

# ACUTE EFFECTS OF ISOINERTIAL TRAINING ON COUNTERMOVEMENT JUMP PERFORMANCE IN ELITE YOUTH MALE BASKETBALL PLAYERS

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## Abstract:

The aim of this study was to examine the acute effect of flywheel training on countermovement jump performance in elite youth male basketball players, by measuring jump height at the 1-minute, 3-minute and 5-minute post-training. Fifteen young, healthy, elite male athletes (age:  $17.0 \pm 1.0$  years; height:  $193.1 \pm 7.3$  cm; body mass:  $83.6 \pm 8.2$  kg; BMI:  $22.4 \pm 1.7$  kg/m<sup>2</sup>) participated in the study. The participants were randomly assigned to two groups, performing the experimental (PAPE) and control protocol in a crossover design. Both protocols included standardized warm-up and countermovement jumping, while the experimental protocol additionally involved flywheel training between the warm-up and jumping. The flywheel training consisted of the half-squat exercise in three sets of six maximal repetitions, with a flywheel inertia of 0.025 kg·m<sup>2</sup>. The results showed no statistically significant differences in countermovement jump height at 1-minute, 3-minute and 5-minute post-intervention time points ( $p > .05$ ). Such an outcome was expected at the first time point, due to the well-known dominance of fatigue over potentiation in the initial minutes following an activation exercise. However, the results obtained at the second and third time points were not consistent with previous findings. The absence of acute improvements is most likely attributable to the participants' age, which contributes to increased susceptibility to central fatigue. Further research is needed to determine whether this type of training can acutely enhance countermovement jump height in young athletes.

**Keywords:** *postactivation potentiation, fatigue, flywheel training*

## Introduction

Basketball is a sport characterized by continuous alternation between low- and high-intensity activities, with players performing approximately 1,000 actions per game and changing activity every two seconds (McInnes, Carlson, Jones, & McKenna, 1995). These actions include accelerations, decelerations, shuffling, cutting, and frequent jumps—on average 40–60 per game depending on player position—thus making explosive lower-body performance a key determinant of competitive success. High-intensity actions such as jumping, sprinting, and defensive shuffling are critical for performance, as they contribute directly to scoring opportunities, defensive efficiency, and overall effectiveness on the court (Puente, Abián-Vicén, Areces, López, & Del Coso, 2017). Consequently, training strategies in basketball should prioritize the development of explosive movements to enhance in-game performance (Xie, et al., 2022).

Explosive abilities can be improved both chronically and acutely. Chronic adaptations arise from

repeated resistance training, plyometric exercises, sprinting, or combinations thereof, leading to neuromuscular changes that increase maximal power output (Fatouros, et al., 2000; Marković, Jukic, Milanovic & Metikos, 2007). These adaptations include increases in muscle cross-sectional area, neural drive, tendon stiffness, and rate of force development. In contrast, acute improvements are often attributed to post-activation potentiation (PAP) or post-activation performance enhancement (PAPE), the phenomena in which a preceding high-intensity conditioning activity temporarily improves subsequent muscle performance (Beato, et al., 2019; Cuenca-Fernández, et al., 2017; De Keijzer, McErlain-Naylor, Dello Iacono, & Beato, 2020; Sanchez-Sanchez, et al., 2018). While PAP refers to enhancements in electrically evoked twitch force and peaks within the first minute, PAPE describes improvements in voluntary contractions that emerge later, typically within 3-10 minutes, and are generally smaller in magnitude, averaging around 5% (Cuenca-Fernandez, et al., 2017; Wilson, et al., 2013).

The physiological mechanisms underlying potentiation are multifactorial. The mechanisms include changes in muscle contractile behavior, neuromuscular activation, and musculotendinous stiffness. PAPE is primarily linked to phosphorylation of myosin regulatory light chains (RLC), which enhances force production and the rate of force development (RFD) during low-frequency contractions by increasing the sensitivity of the contractile apparatus to  $\text{Ca}^{2+}$  (Szczena, et al., 2002; Tillin & Bishop, 2009). In contrast, PAPE appears to rely less on RLC phosphorylation and more on acute physiological responses such as increased muscle temperature (+1 to 2 °C after high-intensity protocols), enhanced calcium sensitivity, changes in muscle water content that increase fiber pennation, heightened neural drive, and increased muscle-tendon stiffness (Blazevich & Babault, 2019). Recruitment of high-threshold fast-twitch motor units is central to potentiation since these units produce higher force in shorter time intervals and are selectively activated during near-maximal movements (Haff & Triplett, 2016; Purves, et al., 2001). Eccentric muscle actions further contribute to acute performance enhancement due to their ability to produce 40-50% greater force than concentric actions and selectively recruit fast-twitch fibers while minimizing metabolic cost (Hughes, Massiah, & Clarke, 2016; Maroto-Izquierdo, Bautista, & Rivera, 2020).

Among conditioning methods, flywheel training has gained considerable attention for its potential to elicit strong eccentric overload and subsequently induce PAPE. The flywheel device provides resistance through the inertia of one or more rotating flywheels, thereby generating variable resistance across the entire range of motion requiring from the athlete to absorb high eccentric forces (Berg & Tesch, 1994; Martinez-Hernandez, 2024). This allows for individualized loading because the intensity depends on the athlete's effort rather than a fixed external mass. Studies have demonstrated positive effects of flywheel half-squat protocols on countermovement jump (CMJ) height, with improvements ranging from 4.8% to 14.3% (Beato et al., 2019; Beato, De Keijzer, et al., 2021; De Keijzer, et al., 2019; Maroto-Izquierdo, et al., 2020; Sun, et al., 2024). Notably, protocols involving moderate-to-high inertia (0.05-0.11 kg·m<sup>2</sup>), 2-3 sets, and concentric–eccentric emphasis appear most effective for eliciting PAPE.

On the other hand, some studies report no significant improvements following flywheel conditioning (Loturco, et al., 2024; Spudić, Dakskobler, & Štirn, 2023; Xie, et al., 2022). These disparities highlight the importance of protocol characteristics; differences in training volume, training intensity, rest duration, inertia settings, and movement execution critically influence the magnitude and timing of PAPE effects (Garbisu-Hualde & Santos-Conce-

jero, 2021; Sun, et al., 2024). Evidence indicates that multiple sets ( $\geq 2$ ) are generally necessary to elicit measurable improvements and that rest durations of at least three minutes—often 5 to 9 minutes—are required for PAPE to surpass fatigue. Some authors even propose individualizing the rest interval based on each athlete's readiness to optimize the performance enhancement window (Beato, et al., 2019; Beato, De Keijzer, et al., 2021; Beato, Stiff, & Coratella, 2021; De Keijzer, et al., 2019; Maroto-Izquierdo, et al., 2020; Loturco, et al., 2024; Spudić, et al., 2023; Sun, et al., 2024; Xie, et al., 2022).

Also, despite the growing body of research on flywheel-induced PAPE, existing studies have been conducted almost exclusively on physically active adult men, with no studies specifically examining young basketball players. This represents a substantial gap in literature, given that youth athletes differ from adults in neuromuscular maturity, training history, strength levels, fatigue profiles, and responsiveness to eccentric overload.

Given the importance of enhancing explosive performance in basketball and the potential of flywheel training to induce acute PAPE responses, the present study aims to investigate whether a flywheel half-squat protocol can acutely improve countermovement jump height in elite young male basketball players, assessed at 1-, 3-, and 5-minutes following the protocol.

## Methods

### Participants

The study included 15 young male basketball players from the U17 and U19 categories (age:  $17.0 \pm 1.0$  years; height:  $193.1 \pm 7.3$  cm; body mass:  $83.6 \pm 8.2$  kg; BMI:  $22.4 \pm 1.7$  kg/m<sup>2</sup>). The primary inclusion criterion was the absence of any injury or illness. According to the classification by McKay and associates (2022), seven players were categorized as level 4 (elite international athletes), while eight participants were classified as level 3 (highly trained national-level athletes). The study objectives and protocol were thoroughly explained in advance to both the participants and their parents. They were informed of the potential risks and their right to withdraw from the study at any time without any consequences. Written informed consent was obtained from the participants' parents or legal guardians. The study protocol was approved by the institutional ethics committee (Approval No. 76/2025). Participants were randomly assigned to complete both the experimental (PAPE) and control (CON) protocols using a crossover design.

### Measurement procedures

Experiment was conducted in May 2025 over the three consecutive weeks. The first three sessions were dedicated to familiarization with flywheel

training as recommended in literature (Beato, McErlain-Naylor, Halperin, & Dello Iacono, 2020), and for the assessment of anthropometric characteristics. During the next two visits, participants performed a standardized warm-up followed by either the PAPE intervention or CON condition, and completed a countermovement jump at 1-, 3-, and 5-minute post-intervention. Both protocols were separated by a minimum interval of 72 hours to ensure full recovery of the neuromuscular system prior to testing. Participants were instructed to refrain from any additional training outside their regular club sessions during the experiment to avoid extra physical exertion that could potentially influence the results.

Data on *anthropometric characteristics* were collected during the third session. Body height was measured in a standing position, without shoes, using a wall-mounted stadiometer to the nearest 0.1 cm (Mišigoj-Duraković, 2008). Body mass was measured with a mechanical beam balance scale (Detecto DTC-437, Detecto Scale Company, Webb City, USA). Body mass index (BMI) was calculated using the following formula:  $BMI = \text{body mass (kg)} / \text{height (m)}^2$ .

*Jumping performance* was evaluated using OptoJump system (Microgate, Bolzano, Italy), which proved to be a reliable instrument for the evaluation of the vertical jump (Attia, et al. 2017). The countermovement jump (CMJ) was performed at 1-, 3-, and 5-minute following both protocols. Participants were instructed to descend into a self-selected squat depth from a standing position and then immediately perform a maximal vertical jump without pausing. Throughout the jump, the hands were placed on the hips to eliminate any influence of arm swing on jump performance. Participants were encouraged to perform each jump with maximal effort, and feedback on the results was provided after the completion of all testing. Jump height was calculated based on the total flight time using manufacturer software (OptoJump Next software; version 1.14.11.) using the following formula:  $h = (g \times t^2) / 8$ , where  $h$  is jump height,  $g$  is the acceleration due to gravity ( $9,81 \text{ m/s}^2$ ), and  $t$  is flight time (in seconds).

## Intervention

Prior to the intervention, a standardized 5-minute warm-up was performed. It consisted of low intensity running and preparatory exercises. Participants were instructed to maintain an intensity at which they could comfortably carry on a conversation without effort, corresponding to the positive Talk Test zone (Bok, Rakovac, & Foster, 2022). Following the run, participants performed several preparatory exercises, including joint mobilization, dynamic stretching, and a specific exercise simulating the squat movement on the flywheel

device (Beato, et al., 2021). The same warm-up protocol was applied in both the experimental and control conditions.

After the warm-up, the experimental condition (PAPE) consisted of flywheel training sets followed by countermovement jumps at three time points: 1-, 3-, and 5-minute post-intervention, whereas the control condition (CON) consisted of only the warm-up and countermovement jumps at the same time points.

The flywheel training intervention involved the half-squat exercise on a kBox4 Pro flywheel ergometer (Exxentric, AB, Stockholm, Sweden) (Fig. 1). A medium-sized flywheel (M) with a moment of inertia of  $0.025 \text{ kg}\cdot\text{m}^2$  was used for all participants, while the inertia of the device itself was estimated at approximately  $0.0011 \text{ kg}\cdot\text{m}^2$ . The protocol consisted of three sets of six repetitions performed with maximal effort, with a 2-minute passive rest between the sets. Participants were encouraged to exert maximal effort and were instructed to perform the concentric phase of the movement as rapidly as possible, while controlling the eccentric phase until the knees reached approximately  $90^\circ$  of flexion.



Figure 1. Starting position on a kBox4 Pro flywheel ergometer.

## Statistical analyses

The collected data were processed and analyzed using Statistica, version 14.1.0.8 (StatSoft, Inc., Tulsa, USA). Descriptive statistics (mean  $\pm$  standard deviation) were calculated for all variables. The normality of the distribution of differences between the experimental (PAPE) and control

(CON) protocols was assessed using the Shapiro-Wilk test. Differences in countermovement jump (CMJ) height between the experimental and control protocols at 1-, 3-, and 5-minutes post-intervention were analyzed using paired-samples t-tests, with statistical significance set at  $p < .05$ .

Effect sizes (ES) were calculated using Cohen's  $d_z$  for within-subject comparisons, with thresholds interpreted as small (0.2), moderate (0.5), and large (0.8) (Lakens, 2013). Individual data points for each time point were further visualized in figures to illustrate variability across the participants.

## Results

Table 1 presents the descriptive statistics for countermovement jump (CMJ) height following the experimental (PAPE) and control (CON) protocols at 1-, 3-, and 5-minute time points. In the PAPE condition, CMJ height increased from 1-minute (37.97 cm) to 3-minute (39.03 cm) and showed an additional rise at 5-minute (39.20 cm). In the CON condition, CMJ performance remained stable, with mean values of 38.99 cm at 1-minute, 39.17 cm at

3-minute, and 38.93 cm at 5-minute, indicating minimal variation over time.

Within-subject differences in CMJ height between the experimental (PAPE) and control (CON) protocols were minimal across all time points. Shapiro-Wilk tests indicated no significant deviations from normality for the difference scores at 1-minute ( $p = .856$ ), 3-minutes ( $p = .163$ ), or 5-minute post-intervention ( $p = .385$ ), supporting the use of parametric analyses. At 1-minute, the mean difference was  $-1.02 \pm 2.12$  cm, corresponding to a small-to-moderate effect (Cohen's  $d_z = -0.48$ , 95% CI  $[-1.07, 0.11]$ ). Differences at 3-minute ( $-0.15 \pm 2.67$  cm; Cohen's  $d_z = -0.06$ , 95% CI  $[-0.61, 0.50]$ ) and 5-minute ( $0.27 \pm 2.69$  cm; Cohen's  $d_z = 0.10$ , 95% CI  $[-0.46, 0.66]$ ) were negligible. These results indicate that the PAPE protocol did not elicit meaningful acute changes in CMJ performance relative to the control condition. Individual values of countermovement jump height following the control and experimental protocols are presented in the graphs for each time point (Fig. 2a, Fig. 2b, and Fig. 2c).

Table 1. Descriptive statistics of CMJ height following the experimental (PAPE) and control (CON) protocols at different time points

Variable	AS (cm)	SD (cm)	Min (cm)	Max (cm)
PAPE 1 min	37.97	6.06	29.30	54.50
PAPE 3 min	39.03	6.29	32.00	57.00
PAPE 5 min	39.20	6.49	30.90	56.50
CON 1 min	38.99	5.66	32.40	54.20
CON 3 min	39.17	5.48	31.80	53.20
CON 5 min	38.93	5.66	31.00	55.40

Note. AS = arithmetic mean; SD = standard deviation; Min = minimum; Max = maximum; CMJ = countermovement jump; PAPE = CMJ following the experimental protocol (1, 3, and 5 minutes post-intervention); CON = CMJ following the control protocol (1, 3, and 5 minutes post-intervention).

Table 2. Results of the paired-samples t-test assessing differences in CMJ height following the experimental and control protocols

	CON (AS $\pm$ SD)	PAPE (AS $\pm$ SD)	t	p
1-min	38.99 $\pm$ 5.66	37.97 $\pm$ 6.06	-1.86	0.084
3-min	39.17 $\pm$ 5.48	39.03 $\pm$ 6.29	-0.21	0.835
5-min	38.93 $\pm$ 5.66	39.20 $\pm$ 6.49	0.39	0.700

Note. AS = arithmetic mean; SD = standard deviation; t = difference between the observed conditions; p = level of statistical significance.

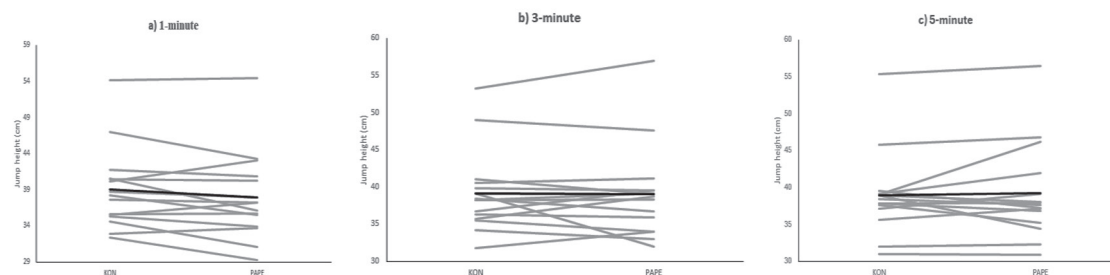


Figure 2. Countermovement jump height following the control (CON) and experimental (PAPE) protocols at the 1-minute (a), 3-minute (b), and 5-minute (c) time points. Note: grey lines connect individual values, while the black line connects the mean values for both protocols.

A paired-samples t-test revealed no statistically significant differences in CMJ height between the control (CON) and experimental (PAPE) protocols (Table 2). CMJ performance did not differ at 1-minute post-intervention (PAPE:  $37.97 \pm 6.06$  cm; CON:  $38.99 \pm 5.66$  cm), at 3-minute (PAPE:  $39.03 \pm 6.29$  cm; CON:  $39.17 \pm 5.48$  cm), nor at 5-minute post-intervention (PAPE:  $39.20 \pm 6.49$  cm; CON:  $38.93 \pm 5.66$  cm).

## Discussion and conclusions

The main findings of this study indicate that flywheel half-squat exercise does not induce an acute enhancement of CMJ height in elite youth male basketball players since no significant differences were detected between the experimental and control conditions at any of the post-intervention time points. Considering the mean jump heights, performance decreased by 2.6% at 1-minute, by 0.36% at 3-minute, and increased by 0.69% at 5-minute following the intervention. Such a result was expected for the first time point, as fatigue dominates over potentiation after one minute. However, based on previous research, this type of training would have been expected to enhance vertical jump performance at the second and third time points, i.e., after three minutes and more pronouncedly after five minutes.

The results of our study are not consistent with expectations or previous literature, even though the main training variables—such as intensity, volume, rest duration, and exercise selection—were determined based on the established recommendations (Beato, et al., 2020) and aligned with prior studies reporting positive effects of flywheel training. In a methodologically similar study, Beato and associates (2021) reported a significant increase in CMJ height at 3- and 5-minute post-intervention (14.24% and 12.46%, respectively), while no statistically significant improvement was observed at 1-minute. This substantial improvement was achieved using the half-squat exercise, with the number of repetitions, sets, and rest periods identical to those applied in our study. The study also employed a flywheel with similar inertia ( $0.029 \text{ kg}\cdot\text{m}^2$ ), with the only notable difference being the participants' training status and age ( $20.2 \pm 1.4$  years vs.  $17.0 \pm 1.0$  years in our study). Sanchez-Sanchez and associates (2018) report that PAPE effects are more pronounced in elite athletes and in those with greater resistance training experience (1-3 years). Significant improvements have been reported in several previous studies (Beato, et al., 2019; Beato, De Keijzer, et al., 2021; De Keijzer, et al., 2019; Maroto-Izquierdo, et al., 2020; Sun, et al., 2024), with participant samples ranging from physically active individuals to elite athletes. If competitive level was a critical factor in eliciting PAPE, it would likely have represented a favorable condi-

tion in our study, as the participants were highly trained basketball athletes with at least one year of resistance training experience and had completed a familiarization period with the flywheel device, in accordance with the established recommendations (Beato, et al., 2020). Although training experience, particularly in flywheel-based exercise, may facilitate the induction of PAPE, it does not appear to be a determining factor, given that acute performance enhancements have been observed in participants with similar or lower training experience. On the other hand, in none of the aforementioned studies was the mean participant age below 20 years. It is possible that age—specifically developmental and neuromuscular immaturity—limits the occurrence of PAPE in younger athletes. Coutinho and associates (2022) suggested that the lack of positive effects of flywheel training observed in their study was likely attributable to the participants' limited experience with flywheel and resistance training, as well as their younger chronological age ( $16.2 \pm 0.6$  years). Younger athletes may be more susceptible to central fatigue (Streckis, Skurvydas, & Ratkevicius, 2007), which could hinder the occurrence of PAPE and highlight the potential need for longer recovery periods ( $>15$  min). Although human skeletal muscles consist of a mixture of slow-twitch (type I) and fast-twitch (type II) fibers, longitudinal and review studies indicate that the proportion of these fibers changes throughout development (Glenmark, Hedberg, & Jansson, 1992; Hager, Mazurak, Noga, Gilmour, & Mager, 2023). The relative proportion of slow-twitch fibers is generally higher in early adolescence, whereas the proportion of fast-twitch fibers increases through puberty into adulthood, particularly in males. These changes are associated with enhanced strength and explosive performance capacity and reflect neuromuscular maturation, which may influence the recovery rate following eccentric contractions. Given the potentially higher central fatigue susceptibility of younger athletes and potential differences in muscle fiber content, it would be reasonable to examine the effects of longer recovery intervals. Since the acute effects of flywheel training have not been sufficiently investigated in young athletes, further research is needed to determine whether this form of training can induce acute improvements in vertical jump performance in this population.

Observing individual results (Fig. 2), it can be noted that some participants did achieve a positive effect. Specifically, in the first minute, only one participant showed improvement ( $>5\%$ ), which is expected given the predominance of fatigue over PAPE within this time frame. At the 3-minute post-intervention time point, four participants demonstrated an improvement, while at the 5-minute time point, three participants did. These heterogeneous individual responses to the same protocol

highlight the variability of PAPE expression and suggest the importance of individualized strategies to optimize its elicitation in training. Individualization of training intensity has been shown to positively affect CMJ performance in the studies by Maroto-Izquierdo and associates (2020) and Sun and associates (2024). In the former study, intensity was determined based on the load that elicited maximal concentric power, whereas in the latter it was adjusted according to the concentric phase velocity during half-squat exercise performed with 80% of one-repetition maximum (1RM). In contrast, Spudić and associates (2023) also applied an individualized intervention intensity based on maximal concentric power but did not observe significant post-intervention effects in the experimental flywheel group. However, it is important to note that only a single set of repetitions was implemented, which may be insufficient to maximize the PAPE response (Beato, et al., 2020).

In addition to intensity (i.e., inertia at which the participant generates maximal concentric power), individualization of recovery time following flywheel protocols has also been proposed as a potentially effective strategy (Sun, et al., 2024). Although this approach has been applied in relatively few studies to date, it is assumed to further optimize the PAPE effect. Given the substantial interindividual variability, current literature recommends that coaches assess athletes' acute responses to different protocols and define key training variables accordingly (Kobal, et al., 2019).

Although jumping ability is of great importance for basketball players, the practical application of the PAPE effect within a competitive match context appears limited. Given the relatively short time window in which acute performance enhancements may occur, in combination with the overall duration of a basketball game, it is unlikely that implementing such protocols during pre-game

warm-up would meaningfully influence match outcomes. Furthermore, as players are exposed to high-intensity activities from the very beginning of the game, the rapid accumulation of fatigue may further attenuate any potentiation effects. Accordingly, Xie and associates (2022) suggested that PAPE protocols should primarily be implemented within explosive strength training sessions, with the aim of enhancing training efficiency and increasing the likelihood of achieving favorable chronic adaptations.

It is important to note that this study has some limitations. Only the countermovement jump height was assessed, without additional measures of neuromuscular activity or force production, which may have provided a more comprehensive understanding of PAPE responses. Although previous research typically reports PAPE effects within three to five minutes post-intervention, the temporal dynamics in youth athletes remain largely unexplored; future studies may consider additional measurements up to 10 minutes to better capture the full potentiation profile. Finally, the flywheel intervention consisted of a single exercise (half-squat) with fixed sets and inertia, without individualization of intensity or recovery time, which may have reduced the likelihood of eliciting maximal potentiation.

In conclusion, flywheel training performed using the half-squat exercise did not result in acute improvements in countermovement jump (CMJ) height in young highly trained male basketball players at any of the observed time points. These results highlight the potential importance of individualizing the timing, intensity, and recovery parameters of flywheel protocols to maximize acute performance responses. Further research in young athletes is warranted to determine optimal protocols and time frames for eliciting any potential maximal potentiation.

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