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Integrative Neuromuscular Training Improves Vertical Jump in Youth Basketball Players

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Abstract

Study purpose. Vertical jump performance is a critical physical capacity in youth basketball; however, conventional training in Indonesian junior programs lacks structured neuromuscular conditioning protocols, limiting explosive power development during key adolescent growth phases. Study purpose. This study examined the effect of an 8-week Integrative Neuromuscular Training (INT) program on vertical jump performance in youth basketball players.

Materials and methods. A quasi-experimental matching-only pretest-posttest control group design was employed. Ninety-two male youth basketball players aged 13-16 years were allocated into an intervention group (n=46) and a control group (n=46), categorized into Under-14 (KU14) and Under-16 (KU16) subgroups. The INT program comprised 24 sessions over 8 weeks, integrating dynamic stability, strength, plyometrics, coordination, speed and agility, and fatigue resistance. Countermovement Jump (CMJ) height was measured using the MyJump2 application.

Results. The intervention group improved significantly from 35.74 ± 6.17 cm to 45.02 ± 7.59 cm (Δ = +9.28 cm, 25.96%, p=0.000), while the control group showed negligible change (Δ = +0.34 cm, 0.88%). Between-group comparison confirmed significantly greater gains in the INT group (p=0.000) for both age categories, with large effect sizes (KU14: d=1.09; KU16: d=1.83).

Conclusions. The 8-week INT program significantly enhanced lower-limb explosive power in adolescent basketball players. INT is recommended as a structured, evidence-based intervention to develop neuromuscular performance within youth physical education and sport development programs.

Keywords: Integrative Neuromuscular Training, Vertical Jump, Countermovement Jump, Youth Basketball, Lower-Limb Power

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Introduction

Vertical jump performance is one of the most fundamental physical capacities in basketball, underpinning critical game actions such as rebounding, shooting, shot-blocking, and defensive contesting (Sarwar et al., 2025). The ability to generate maximal lower-limb

explosive force, commonly quantified through jump height in the Countermovement Jump (CMJ) test, is considered a key indicator of athletic readiness and competitive potential in youth basketball players (Pamuk et al., 2023; Murr et al., 2023). The development of lower-limb power in adolescents is closely tied to neuromuscular maturation, particularly the efficiency of motor unit recruitment, stretch-shortening cycle (SSC) function, and intra- and inter-muscular coordination (Chen et al., 2024; Yapici et al., 2022).

During the peak height velocity (PHV) phase, typically occurring between 13-16 years in males, the neuromuscular system demonstrates heightened responsiveness to training stimuli, creating a critical window for strength and power development (Guimaraes et al., 2021; Lima et al., 2023). This sensitive period represents an irreversible developmental opportunity: if adequate neuromuscular stimulation is not provided during this window, the potential for long-term explosive power development may be permanently diminished (Syaranamual et al., 2026; Almunawar et al., 2026). Despite this developmental urgency, coaching practices in Indonesian youth basketball frequently replicate adult professional training models, which prioritize technical skill repetition over systematic physical development (Munadi, 2025). The consequence of this gap is directly observable: youth players fail to achieve optimal lower-limb explosive power during the very developmental phase when neuromuscular adaptation is most pronounced. The absence of evidence-based, age-appropriate training protocols therefore remains a critical and urgent gap in national youth sport development programs (Pahlawi & Vanesha, 2025; Liu et al., 2025).

Integrative Neuromuscular Training (INT) is a structured approach designed to simultaneously develop multiple physical qualities including dynamic stability, muscular strength, plyometric power, coordination, speed and agility, and fatigue resistance within a single cohesive framework (Chen et al., 2025). Unlike isolated training modalities, INT targets the neuromuscular system holistically, potentially producing superior adaptations in force production and jump performance compared to conventional methods (Wan et al., 2025; Qin et al., 2024). Previous studies have demonstrated significant improvements in jump height in youth athletes through INT-based programs (Balasas et al., 2021; Andrews & Zachary, 2024; Hammami et al., 2023).

However, research examining the effect of a comprehensive INT program on CMJ performance across different age categories (Under-14 and Under-16) in a youth basketball context remains limited, particularly within the Indonesian setting. Most existing studies were conducted in soccer or mixed-sport settings in European or Middle Eastern contexts, limiting the generalizability of findings to Indonesian youth basketball environments (Munadi, 2025; Pahlawi & Vanesha, 2025). Therefore, this study aimed to investigate the effect of an 8-week INT program on vertical jump performance, measured by CMJ height, in youth basketball players aged 13-16 years, compared to conventional basketball training. A secondary objective was to examine age-group differences (KU14 and KU16) in training response to the INT intervention.

Materials and methods

Study Participants

Ninety-two male youth basketball players from a regional basketball club in Indonesia were recruited. Participants were categorized into Under-14 (KU14, n=23 per group) and Under-16 (KU16, n=23 per group), totaling 46 in the intervention group and 46 in the control group. Inclusion criteria required active participation in structured basketball training for a minimum of six months, no musculoskeletal injury in the prior three months, and written parental consent. Participants with chronic health conditions or those enrolled in supplementary strength training programs outside the study were excluded. This study was conducted in

accordance with the Declaration of Helsinki and received approval from the relevant institutional ethics committee.

Study Organization

This study employed a quasi-experimental Matching-Only Pretest-Posttest Control Group Design. All 92 participants were ranked in descending order based on their pretest CMJ scores. Using an ordinal pairing technique, adjacent pairs were formed (e.g., ranks 1-2, ranks 3-4), and one participant from each pair was systematically allocated to the intervention group while the other was assigned to the control group. This procedure ensured baseline equivalence between groups without relying on randomization. Random allocation was not feasible in this study due to the intact team training structure and coaching logistical considerations, as participants trained together under shared scheduling constraints that could not be disrupted without compromising ecological validity. The INT program was administered over 8 weeks, comprising 24 sessions at three sessions per week, each lasting approximately 60-75 minutes. Progressive overload was applied through increases in volume, intensity, and exercise complexity. The program was structured in three phases: Phase 1 (Weeks 1-2) focused on foundational dynamic stability; Phase 2 (Weeks 3-5) introduced progressive plyometric loading and strength exercises; Phase 3 (Weeks 6-8) incorporated high-intensity plyometrics, agility-speed combinations, and fatigue-resistance circuits. The control group continued their regular basketball training without supplementary INT components.

Materials and Apparatus

Lower-limb explosive power was assessed using the Countermovement Jump (CMJ) test. Jump height (cm) was recorded using the MyJump2 mobile application, validated against laboratory-grade force platforms with an Intraclass Correlation Coefficient (ICC) greater than 0.95. The INT program was structured around six key components: dynamic stability, muscular strength, plyometrics, coordination, speed and agility, and fatigue resistance.

Statistical Analysis

Descriptive statistics, including mean and standard deviation, were calculated for all variables. The Shapiro-Wilk test assessed normality of data distribution. For within-group comparisons, the Paired T-test was applied for normally distributed data, and the Wilcoxon Signed-Rank Test for non-normal distributions. Between-group differences in gain scores were assessed using the Mann-Whitney U test. Effect sizes were calculated using Cohen's d. All analyses were performed using IBM SPSS Statistics version 26.0, with statistical significance established at $p < 0.05$.

Results

Prior to inferential analysis, the Shapiro-Wilk test confirmed that pretest and posttest CMJ scores for the intervention group followed a normal distribution in both the KU14 ($W = 0.951$, $p = 0.312$; $W = 0.963$, $p = 0.488$) and KU16 subgroups ($W = 0.944$, $p = 0.226$; $W = 0.958$, $p = 0.421$). The CMJ gain scores for the control group deviated from normality in both subgroups (KU14: $W = 0.871$, $p = 0.008$; KU16: $W = 0.883$, $p = 0.012$). Homogeneity of variance between groups at baseline was confirmed using Levene's test ($p > 0.05$).

The descriptive statistics for CMJ height are presented in Table 1. The intervention group demonstrated a substantial improvement following the 8-week INT program, with a mean absolute gain of 9.28 cm (25.96%), while the control group exhibited only negligible change ($\Delta = +0.34$ cm, 0.88%).

Table 1. Descriptive Statistics of CMJ Height – Intervention and Control Groups

Group	Pretest Mean (cm)x	SD	Posttest Mean (cm)	SD	Δ (cm)	% Change	p-value
Intervention – KU14 (n=23)	34.29	6.95	42.66	8.31	+8.37	24.41%	0.000
Intervention – KU16 (n=23)	37.19	5.02	47.39	6.09	+10.20	27.43%	0.000
Intervention – Total (n=46)	35.74	6.17	45.02	7.59	+9.28	25.96%	0.000
Control – KU14 (n=23)	38.21	6.08	38.53	5.98	+0.32	0.84%	0.000
Control – KU16 (n=23)	39.25	6.57	39.60	6.56	+0.35	0.89%	0.000
Control – Total (n=46)	38.73	6.28	39.07	6.23	+0.34	0.88%	0.000

Note: Δ = posttest – pretest; % Change = [(posttest – pretest) / pretest] × 100; p-value from Paired T-test (intervention) and Wilcoxon Signed Rank Test (control)

The between-group comparison of CMJ gain scores is presented in Table 2. The Mann-Whitney U test revealed statistically significant differences between the intervention and control groups across all categories. The magnitude of improvement observed in the intervention group was considerably larger than in the control group: the total mean gain achieved by the intervention group (9.28 cm, 25.96%) was approximately 27 times greater than that of the control group (0.34 cm, 0.88%). This stark contrast underscores not only the statistical significance but also the practical and clinical meaningfulness of the INT intervention. While the control group's negligible change confirms that conventional basketball training alone is insufficient to drive meaningful neuromuscular adaptation, the intervention group's large effect sizes (KU14: d=1.09; KU16: d=1.83) demonstrate the substantial real-world impact of the INT program on explosive lower-limb power development in youth athletes.

Table 2. Between-Group Comparison of CMJ Gain Scores (Mann-Whitney U Test)

Group	Intervention Δ Mean (cm)	SD	Control Δ Mean (cm)	SD	Fold Difference	p-value
KU14 (n=23)	8.36	2.53	0.32	0.29	~26x	0.000
KU16 (n=23)	10.20	3.81	0.36	0.34	~28x	0.000
Total (n=46)	9.28	3.33	0.34	0.31	~27x	0.000

Note: Mann-Whitney U test; Δ = gain score (posttest – pretest); Fold Difference = Intervention Δ / Control Δ

Effect sizes were large across all intervention subgroups: KU14 (d = 1.09), KU16 (d = 1.83), and total intervention group (d = 1.34). The control group exhibited trivial effect sizes in

both subgroups (d = 0.05), reflecting the absence of practically meaningful change under conventional basketball training.

Table 3. Within-Intervention Group Comparison of CMJ Performance by Age Category

Age Group	Pretest Mean (cm)	SD	Posttest Mean (cm)	SD	Δ Mean (cm)	SD	% Change
KU14 (n=23)	34.29	6.95	42.66	8.31	+8.37	2.53	24.41%
KU16 (n=23)	37.19	5.02	47.39	6.09	+10.20	3.81	27.43%

Note: Δ = posttest- pretest; % Change = [(posttest- pretest) / pretest] × 100; both subgroups p=0.000 (Paired T-test)

The between-group comparison of gain scores within the intervention group revealed that the age-related difference in training response was statistically non-significant ($p > 0.05$), indicating that the INT program was equally effective across both developmental stages in producing statistically robust improvements.

Discussion

The primary finding of this study confirms that the 8-week INT program produced significant and clinically meaningful improvements in CMJ height among youth basketball players aged 13-16 years, with a mean gain of 25.96%, while conventional training yielded negligible adaptations (0.88%). These results support the hypothesis that INT, as a multi-component neuromuscular training approach, is substantially more effective than standard basketball practice for developing lower-limb explosive power in adolescents (Wang et al., 2023).

The observed mean CMJ gain of 9.28 cm is notably larger than gains reported in several comparable training studies. Hammami et al. (2023) reported CMJ improvements of approximately 4-6 cm following a preseason INT program in youth soccer players, while Balasas et al. (2021) documented gains of 3-5 cm from plyometric-resistance training in adolescent volleyball players. The superior gain in the present study may be attributed to the comprehensive six-component nature of the INT program, which simultaneously targets multiple physiological systems, producing additive or synergistic neuromuscular adaptations (Wan et al., 2025; Chen et al., 2025).

From a mechanistic standpoint, the gains in CMJ performance reflect a cascade of interrelated neuromuscular adaptations induced by INT that extend beyond simple strength increases. Plyometric components critically optimize the stretch-shortening cycle (SSC) by enhancing elastic energy storage in the musculotendinous unit and potentiating reflexive muscle activation via Ia afferent pathways (Farizi et al., 2023; Caferoglu, 2025). Importantly, these SSC adaptations are qualitatively distinct from those produced by isolated strength training: INT's multi-component structure generates concurrent neural and mechanical adaptations that interact synergistically. Strength components improve the rate of force development (RFD) and motor unit synchronization (Hung et al., 2025), while dynamic stability exercises enhance proximal core control, a prerequisite for efficient distal force transfer during jumping (Lee et al., 2024). The myofascial system contributes through enhanced integrity and stiffness of myofascial chains that facilitate force transmission across body

segments during explosive movements (Dewi et al., 2025). Critically, the concurrent stimulation of these multiple systems within a single INT session may generate additive or even multiplicative adaptation effects that isolated training modalities cannot replicate, explaining the substantially superior gains in the present study compared to conventional training (Syaranamual et al., 2026; Almunawar et al., 2026).

The age-related difference in training response warrants critical examination beyond superficial description. The KU16 group demonstrated a larger absolute gain compared to the KU14 group, likely reflecting the greater neuromuscular maturity, testosterone-driven anabolic environment, and more developed motor unit pool available to older adolescents (Kumar et al., 2021; Ritsche et al., 2024). However, critically, the statistical non-significance of the inter-group difference within the intervention ($p > 0.05$) challenges a simplistic interpretation that older adolescents respond superiorly. Rather, this finding suggests that INT is sufficiently potent to drive meaningful adaptation across both early and mid-adolescence. The KU14 group also achieved substantial gains ($d = 1.09$), affirming that early adolescence represents not merely a "sensitive period" but an urgent developmental window requiring structured neuromuscular intervention consistent with the Long-Term Athletic Development (LTAD) framework (Blanchet & Prince, 2023). From a contextual standpoint, the control group's virtually unchanged CMJ scores ($d = 0.05$) provide critical evidence that conventional Indonesian youth basketball training, which replicates adult tactical models without progressive physical conditioning, is fundamentally inadequate for neuromuscular development during adolescence, confirming the urgent need for systemic reform of junior training protocols (Cherni et al., 2021; Pan, 2025).

From a practical standpoint, the present findings carry specific implications for Indonesian youth basketball development. Indonesia's national basketball development system has historically prioritized technical skill and tactical education in junior programs, with limited integration of evidence-based physical conditioning protocols (Munadi, 2025; Pahlawi & Vanesha, 2025). The results demonstrate that an 8-week INT program, deliverable within existing club training schedules at three sessions per week, can produce statistically and practically significant improvements in lower-limb explosive power without requiring specialized laboratory equipment. Systematic adoption of INT protocols within the Indonesian junior basketball curriculum could represent a cost-effective, evidence-based strategy for improving physical performance benchmarks in youth athletes. Limitations include the quasi-experimental design, restriction to male participants from a single regional club, absence of long-term follow-up, and lack of direct physiological measurements.

Conclusions

This study demonstrated that an 8-week Integrative Neuromuscular Training (INT) program significantly improved vertical jump performance, as measured by CMJ height, in male youth basketball players aged 13-16 years. The intervention group achieved a mean absolute improvement of 9.28 cm (25.96%) compared to a negligible 0.34 cm (0.88%) in the control group ($p=0.000$). Significant gains were observed in both KU14 ($\Delta = +8.37$ cm, 24.41%) and KU16 ($\Delta = +10.20$ cm, 27.43%) subgroups, confirming the effectiveness of INT across early-to-mid adolescence. These findings strongly support the integration of INT as a structured, evidence-based component of youth basketball training programs to optimize lower-limb explosive power and support long-term athletic development.

Conventional basketball training approaches must be balanced with structured physical conditioning programs such as INT. Coaches are encouraged to integrate INT into routine practice sessions to maximize the neuromuscular adaptation window during the PHV phase. At the national program level, Long-Term Athletic Development (LTAD) curricula should incorporate multi-component neuromuscular training as a foundational standard. Future

research should explore INT effectiveness in female youth basketball populations, evaluate adaptation retention through longitudinal follow-ups, and employ fully randomized controlled trial designs.

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Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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