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EFFECT OF FLYWHEEL WARM-UP ON LOWER BODY MUSCLE PERFORMANCE IN YOUTH ATHLETES

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ABSTRACT

Post-activation performance enhancement (PAPE) is a phenomenon that has been used as a warm-up strategy to enhance subsequent muscular performance. The purpose of this study was to examine the efficacy of a flywheel warm-up to elicit a PAPE effect in eight male youth rugby athletes. Participants completed three warm-up interventions (flywheel, stationary cycle, and no warm-up) across three days, each separated by 24 hours. A 5-minute rest followed each warm-up before assessing posterior chain flexibility, countermovement jump (CMJ), and linear acceleration. The results showed a significant increase ($p < .05$) in posterior chain flexibility and 10 m sprint performance following the flywheel warm-up compared to stationary cycling and no warm-up. However, the interventions had no significant differences in CMJ peak power or jump height ($p > .05$). The current findings suggest that the flywheel warm-up is effective in improving posterior chain flexibility and sprint performance in youth rugby players.

Keywords: *Post-activation potentiation, sprint, countermovement jump, sit and reach*

INTRODUCTION

As youth athletes develop in their sports, the importance of effective preparation becomes increasingly important. The quality of their warm-up, whether for a training session or a competitive match, can significantly influence key performance outcomes. These outcomes may range from reaching optimal training intensity to gaining a competitive edge over opponents. In team contact sports like rugby, attributes such as power and sprint speed are essential for peak performance. Traditional training methods typically focus on enhancing power performance over time. However, using training techniques that promote acute increases in power output presents a novel approach to athlete warm-ups. Bevan et al. (2010) observed enhanced sprint performance following a preload stimulus, suggesting that rugby athletes might improve their training and match performance through an appropriate pre-loading style warm-up approach.

A concept known as post-activation potentiation suggests that when achieved, it can cause acute enhancements of power-based movements through a short-term increase in an athlete's peak force and rate of force development. One proposed mechanism to generate post-activation potentiation is the phosphorylation of myosin regulatory light chains, which increases myofibrillar sensitivity to calcium secretion from the sarcoplasmic reticulum, facilitating more forceful contractions (Hodgson et al., 2008). Additionally, post-activation potentiation is thought to enhance neuromuscular efficiency by recruiting higher-order motor units (Hamada et al., 2000), typically involved in generating explosive power during high-intensity movements. Another proposed mechanism involves an acute reduction in pennation angle, which may produce greater force production (Mahlfeld et al., 2015). In the long term, if post-activation potentiation is consistently applied, short-term improvements may accumulate, potentially leading to adaptations that enhance long-term performance outcomes. For example, repeated exposure to eccentric training, a key component of flywheel warm-up, could improve motor unit recruitment and rate of force development, which may benefit athletic performance in the long term. To align with the current research terminology, we refer to these performance gains as post-activation performance enhancement (PAPE), which considers the practical, performance-focused outcomes, compared to post-activation potentiation that denotes the mechanistic approach (Blazevich & Babault, 2019; Prieske et al., 2020).

PAPE methods commonly involve performing one or several sets of high-load resistance exercises, followed by lower-load movements of a plyometric or ballistic nature throughout a resistance training session. This concept could be modified to include heavy-load exercises in a pre-game or pre-training warm-up, with the lower loads being high-velocity and explosive movement components of rugby. However, Blazevich and Babault (2019) suggest that further research is needed to explore aspects such as movement types, load, rest intervals, individual fiber type composition, exercise duration, and the actual effect of the potentiation. While dynamic and isometric movements can enhance PAPE, warm-up exercises must be able to mimic the biomechanics of the targeted activity if they are to be effective. Flywheel ergometers achieve this by using rotational acceleration to generate inertial torque during the concentric phase before being returned during the eccentric phase. This allows for repetitive and rapid concentric-eccentric cycles, improving performance (Beato et al., 2020). Compared to traditional isotonic weightlifting exercises such as a barbell squat, which do not allow for that level of contraction cycle, the rapid and repetitive nature of the flywheel are significantly similar to the biomechanical tasks of rugby such as running at high velocities, scrummaging, and contact force at the tackle.

While flywheel training has traditionally been utilized to gain chronic adaptations, limited studies have analyzed the acute potentiation advantages to date. The rationale for using a flywheel ergometer to achieve PAPE is based on the flywheel's fundamental central and peripheral mechanisms. Eccentric contractions are more effective in recruiting higher-order motor units than concentric contractions because they increase motor unit discharge rate and synchrony (Beato et al., 2021a). This may be further enhanced during compound multi-joint movements often performed using a flywheel, such as squats. Flywheel training generates consistently greater eccentric force, power, and derivative outputs. These developed eccentric kinetic outputs may enhance the stretch-shortening cycle component, possibly improving the transfer effects on fast mixed eccentric/concentric actions in rugby, such as sprinting, scrumming, and direction changes (Beato et al., 2021a). Therefore, rugby athletes' performance may be enhanced by applying flywheel loading as a warm-up to functionally overload the musculotendinous system with specific eccentric contractions and similar muscle actions and joint kinematics.

While research on flywheels as a warm-up approach remains limited, emerging findings present promising evidence for its efficacy. Fiorilli et al. (2020) revealed notable enhancements in countermovement jump (CMJ) flight time, drop jump flight time, 40 m sprint time, and Illinois agility time following a flywheel warm-up compared to a traditional dynamic bodyweight. Additionally, performance benefits achieved from the flywheel method were presented for longer than those of the control group. Similarly, Maroto-Izquierdo et al. (2020) reported post-activation performance enhancements only after the flywheel warm-up consisting of one set of six reps. Vertical jump height, concentric peak power, and concentric peak increased after the warm-up protocol compared to baseline data. Furthermore, significant differences in performance measures were observed when comparing control and experimental protocols at each time tested (Maroto-Izquierdo et al., 2020). These results suggest that a flywheel warm-up may induce earlier adaptation in explosive and reactive strength, leading to prolonged benefits for athletes.

Current research on flywheel warm-up is scant in youth athletes, but anecdotally, it appears to be a promising warm-up approach. Therefore, further exploration is required to determine the flywheel's efficacy as a warm-up strategy. This study aimed to evaluate using a flywheel warm-up protocol for youth rugby athletes. From previous adult research findings, it was hypothesized that using a flywheel warm-up protocol will achieve post-activation potentiation enhancements to improve muscular performance measures compared to a traditional warm-up protocol.

METHODS

Participants

Eight male participants (mean age 17.4 ± 0.5 years; mean body mass 86.8 ± 5.8 kg; mean height 182 ± 4.3 cm) who played First XV rugby volunteered for the study. The athletes' playing experience ranged from 10 to 12 years. They had regularly trained for strength and conditioning for three years. All participants were informed of the potential risks and benefits associated with the procedures of this study before giving verbal and written informed consent.

Procedure

In a randomized order, participants completed three warm-up interventions of the flywheel, stationary cycle, and no warm-up on three days, separated by 24-hour rest. The study was conducted indoors on a rubber-tiled floor strength and conditioning facility. Each participant attended a familiarisation session on the correct use of the flywheel and the procedures of the warm-up interventions and testing measures. Participants completed all warm-up interventions at the same time of day. On arrival to each session, participants were seated and rested for 10 minutes before undertaking one of the three warm-up interventions. A 5-minute rest was enforced after each warm-up intervention, where participants were assessed on posterior chain flexibility, CMJ, and linear acceleration. Previous research suggests that PAPE can be induced through a recovery period of 3 to 9 minutes. Selecting a 5-minute rest interval provided a sufficient recovery time to alleviate residual fatigue and minimize potential reductions in the magnitude of PAPE (Beato et al., 2021b). Further, CMJ and 30 m sprint performance have been shown to peak at 4 mins following flywheel training; the author suggests the most effective elicitation of the PAPE was at 4–8 min after the flywheel training (Fu et al., 2023).

Warm-Up Interventions

Flywheel

A flywheel ergometer (Exerfly Advanced, New Zealand) was used to execute a flywheel squat. The protocol consisted of 3 sets of 6 repetitions, with the first two repetitions being submaximal to establish initial momentum, followed by four maximal concentric velocity repetitions and a 2-minute rest period between each set. Given that this study focused on youths rather than adult males, a load consisting of 1 large disc (diameter=40 cm, mass=5 kg, moment of inertia=$0.1 kg \cdot m^2$) was used. This selection of inertial loads was based on the findings of Beato et al. (2021a). Participants were instructed to perform the concentric phase with maximal velocity, achieving 90° of knee flexion during the eccentric phase. The lead researcher evaluated each repetition, and real-time technique feedback was given to each participant, who was encouraged to perform with maximal effort and intensity.

Stationary Cycle

The stationary cycle warm-up was performed on an assault cycle (Force USA assault bike, Torpedo 7, Draper UT, USA). Participants were instructed and monitored to cycle at a constant power output of 1 W per kg of body mass for 10 minutes.

No Warm-Up

Participants were instructed to sit and rest for 10 minutes before the physical tests.

Physical Tests

Posterior chain flexibility

This was measured using a sit-and-reach test (XLR8, SA67, New Zealand). Participants were instructed to remove their shoes, with locked knees hinge forward from the hips, breathe out, and hold the end position for 3 seconds without shunting the plate or bending the knees during the movement.

Countermovement Jump

This was performed using a linear position transducer (LPT, GymAware Kinetic Performance Technology, Canberra, Australia) tethered to a waist belt. Participants were instructed to self-select the depth of CMJ, and with hands placed on their hips, they jumped maximally. Peak power (W) and jump height (cm) were measured and used for subsequent analysis.

Linear Acceleration

A 10 m sprint test was performed using dual beam electronic timing gates (Fusion Sport, Smartspeed, Australia). Participants were instructed to self-select a stationary split stance starting position on a marked line 20 cm from the starting gate, where they initiated the sprint in their own time.

Statistical Analysis

Dependent variables were compared using a repeated measures analysis of variance (ANOVA). When a significant F-value was achieved, posthoc comparisons were performed using the Bonferroni correction, and the level of significance was set at $p \leq .05$. The normality of the data was analyzed using the Shapiro-Wilk test, which showed a normal distribution and sphericity was not breached. All data were analyzed using the Statistical Package for Social Sciences (SPSS, Statistics version 28, IBM New York, USA).

RESULTS

The mean and standard deviation (*SD*) for the sit-and-reach was 16.64 ± 4.27 cm for the flywheel warm-up, 14.00 ± 4.58 cm for the stationary cycle, and 13.07 ± 4.98 cm for the no warm-up condition. A significant increase in sit-and-reach was observed ($p = .006$), with the flywheel warm-up showing significantly greater improvements compared to both the stationary cycle ($p = .032$) and no warm-up ($p = .046$) (Table 1).

For CMJ peak power, the *mean* ± *SD* values were 7,309.6 ± 1,318.9 W for the flywheel warm-up, 7,943.1 ± 2,251.5 W for the stationary cycle, and 6,863.1 ± 1,800.6 W for the no warm-up condition. No significant differences were found in CMJ peak power (*p* = .161) or CMJ height (*p* = .905) across the three warm-up interventions (Table 1).

The *mean* ± *SD* for 10 m sprint times were 1.84 ± 0.08 sec for the flywheel warm-up, 1.96 ± 0.10 sec for the stationary cycle, and 2.01 ± 0.18 sec for the no warm-up condition. A significant difference was observed between the warm-up interventions (*p* = .001), with the flywheel warm-up leading to faster sprint performance compared to both the stationary cycle (*p* = .007) and no warm-up (*p* = .03) (Table 1).

Table 1. *Mean ± SD warm-up interventions of the flywheel, stationary cycle, and no warm-up for CMJ, 10 m sprint, and sit and reach*

	Flywheel	**Stationary Cycle**	**No Warm-up**
Sit and Reach (cm)	16.64 ± 4.27*	14.00 ± 4.58	13.07 ± 4.98
CMJ Peak Power (W)	7,309.57 ± 1,318.85	7,943.14 ± 2,251.52	6,863.14 ± 1,800.55
CMJ Height (cm)	44.43 ± 6.65	44.00 ± 4.73	43.14 ± 5.58
10 m Sprint (sec)	1.84 ± 0.08*	1.96 ± 0.10	2.01 ± 0.18

* Significantly different (*p*<.05) compared to stationary cycle and no warm-up

DISCUSSION

This study aimed to compare the effectiveness of a flywheel warm-up on post-activation potentiation in youth rugby athletes. The results showed that the flywheel warm-up significantly increased sit and reach and 10 m sprint time performance compared to the stationary cycle and no warm-up. Previous flywheel warm-up protocols have improved CMJ in adult males (Beato et al., 2021b; Fu et al., 2023; Sun et al.,2024). However, in this study, there was no evidence of improvement in CMJ power and height between the three warm-up interventions. The flywheel is characterized by an intense concentric phase, immediately followed by a more demanding eccentric phase. The eccentric contraction has the potential to stimulate PAPE and selectively recruit higher-order motor units to a greater extent than concentric and isometric contractions. This may partially explain why the flywheel improved performance more than stationary cycling, a concentric-only loading exercise. However, it does not explain why CMJ performance was not enhanced, as shown by previous research (Beato et al., 2021b), which reported significant increases in CMJ jump height and peak power following a flywheel warm-up. The dissonance in results can be explained by variations in methodology. Our study used a lighter load consisting of one large disc instead of the large and medium disc used by Beato et al. (2021b). The load of this study took into consideration the maturation and training age of youth athletes, which could have reduced the amount of eccentric load needed for significant PAPE. Maroto-Izquierdo et al. (2020) also observed PAPE effects on CMJ height and peak power following 1 set of 6 repetitions of a flywheel warm-up. This suggests that the effects of PAPE following a flywheel warm-up may be influenced by the loads used in the intervention rather than the total number of working sets and repetitions. This has been noted by Fu et al. (2023), where an increase in CMJ performance was related to the inertial load of the flywheel.

In this study, the flywheel warm-up improved 10 m sprint performance compared to a stationary cycle warm-up and no warm-up. This finding is supported by Beato et al. (2021a), who observed a similar significant improvement in a 5 m change of direction test among adult male athletes. Interestingly, they found no significant variance in PAPE effects when comparing high-load versus medium-load flywheel warm-ups. In contrast, Fu et al. (2023) showed no significant difference in 0-10 m of a 30 m sprint between three flywheel loads and a control. The use of lighter loads with youth athletes in this study may be crucial to facilitating this performance enhancement, especially considering the emerging nature of this area of research. In considering the classification of CMJ and sprint, the extended ground contact time of CMJ (>0.25 s) is regarded as a slow stretch-shortening cycle (SSC), while the 10 m sprint is a fast SSC activity. Therefore, the benefits of PAPE from eccentric loading may not have fully translated to slow SSC activities. CMJ performance relies on more controlled, deliberate muscular actions that may not leverage the rapid muscle activation improvements associated with PAPE. In other words, while PAPE enhances the ability to generate force quickly (beneficial for fast SSC), it may not significantly enhance the more sustained force production needed for CMJ in youth athletes.

Currently, there is a lack of studies explicitly analyzing the effects of flywheel warm-up and flexibility, making it challenging to draw conclusions. However, a recent review reported that longitudinal eccentric exercise over several weeks increased flexibility measures in healthy adults (Diong et al., 2022). It is reasonable, therefore, to hypothesize that engaging in acute 10-minute flywheel activity may result in enhanced muscle elongation and flexibility, which could be potentially attributed to an expanded range of motion during the eccentric phase of muscle contraction. However, this warrants further investigation to elucidate the underlying mechanisms in an acute setting.

As suggested by Kilduff et al. (2008) and McCann & Flanagan (2010), recovery intervals are essential in optimizing PAPE effects. This is particularly relevant for youth athletes, where individualized loading and recovery protocols may be essential to prevent fatigue, a factor known to diminish PAP benefits (Hodgson et al., 2005). Given the relatively lighter loads used in the present study and the short recovery times between sets, it is possible that the current recovery protocol was insufficient to fully realize PAPE effects in CMJ performance. Future research should explore the impact of more extended recovery periods in youth populations to maximize potentiation before performance testing.

The advancement in youth strength and conditioning programs has increased physical demands in youth sports. Coupled with the increased demands of the season, there is now a greater need for adequate preparation before training and matches to improve performance. However, the current findings are limited to the maturation age and the sport of rugby. It is crucial to approach research to account for the unique characteristics of youth athletes, including their physical maturation and disparity in training age compared to mature elite athletes. By tailoring warm-up strategies appropriately and considering these factors, youth athletes can benefit from the training protocols. Future research should explore various aspects of prescribing flywheel eccentric warm-ups for various youth sports. This involves evaluating different loads, intensities, rest intervals, repetitions and sets to establish a standard strategy for practitioners. It is essential to acknowledge some limitations of this study. The results cannot be generalized to other youth sports, and future studies should investigate this further. One load (moment of inertia=$0.1 \mathrm{kg \cdot m^2}$) was only assessed, and it would be appropriate in future investigations to include other loads to determine if they can elicit PAPE in youth athletes. Although our study provides preliminary insights into the effects of flywheel warm-ups on youth rugby athletes, the sample size is small compared to previous estimates for studies of similar protocols. For example, previous studies (Sun et al., 2023; Beato et al., 2021b) have reported effect sizes of 0.25 and 0.3, respectively, with an *alpha* of 0.05 and a power of 0.8 equated to a sample of 14 to 15 participants. Based on these findings, future studies aiming to achieve statistical significance should consider including at least 14 participants to reach adequate power. Expanding the sample size in future research would improve the robustness of the results in conclusively determining the efficacy of flywheel warm-ups in youth athletic populations.

CONCLUSION

To the best of the authors' knowledge, this is the only study that has examined the efficacy of a flywheel warm-up in achieving a PAPE performance increase in youth rugby athletes. The findings suggest that the flywheel warm-up can acutely enhance flexibility and 10 m sprint performance but did not significantly improve CMJ peak power or jump height. Consequently, the flywheel warm-up may offer specific benefits in certain performance areas, but its overall effectiveness for youth athletes remains inconclusive. Future research should examine the potential synergistic effects of combining flywheel warm-ups with traditional warm-up methods, such as dynamic stretching, to further elucidate its role in an optimal pre-exercise routine.

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