements (Asadi et al., 2015; Chaabene et al., 2021; Ramirez-Campillo et al., 2018). Unlike conventional resistance or endurance training, plyometric exercises specifically target the capacity to produce substantial force over a very brief duration intervals. Repeated exposure to these movement patterns enhances the synchronization of motor unit recruitment, increases neural drive to the working musculature, and improves intermuscular coordination among the hip, knee, and ankle extensors (Chimera et al., 2004; Chu & Myer, 2013).

One of the principal mechanisms responsible for these improvements is optimization during the stretch-shortening cycle (SSC) (Chimera et al., 2004; Chu & Myer, 2013; Davies et al., 2015). During plyometric movements, muscles undergo a fast eccentric action that is instantly succeeded by a powerful concentric movement. During the eccentric stage, elastic energy is accumulated within the muscle-tendon complex while simultaneously activating muscle spindles through stretch reflex mechanisms. If the transition period between eccentric and concentric contractions, commonly referred to as the amortization phase, remains sufficiently brief, a greater proportion of this stored elastic energy is reutilized during the subsequent concentric contraction. The result is enhanced mechanical efficiency and greater force production without additional metabolic cost. Consequently, participants become capable of accelerating, decelerating, and reaccelerating more effectively during multidirectional tasks such as the Modified Agility Test. These

physiological adaptations have consistently been identified as the primary mechanism underlying improvements following plyometric training across multiple comprehensive evidence syntheses and quantitative research summaries (Chaabene et al., 2021; Sun et al., 2025).

Beyond improvements in mechanical efficiency, plyometric training also induces substantial neural adaptations that contribute to enhanced agility. Repeated high-velocity movements facilitate more efficient activation of motor units requiring greater recruitment thresholds, especially type II motor units responsible for explosive force production (Asadi et al., 2015; Chimera et al., 2004; Sun et al., 2025). Increased activation frequency of these fast motor units enables participants to develop force more rapidly during short-duration movements requiring sudden acceleration and directional changes. Simultaneously, improvements in rate of force development allow muscles to achieve maximal torque earlier during ground contact, thereby reducing contact time while maintaining movement stability (Chaabene et al., 2021; Ramirez-Campillo et al., 2021).

Another mechanism likely contributing to the observed improvement is enhanced motor learning. Plyometric exercises involve repetitive execution of complex movement patterns that require precise coordination between multiple joints and muscle groups. Repeated practice facilitates central nervous system adaptations through improved motor planning (Abernethy et al., 1999; Young et al., 2022), movement timing, and coordination of agonist-antagonist muscle activation. Over time, these adaptations reduce unnecessary co-contraction of antagonist muscles, improve movement economy, and enhance the precision of lower-limb positioning during directional changes. Consequently, participants become capable of executing rapid multidirectional movements with greater efficiency and less energy expenditure. The present results agree with contemporary concepts of neuromuscular training (Abernethy et al., 1999; Young et al., 2022), which emphasize that enhanced agility is attributable not only to greater muscular strength but

additionally to enhanced neural control of movement.

Because the control group exhibited no meaningful improvement, the interpretation that the observed findings gains resulted from the plyometric intervention rather than from routine military physical training alone (Liu et al., 2025; Smith et al., 2022). Although conventional military training typically includes running, calisthenics, endurance conditioning, and general strength exercises, these activities may provide insufficient stimulus to optimize change-of-direction performance. Agility requires highly specific neuromuscular adaptations involving explosive eccentric-concentric actions, multidirectional force production, and rapid sensorimotor responses, all of which are only partially challenged during traditional conditioning programs (Dijksma et al., 2019; Young et al., 2022).

The present findings therefore reinforce the growing body of evidence suggesting that plyometric training should be considered a fundamental component of performance-oriented conditioning rather than merely a supplementary exercise modality (Jiang et al., 2026; Liu et al., 2025; Sun et al., 2025). From a physiological perspective, the agility gains documented throughout this investigation likely resulted from the combined influence of enhanced stretch-shortening cycle efficiency, improved recruitment of fast motor units, greater rate of force development, superior intermuscular coordination, and repeated motor learning adaptations.

Another important finding identified in this investigation was a marked enhancement in dynamic balance after six-week lower-limb plyometric training program. Participants allocated to the intervention group demonstrated significant increases in composite reach length on the Y Balance Test for both the dominant and non-dominant limbs, whereas routine military physical training alone produced only a modest improvement in the dominant limb and no significant change in the non-dominant limb. These findings indicate that the

addition of structured plyometric exercises elicited neuromuscular adaptations that extended beyond improvements in explosive performance and substantially enhanced postural stability during dynamic functional tasks, consistent with recent randomized controlled trials and systematic reviews demonstrating the beneficial effects of the influence of neuromuscular together with plyometric exercise on dynamic balance outcomes (Liu et al., 2025; Sun et al., 2025; Wang et al., 2024).

Dynamic balance is a multifactorial component of physical performance that requires continuous integration of sensory input, central nervous system processing, and coordinated neuromuscular output to maintain the body's center of mass within the base of support during movement (MacKinnon, 2018; Pollock et al., 2000; Shumway-Cook & Woollacott, 2017). Unlike static balance, which primarily reflects the ability to maintain a stable posture under stationary conditions, dynamic balance requires continuous postural adjustments while the body is accelerating, decelerating, changing direction, or responding to external perturbations. Military personnel are frequently exposed to these demands during obstacle negotiation, tactical maneuvers, rapid transitions between standing and kneeling positions, load carriage, and movement across irregular terrain (Chimera et al., 2004; Knapik et al., 2004; Smith et al., 2022). Consequently, improvements in dynamic balance are particularly relevant for enhancing functional performance under operational conditions.

The observed improvements in dynamic balance are likely attributable to enhanced proprioceptive function induced by repeated exposure to plyometric loading. During each landing phase of a plyometric exercise, mechanoreceptors located within muscles, tendons, joint capsules, and ligaments are subjected to rapid mechanical deformation, generating afferent sensory input to the central nervous system. Repeated exposure to these stimuli increases the sensitivity and responsiveness of muscle spindles and Golgi

tendon organs, thereby improving joint position sense and kinesthetic awareness (Herb & Hertel, 2014; Hertel, 2002). Enhanced proprioceptive acuity enables individuals to detect subtle changes in joint orientation more rapidly and initiate corrective muscular responses before excessive displacement of the center of mass occurs.

In addition to improved proprioception, plyometric training appears to facilitate more efficient postural control strategies. Dynamic postural control depends on the coordinated activation of multiple muscle groups surrounding the ankle, knee, hip, and trunk (MacKinnon, 2018; Shumway-Cook & Woollacott, 2017). During landing, these muscles must rapidly absorb ground reaction forces while simultaneously maintaining alignment of the lower extremity and trunk. Repeated execution of plyometric exercises strengthens these neuromuscular control mechanisms by refining the timing, magnitude, and sequencing of muscle activation (Asadi et al., 2015; Huang et al., 2021).

Another important physiological mechanism involves improvements in dynamic stability through increased intermuscular coordination. Plyometric training requires simultaneous control of multiple joints during high-velocity eccentric and concentric contractions (Chimera et al., 2004; Chu & Myer, 2013). Such movements demand precise coordination between agonist, antagonist, and synergistic muscles to control landing mechanics and absorb impact forces safely. Over repeated training sessions, the central nervous system develops more efficient movement strategies characterized by reduced antagonist co-contraction, improved synchronization of stabilizing musculature, and greater mechanical efficiency throughout the kinetic chain. These adaptations permit more effective maintenance of the body's center of mass while multidirectional movements, which is directly reflected by greater reach distances on the Y Balance Test (Gasim et al., 2022; Guo et al., 2021).

Enhanced eccentric strength may also have contributed substantially to the observed improvements in balance (Chu & Myer, 2013; Davies et al., 2015). Successful performance on the Y Balance Test requires participants to maintain unilateral stability while the contralateral limb reaches maximally in multiple directions. This task imposes considerable eccentric loading on the supporting limb, particularly at the hip and knee extensors, as well as the ankle plantarflexors and dorsiflexors. Plyometric exercises repeatedly challenge these muscle groups during landing, promoting greater eccentric force-generating capacity and improved mechanical stiffness of the muscle-tendon unit. Increased eccentric strength enables participants to better resist joint collapse and maintain postural alignment under increasing mechanical demands, thereby facilitating greater reach distances without compromising stability. Contemporary evidence suggests that improvements in eccentric neuromuscular capacity represent one of the primary determinants of enhanced dynamic balance following plyometric interventions (Sun et al., 2025; Wang et al., 2024).

The present findings may also be explained by adaptations occurring within the vestibular and sensorimotor systems. Maintenance of balance depends upon ongoing processing of input from the visual, vestibular, and somatosensory systems (Fuchs, 2018; MacKinnon, 2018). During plyometric training, participants repeatedly experience rapid changes in body orientation, acceleration, and deceleration that challenge vestibular function while simultaneously requiring rapid postural corrections. Repeated exposure to these stimuli improves central sensory integration, enabling more efficient weighting and processing of multisensory information (Huang et al., 2021; Wang et al., 2024).

Interestingly, the intervention improved balance in both lower limbs despite all participants demonstrating right-limb dominance. The greater relative improvement observed in the non-dominant limb is consistent with the concept that limbs with lower baseline

neuromuscular capacity possess greater potential for adaptive improvement following structured training. Bilateral and unilateral plyometric exercises likely reduced pre-existing interlimb asymmetry by stimulating symmetrical neuromuscular adaptations across both extremities (Bailey et al., 2015; Bishop et al., 2021). This finding is particularly relevant in military populations because excessive limb asymmetry has consistently been linked to impaired movement efficiency, increased injury susceptibility, and reduced physical performance during occupational tasks requiring bilateral coordination (Guo et al., 2021; Liu et al., 2025). Therefore, the ability of plyometric training to improve postural control bilaterally may represent an additional functional advantage beyond improvements in athletic performance alone.

An equally important observation is the relatively limited improvement demonstrated by participants undergoing routine military physical training. Although a small increase in right-limb balance was detected, no meaningful improvement occurred in the left limb. Conventional military conditioning training programs generally aim to improve overall physical conditioning through endurance running, calisthenics, and strength exercises (Liu et al., 2025; Smith et al., 2022). While these activities undoubtedly improve aerobic capacity and muscular endurance, they provide relatively limited stimulation of the rapid sensorimotor adjustments, multidirectional landing mechanics, and unilateral postural control required to substantially improve dynamic balance. In contrast, plyometric exercises repeatedly challenge postural control under conditions of high mechanical and neuromuscular demand, thereby producing adaptations that extend beyond those achieved through conventional conditioning alone (Chaabene et al., 2021; Dijkema et al., 2019).

Collectively, these findings suggest that improvements in dynamic balance observed in the present study resulted from multiple complementary physiological adaptations, including enhanced proprioceptive sensitivity,

more efficient anticipatory postural control, improved intermuscular coordination, greater eccentric force production, optimized sensorimotor integration, and bilateral neuromuscular adaptations (Jiang et al., 2026; Sun et al., 2025; Wang et al., 2024). Rather than acting through a single mechanism, plyometric training appears to improve dynamic balance by simultaneously enhancing the sensory, neural, and mechanical components responsible for maintaining postural stability during complex functional movements.

Among the currently available literature, the study by Liu et al. (2025) provides the closest comparison with the present investigation because both studies employed randomized controlled designs within military populations of comparable age. Liu et al. found that participation in an eight-week integrated neuromuscular training (INT) intervention performed three times weekly produced significant improvements in strength, sprint performance, and Illinois Agility Test performance compared with traditional military physical training. The intervention further produced a strong interaction effect between group and time for agility while maintaining full participant compliance without adverse events, supporting the feasibility of implementing neuromuscular conditioning within military education programs.

Our findings are also highly consistent with the a recently published systematic review accompanied by a meta-analysis by Sun et al. (2025), which concluded that plyometric training consistently improves lower-limb power, strength, and agility across trained adult populations. Likewise, Deng, Soh, Abdullah, & Huang (2024) demonstrated that plyometric interventions significantly enhance multiple domains of health-related physical fitness even among previously untrained individuals, suggesting that the neuromuscular benefits of plyometric exercise are robust across populations with varying training backgrounds. More importantly, Jiang et al. (2026) further confirmed through meta-analysis that integrative neuromuscular training improves both athletic

performance and injury-related outcomes, reinforcing the concept that neuromuscular exercise simultaneously enhances performance while reducing biomechanical injury risk. Collectively, these higher-level evidence syntheses strongly support the physiological interpretation of the present findings and indicate that the improvements observed in Indonesian military personnel are consistent with broader international evidence.

The balance outcomes observed in this study are likewise supported by previous investigations evaluating neuromuscular interventions. Wang et al. (2024) demonstrated through systematic evidence synthesis indicating that neuromuscular training produces meaningful improvement in dynamic balance by enhancing sensorimotor integration, postural control, and lower-limb neuromuscular coordination. Similarly, Huang et al. (2021) reported that plyometric and balance training significantly improved neuromuscular control and dynamic postural control in people experiencing functional ankle instability, indicating that repetitive stretch-shortening cycle activities facilitate adaptations extending beyond muscular strength alone. These previous findings closely correspond to the bilateral improvements in Y Balance Test performance observed in the present study, suggesting that enhanced proprioceptive acuity, anticipatory postural control, and intermuscular coordination collectively contribute to improved postural stability following lower-limb plyometric training.

Additional support for the present findings is provided by studies conducted in athletic populations. Guo et al. (2021) demonstrated that combining balance and plyometric exercises produced superior improvements in dynamic stability compared with conventional training alone, while Maciejczyk et al. (2021) reported significant improvements in sprint capacity, directional transition skills, and lower-body force production after completing plyometric exercises in soccer players. Although these studies involved athletes rather than military personnel, both populations require rapid

acceleration, multidirectional movement, and efficient neuromuscular control under physically demanding conditions.

The military implications of the present findings are particularly important. Modern military operations require considerably more than aerobic endurance and maximal strength. Soldiers are expected to negotiate obstacles, perform rapid changes of direction while carrying external loads, maintain postural stability on uneven terrain, recover quickly following landings, and execute tactical maneuvers under unpredictable environmental conditions. These occupational demands closely resemble the neuromuscular characteristics developed through plyometric training. Accordingly, improvements in agility and dynamic balance should not be interpreted merely as enhancements in athletic performance but rather as functional adaptations directly relevant to operational readiness.

Overall, the present study provides robust evidence that lower-limb plyometric training represents a practical, safe, and time-efficient strategy for enhancing agility and dynamic balance in military personnel. When integrated into conventional military conditioning programs, this training modality may contribute beyond enhancing physical capabilities by additionally to strengthen movement quality.

5. Conclusion

This randomized controlled trial demonstrated that a six-week lower-extremity plyometric exercise protocol under direct supervision produced substantial improvements in agility and dynamic balance in young Indonesian military personnel undergoing initial military education. Compared with routine military physical training alone, the addition of structured plyometric exercises resulted in greater improvements in Modified Agility Test performance and bilateral Y Balance Test composite reach distance, indicating enhanced neuromuscular function, movement efficiency, and postural control.

6. References

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