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Section III – Sports and Physical Activity

Unilateral Flywheel versus Traditional Split-Squat Exercise for Post-Activation Performance Enhancement: Effects on Jump, Change-of-Direction, and Sprint Performance in Junior Basketball Players

by

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Post-activation performance enhancement strategies are increasingly used to improve explosive performance in team sports. This study examined the acute effects of unilateral flywheel eccentric overloading and traditional split-squat conditioning on vertical jump (VJ), change-of-direction (COD), and sprint performance in junior basketball players. Eighteen male players were randomly assigned to a flywheel group (FLY; n = 9; age 17.5 ± 0.53 years; body mass 76.0 ± 5.9 kg) or a traditional resistance group (TRAD; n = 9; age 18.0 ± 0.47 years; body mass 81.8 ± 8.1 kg). The FLY group performed unilateral split squats using a flywheel device (0.025 kg·m² inertia), whereas the TRAD group performed Bulgarian split squats with free weights at 80% one-repetition maximum. Each group performed two sets of six repetitions. Performance was assessed at baseline and at the 2nd, the 4th, the 8th, and the 15th min following the conditioning activity. A significant group × time interaction was observed for COD performance (p = 0.001). Post-hoc comparisons showed that T-test performance improved in the FLY group at the 8th min (−5.7%, Cohen's d = 0.83) and the 15th min (−8.4%, d = 1.12) relative to baseline, whereas no significant changes were observed in the TRAD group. No significant interactions were found for VJ or sprint performance. These findings suggest that the unilateral flywheel split-squat protocol acutely enhanced COD performance more than the traditional split-squat protocol. Performance improvements occurred between the 8th and the 15th min following the conditioning activity, suggesting that flywheel-based priming may represent a practical strategy for short-term COD readiness in basketball.

***Keywords**: eccentric overload; neuromuscular priming; re-warm-up; team sports; agility*

Introduction

Effective warm-up and re-warm-up strategies are considered critical components for preparing basketball athletes for both training and competition demands (Aerts et al., 2015). The actions performed during the warm-up have been widely recognized for their acute performance-enhancing potential primarily by elevating muscle temperature, which improves muscle contractility and enzymatic activity, thereby facilitating neuromuscular readiness (Blazevich and Babault, 2019). In basketball, however, readiness is not only determined by the initial pre-game warm-up; it can be compromised when players spend prolonged periods seated on the bench before entering the game as substitutions. This concern is not confined to basketball: in futsal, where rolling substitutions are frequent, the activity performed by non-starters during the post warm-up period has been shown to influence subsequent neuromuscular performance, indicating that the content of the re-warm-up, rather than its provision alone,

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determines readiness upon re-entry (Silva et al., 2025). In contemporary high-level basketball settings, sideline cycle ergometers are commonly used near the bench to help non-playing athletes remain warm and prepared to play, but such approaches may not optimally target the eccentric braking and re-acceleration demands that underpin decisive match actions. This creates a practical rationale to examine brief "priming" or "re-warm-up" protocols that may be transferable to constrained basketball environments.

Building upon these general benefits, strengthening exercises have become common in basketball pre-practice and pre-game routine (Flórez-Gil et al., 2025) due to their ability to acutely enhance neuromuscular readiness. A key mechanism underlying these acute performance benefits is post-activation performance enhancement (PAPE). PAPE refers to transient improvements in voluntary muscle performance following brief high-intensity conditioning activities (Blazevich and Babault, 2019). Unlike classic post-activation potentiation, which primarily involves phosphorylation of myosin regulatory light chains, PAPE encompasses a combination of physiological responses—including increased muscle temperature, altered muscle-tendon stiffness, fluid shifts, and enhanced neural activation—that collectively contribute to improved performance (Cuenca- Fernández et al., 2017; Docherty and Hodgson, 2007; Tillin and Bishop, 2009). There is strong evidence that, when appropriately prescribed, PAPE can be exploited to acutely enhance lower-limb explosive performance and sport-specific tasks such as jumping, change of direction (COD), and sprinting (Beato et al., 2019a; Dobbs et al., 2018; Gołaś et al., 2016; Petisco et al., 2019; Seitz and Haff, 2015), making it a promising target for warm-up and re-warm-up protocols in basketball. To maximize these benefits, conditioning activities are generally prescribed at high relative intensities and moderate volumes, with performance enhancement often emerging within ~5–15 min after the stimulus (Pereira et al., 2025; Tillin and Bishop, 2009). However, the magnitude and timing of PAPE depend strongly on the characteristics of the conditioning exercise, including the contraction type, volume, and intensity.

Among contraction types, eccentric-overload conditioning has been recently proposed as a potentially effective strategy (Bogdanis et al., 2014). Recent evidence indicates that maximal-effort, multi-joint eccentric muscle actions are in themselves sufficient to elicit post-activation performance enhancement, independently of the device used to impose the eccentric load (Dickey et al., 2025). Eccentric overloading (Maroto-Izquierdo et al., 2017) can increase force production during the lengthening phase, elevate overall mechanical demand, and promote greater recruitment of higher-threshold motor units than traditional free weight exercises, potentially enhancing the magnitude and duration of the PAPE effect (Douglas et al., 2016; Hodgson et al., 2005). Flywheel resistance training, through inertia-based loading, is currently considered one of the most practical methods for applying eccentric overloading in strength and conditioning settings, offering unique benefits over traditional free-weight training. Its compact and portable design makes flywheel training particularly attractive for basketball environments where space and equipment access are limited (Beato and Iacono, 2020; Buonsenso et al., 2023; Martinez-Aranda and Fernandez-Gonzalo, 2016).

However, studies comparing flywheel and traditional free-weight conditioning activities have reported mixed findings for jump and sprint performance, with both comparable (Beato et al., 2019b; Galiano et al., 2025) and superior (Timon et al., 2019; Xie et al., 2022) potentiation effects reported for flywheel protocols. A recent work in basketball cohorts has reinforced the relevance of this modality, including direct comparisons of flywheel eccentric-overload and traditional barbell training in female players (Xue et al., 2025) and of unilateral versus bilateral flywheel loading in youth male players (Belegišanin et al., 2025). Consistently with this, flywheel resistance training has been shown to improve change-of-direction and sprint performance in professional team-sport players (Pecci et al., 2023) as well as to enhance jumping and stretch-shortening-cycle function in collegiate basketball players (Shimizu et al., 2025), and recent international consensus recommendations endorse it as a practical means of delivering eccentric overloading in applied settings (Beato et al., 2024). Eccentric-based resistance training also appears to be an effective and developmentally appropriate stimulus for enhancing physical performance in youth athletes

(Bright et al., 2023). Notably, most flywheel PAPE studies have used bilateral conditioning activities (Suchomel et al., 2016; Young, 2006), whereas unilateral training has become increasingly common in practice and may offer greater movement specificity for multidirectional sports such as basketball (Bogdanis et al., 2017; Krzysztofik et al., 2022; Tao et al., 2025; Zhang et al., 2023). This may be particularly relevant for COD performance, given the unilateral and multi-planar demands of deceleration, lateral shuffling, and re-acceleration (Chaabene et al., 2018). To the best of our knowledge, no previous study has directly compared the acute PAPE responses of unilateral flywheel eccentric overload and traditional unilateral split-squat conditioning on basketball-specific performance outcomes such as change-of-direction ability (Andrić et al., 2026; Tsoukos and Bogdanis, 2025; Tsoukos et al., 2025). Importantly, beyond the initial warm-up, basketball practitioners increasingly use brief re-warm-up activities during game interruptions or while players remain on the bench to maintain neuromuscular readiness. In this context, compact resistance modalities such as flywheel devices may provide a practical means of inducing PAPE without requiring extensive space or equipment, although this application has not yet been tested directly in game settings.

Therefore, the aim of this study was to compare the acute PAPE responses of unilateral flywheel eccentric overloading (FLY) and traditional unilateral split-squat exercise (TRAD) on vertical jump (VJ), change-of-direction (COD), and sprint performance in young male basketball players. The TRAD protocol was included as a comparator aligned with established PAPE methodology, whereas the FLY protocol was evaluated as a potentially more deployable solution for brief re-warm-up contexts. It was hypothesized that unilateral flywheel conditioning would elicit greater acute enhancement of COD performance compared with unilateral traditional split-squat exercise. A secondary applied hypothesis was that any flywheel-induced improvements would emerge within a practically actionable time window (≈8–15 min) relevant to pre-substitution preparation.

Methods

Participants

A statistical power calculation was performed with G*Power software (version 3.1.9.7, Heinrich Heine University Düsseldorf, Germany), using a repeated measures, within-between interaction analysis of variance (ANOVA). This analysis indicated a minimum sample size of 18 participants, with the following input parameters: α = 0.05, power (1-β error probability) = 0.8, correlation among repeated measurements of 0.6, with two groups and five measurements. The input effect size was set a priori to a moderate group × time interaction (Cohen's f = 0.25, equivalent to partial $\eta^2 \approx 0.06$), a value consistent with the acute potentiation responses to flywheel eccentric-overload conditioning previously reported in team-sport athletes (Andrić et al., 2026; Beato et al., 2019a). Twenty junior male basketball players from Novi Sad, Serbia, volunteered to participate in the study; two discontinued due to illness during the study period. The remaining 18 players were randomly allocated to two experimental groups: a flywheel group (FLY; n = 9; age = 17.5 ± 0.53 years; body height = 190.1 ± 5.7 cm; body mass = 76.0 ± 5.9 kg; training experience = 5.7 ± 1.8 years) who performed unilateral split squats on a flywheel device (kBox; Exxentric AB, Bromma, Sweden), and a traditional resistance exercise group (TRAD; n = 9; age = 18.0 ± 0.5 years; body height = 194.1 ± 3.9 cm; body mass = 81.8 ± 8.1 kg; training experience = 6.5 ± 1.5 years) who performed Bulgarian split squats with free weights. All participants competed at the regional level and represented teams in the Vojvodina province top junior league during the season of data collection. Athletes had a minimum of four years of basketball training experience, no lower-limb injury within the prior six months, and no acute illness in the 14 days preceding the study. All participants had at least two years of strength training experience and were familiar with both free-weight and flywheel training and testing procedures. Using the participant-classification framework proposed by McKay et al. (2022), the present cohort would be classified as Tier 2: trained/developmental, as participants were organized junior basketball players competing at the regional level, with several years of sport-specific and resistance-training experience.

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Study aims and procedures were explained to all participants, who retained the right to withdraw at any time. No injuries were reported during the experiment. Participation was voluntary, and written informed consent was obtained from all participants; for minors, consent was provided by their legal guardians. Procedures followed the World Medical Association Declaration of Helsinki (2013, as amended in 2024), and the protocol was approved by the Ethics Committee of the Faculty of Sport and Physical Education, University of Novi Sad, Novi Sad, Serbia (Ref. approval no. 03–10-01/2026–1; approval date: 18 March 2026).

Measures

Prior to baseline testing, participants' training history and anthropometric measures (standing height and body mass) were recorded by an ISAK (International Society for the Advancement of Kinanthropometry) Level 3 anthropometrist according to standard procedures. The technical error of measurement for body height and body mass was <0.02%. Body height was measured using a SECA stadiometer (accuracy of 1 mm; range: 130–210 cm), and body mass was measured using a SECA scale (accuracy of 0.1 kg; range: 2–130 kg).

The vertical jump, the T-test, and a 20-m sprint were selected because they index the principal explosive actions that determine basketball performance: repeated jumping during rebounding, blocking and shooting, rapid braking and re-acceleration during defensive slides, closeouts and cuts, and short linear accelerations during transition play. These field tests are reliable, time-efficient and ecologically meaningful indicators of neuromuscular readiness in court-sport athletes and have been widely used to characterize basketball-specific physical qualities (Andrić et al., 2026; Chaabene et al., 2018; Flórez-Gil et al., 2025). The VJ, i.e., a vertical jump test with countermovement and an arm swing, was performed using an electronic contact platform (Just Jump, Probotics, USA). Participants stood upright on the mat and performed a self-selected countermovement to a semi-squat depth, immediately followed by a maximal vertical jump, landing upright. The arm swing was permitted. Participants were instructed to minimize the transition time between eccentric (braking) and concentric (propulsive) phases to optimize stretch-shortening cycle utilization. Two trials were performed, and the highest jump height was used for subsequent analysis.

The T-test was used to assess change-of-direction ability. Participants began with the front foot 0.3 m behind the timing gates. The test included forward sprinting, lateral shuffling, and backward running. Trials were invalidated if participants crossed feet during shuffling or failed to touch the top of the cones. Timing was recorded via photocell gates (Microgate Witty, Italy) placed at the start and the finish. Two trials were performed, and the best (fastest) time was used for further analysis.

The 20-m sprint test (including 5-m split time) was measured using photocell timing gates (Microgate Witty, Italy). Participants placed the front foot 0.3 m behind the first timing gate and initiated the sprint voluntarily to minimize reaction-time influence. Participants were instructed to sprint maximally through the finish line. Two trials were performed, and the best (fastest) time was used for analysis. Reliability for these measures had been established in comparable team-sport populations. In professional basketball players, vertical-jump and 5–20 m linear-sprint assessments performed with the present methods showed good-to-excellent relative reliability (ICC = 0.81–0.97) and high absolute reliability (CV = 0.1–2.6%) (de Pedro-Múñez et al., 2025), whereas the T-test had shown comparable test-retest reliability (ICC = 0.70–0.95; CV = 0.8–4.0%) (Altmann et al., 2019). Using the best of two trials further limited within-session measurement error in the present cohort.

Design and Procedures

This study employed a randomized, parallel-group design with repeated measures (Figure 1). The objective was to compare the acute effects of flywheel versus traditional unilateral conditioning activities on vertical jump, COD, and sprint performance. The post-conditioning assessment time points (2–15 min) were selected to reflect a realistic operational window for warm-up and re-warm-up/priming strategies, including possible practical transfer before anticipated match entry (e.g., substitutions). Each participant attended five sessions separated by 72 h. The first session served for familiarization. During the

second session, participants completed a standardized warm-up and baseline assessments for the 20-m sprint (including 5 m split), the T-test, and the vertical jump (VJ). In subsequent sessions, participants repeated the same warm-up and performed their assigned conditioning activity (FLY or TRAD), followed by post-conditioning performance assessments at the 2nd, the 4th, the 8th, and the 15th min (Figure 1). The order of performance tests within each post-conditioning session was randomized as follows: a) 20-m sprint and 5-m split, b) COD T-test, and c) vertical jump. Each participant completed three such conditioning sessions (visits 3–5; Figure 1). At each post-conditioning time point (2, 4, 8 and 15 min), the three tests were performed in a brief, standardized sequence separated by short passive recoveries, and the order of the three tests was counterbalanced across the three sessions so that no single test was systematically advantaged or disadvantaged by its position in the sequence. This compact battery was adopted deliberately: the rapid succession of a linear sprint, a change-of-direction effort and a vertical jump reproduces the continuum of explosive actions that a player performs upon entering a game, thus the protocol was designed to probe neuromuscular readiness under game-representative conditions rather than in isolation, while the counterbalanced ordering distributed any residual test-induced fatigue evenly across the three outcomes. Testing was conducted in the post-competition period (seven days following the last official game or team training session) to minimize accumulated fatigue. Participants were instructed to avoid strenuous exercise and supplements that could influence performance throughout the experiment. All sessions were conducted in the morning at the Training Expertise Laboratory, Faculty of Sport and Physical Education, University of Novi Sad. All procedures were administered by certified strength and conditioning coaches (PhD candidates) under supervision of a professor specializing in training theory (M.D.M.S). Although testing was conducted in a laboratory setting, both protocols were designed to be brief and practically scalable to applied basketball environments.

Conditioning Activities

The FLY group completed two sets of six repetitions of unilateral split squat exercises using a flywheel device (kBox; Exxentric AB, Bromma, Sweden), alternating legs: right leg for 6 repetitions, followed by the left leg for 6 repetitions, with 2 min of passive recovery between sets. Each set included 2 repetitions to build momentum, which were not counted. Participants started in a split squat position with 90-degree knee flexion, then executed a concentric contraction towards nearly full knee extension, followed immediately by an eccentric contraction without pausing. They were instructed to perform maximal effort during the concentric phase, while during the eccentric phase, they were advised to delay the initial third of the lengthening contraction and then apply maximal braking force at 90 degrees of knee flexion to induce eccentric overloading. A moderate load of 0.025 kg·m² was used for the flywheel group (Tsoukos et al., 2025). This load was selected to balance eccentric overloading with technical control and feasibility for brief priming bouts in constrained environments. This low-to-moderate inertia was chosen on a principled rather than arbitrary basis: a setting of 0.025 kg·m² has recently been shown to acutely potentiate countermovement-jump and reactive-strength performance to the same degree as a four-fold higher inertia when the force impulse is equated (Tsoukos et al., 2025), indicating that a low inertia is sufficient to elicit the potentiating stimulus. A lower inertia additionally permits higher movement velocity and a more pronounced terminal eccentric braking phase, which is mechanically congruent with the rapid deceleration-reacceleration actions of change of direction, while keeping the bout brief and technically controllable in space-restricted settings (Martinez-Aranda and Fernandez-Gonzalo, 2016). The appropriateness of a comparatively low inertia for eliciting eccentric overloading is further supported by recent load-characterization studies and international consensus guidelines (Beato et al., 2024; Muñoz-López et al., 2023).

The TRAD group performed two sets of six repetitions of Bulgarian split squats with a 2-min passive recovery, using free weights. Participants began with the front leg on the ground and the other leg on a bench behind them, maintaining an upright posture. They initiated the exercise with a controlled eccentric movement down to 90 degrees of knee flexion, lasting approximately 3 s, then

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performed an immediate concentric phase to near full knee extension. Participants were instructed to execute the concentric effort maximally, with the exercise intensity set at 80% of their 1RM (Petisco et al., 2019). The unilateral one-repetition maximum (1RM) for the Bulgarian split squat was determined directly for each leg during the familiarization session using a standardized incremental protocol. After a specific warm-up, the load was progressively increased over three to five attempts, with 3-min rest intervals between attempts, until the heaviest load that could be completed once through the full range of motion with correct technique and the rear foot elevated on a standard bench was reached; the 80% load used in the conditioning sessions was calculated from this measured 1RM.

Statistical Analysis

Values are presented as mean ± *SD*. Percentage changes relative to baseline are additionally reported with 90% confidence intervals (90% CI). A two-way (2 × 5) mixed repeated-measures ANOVA (Group [FLY, TRAD] × Time [baseline (T0), +2 min (T1), +4 min (T2), +8 min (T3), +15 min (T4)]) was used for each dependent variable. Sphericity was evaluated using the Mauchly's test, and Greenhouse-Geisser corrections were applied when required. Post hoc pairwise comparisons were conducted on the estimated marginal means, using paired-samples T-tests for within-group (time) contrasts and independent-samples T-tests for between-group contrasts, with Bonferroni adjustment of the *p* values for multiple comparisons. To enhance the understanding of the results, partial eta squared (η^2) was computed as a measure of effect size. Values of η^2 between 0.01 and 0.06, between 0.06 and 0.14 and above 0.14 were considered small, medium and large effect sizes, respectively (Grice and Barrett, 2014).

Effect sizes for post hoc pairwise comparisons were calculated using Cohen's *d*; for the within-group (repeated-measures) contrasts, *d* was computed as the mean change between the two time points divided by the average of their standard deviations (d_{av}), an approach appropriate for repeated-measures designs and comparable across studies (Lakens, 2013), with interpretations as follows: values ranging from 0.00 to 0.19 were deemed trivial, those from 0.20 to 0.59 were classified as small, values between 0.60 and 1.19 were considered moderate, and values exceeding 1.20 were categorized as large (Hopkins et al., 2009). Data were processed using SPSS (version 20; Chicago, IL). In addition, results were interpreted with consideration of both statistical significance and practical relevance (effect sizes and time-course patterns) for applied readiness contexts.

Results

The results of the two-way ANOVA for the VJ showed a significant main effect of time (F = 7.30, p = 0.001, η^2 = 0.31) with no significant effects of the group or the group × time interaction (p = 0.707). Pairwise comparisons for the FLY group showed significant differences between the 2nd and the 4th min (p = 0.011, d = 0.91), the 2nd and the 8th min (p = 0.006, d = 1.01), the 2nd and the 15th min (p = 0.001, d = 1.73), and the 8th and the 15th min (p = 0.037, d = 0.71). The baseline-to-15-min comparison approached statistical significance (p = 0.058). Pairwise comparisons for the TRAD group showed significant differences between the 2nd and the 15th min (p = 0.002, d = 1.20) and between the 4th and the 15th min (p = 0.016, d = 0.86). In the FLY group, the VJ increased by +4.0% at the 15th min, whereas the TRAD group increased by +4.7%. The largest mean improvement observed at any post-conditioning time point was +5.0% in both the FLY and TRAD groups (Table 1).

For the T-test, there was a significant main effect of time (F = 3.15, p = 0.020, η^2 = 0.16) and a significant group × time interaction (F = 5.71, p = 0.001, η^2 = 0.26), with no significant main effect of the group (p > 0.05). The post hoc tests revealed significant improvements under the flywheel condition at the 8th and the 15th min (−5.7%, d = 0.83 and −8.4%, d = 1.12) compared with baseline, with confidence intervals that did not overlap zero at the later time points, indicating a meaningful potentiation effect following the flywheel conditioning activity. In contrast, no significant differences were observed across time points under the TRAD condition. Notably, the earliest clear improvement under the flywheel condition occurred at the 8th min post-conditioning and persisted at the 15th min, which represents a practically actionable readiness window for pre-entry priming. The best improvement in T-test performance was 9.0% in the FLY group, compared with 4.5% in the TRAD group (Table 1).

For 5-m and 20-m sprint performance, the two-way ANOVA revealed no significant main effects of time or the group and no group × time interactions (5 m: $p = 0.458$; 20 m: $p = 0.915$; Table 2). Sprint performance showed minimal changes under both conditions. For the 5-m sprint, times changed by +3.3% in the FLY group and +0.4% in the TRAD group at the 15th min, whereas for the 20-m sprint, changes were −0.9% in the FLY group and +0.1% in the TRAD group. No consistent improvements were observed in sprint performance in either group (Table 2).

Overall, the time course indicates that the flywheel protocol selectively enhanced COD (T-test) performance, whereas jump and sprint outcomes did not demonstrate clear potentiation following the present exercise intervention.

Table 1. Percentage changes from baseline in vertical jump and T-test performance following flywheel and traditional split-squat conditioning.

		Baseline (mean ± SD)	Time	%Mean change (90% CI)	Cohen's d	%Best improvement (90% CI)
Flywheel exercise group	Vertical Jump	57.8 ± 10.0 cm	2 min	−3.5 (−7.3 to 0.2)	0.58	5.0 (2.3 to 7.8)
			4 min	0.4 (−1.9 to 2.8)	0.10	
			8 min	1.6 (−2.1 to 5.3)	0.17	
			15 min	4.0 (0.8 to 7.2)	0.55	
	T-test	9.94 ± 0.5 s	2 min	−0.3 (−2.1 to 1.4)	0.10	−9.0 (−12.5 to −5.5)
			4 min	−1.2 (−2.6 to 0.1)	0.40	
			8 min	−5.7 (−9.4 to −1.9)	0.83	
			15 min	−8.4 (−12.3 to −4.4)	1.12	
Traditional exercise group	Vertical Jump	57.7 ± 7.4 cm	2 min	−0.5 (−5.0 to 3.9)	0.13	5.4 (0.4 to 10.4)
			4 min	0.9 (−4.3 to 6.1)	0.06	
			8 min	2.2 (−2.3 to 6.7)	0.35	
			15 min	4.7 (−0.7 to 10.1)	0.65	
	T-test	9.68 ± 0.64 s	2 min	−1.2 (−3.7 to 1.3)	0.41	−4.5 (−15.0 to −7.5)
			4 min	−1.6 (−4.0 to 0.7)	0.57	
			8 min	1.7 (−3.2 to 6.7)	0.20	
			15 min	−0.1 (−5.7 to 5.6)	0.04	

CI = confidence interval; SD = standard deviation; VJ = vertical jump

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Table 2. Percentage changes from baseline in 5-m and 20-m sprint performance following flywheel and traditional split-squat conditioning.

		Baseline (mean ± SD)	Time	%Mean change (90% CI)	Cohen's d	%Best improvement (90% CI)
Flywheel exercise group	5-m sprint	1.11 ± 0.06 s	2 min	1.5 (−1.8 to 4.8)	0.25	−2.6 (−7.5 to 2.3)
			4 min	2.6 (−2.7 to 7.8)	0.33	
			8 min	3.9 (−2.0 to 9.8)	0.46	
			15 min	3.3 (−2.4 to 9.0)	0.38	
	20-m sprint	3.23 ± 0.20 s	2 min	0.0 (−2.2 to 2.3)	0.01	−4.2 (−7.9 to −0.5)
			4 min	0.9 (−3.4 to 5.2)	0.06	
			8 min	−2.2 (−6.3 to 2.0)	0.45	
			15 min	−0.9 (−3.2 to 1.4)	0.30	
Traditional exercise group	5-m sprint	1.16 ± 0.06 s	2 min	−0.9 (−4.0 to 2.1)	0.21	−3.5 (−6.5 to −0.5)
			4 min	1.9 (−2.1 to 5.9)	0.26	
			8 min	−1.5 (−5.0 to 2.0)	0.21	
			15 min	0.4 (−3.5 to 4.2)	0.05	
	20-m sprint	3.26 ± 0.14 s	2 min	0.4 (−0.9 to 1.7)	0.18	−4.6 (−7.9 to −1.3)
			4 min	1.6 (−5.9 to 9.1)	0.13	
			8 min	0.4 (−1.3 to 2.1)	0.18	
			15 min	0.1 (−1.5 to 1.8)	0.05	

CI = confidence interval; SD = standard deviation

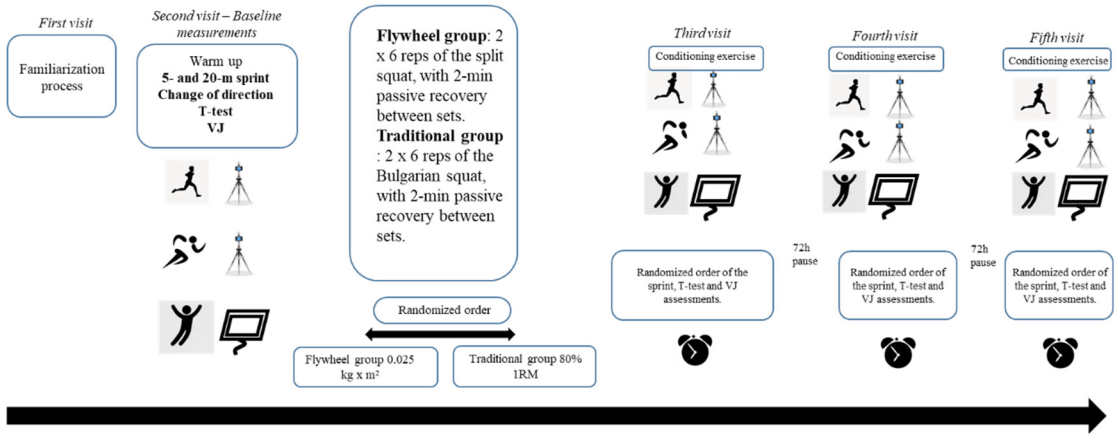


Figure 1. Overview of the study design and testing timeline. Session 1 served for familiarization; Session 2 established baseline measures (5-m and 20-m sprint, T-test, and vertical jump [VJ]) following a standardized warm-up. Sessions 3–5, separated by 72 h, comprised the assigned conditioning activity (flywheel unilateral split squat or traditional Bulgarian split squat) followed by post-conditioning assessments of sprint, T-test, and VJ performance at the 2nd, the 4th, the 8th, and the 15th min, with test order randomized/counterbalanced across sessions.

FLY: flywheel group; TRAD: traditional resistance group; VJ: vertical jump

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Discussion

This study examined the acute PAPE responses following unilateral flywheel versus unilateral traditional free-weight conditioning activities on vertical jump, COD, and sprint performance in young basketball players. The main finding was a greater effect of the unilateral flywheel protocol compared with the unilateral traditional protocol on COD performance, as evidenced by a significant group × time interaction for the T-test. Specifically, T-test performance improved at the 8th min (−5.7%) and the 15th min (−8.4%) following flywheel conditioning relative to baseline, whereas no significant time-point differences were observed in the TRAD group. In contrast, neither protocol produced significant PAPE effects for vertical jump height or sprint performance. Accordingly, in junior basketball players, unilateral flywheel conditioning may be practically useful for enhancing COD performance, with an interval of approximately 8 min appearing sufficient for potentiation to be expressed under the current protocol.

A key applied contribution of the present investigation is that it provides preliminary support for translating a brief unilateral flywheel priming bout to basketball re-warm-up contexts, to help substitutes maintain readiness to enter the match. In contemporary high-level basketball, sideline cycle ergometers are frequently used to help bench players stay warm. However, cycling is unlikely to provide a strong eccentric braking stimulus or to specifically target rapid deceleration and re-acceleration capacities. Comparable considerations have been raised in futsal, where the post warm-up strategies adopted by non-starters were shown to affect neuromuscular performance differentially before re-entry (Silva et al., 2025). Since COD actions are frequent and decisive immediately after entry (defensive slides, close-outs, cuts), a modality that can acutely enhance COD within a realistic pre-entry window could offer meaningful practical value. At the same time, this applied interpretation should be viewed cautiously, because the present protocol was tested in a laboratory setting rather than during live sideline implementation.

Previous research comparing flywheel and traditional conditioning activities has reported heterogeneous effects on jump and sprint performance. Some studies have reported superior potentiation following flywheel protocols under comparable set-rep structures and rest intervals (Timon et al., 2019; Xie et al., 2022), whereas others have reported comparable responses between modalities (Beato et al., 2019a; Galiano et al., 2025). Reviews and meta-analyses emphasize that the magnitude and timing of potentiation depend on conditioning activity characteristics, the rest interval, and the individual strength level, reflecting the balance between fatigue and potentiation (Beato et al., 2019b; Pereira et al., 2025; Seitz and Haff, 2015). The present study extends this literature by using unilateral conditioning activities and including a COD outcome. COD performance is a key determinant of team-sport success and is strongly influenced by eccentric strength, braking capacity, and rapid eccentric-concentric transitions (Chaabene et al., 2018). The observed improvements in the T-test after unilateral flywheel conditioning may relate to the eccentric overload stimulus and its acute influence on force production during braking and re-acceleration phases. Mechanistically, eccentric overloading may increase neuromuscular activation and enhance recruitment of higher-threshold motor units, which could support subsequent COD performance (Dickey et al., 2025; Douglas et al., 2016; Hodgson et al., 2005). In addition, the demands of COD involve short coupling times and rapid transitions between eccentric and concentric actions, which may align more closely with the eccentric overload characteristics of properly executed flywheel unilateral split squats than with traditional free-weight split squats (Chaabene et al., 2018; Martinez-Aranda and Fernandez-Gonzalo, 2016).

These findings highlight the potential value of unilateral flywheel conditioning as a warm-up or re-warm-up strategy in basketball. Its portability and capacity to provide an eccentric-overload-oriented stimulus make it an attractive option where space and equipment are limited. The identified 8–15-min window for performance enhancement provides a useful guideline for optimizing player preparedness for changing direction during competition. From a practitioner standpoint, the current time-course suggests an operational approach where flywheel priming is scheduled approximately 8–15 min before anticipated match entry, potentially complementing lower-intensity methods (e.g., cycling) already used near the bench.

Although neither protocol produced statistically significant effects on vertical jump performance, a consistent pattern was observed in both groups: a post-conditioning decline followed by progressive recovery and a later increase. In the flywheel group, the baseline-to-15-min comparison approached significance. This pattern is consistent with the concept that fatigue may dominate early time points, with potentiation emerging later as recovery progresses (Seitz and Haff, 2015). However, the present study did not quantify conditioning activity power/velocity or athletes' strength levels in a manner that would allow robust moderation analyses. Therefore, explanations involving insufficient strength or suboptimal inertia-velocity relationships remain speculative and should be interpreted cautiously. In addition, the bilateral countermovement jump with an arm swing may have been suboptimal for detecting unilateral PAPE transfer, as bilateral execution permits inter-limb compensation and the arm swing increases measurement noise; unilateral jump tests and/or a standardized arm position may provide greater sensitivity in future work.

Linear sprint performance (5 m and 20 m) was not affected by either unilateral conditioning protocol in this cohort. Prior evidence indicates that sprint potentiation responses are variable and influenced by the strength level, biomechanical similarity between conditioning and sprint tasks, and the timing of post-conditioning assessment (Seitz and Haff, 2015). Short sprint distances also present measurement challenges and may be influenced by technical and coordination factors, potentially limiting sensitivity to acute potentiation effects. It is also plausible that the present unilateral split-squat prescriptions did not provide a sufficiently horizontal-force-specific stimulus to transfer to sprint acceleration in this cohort.

The present study also has some strengths that help frame the contribution of these findings. To our knowledge, this is the first investigation to compare unilateral flywheel and free-weight resistance exercise as priming stimuli using a change-of-direction outcome in junior basketball players, thereby extending earlier potentiation work that focused predominantly on vertical jumping. Repeated assessment at the 2nd, the 4th, the 8th, and the 15th min characterized the time course of the response rather than capturing it at a single arbitrary time point, which is directly informative for prescribing the recovery window in applied settings. In addition, the conditioning protocol was brief, portable, and operationally realistic, increasing the likelihood that it can be applied within the constraints of a competitive basketball schedule.

Some caution is nonetheless warranted when translating the observed change-of-direction gains to match play. The T-test is a pre-planned change-of-direction task and, unlike reactive agility, does not contain a perceptual or decision-making component; it therefore reflects the physical determinants of changing direction rather than the ability to respond to an unanticipated stimulus. The present data show that these physical determinants can be acutely primed, yet a faster pre-planned change-of-direction time should not be equated with improved on-court agility or game performance, which additionally depend on perception, anticipation, and the tactical context. The T-test was selected because it is reliable, time-efficient, and widely used in basketball, which facilitates comparison with the existing literature; future studies should incorporate reactive-agility or small-sided game tasks to establish whether this priming effect transfers to game-representative actions.

This study had several limitations. First, the comparison between flywheel and free-weight modalities was performed using one inertia setting and one relative free-weight intensity. Future studies should examine a range of inertias and loading intensities and quantify mechanical output (e.g., force, peak/mean power) to better match the stimulus dose across modalities. A related limitation is that no kinetic or kinematic instrumentation (e.g., linear position transducers or force plates) was used to monitor the conditioning activity. Consequently, the eccentric-overload mechanism proposed to underlie the present effects is inferred from the broader flywheel literature rather than directly demonstrated here, and subsequent studies should incorporate such measurements to verify the mechanistic basis of the observed change-of-direction improvements. Second, a bilateral vertical jump test with the arm swing was used to assess potentiation after unilateral conditioning; inclusion of unilateral jump outcomes and a standardized arm position may improve

sensitivity and ecological validity. A further point concerns the conditioning exercises themselves: the flywheel group performed a split squat with both feet on the floor, whereas the free-weight group performed a Bulgarian split squat with the rear foot elevated, thus the two conditions differed in stance as well as in resistance modality. It should be emphasized, however, that the primary aim of the present study was practical rather than purely mechanistic, namely to identify a convenient and time-efficient means of activating players immediately before they enter the court. From this applied standpoint, the comparison was deliberately drawn between a flywheel device—which is compact, portable and considerably more practical for court-side use than alternatives such as a cycle ergometer—and a widely used, classic free-weight resistance exercise, each implemented in the form in which it is typically prescribed in practice. The present findings are therefore best read as a comparison of two readily applicable priming options rather than as an isolation of resistance modality per se; future studies that match the foot position across conditions would nonetheless help separate the specific contribution of the stance from that of the flywheel modality. Third, findings may be generalized only to similar populations and competitive levels. In addition, with nine participants per group the standardized effect sizes are susceptible to small-sample upward bias; they should therefore be regarded as approximate and interpreted in conjunction with their 90% confidence intervals rather than as precise point estimates, and the present effects warrant confirmation in adequately powered samples. Finally, although the present investigation was motivated by a practical re-warm-up scenario, the protocol was not implemented during live matches or simulated bench conditions; future work should evaluate feasibility, compliance, and safety in space-constrained settings, and determine whether COD readiness improvements translate to actual in-game actions immediately after substitution entry.

Practical Implications

The present findings suggest that a brief unilateral flywheel split-squat protocol may be used as a priming stimulus to acutely enhance change-of-direction performance in young basketball players. Performance improvements were observed approximately 8–15 min after the conditioning activity, indicating a practical timeframe for pre-performance preparation. Due to the compact and portable nature of flywheel devices, such protocols may be feasible in space-restricted environments, including courtside warm-up areas. Coaches may therefore consider incorporating short flywheel priming bouts before anticipated high-intensity movements or substitutions, particularly when rapid deceleration and re-acceleration actions are expected.

Conclusions

Under the conditions of the present study, the unilateral flywheel split-squat protocol elicited greater acute improvements in change-of-direction performance (T-test) than the traditional free-weight protocol in young basketball players. Under the present protocol, performance enhancement was evident at the 8th min post-conditioning and persisted at the 15th min. No significant effects were observed for vertical jump height or 5-m and 20-m sprint performance. These findings suggest that unilateral flywheel exercise may represent a practical option for short pre-performance priming when the goal is to improve COD readiness. However, further research is needed to determine whether such protocols are effective when implemented directly in game environments and to refine optimal loading variables for applied settings.

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