Acute neuromuscular fatigue following contrast training in university athletes: evidence from vertical jump performance

Fatiga neuromuscular aguda tras el entrenamiento de contraste en atletas universitarios: evidencia del rendimiento en salto vertical

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Abstract

Introduction: Optimizing training efficiency is critical for university athletes who must balance academic and athletic demands. Contrast training (CT), which pairs heavy resistance with plyometric exercises, is proposed to acutely enhance explosive power via post-activation performance enhancement (PAPE). However, evidence is mixed and often lacks contextual specificity. Objective: This study investigated the acute effect of a single CT session on lower-body explosive power, as measured by vertical jump performance, in athletes from the National Defence University of Malaysia (UPNM).
Methodology: Using a quasi-experimental, single-group, pre-test-post-test design, 30 male university athletes (age: 20.7 ± 0.7 years) performed a CT protocol of 3 sets of 4 back squats at 80% 1RM, immediately followed by 10 maximal squat jumps. Vertical jump height was measured pre- and 60 seconds post-intervention using a Vertec. A Wilcoxon signed-rank test was used for analysis.
Results: A statistically significant decrease in vertical jump performance was observed post-intervention ($Z = -4.85$, $p < .001$).
Discussion: This finding contradicts the hypothesis of acute PAPE and suggests that the high-intensity stimulus induced short-term neuromuscular fatigue, overriding any potentiating effect. This aligns with research emphasizing the delicate balance between potentiation and fatigue, which is influenced by factors like training status and rest intervals.
Conclusions: A single CT session acutely impairs explosive power in this cohort. This highlights the importance of strategic training periodization, where CT is placed sufficiently before competition to allow recovery. The study provides critical context-specific data for Malaysian university athletes and underscores the need for practitioners to consider acute fatigue responses when implementing CT.

Keywords

Acute effect; contrast training; explosive power; university athletes.

Resumen

Introducción: Optimizar la eficiencia del entrenamiento es fundamental para los atletas universitarios que deben equilibrar las exigencias académicas y deportivas. Se propone que el entrenamiento de contraste (EC), que combina ejercicios de resistencia pesada con ejercicios pliométricos, mejora de forma aguda la potencia explosiva mediante el aumento del rendimiento postactivación (PAPE, por sus siglas en inglés), aunque la evidencia es variada y a menudo carece de especificidad contextual.
Objetivo: Este estudio investigó el efecto agudo de una sola sesión de EC sobre la potencia explosiva del tren inferior, medida mediante el salto vertical, en atletas de la Universidad Pertahanan Nasional Malaysia (UPNM).
Metodología: Mediante un diseño cuasiexperimental de un solo grupo con prueba pre y post, 30 atletas universitarios varones (edad: 20.7 ± 0.7 años) realizaron un protocolo de EC de 3 series de 4 sentadillas traseras al 80% de 1RM, seguidas inmediatamente de 10 saltos en cuclillas máximos. La altura del salto vertical se midió antes y 60 segundos después de la intervención con un Vertec. Se utilizó la prueba de rangos con signo de Wilcoxon para el análisis.
Resultados: Se observó una disminución estadísticamente significativa en el rendimiento del salto vertical tras la intervención ($Z = -4.85$, $p < .001$).
Discusión: Este hallazgo contradice la hipótesis de la PAPE aguda y sugiere que el estímulo de alta intensidad indujo una fatiga neuromuscular a corto plazo, lo que anuló cualquier efecto potenciador. Esto se alinea con la investigación que enfatiza el delicado equilibrio entre la potenciación y la fatiga, influido por factores como el estado de entrenamiento y los intervalos de descanso.
Conclusiones: Una sola sesión de EC perjudica de forma aguda la potencia explosiva en esta cohorte. Esto destaca la importancia de una periodización estratégica del entrenamiento, en la que el EC se coloque con suficiente antelación a la competición como para permitir la recuperación. El estudio proporciona datos contextuales críticos para los atletas universitarios malayos y subraya la necesidad de que los profesionales consideren las respuestas ante la fatiga aguda al implementar el EC.

Palabras clave

Efecto agudo; entrenamiento de contraste; potencia explosiva; atletas universitarios.

Introduction

In the competitive landscape of collegiate sports, the pursuit of effective and time-efficient training methodologies is paramount for optimizing athletic performance within constrained schedules. Explosive lower-body power, a critical determinant of success in sports requiring jumping, sprinting, and rapid directional changes, is commonly assessed through vertical jump performance. This metric directly reflects the neuromuscular system's capacity to rapidly generate maximal force, a quality underpinned by the rate of force development and intermuscular coordination (Suchomel et al., 2022). For student-athletes at institutions such as the National Defence University of Malaysia (UPNM), the dual demands of academic rigor and athletic excellence necessitate training strategies that yield significant physiological adaptations with minimal time commitment.

Training Efficiency in University Athletes

University athletes represent a unique population whose training schedules are often compressed by academic commitments, making time-efficient training methods particularly valuable. Research examining resistance training during periods of constraint, such as the fasting month, has demonstrated that well-structured, time-efficient protocols can produce meaningful physiological adaptations (Nor Ikhmar Madarsa et al., 2023). Similarly, investigations into time-efficient warm-up protocols have shown that strategically designed brief interventions can significantly enhance subsequent strength performance (Madarsa et al., 2023). Such evidence supports exploring compact, high-impact training strategies, such as contrast training, for university athletic populations.

Contrast training (CT) has emerged as a prominent strategy within the strength and conditioning domain, specifically designed to address this need for efficiency. CT is characterized by the intentional alternation of a high-load resistance exercise (e.g., back squat) with a biomechanically similar plyometric or ballistic exercise (e.g., squat jump) within the same session (Prieske et al., 2023). This pairing strategy is theorized to exploit post-activation performance enhancement (PAPE), in which a high-intensity conditioning activity primes the neuromuscular system, potentially increasing motor unit recruitment and neural drive, thereby augmenting power output during a subsequent explosive movement (Boullosa, 2022).

The Potentiation-Fatigue Balance

The mechanistic underpinnings of CT derive from the complex interplay between potentiation and fatigue within the neuromuscular system. Following a high-intensity muscle contraction, two competing physiological processes are simultaneously activated: potentiation, which enhances force production capacity, and fatigue, which diminishes performance through metabolic byproduct accumulation (Boullosa, 2021). The net performance outcome following a conditioning activity represents the algebraic sum of these opposing effects, with the expression of PAPE requiring that potentiating effects outweigh residual fatigue at the moment of the subsequent explosive effort.

The manipulation of training variables critically influences this balance. Factors including the intensity and volume of the conditioning activity, the specificity of the paired exercises, the athlete's training status, and particularly the duration of the recovery interval all modulate whether potentiation or fatigue predominates (Xavier et al., 2023; Mola et al., 2022). Research examining acute muscular hypertrophy responses has demonstrated that the temporal sequencing of training stimuli significantly affects acute physiological responses (Madarsa & Mohamad, 2025). When CT protocols are optimally configured, potentiating effects may temporarily exceed fatigue, resulting in enhanced power output. However, inappropriate prescription can tip the balance toward fatigue, negating any potential benefit and potentially impairing performance.

Inconsistencies in the Acute CT Literature

Despite the theoretical appeal and demonstrated chronic efficacy of CT for improving strength and power over training cycles (Prieske et al., 2023), the evidence for its acute, session-specific effects remains inconsistent. While some studies have reported significant acute improvements in vertical jump height following CT protocols (Xavier et al., 2023), others have observed trivial changes or even performance decrements attributable to accumulated fatigue (Mola et al., 2022). This heterogeneity reflects the sensitivity of the potentiation-fatigue relationship to subtle variations in protocol design and individual athlete characteristics.

A critical moderator consistently identified in the literature is an athlete's maximal strength level. Stronger individuals typically demonstrate more robust and reliable PAPE responses, likely due to their greater capacity to tolerate high-intensity loading without disproportionate fatigue accumulation (Loturco et al., 2021). Other moderating factors include training age, exercise pairing, and individual differences in recovery kinetics (Jiménez-Reyes et al., 2022). These moderators complicate the extrapolation of findings across different athletic populations and underscore the need for context-specific investigation.

The Contextual Gap: Malaysian University Athletes

A significant limitation of the existing CT literature is its predominant focus on Western, professional, or elite collegiate athlete populations. The physiological characteristics, training backgrounds, and cultural practices of athletes in Southeast Asian contexts may differ meaningfully from those populations in which most CT research has been conducted (Lim et al., 2023). Research examining the effectiveness of football training in Indonesian contexts has highlighted the importance of considering local environmental and cultural factors when implementing training programs (Yudi et al., 2024). Similarly, investigations into the relationship between sprint performance and training load among professional soccer players have emphasized the need for sport-specific and context-specific normative data (Madarsa et al., 2020).

This contextual gap is particularly pronounced in the Malaysian university sports system. While international research has established CT as a potentially valuable training method, the acute responses of Malaysian university athletes to standardized CT protocols remain unexplored. Differences in typical training age, genetic predispositions, nutritional practices, and environmental conditions could all influence the potentiation-fatigue relationship. Furthermore, the dual roles of UPNM students as both athletes and military cadets may impose unique physiological demands that influence their response to high-intensity training stimuli.

Study Rationale and Objectives

The present study, therefore, addresses a dual gap in the literature. First, it seeks to establish baseline data on lower-limb explosive power in UPNM university athletes, providing a reference point for future research and practice in this population. Second, it aims to investigate the acute effect of a standardized CT protocol on vertical jump performance in these athletes, thereby providing localized evidence to inform strength and conditioning practice within the Malaysian university sports context.

Given the equivocal findings in the literature regarding the balance between acute potentiation and fatigue and the complete lack of data in this specific population, this study adopted an exploratory approach. It was hypothesized that a single CT session would elicit a significant acute modulation of vertical jump performance; however, the direction of this effect (enhancement or impairment) was not predetermined.

Method

Study Design

A quasi-experimental, single-group, pre-test-post-test design was employed to investigate the acute effects of a single contrast training session on vertical jump performance. This design was chosen to directly observe performance changes within the same group of participants in response to a controlled intervention, with each participant serving as their own control. It is important to note that the absence of a non-intervention control group limits the ability to definitively attribute causality; therefore, the findings are interpreted as exploratory and specific to this cohort under controlled conditions.

Participants

Participant Recruitment and Sampling

A sample of 30 male athletes from the National Defence University of Malaysia (UPNM) was selected using purposive sampling, representing an intact group drawn from various university sports teams (football, volleyball, basketball, athletics, and rugby). This non-probability sampling method was employed to ensure the recruitment of participants with specific athletic characteristics appropriate for the high-intensity demands of the contrast training protocol. As an exploratory study, this intentional sampling approach is appropriate; however, it requires caution when generalizing findings to broader populations and inferring causality.

The sample size of 30 participants was determined via an a priori power analysis using G*Power (Version 3.1.9.7). Based on a moderate expected effect size (d = 0.6) derived from previous contrast training literature, an alpha level of 0.05, and desired power of 0.80, the analysis indicated that a minimum of 30 participants would be required for the Wilcoxon signed-rank test (actual power = 0.812).

Inclusion Criteria

Participants were eligible for inclusion if they met all of the following criteria:

Engaged in university-level sports training (≥3 sessions/week);

At least one year of continuous resistance training experience;

Medically cleared for high-intensity exercise; and

Aged 18–25 years.

Exclusion Criteria

Individuals were excluded if they met any of the following criteria:

- Lower-limb or spinal injury within the preceding six months;
- Use of performance-enhancing substances or medications affecting strength/power;
- Inability to attend the single testing session; or
- Acute illness or infection on the day of testing.

Participant Characteristics

The final sample consisted of 30 male university athletes (N = 30) meeting all eligibility criteria. The mean age of participants was 20.7 ± 0.7 years (range: 20–22 years). Mean height was 166.7 ± 7.2 cm (range: 155–182 cm), and mean body mass was 57.2 ± 3.3 kg (range: 38–91 kg). This anthropometric variability reflects the diverse sporting disciplines represented in the sample and is typical of university-level athletic populations. Preliminary data screening confirmed the absence of extreme statistical outliers that could unduly influence the results. The within-subjects design inherently controls for inter-individual differences in physical characteristics, as each participant serves as their own baseline comparator.

Sample Size Determination

The sample size of 30 participants was determined through an a priori power analysis conducted using G*Power software (Version 3.1.9.7; Faul et al., 2007). Based on a moderate expected effect size (d = 0.6) derived from previous contrast training literature, an alpha level of 0.05, and desired power of 0.80, the analysis indicated that a minimum of 30 participants would be required for the Wilcoxon signed-rank test (actual power = 0.812). This sample size is consistent with or exceeds those reported in comparable acute training studies.

Ethical Considerations

This study was conducted in accordance with the ethical standards outlined in the Declaration of Helsinki. Written informed consent was obtained from all participants prior to data collection. All procedures were directly supervised by qualified research personnel, with spotters present during all 1RM and back squat exercises to ensure participant safety.

Procedure

Data collection was conducted in a single session at the UPNM gymnasium, with standardized timing (5:00-7:00 PM) and environmental conditions to minimize confounding variables.

One-Repetition Maximum (1RM) Assessment

In a session conducted 3–7 days prior to the main experimental trial, each participant's one-repetition maximum (1RM) for the parallel back squat was determined using standardized procedures (Naclerio et al., 2021). Following a specific warm-up, participants performed incremental loads until their maximal lift was achieved, with proper technique verified by certified strength and conditioning specialists. The obtained 1RM value was used to calculate the individualized 80% 1RM load for the contrast training intervention.

Experimental Session

The main experimental session comprised five distinct phases, conducted in the following sequential order:

i. Standardized Warm-up: All participants performed an identical dynamic warm-up routine consisting of 10 push-ups, 10 bodyweight squats, 5 lunges per leg, a 10-second plank hold, and 5 submaximal squat jumps. This protocol was designed to elevate core temperature and prepare the neuromuscular system for high-intensity activity without inducing fatigue.

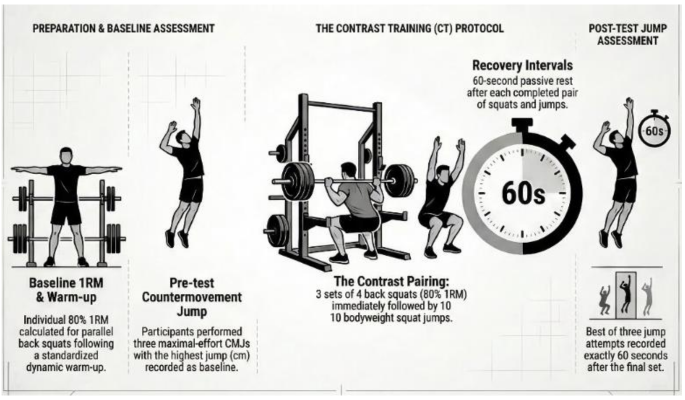
ii. Pre-test (Baseline Measurement): Three minutes following the warm-up, participants performed three maximal-effort countermovement jumps using a Vertec apparatus (Trident, Malaysia). A standardized protocol was employed: participants started from a standing position, performed a rapid downward countermovement to a self-selected depth, and immediately jumped vertically for maximum height, contacting the highest possible vane. A no-arm-swing protocol was used, with one hand placed on the waist and the dominant hand used to contact the vanes. The highest jump height (cm) from three attempts, with 60 seconds of rest between attempts, was recorded as the baseline explosive power score.

iii. Contrast Training Intervention: Three minutes after completing the pre-test, participants began the contrast training protocol. A single contrast pair consisted of 4 repetitions of back squat at 80% of the predetermined 1RM, performed with controlled tempo, immediately followed by 10 repetitions of maximal-effort bodyweight squat jumps. This heavy-to-light sequence constituted one set. A 60-second passive rest interval was provided after each completed pair. The entire protocol consisted of three total sets.

iv. Recovery Period: Upon completion of the third set, a standardized passive recovery period of 60 seconds was provided to all participants before post-testing commenced.

v. Post-test (Acute Effect Measurement): Sixty seconds after the intervention, participants performed the vertical jump test again under identical conditions to the pre-test (three maximal attempts, 60 seconds rest between attempts). The highest jump height recorded from the post-test attempts was used for analysis.

Figure 1. Procedural Workflow: Contrast Training Intervention for Vertical Jump



Instruments

One-Repetition Maximum (1RM) Back Squat Test

A standardized 1RM back squat test was conducted using an Olympic barbell and weight plates (Eleiko, Sweden). Spotters were positioned at each end of the barbell throughout all maximal attempts. Technique was monitored continuously, with successful lifts requiring descent to parallel (hip crease below knee) and ascent to full hip and knee extension without deviation from proper form.

Vertical Jump Test (Vertec System)

Vertical jump height was measured using a Vertec apparatus (Trident, Malaysia), a widely used and validated tool for assessing vertical jump performance in athletic populations (Rodríguez-Rosell et al., 2017). The device consists of movable plastic vanes spaced at 1 cm intervals, allowing for precise measurement of jump height. Prior to testing, standing reach height was recorded for each participant, and the Vertec was adjusted accordingly. Jump height was calculated as the difference between standing reach and the highest vane displaced during the jump.

Data Analysis

All statistical analyses were performed using SPSS version 28.0 (IBM Corp., 2021). Descriptive statistics (mean ± standard deviation) were calculated for participant demographic characteristics and for pre-test and post-test vertical jump scores.

Normality Testing

To determine the appropriate statistical test for comparing pre-test and post-test scores, the distribution of difference scores was assessed for normality. A new variable, "Difference," was computed as post-test vertical jump height minus pre-test vertical jump height for each participant. The Shapiro-Wilk test was then conducted on the difference score variable to evaluate whether the data met the normality assumption required for parametric testing.

Primary Analysis

Based on the normality assessment, the nonparametric Wilcoxon signed-rank test was used to compare median vertical jump heights between the pre-test and post-test conditions. Statistical significance was set at $\alpha = 0.05$.

Effect Size Calculation

To complement the significance testing and provide a measure of the magnitude of the intervention effect, an effect size was calculated. For the Wilcoxon signed-rank test, the matched-pairs rank-biserial correlation (r) was computed using the formula: $r = Z / \sqrt{N}$, where Z is the standardized test statistic from the Wilcoxon test, and N is the number of matched pairs (N = 30). Effect size magnitudes were interpreted according to Cohen's (1988) conventions: small (r = 0.10), medium (r = 0.30), and large (r = 0.50).

Results

Descriptive Statistics

The demographic and anthropometric characteristics of the 30 male university athletes are presented in Table 1. The sample was relatively homogeneous in age (M = 20.7 years, SD = 0.7), with a mean height of 166.7 cm (SD = 7.2) and a mean body mass of 57.2 kg (SD = 3.3).

Table 1. Descriptive Characteristics of Participants (N = 30)

Variable	Mean	SD	Minimum	Maximum
Age (years)	20.7	0.7	20	22
Height (cm)	166.7	7.2	155	182
Body mass (kg)	57.2	3.3	38	91

Vertical Jump Performance

Descriptive statistics for vertical jump height pre- and post-intervention are presented in Table 2. The mean jump height decreased from 45.2 cm (SD = 6.8) in the pre-test to 41.5 cm (SD = 7.1) in the post-test. The minimum and maximum jump heights also decreased after the intervention.

Table 2. Descriptive Statistics for Vertical Jump Height Pre- and Post-Intervention (N = 30)

Measurement	Mean (cm)	SD	Minimum (cm)	Maximum (cm)
Pre-test	45.2	6.8	32.0	58.0
Post-test	41.5	7.1	28.0	55.0

Normality Assessment

To determine the appropriate statistical test for comparing pre-test and post-test vertical jump scores, the distribution of difference scores was assessed for normality. A new variable, "Difference," was computed for each participant as post-test vertical jump height minus pre-test vertical jump height. The Shapiro-Wilk test was conducted on this difference score variable, as highlighted in Table 3.

Table 3. Shapiro-Wilk Test of Normality on Difference Scores

Variable	Shapiro-Wilk Statistic	df	p-value
Difference (Post - Pre)	0.91	30	0.02

The Shapiro-Wilk test revealed a statistically significant deviation from normality for the difference scores ($W = 0.91$, $p = 0.02$), indicating that the data were not normally distributed. Consequently, the assumption of normality required for parametric testing was violated, justifying the use of the non-parametric Wilcoxon signed-rank test for the primary analysis.

Primary Analysis: Acute Effect of Contrast Training

The Wilcoxon signed-rank test was used to evaluate whether vertical jump performance differed significantly between immediately before and after a single session of contrast training. The results are presented in Table 4.

Table 4. Wilcoxon Signed-Rank Test Results for Vertical Jump Performance

Variable Comparison	n	Z	p-value	Effect Size (r)
Pre-test vs. Post-test	30	-4.85	< .001	-0.885

The analysis revealed a statistically significant reduction in vertical jump height from pre-test to post-test ($Z = -4.85$, $p < .001$). The negative Z-value indicates that post-test scores were consistently lower than pre-test scores across the sample.

Effect Size Interpretation

The effect size, calculated as the matched-pairs rank-biserial correlation ($r = Z / \sqrt{N} = -4.85 / \sqrt{30} = -4.85 / 5.48 = -0.885$), indicates a very large effect size according to Cohen's (1988) conventions ($r > 0.50$ = large effect). This indicates that the observed decrease in vertical jump performance following the contrast training intervention was not only statistically significant but also practically meaningful in terms of its magnitude.

Direction of Change

Examination of the direction of change revealed that 28 of the 30 participants (93.3%) decreased their vertical jump height post-intervention, while 2 participants (6.7%) showed a slight increase. The consistency of this negative response across the vast majority of participants further supports the robustness of the finding.

Discussion

The primary finding of this study was a statistically significant decrease in vertical jump performance immediately following a single session of contrast training in UPNM university athletes (Z = -4.85, p < .001), with a very large effect size (r = -0.885). This result does not support the hypothesis predicting acute performance enhancement and instead reveals a fatigue-dominant response within the specific conditions of this study. The consistency of this negative effect across 93.3% of participants further underscores its reliability within this specific cohort and protocol.

The Potentiation-Fatigue Balance

The observed performance decrement is likely attributable to neuromuscular fatigue resulting from the high-intensity stimulus, which appears to have exceeded the threshold for potentiation under the specific conditions of this study. Following a high-intensity conditioning activity, two competing physiological processes are simultaneously activated: potentiation, which enhances force production capacity through mechanisms such as phosphorylation of myosin regulatory light chains and increased alpha-motoneuron excitability, and fatigue, which diminishes performance through metabolic byproduct accumulation and impaired excitation-contraction coupling (Boullosa, 2021). The net performance outcome represents the algebraic sum of these opposing effects, with post-activation performance enhancement (PAPE) requiring that potentiating effects outweigh residual fatigue at the moment of the subsequent explosive effort.

In the present study, the combination of 4 repetitions at 80% 1RM back squat, followed immediately by 10 maximal-effort squat jumps across three sets, appears to have decisively tipped the balance toward fatigue. While some studies have reported acute improvements with similar loads (Xavier et al., 2023), others have noted that insufficient recovery or excessive volume can negate PAPE (Mola et al., 2022). The 60-second rest interval between sets and the 60-second post-intervention recovery period employed in this study may have been insufficient for this specific cohort to dissipate fatigue and allow potentiation to manifest.

The Role of Athlete Characteristics

A critical moderator consistently identified in the literature is an athlete's maximal strength level. Stronger individuals typically demonstrate more robust and reliable PAPE responses, likely due to their greater capacity to tolerate high-intensity loading without disproportionate fatigue accumulation and their enhanced ability to voluntarily activate motor units (Loturco et al., 2021). The participants in this study, with a mean body mass of 57.2 ± 3.3 kg and no formal assessment of relative strength, may not have had the requisite strength to effectively perform PAPE following this demanding protocol. This interpretation aligns with research demonstrating that stronger athletes exhibit more consistent potentiation effects (Jiménez-Reyes et al., 2022).

The heterogeneity of our sample, particularly the wide range in body mass (38–91 kg) and height (155–182 cm), may have contributed to individual variability in the fatigue response. However, the significant and highly consistent directional change (Z = -4.85, with 93.3% of participants showing decreased performance) suggests the fatigue effect was remarkably robust across this diverse cohort. This uniformity of response despite considerable anthropometric variation strengthens confidence in the finding that this specific protocol induces acute fatigue rather than enhancement in this population. Future studies with larger, more stratified samples could explore whether body mass, strength level, or sport-specific background moderates the acute response to contrast training protocols.

Contextual Specificity and Local Evidence

A key contribution of this study is its provision of context-specific evidence for Malaysian university athletes. The results from this UPNM athlete population provide a crucial counterpoint to the predominantly positive findings reported in Western elite cohorts, though these observations are specific to the cohort and protocol employed. This aligns with the observations of Lim et al. (2023), who noted a scarcity of localized sports science research in Southeast Asia and the potential for differing responses due to variations in training age, genetic predispositions, nutritional practices, and environmental conditions.

Research examining the effectiveness of football training in Indonesian contexts has similarly highlighted the importance of considering local factors when implementing training programs (Yudi et al., 2024). The dual roles of UPNM students as both athletes and military cadets may impose unique physiological and psychological demands that influence their readiness and response to high-intensity training stimuli. Therefore, the outcome of this study should not be interpreted as a failure of contrast training as a concept, but rather as a demonstration of its context-dependent nature and the critical importance of local validation for global training methodologies.

Comparison with Previous Research

The significant and uniform negative response observed in this study contrasts with some previous investigations reporting acute enhancements following contrast training protocols (Xavier et al., 2023; Prieske et al., 2023). However, it aligns with research emphasizing the sensitivity of the potentiation-fatigue relationship to protocol design and individual characteristics (Mola et al., 2022). Studies examining acute muscular hypertrophy responses have demonstrated that the temporal sequencing of training stimuli significantly affects acute physiological outcomes (Madarsa & Mohamad, 2025), supporting the notion that subtle variations in protocol configuration can substantially influence results.

The very large effect size (r = -0.885) observed in this study indicates that the prescribed protocol was a potent physiological stressor, effectively manipulating the acute fatigue state. This is valuable information in itself, as it maps the boundaries of the "fatigue" side of the potentiation-fatigue relationship for this population. Future research should explore longer rest intervals (e.g., 3–7 minutes) to determine whether a PAPE window can be identified in these athletes, and investigate whether modifications to volume or intensity might shift the balance toward potentiation.

Methodological Considerations and Limitations

Several methodological considerations should be acknowledged when interpreting these findings. First, the 60-second post-intervention recovery period may have been insufficient to allow for the expression of PAPE, capturing only the initial fatigue state. Research suggests that optimal recovery intervals for PAPE expression often range from 4 to 12 minutes, depending on the individual and protocol (Mola et al., 2022). The absence of multiple post-test time points prevents mapping of the complete recovery trajectory and identification of any delayed potentiating effect.

Second, the single-group design without a non-intervention control group limits the ability to definitively attribute the performance decrease solely to contrast training, as factors such as measurement fatigue or daily variation cannot be ruled out entirely. However, the controlled laboratory conditions, standardized procedures, and consistent directional change across participants strengthen causal inference.

Third, the reliance on vertical jump height as the sole performance metric, while ecologically valid and practically accessible, may not capture more nuanced changes in force-time characteristics that could be revealed through force plate analysis (Pérez-Castilla et al., 2021). Future studies employing more sophisticated instrumentation could provide deeper insight into the mechanistic underpinnings of the observed fatigue response.

Fourth, the absence of direct measurement of 1RM strength relative to body mass precludes analysis of whether stronger individuals within the sample exhibited differential responses. Given the established moderating role of maximal strength in PAPE expression (Loturco et al., 2021), this represents an important avenue for future investigation.

Finally, while the sample size was adequately powered for the primary analysis, the heterogeneity in participant characteristics precludes subgroup analyses that might identify moderators of the response. Future research with larger, stratified samples could explore whether factors such as sport type, training age, or strength level influence acute responses to contrast training.

Conclusions

Within the specific conditions of this study, a single bout of contrast training, consisting of three sets of four back squats at 80% 1RM immediately followed by ten maximal squat jumps, induced acute neuromuscular fatigue resulting in significant and immediate impairment of lower-body explosive power in UPNM university athletes. The very large effect size (r = -0.885) and remarkable consistency of response across 93.3% of participants underscore the robustness of this fatigue-dominant effect under the specific conditions investigated.

These findings highlight a critical distinction between the well-documented chronic benefits of contrast training over training cycles and its acute suppressive effect immediately following a single session in this population. For practitioners working with Malaysian university athletes, this implies that contrast training sessions should be strategically periodized within the training week, with adequate recovery (potentially 24–48 hours) scheduled before any competition or testing session requiring maximal explosive power output. The placement of contrast training during dedicated strength and power development phases, rather than immediately preceding performance evaluation, is strongly recommended.

The study successfully provides foundational, context-specific data for a Malaysian athletic population, addressing a significant gap in the literature and highlighting the importance of local validation for global training methodologies. The results caution against the uncritical extrapolation of findings from Western elite athlete populations to different athletic contexts and underscore the need for population-specific evidence to inform evidence-based practice.

Future research should employ controlled designs with non-intervention control groups, incorporate multiple post-test measurements at extended intervals (e.g., 6, 24, and 48 hours) to map the complete recovery and potential supercompensation curve, and investigate the longitudinal effects of multi-week contrast training programs on chronic adaptations in explosive power. Additionally, exploring these effects in more diverse athletic populations, including female athletes and different age groups, and using a wider array of performance assessments, including force plate analysis, would further elucidate the mechanisms and moderators of acute responses to contrast training.

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