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No Post-Activation Performance Enhancement Following a Single Set of Plyometric or Flywheel Exercises in National Team Rugby Players

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Abstract: Post-activation performance enhancement (PAPE) is a key objective following regular warm-up routines, especially in sports that rely heavily on sprinting speed and power. Rugby is a team sport characterized by a range of repeated high-intensity efforts, irrespective of positional roles or match demands. In this study, we examined and compared the effects of two different conditioning activities (CAs) on the power- and speed-related abilities of National Team rugby players. Thirteen male rugby union players sequentially performed countermovement jump (CMJ), 30 m sprint, and change-of-direction (COD) tests (pre-testing session) 5 min before executing either one set of six repetitions of 45 cm drop jumps or one set of six repetitions of flywheel eccentric-overload squats. In addition to the sport-specific tests, the muscle mechanical properties of the athletes were also assessed through the use of tensiomyography (TMG). At post-testing sessions conducted 5 and 10 min after the PAPE protocols, no significant changes were observed in any of the assessed variables, either in positions as backs or forwards. However, some meaningful variations were detected at the individual level when using the "true-changes" analysis. Despite some positive individual changes, it can be concluded that these specific protocols did not elicit the expected responses typically observed in other team-sport athletes. Practitioners are encouraged to implement more comprehensive (but not exhaustive) and tailored PAPE interventions prior to training sessions and competitions.

Keywords: team sports; eccentric exercises; athletic performance; potentiation; sprint speed; power

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1. Introduction

Increases in strength, speed, and power are among the primary objectives in many sports disciplines [1–4]. In collision sports, such as rugby and American football, these improvements are of utmost importance, as the majority of sport-specific tasks (e.g., tackling, rucking, and scrumming) heavily rely on high levels of these physical capacities [3,5,6]. In this context, throughout the annual season, a substantial portion of the physical training routine in these sports is composed of strength, speed, and power training sessions [6–8]. However, despite this priority, variations in these independent measures of athletic performance (e.g., speed and power) tend to be minimal or even nonexistent in elite players [3,9], leading to a constant search for novel and more effective training strategies.

While the majority of these processes are focused on investigating distinct training programs and their mid- or long-term adaptations in physical and technical performance, there has recently been a growing interest in examining the potential effects of acute enhancements that can be promoted by certain types of conditioning activities (i.e., CAs). In the literature, the term commonly used to describe this phenomenon is "post-activation performance enhancement" (PAPE), which refers to improvements in performance achieved during voluntary activities (e.g., a short sprint or a jump trial) after a CA [10,11]. For this purpose, a myriad of exercises and methods (e.g., loaded and unloaded jumps, resistance exercises, and resistance sprints) are frequently used by coaches and sport scientists with athletes from various sports. Specifically for rugby—a team sport that requires exercises and techniques that can be applied quickly and simultaneously to multiple athletes [6,12,13]—only a few studies [14,15] have examined the acute effects of different CAs. In one study [14], the authors found no effect of either heavy hip thrust or back squat exercises on short sprinting capacity (i.e., 5–10 m). More recently, another study [15] identified that heavier (50% 1RM) but not lighter (30% 1RM) jump squats promoted greater muscle stiffness during drop jumps (DJs). Therefore, more studies examining the effectiveness of alternative CAs on the specific performance of rugby players are warranted.

In this regard, a series of previous studies support the use of various types of vertical jumps (e.g., sequential countermovement jumps [CMJs] or drop jumps [DJs] [16,17]) and isoinertial exercises (e.g., isoinertial squats or deadlifts [18,19]) as effective methods for improving speed- and power-related performance in athletes and individuals with diverse training backgrounds. For example, a randomized crossover study compared the effects of two different PAPE protocols (i.e., 3 sets × 6 reps of traditional half squats or isoinertial flywheel [FW] squats), conducted one week apart, on the squat jump performance of physically active students [20]. Although both protocols were executed at the load that maximized power output, only the FW squat demonstrated a PAPE effect on squat jump performance, as measured by jump height, velocity, and power [20]. Other studies (including reviews) [21–25] have already identified acute increases in subsequent physical performance tests (e.g., jump, directional changes, and sprint measurements) and in a range of kinetic and kinematic parameters, such as force, impulse, power, and acceleration rate, following the use of various types of FW eccentric-overload (EOL) exercises. However, it is worth noting that some authors have highlighted important points related to the CAs performed to induce PAPE, as well as the transient responses of these potential improvements. According to these authors, the kinetic and kinematic characteristics of the CA should be as similar as possible to evoke an enhanced effect on the succeeding motor task (e.g., FW squat and CMJ) [21,24,26,27]. Another issue to consider is the temporary and transitory nature of PAPE [10,25,28], which, regardless of the method or exercise used as the CA, could be ineffective during matches or even shorter competitions (e.g., certain track and field disciplines). In this respect, current evidence [10,21,28] may suggest that plyometric exercises, such as DJs, could exhibit a PAPE effect closer to the CA (e.g., <5 min) compared to other resistance exercises (e.g., flywheel EOL exercises, back squats, etc.) whose effects are more pronounced after 5 min of recovery.

Another common type of CA utilized by athletes, especially in team sports, is jumping under loaded or unloaded conditions [29–32]. Among these drills, the DJ unquestionably emerges as one of the most frequently used and studied exercises [16,33]. In a study comparing different volumes and intra-repetition rest periods of DJs in 29 male hurling players competing at college and club levels, the authors reported that one set of three DJs, with individualized drop heights based on the reactive strength index (RSI, i.e., the ratio between jump height and ground contact time), and 15 s intervals between repetitions followed by a 15 s recovery after the last DJ, was effective in enhancing subsequent 20 m sprint speed [16]. Dello Iacono et al. [33] also found positive results after examining the acute effects of vertical and horizontal DJs (VDJs and HDJs, respectively) on the physical performance of under-20 National Team handball players. Nevertheless, in that study, the acute effects on athletic abilities were retested 8 min after completing CAs composed of either three sets of five vertical-alternate single-leg DJs or three sets of five horizontal-alternate single-leg DJs, and the responses observed were very specific. While the VDJ condition induced greater changes in variables related to vertical jump performance, such as peak ground reaction forces (+ 9.6% vs. +1.3%) and RSI (+7.3% vs. +2.4%), the HDJ condition significantly improved the change-of-direction (COD) performance by reducing contact time (CT) during directional changes more than the VDJ condition (−13.3 vs. −22.4%, respectively) [33]. These results suggest that the HDJ condition is more effective at significantly reducing the CT of the "plant" step, thereby reinforcing the correlation between shorter contact times during deceleration maneuvers and superior COD techniques [33–35]. Other speed-related metrics, such as 25 m sprint speed, also exhibited a more substantial increase after executing the HDJ protocol compared to the VDJ protocol [33]. Together, these diverse effects may suggest that the nature and orientation of the CAs could be highly specific and should be prescribed according to the sport-specific tasks and their respective demands. However, this concept has not been consistently confirmed and requires further investigation [10,33].

The primary aim of the current study was to examine the effects of two different CAs (i.e., FW EOL squats vs. 45 cm DJs) on the power- and speed-related performance of elite rugby players. Furthermore, as a secondary objective, to better understand and explain the potential changes in certain physical capabilities, we also analyzed the variations in muscle mechanical properties through the use of tensiomyography (TMG) after the execution of both PAPE protocols. We hypothesized that both protocols would be effective, but that the DJ protocol would enhance players' performance earlier than the FW protocol.

2. Materials and Methods

2.1. Subjects

Thirteen male rugby union players (24.5 ± 4.7 years; 185.3 ± 5.9 cm; 98.1 ± 12.0 kg) from the Brazilian National Team participated in this study. The athletes were tested during the competitive period of the season. Prior to participating in the study, they signed an informed consent form. The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of the Federal University of São Paulo (protocol code 4.355.629, 22 October 2020).

2.2. Study Design

Over two consecutive weeks, athletes were tested on two separate occasions using a crossover design, with the study methodology and PAPE protocols illustrated in Figure 1. In each testing session, which was conducted at the same time of day (from 9:00 to 11:00 a.m.), athletes were randomly assigned to the experimental protocols. The athletes performed all testing sessions and CAs during their regular training periods, following their professional and daily training routines. Additionally, the experimental procedures were selected and defined in collaboration with the coaching staff to align with the current literature [21,30] and to reflect the actual warm-up and training practices adopted by the players over the respective study period. During the week between experimental sessions, players engaged in low-intensity training sessions, including technical training (i.e., passing drills, ball reception, and shooting accuracy), physical therapy, recovery procedures, nutritional assessments, and personal meetings with the psychology team. All participants were familiarized with the testing procedures and both CAs (i.e., FW squat and DJ) and were required to avoid caffeine and alcohol consumption for 24 h before the procedures. After the baseline TMG and prior to the first jump and speed-related tests, players performed a standardized warm-up, which was replicated in both experimental conditions. The warm-up consisted of 10 min of moderate-speed running, followed by 5 min of dynamic stretching exercises, 3 submaximal vertical jumps, and 2 submaximal sprints (≈70% of maximal sprint speed) with 2 min of passive recovery between sprints.

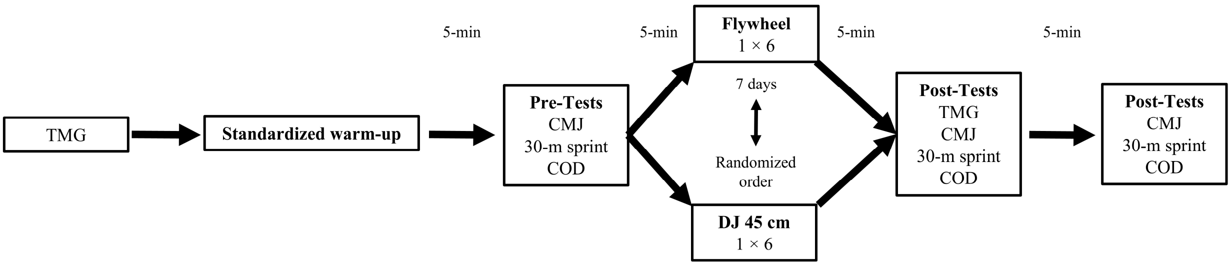

Figure 1. A schematic presentation of the study design. CMJ: countermovement jump; DJ: drop jump; TMG: tensiomyography; COD: change of direction.

The rugby players performed the concentric phase of the FW squat using the same load (due to time constraints) and were instructed to execute each repetition with maximal velocity while maintaining control of the eccentric phase until reaching approximately 90° of knee flexion [36]. The athletes used an absolute load that represented, on average, 5% of the team's mean body mass (≈100 kg). Specifically, we used 2 large disks weighing 1.9 kg each (totaling 3.8 kg) and 1 small disk weighing 1.3 kg, for a total load of ≈5 kg. Each large disk generates an inertia equal to 0.02 kg·m^2, and the small disk generates an inertia of 0.008 kg·m^2. For the 45 cm DJs, the players were instructed to jump as high and as quickly as possible. Two experienced researchers were responsible for ensuring the technique and quality of each movement (Figure 2).

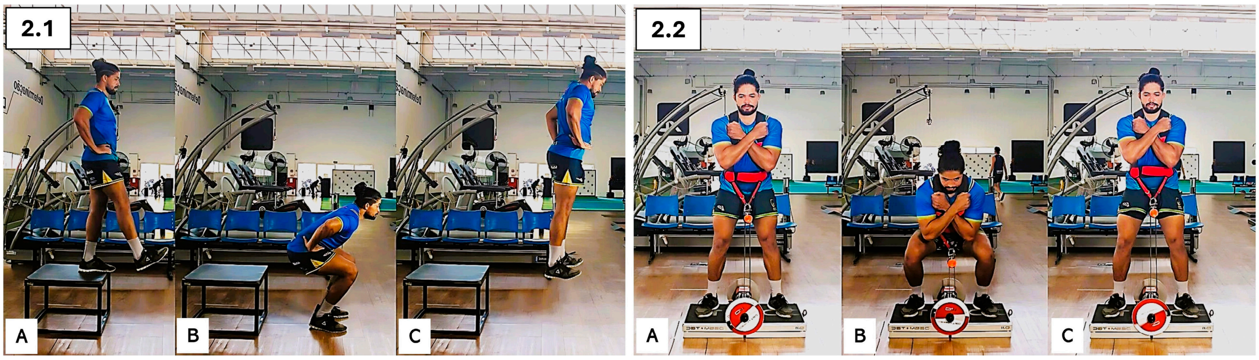

Figure 2. A National Team rugby player performing two conditioning activities: (**2.1**) the 45-cm drop jump–dropping (**A**), landing (**B**), and jumping (**C**); (**2.2**) the flywheel squat–starting the eccentric phase (**A**), at the end of the eccentric phase (**B**), and at the end of the concentric phase (**C**), respectively.

2.3. Procedures

2.3.1. Tensiomyography Assessment

The radial displacement (Dm), contraction time (Tc), and delay time (Td) were measured and recorded in both the biceps femoris (BF) and rectus femoris (RF) muscles of the dominant leg, using a TMG device (TMG Measurement System, TMG-BMC Ltd., Ljubljana, Slovenia) as described elsewhere [37,38]. An accurate pressure transducer (Trans-TekwGK40, Ljubljana, Slovenia) was positioned perpendicular to the muscle axis. The radial displacement was assessed in the muscle belly after an external electrical stimulus. To induce twitch responses, adhesive electrodes (5 × 5 cm; Compex Medical AS, Ecublens, Switzerland) were connected to an electric stimulator and positioned on the muscle surface, following the alignment of muscle fibers [38,39]. The electric pulse was set to 1 ms, and the signal amplitude started at 20 mA. For each pulse, the current amplitude was increased by 10 mA, until maximal displacement of the muscle belly was reached. To avoid fatigue or potentiation effects, a 15 s rest period was allowed between the successive electrical stimuli. All TMG measurements were conducted by the same experienced researcher. The TMG-derived velocity of contraction (Vc) was calculated by dividing Dm by the sum of Tc and Td.

2.3.2. Vertical Jump

Vertical jumping height was assessed using the countermovement jump (CMJ). The athletes started from a standing position and were required to perform a downward movement followed by a complete extension of the lower limbs, with the amplitude of the countermovement freely determined to avoid changing the jumping coordination pattern. All jumps were executed with the hands on the hips. A total of three trials were allowed, interspersed by 15 s intervals between trials. The jump test was performed on a contact mat (Elite Jump®, S2 Sports, São Paulo, Brazil), which automatically calculated the vertical jump height (h) from the flight time (t) using the formula $h = gt^2/8$. The best attempt was considered for analysis.

2.3.3. Thirty-Meter Sprint Performance

Three pairs of photocells (Elite Speed®, S2 Sports, São Paulo, Brazil) were positioned at the starting line and at distances of 10 and 30 m along the sprint course. The athletes sprinted twice, starting from a standing position 0.5 m behind the starting line. To avoid weather influences, the sprint speed measurements were performed on an indoor running track. A 5 min rest interval was allowed between the two attempts, and the fastest time was considered for analysis.

2.3.4. Zigzag Change-of-Direction Test

The Zigzag COD test consisted of four 5 m sections (a total of 20 m of linear distance) marked with cones set at 100° angles, requiring the athletes to decelerate and accelerate as fast as possible around each cone. Two maximal attempts were performed with a 5 min rest interval between them. Starting from a standing position with the front foot placed 0.5 m behind the first pair of timing gates (Elite Speed®, S2 Sports, São Paulo, Brazil) (i.e., starting line), the athletes were instructed to complete the test as quickly as possible, continuing until they crossed the second pair of timing gates, placed 20 m from the starting line. The fastest time was considered for the analysis.

2.4. Statistical Analyses

After checking the normality of data, differences between time periods, positional roles (i.e., backs vs. forwards), and conditions (i.e., DJs vs. FW squats) were assessed using a repeated measures analysis of variance (ANOVA). The level of significance was set at $p < 0.05$. Effect sizes (ESs) [40] with 95% confidence intervals (CIs) were also calculated to determine the magnitude of the differences between variables. The ESs were interpreted using the thresholds proposed by Rhea [41] for highly trained subjects, as follows: <0.25, 0.25–0.50, 0.50–1.00, and >1.00 for trivial, small, moderate, and large, respectively. The statistical power was calculated using G*Power software (v. 3.1.9.7), based on the number of subjects, ESs, and α values for the various comparisons performed across all tested variables. Absolute and relative reliability were assessed using the coefficient of variation (CV) and the two-way random intraclass correlation coefficient (ICC), respectively. Percentage changes were computed for all variables and compared with the individual CV values at baseline to determine whether changes in sprint and jump performance exceeded the test variance, thereby indicating whether true changes occurred on an individual basis [3,42].

3. Results

The statistical power values achieved for the various comparisons performed were all >80%. All measurements used in the current study demonstrated high levels of absolute and relative reliability (i.e., ICC > 0.90 and CV < 10%). No significant differences were observed between backs and forwards in any of the variables tested ($p > 0.05$). Therefore, to maximize the statistical power, the data were not stratified by playing position and were analyzed and presented without considering the “group” factor.

Table 1 shows the comparisons of CMJ performance between both CAs at different time periods. No significant differences were observed in any PAPE condition for CMJ performance (ESs [95% CI] ranging from 0.07 [−0.70; 0.84] to 0.37 [−0.42; 1.13]; $p > 0.05$). Table 2 presents the comparisons of 10 m sprint times between both CAs at different time periods. No significant changes were detected for 10 m sprint performance after both DJ and FW conditions (ESs [95% CI] ranging from 0.04 [−0.73; 0.81] to 0.16 [−0.62; 0.92]; $p > 0.05$). Table 3 displays the comparisons of 30 m sprint times between both CAs at different time periods. No significant differences were observed in any PAPE condition for 30 m sprint performance (ESs [95% CI] ranging from 0.08 [−0.69; 0.85] to 0.27 [−0.51; 1.03]; $p > 0.05$). Table 4 shows the comparisons of the Zigzag COD test between both CAs at different time periods. No significant changes were detected for COD performance after both DJ and FW conditions (ESs [95% CI] ranging from 0.05 [−0.72; 0.82] to 0.23 [−0.55; 0.99]; $p > 0.05$). Tables 1–4 also present the individual analyses rated as true changes, with their respective percentage differences, highlighted in *italics*.

Table 1. Comparisons of vertical jump performance between both conditioning activities at different time periods.

	DJ 45 cm							**Flywheel**						
	CMJ (cm)				**% Difference**			**CMJ (cm)**				**% Difference**		
Athletes	**Pre**	**Post 5 min**	**Post 10 min**	**CV %**	**Pre vs. Post 5**	**Pre vs. Post 10**	**Post 5 vs. Post 10**	**Pre**	**Post 5 min**	**Post 10 min**	**CV %**	**Pre vs. Post 5**	**Pre vs. Post 10**	**Post 5 vs. Post 10**
1	41.4	38.5	41.3	4.1	*−7.1*	−0.3	*7.3*	45.6	39.3	40.8	7.9	*−13.9*	*−10.5*	3.9
2	32.3	31.3	30.2	3.4	−3.1	*−6.5*	*−3.5*	34.2	30.4	32.4	5.8	*−11.0*	−5.2	6.5
3	36.8	35.5	35.0	2.7	*−3.6*	*−5.0*	−1.5	39.4	34.8	36.4	6.3	*−11.6*	*−7.6*	4.6
4	47.0	42.4	44.9	5.1	*−9.8*	−4.5	*5.9*	45.6	43.4	47.1	4.1	*−4.9*	3.3	*8.6*
5	57.2	56.7	58.4	1.5	−0.9	*2.1*	*3.0*	58.6	58.4	58.9	0.4	−0.3	0.6	*0.9*
6	47.0	42.1	49.6	8.2	*−10.4*	5.6	*17.8*	43.9	43.6	44.6	1.2	−0.7	*1.7*	*2.4*
7	45.0	42.7	41.4	4.3	*−5.2*	*−8.1*	−3.0	48.5	40.7	45.0	8.8	*−16.1*	−7.2	*10.7*
8	41.0	37.2	38.6	4.9	*−9.1*	*−5.8*	3.7	41.1	38.0	39.6	3.9	*−7.5*	−3.8	*4.0*
9	39.4	38.0	40.5	3.2	*−3.5*	2.8	*6.6*	39.6	37.2	38.6	3.0	*−5.9*	−2.4	*3.7*
10	45.8	43.3	42.7	3.7	*−5.5*	*−6.8*	−1.3	45.5	42.5	45.6	3.9	*−6.5*	0.3	*7.3*
11	38.6	35.6	39.0	4.9	*−7.7*	1.1	*9.5*	42.0	39.3	41.0	3.3	*−6.4*	−2.4	*4.3*
12	40.7	37.5	41.8	5.6	*−7.8*	2.8	*11.5*	41.3	39.0	39.7	2.9	*−5.4*	*−3.8*	1.8
13	45.8	45.2	46.4	1.3	*−1.3*	1.3	*2.7*	47.7	49.9	52.9	5.2	4.5	*10.9*	*6.0*
Mean	**42.9**	**40.5**	**42.3**	**4.1**	**−5.8**	**−1.6**	**4.5**	**44.1**	**41.3**	**43.3**	**4.4**	**−6.6**	**−2.0**	**5.0**
SD	**6.1**	**6.2**	**6.9**	**1.8**	**3.2**	**4.6**	**6.2**	**5.8**	**6.9**	**7.0**	**2.4**	**5.7**	**5.5**	**2.8**
p-values					*0.339*	*0.806*	*0.476*					*0.278*	*0.759*	*0.435*
Effect size					*0.38*	*0.10*	*0.28*					*0.43*	*0.12*	*0.31*

CMJ: countermovement jump; CV: coefficient of variation; DJ: drop jump. % differences highlighted in *italics* represent changes greater than the CV and, thus, were rated as *true changes*.

Table 2. Comparisons of 10 m sprint times between both conditioning activities at different time periods.

	DJ 45 cm							**Flywheel**						
	10 m (s)				**% Difference**			**10 m (s)**				**% Difference**		
Athletes	**Pre**	**Post 5 min**	**Post 10 min**	**CV %**	**Pre vs. Post 5**	**Pre vs. Post 10**	**Post 5 vs. Post 10**	**Pre**	**Post 5 min**	**Post 10 min**	**CV %**	**Pre vs. Post 5**	**Pre vs. Post 10**	**Post 5 vs. Post 10**
1	2.09	2.05	2.06	1.2	*−2.2*	*−1.7*	0.5	1.96	1.96	2.00	1.2	0.1	*2.2*	*2.1*
2	1.85	1.89	1.90	1.5	*2.3*	*3.0*	0.7	1.93	1.93	1.93	0.1	−0.1	0.1	0.1
3	2.04	2.20	2.02	4.9	*8.1*	−1.0	*−8.5*	2.01	2.03	2.08	1.8	1.0	*3.5*	*2.5*
4	1.93	1.98	1.86	3.1	2.6	*−3.6*	*−6.1*	1.94	1.94	1.88	1.6	−0.2	*−2.9*	*−2.7*
5	1.91	1.85	1.83	2.1	*−2.9*	*−3.9*	−1.0	1.88	1.81	1.81	2.2	*−3.8*	*−3.6*	0.3
6	1.86	1.74	1.79	3.4	*−6.6*	*−3.8*	3.0	1.80	1.78	1.79	0.4	−0.8	*−0.5*	0.3
7	1.95	1.95	1.89	1.8	−0.2	*−3.2*	*−3.0*	1.80	1.74	1.75	1.7	*−3.3*	*−2.5*	0.8
8	1.93	1.96	1.91	1.2	1.2	−1.1	*−2.4*	1.87	1.93	1.95	2.1	*3.2*	*4.2*	1.0
9	1.89	1.86	1.86	0.8	*−1.4*	*−1.2*	0.2	1.99	1.80	1.90	4.9	*−9.4*	−4.7	*5.2*
10	1.78	1.85	1.82	1.8	*3.7*	*2.2*	−1.4	1.84	1.85	1.81	1.1	0.9	*−1.3*	*−2.2*
11	1.90	1.91	1.96	1.6	0.6	*3.1*	*2.5*	1.98	2.00	1.94	1.7	1.0	*−2.4*	*−3.3*
12	1.89	1.90	1.91	0.6	0.8	*1.2*	0.4	1.90	1.91	1.88	0.8	0.5	*−1.1*	*−1.6*
13	1.80	1.84	1.83	1.3	*2.4*	*1.8*	−0.6	1.80	1.80	1.91	3.5	0.3	*6.3*	*5.9*
Mean	**1.91**	**1.92**	**1.90**	**1.9**	**0.6**	**−0.6**	**−1.2**	**1.90**	**1.88**	**1.89**	**1.8**	**−0.8**	**−0.2**	**0.6**
SD	**0.09**	**0.11**	**0.08**	**1.2**	**3.6**	**2.6**	**3.2**	**0.08**	**0.09**	**0.09**	**1.3**	**3.1**	**3.3**	**2.8**
p-values					*0.729*	*0.696*	*0.462*					*0.634*	*0.879*	*0.745*
Effect size					*0.14*	*0.15*	*0.29*					*0.19*	*0.06*	*0.13*

CV: coefficient of variation; DJ: drop jump. % differences highlighted in *italics* represent changes greater than the CV and, thus, were rated as *true changes*.

Table 3. Comparisons of 30 m sprint times between both conditioning activities at different time periods.

	DJ 45 cm							**Flywheel**						
Athletes	**30 m (s)**			**CV %**	**% Difference**			**30 m (s)**			**CV %**	**% Difference**		
	Pre	**Post 5 min**	**Post 10 min**		**Pre vs. Post 5**	**Pre vs. Post 10**	**Post 5 vs. Post 10**	**Pre**	**Post 5 min**	**Post 10 min**		**Pre vs. Post 5**	**Pre vs. Post 10**	**Post 5 vs. Post 10**
1	4.75	4.78	4.76	0.4	*0.7*	0.4	−0.3	4.75	4.78	4.76	1.0	*1.2*	*2.1*	0.8
2	4.39	4.50	4.38	1.5	*2.5*	−0.2	*−2.7*	4.39	4.50	4.38	1.3	*2.5*	1.2	−1.3
3	4.67	4.68	4.67	0.2	0.4	0.0	−0.3	4.67	4.68	4.67	0.9	*1.3*	*1.9*	0.6
4	4.34	4.48	4.36	1.8	*3.3*	0.5	*−2.8*	4.34	4.48	4.36	1.1	*1.2*	−1.0	−2.2
5	4.48	4.37	4.29	2.1	*−2.5*	*−4.2*	−1.7	4.48	4.37	4.29	1.5	*−2.0*	*−2.8*	−0.8
6	4.31	4.18	4.23	1.5	*−2.9*	*−1.8*	1.2	4.31	4.18	4.23	2.8	0.2	*5.0*	*4.8*
7	4.36	4.51	4.33	2.1	*3.3*	−0.7	*−3.9*	4.36	4.51	4.33	0.4	0.1	0.7	*0.7*
8	4.45	4.50	4.46	0.6	*1.1*	0.3	*−0.8*	4.45	4.50	4.46	2.1	*4.0*	*3.6*	−0.4
9	4.36	4.42	4.35	0.9	*1.5*	−0.1	*−1.6*	4.36	4.42	4.35	2.1	*−3.9*	−1.0	*3.0*
10	4.21	4.26	4.33	1.4	1.2	*2.9*	*1.7*	4.21	4.26	4.33	0.3	−0.4	*−0.6*	−0.1
11	4.45	4.52	4.64	2.1	1.7	*4.2*	*2.5*	4.45	4.52	4.64	1.2	*1.5*	−0.7	−2.2
12	4.38	4.54	4.51	1.9	*3.7*	*2.9*	−0.7	4.38	4.54	4.51	1.4	*−2.0*	*−2.6*	−0.6
13	4.23	4.27	4.26	0.6	*1.2*	*0.7*	−0.4	4.23	4.27	4.26	1.2	0.7	*2.3*	*1.6*
Mean	**4.41**	**4.46**	**4.43**	**1.3**	**1.2**	**0.4**	**−0.8**	**4.41**	**4.42**	**4.44**	**1.3**	**0.3**	**0.6**	**0.3**
SD	**0.15**	**0.17**	**0.17**	**0.7**	**2.0**	**2.1**	**1.8**	**0.15**	**0.17**	**0.16**	**0.7**	**2.1**	**2.3**	**2.0**
p-values				*0.442*	*0.816*	*0.591*						*0.798*	*0.660*	*0.855*
Effect size				*0.30*	*0.09*	*0.21*						*0.10*	*0.17*	*0.07*

CV: coefficient of variation; DJ: drop jump. % differences highlighted in *italics* represent changes greater than the CV and, thus, were rated as *true changes*.

Table 4. Comparisons of the Zigzag change-of-direction testing times between both conditioning activities at different time periods.

	DJ 45 cm							**Flywheel**						
Athletes	**Zigzag (s)**			**CV %**	**% Difference**			**Zigzag (s)**			**CV %**	**% Difference**		
	Pre	**Post 5 min**	**Post 10 min**		**Pre vs. Post 5**	**Pre vs. Post 10**	**Post 5 vs. Post 10**	**Pre**	**Post 5 min**	**Post 10 min**		**Pre vs. Post 5**	**Pre vs. Post 10**	**Post 5 vs. Post 10**
1	6.42	6.64	6.27	2.9	*3.5*	−2.2	*−5.5*	6.42	6.64	6.27	1.1	*1.9*	−0.1	*−2.0*
2	6.23	6.35	5.99	3.0	1.8	*−3.9*	*−5.7*	6.23	6.35	5.99	1.5	*3.0*	1.2	*−1.7*
3	6.00	6.06	6.02	0.5	0.9	0.3	−0.7	6.00	6.06	6.02	0.7	*0.9*	1.4	0.4
4	5.99	6.08	5.99	0.8	*1.4*	−0.1	*−1.5*	5.99	6.08	5.99	0.6	0.6	1.1	0.5
5	6.04	6.01	5.83	1.9	−0.4	*−3.5*	*−3.1*	6.04	6.01	5.83	1.6	*−2.6*	*−2.7*	−0.1
6	5.79	5.68	5.69	1.1	*−2.0*	*−1.7*	0.3	5.79	5.68	5.69	0.5	*1.0*	*0.8*	−0.2
7	5.80	5.79	5.71	0.8	−0.1	*−1.4*	*−1.4*	5.80	5.79	5.71	2.2	*3.9*	0.0	*−3.7*
8	5.93	6.06	5.90	1.5	*2.3*	−0.4	*−2.7*	5.93	6.06	5.90	2.0	*2.8*	−1.1	*−3.8*
9	6.04	6.21	6.10	1.5	*2.9*	1.1	*−1.8*	6.04	6.21	6.10	0.6	*−1.0*	0.1	*1.1*
10	5.82	5.89	5.80	0.8	*1.2*	−0.4	*−1.5*	5.82	5.89	5.80	0.8	0.7	*−0.9*	*−1.5*
11	5.80	5.86	5.78	0.7	*1.0*	−0.3	*−1.3*	5.80	5.86	5.78	1.4	1.1	*2.9*	*1.7*
12	6.08	6.05	6.23	1.6	−0.5	*2.5*	*3.1*	6.08	6.05	6.23	1.5	0.7	*2.9*	*2.3*
13	6.47	6.17	6.28	2.4	*−4.6*	*−2.8*	1.9	6.47	6.17	6.28	1.8	0.4	*−2.9*	*−3.2*
Mean	**6.03**	**6.06**	**5.97**	**1.5**	**0.6**	**−1.0**	**−1.5**	**5.94**	**6.00**	**5.95**	**1.3**	**1.0**	**0.2**	**−0.8**
SD	**0.22**	**0.25**	**0.21**	**0.8**	**2.2**	**1.8**	**2.5**	**0.19**	**0.21**	**0.20**	**0.6**	**1.7**	**1.8**	**2.0**
p-values				*0.687*	*0.454*	*0.251*						*0.459*	*0.891*	*0.546*
Effect size				*0.16*	*0.30*	*0.45*						*0.29*	*0.05*	*0.24*

CV: coefficient of variation; DJ: drop jump. % differences highlighted in *italics* represent changes greater than the CV and, thus, were rated as *true changes*.

Table 5 presents the comparisons of the TMG-derived measures between the two CAs at the two assessment periods. No significant changes were observed in any TMG variable across the different time periods for any PAPE condition (ESs [95% CI] ranging from 0.02 [−0.75; 0.79] to 0.23 [−0.55; 0.99]; $p > 0.05$).

Table 5. Comparisons of the tensiomyography-derived variables between the two conditioning activities across different time periods.

		DJ 45 cm		***p*-Values (ES)**	**Flywheel**		***p*-Values (ES)**
		Pre	**Post**		**Pre**	**Post**	
BF	**Tc (ms)**	17.3 ± 2.2	17.5 ± 2.4	*0.797 (0.10)*	16.0 ± 1.7	16.5 ± 2.2	*0.537 (0.24)*
	Td (ms)	20.9 ± 2.6	20.8 ± 3.4	*0.951 (0.02)*	19.3 ± 2.5	19.4 ± 2.7	*0.947 (0.03)*
	Dm (mm)	2.34 ± 1.33	2.19 ± 1.09	*0.731 (0.14)*	1.57 ± 0.92	1.72 ± 1.06	*0.737 (0.13)*
	Vc (mm·ms^{-1})	0.06 ± 0.03	0.06 ± 0.02	*0.642 (0.18)*	0.04 ± 0.02	0.05 ± 0.03	*0.756 (0.12)*

Table 5. *Cont.*

		DJ 45 cm		*p-Values (ES)*	Flywheel		*p-Values (ES)*
		Pre	**Post**		**Pre**	**Post**	
RF	**Tc (ms)**	22.8 ± 5.9	22.3 ± 4.6	*0.827 (0.09)*	21.3 ± 6.0	21.6 ± 6.7	*0.923 (0.04)*
	Td (ms)	22.5 ± 2.2	22.3 ± 2.5	*0.839 (0.08)*	22.4 ± 3.2	21.7 ± 2.2	*0.493 (0.28)*
	Dm (mm)	4.87 ± 2.17	4.63 ± 2.15	*0.771 (0.11)*	4.39 ± 1.97	4.57 ± 2.18	*0.835 (0.09)*
	Vc (mm·ms^{-1})	0.10 ± 0.04	0.10 ± 0.04	*0.759 (0.12)*	0.10 ± 0.04	0.10 ± 0.04	*0.790 (0.11)*

BF: biceps femoris; RF: rectus femoris; DJ: drop jump; ES: effect size; Tc: contraction time; Td: delay time; Dm: radial displacement; Vc: velocity of contraction.

4. Discussion

For the first time, we examined the effects of two novel PAPE protocols, comprising FW squats vs. DJs, on the power- and speed-related performance of elite rugby players. Additionally, we compared the variations in muscle mechanical properties, as assessed by TMG, induced by both protocols. Despite using two CAs that have already demonstrated their effectiveness in previous research [10,16,18,21,30], we did not observe any significant changes in the range of variables considered in this study. Therefore, our initial hypothesis, suggesting that DJ exercises could be more effective and faster in producing acute improvements in speed- and power-related capacities, was not confirmed. This is likely because, for these highly trained athletes, the volume of exercises provided as CAs was insufficient to elicit positive changes in their physical performance [21,43].

Overall, various types of jump exercises (e.g., vertical and horizontal DJs, CMJs, squat jumps, standing long jumps, etc.) are regularly used by coaches and practitioners to induce positive PAPE responses in athletes across various sport disciplines (e.g., track and field, handball, rugby union, hurling, etc.). For example, Zimmermann et al. [17] verified that the simple inclusion of continuous CMJs as CAs (three sets of five CMJs with a 1 min rest interval between sets) in the regular warm-up routine of national-level sprinters increased their 30 m sprint speed 2 and 4 min after the execution of the jumps. In the same vein, Tobin et al. [43] applied an extensive and varied plyometric PAPE protocol that included 2 sets of 10 ankle hops, 3 sets of 5 hurdle hops, and 5 depth jumps from a height of 50 cm (totaling 40 jumps) to a sample of professional rugby union players and observed significant improvements in CMJ height at 1, 3, and 5 min after completing the CAs.

Two studies using only DJs, with or without additional loads, were also able to promote significant increases in CMJ height or sprinting speed [44,45]. In the first study, strength-trained athletes performed one set of five DJs from their optimal drop heights with no additional load and with extra loads (i.e., dumbbells) equal to 10%, 20%, and 30% of their body mass before completing three CMJs following recovery periods of 2, 6, and 12 min. After analyzing and comparing all CAs, the authors concluded that the greatest subsequent CMJ performance was achieved utilizing an extra load of 20% of body mass at the 2 min interval. Similarly, in an investigation involving high-level sprinters, Bonfim Lima et al. [44] found significant improvements in the CMJ and 50 m sprint performances after completing a CA consisting of two sets of five DJs from a 75 cm box, with a 3 min rest after each set. Therefore, it is difficult to explain why our players, regardless of their playing positions, did not show significant improvements in any of the speed-related variables (i.e., 10 m sprint, 30 m sprint, and COD speed). Compared with the aforementioned studies, perhaps the use of a fixed drop height (45 cm) instead of an "optimal drop height" (determined by the reactive strength index [RSI], for example) [10,46] or the execution of only a single (rather than multiple) set(s) of DJs, may have negatively influenced the results, making this stimulus ineffective for the vast majority of the group. These hypotheses should be tested in future studies examining PAPE responses not only in rugby players but also in athletes from other team sports.

Flywheel exercises have been extensively investigated in recent years, showing promising results in terms of PAPE responses [18,20,21,26]. An interesting study compared the effects of two different FW EOL exercises used as CAs (i.e., FW squat vs. FW deadlift) on isokinetic quadriceps and hamstring eccentric and concentric torques in male amateur university athletes [18]. For both exercises, the intervention comprised three sets of six repetitions with a 2 min interval between sets and an inertial load of 0.029 kg·m^2. Isokinetic testing was performed 5 min after the completion of the PAPE protocol, which induced significant and similar improvements in the eccentric torque of both muscles; however, no significant effects were observed for the concentric torque, in either muscle group. Beato et al. [19] evaluated the impact of medium- vs. high-inertia FW squats used as CAs for the enhancement of horizontal jump, CMJ, and COD performance in physically active male subjects. For the medium-EOL squat, subjects used a combined load of one large disk (diameter = 0.285 m; mass = 1.9 kg; inertia = 0.02 kg·m^2) and one medium disk (diameter = 0.240 m; mass = 1.1 kg; inertia = 0.008 kg·m^2); for the high-EOL squat, subjects used one pro disk (diameter = 0.285 m; mass = 6.0 kg; inertia = 0.06 kg·m^2). The PAPE protocol consisted of three sets of six repetitions performed at maximal velocity, with 2 min of passive recovery between consecutive sets. All measured metrics (i.e., horizontal jump distance, CMJ height, and COD speed) showed similar improvements after both interventions, irrespective of the loading condition (i.e., medium- or high-EOL squat). According to the authors [19], the "optimal time window" for the PAPE responses from either medium- or high-EOL occurs between 3 and 6 min.

The evidence for positive PAPE responses following the use of FW exercises as CAs in individuals with varied training backgrounds appears to be highly consistent, even when using different exercises or different inertia profiles [18,19]. In their brief review of PAPE and FW EOL exercises, Beato et al. [21] emphasize the crucial role played by the time interval between CAs and the expected performance responses. These authors [21] highlight that acute fatigue predominates in the initial phase of the recovery period (e.g., 30 s), while PAPE becomes more prominent in the latter (or second) phase (e.g., 3–6 min). As a third aspect, they also recommend that athletes complete multiple sets (e.g., ≈3 sets) of EOL exercises to allow for a stronger PAPE effect. Unfortunately, due to the highly congested training schedule and the regular warm-up procedures of the players, we had to opt for using only one set of FW squats (as well as for DJs). This constraint, as mentioned earlier, may have reduced the positive responses observed in previous research on this topic.

It is worth noting that the lack of changes in muscle mechanical properties, as assessed by TMG, also aligns with our findings. TMG outputs (e.g., Tc, Td, Vc, and Dm) have been widely used to detect muscle fatigue or PAPE effects in athletes from various sports and training backgrounds (e.g., power athletes, endurance athletes, soccer players, resistance-trained individuals, etc.) [36,47,48]. Thus, for example, the absence of significant changes in Dm (e.g., a decrease in Dm can represent an increase in muscle stiffness) associated with no variations in Tc, Td, and Vc (i.e., temporal and spatiotemporal measures) may partially explain our results, as higher muscle stiffness and Vc and lower Td and Tc have also been associated with superior speed–power performance [36,37,49]. In this context, it is plausible to infer that when mechanical parameters related to muscle function present similar pre- and post-PAPE behaviors, the CA might have been incapable of inducing any changes (negative or positive) in speed–power performance.

This study has a series of limitations, as already acknowledged and mentioned in previous paragraphs (e.g., fixed DJ height and a single set of CA). Additionally, due to time constraints (i.e., the study was conducted during the competitive season), it was not possible to adjust (i.e., increase or decrease) the EOL during the execution of the FW squats or test and compare the different ways that FW exercises can be executed (e.g., constant tension in the tether, delayed braking, etc.). However, all athletes were required to perform the concentric phase of the movement as fast as possible, thereby applying the maximum force possible throughout the entire range of motion. Notwithstanding, we should recognize that a more individualized and tailored CA, as suggested by the individual true change analysis (Tables 1–4), might be capable of inducing some positive effects on jump or speed-related performance—an aspect that should be explored in future studies with team-sport players.

We also acknowledge that the inclusion of other jump metrics (e.g., RSI-Mod and time until take-off) could reveal changes in jump strategies that cannot be detected with the variables considered in this study [50], which is also related to the inherent limitations of contact mats that may interfere with testing precision and accuracy. In contrast, as a positive aspect, the absence of negative changes in speed–power performance following both CAs could encourage practitioners to incorporate a few sets of FW or DJ exercises into their regular warm-up routines, even during the competitive period. Given that congested fixture schedules are commonplace in modern sports [51,52], this strategy may at least assist in maintaining well-developed levels of physical performance across the competitive season.

5. Conclusions

According to the current literature, distinct EOL exercises and DJs appear to be effective forms of CAs. Nonetheless, in the current study, neither FW squats nor 45 cm DJs were able to induce significant changes in the power- and speed-related performance of elite rugby players. Perhaps the prescription of multiple sets of CAs (2–3 sets of FW squats or DJs) combined with the use of individualized loads (e.g., RSI for DJs) could have contributed to better outcomes in the post-testing sessions, as well as eliciting significant changes in some sensitive and relevant muscle mechanical properties (e.g., Dm, Tc, and Vc). In contrast, we can also conclude that, at least for highly resistance-trained rugby players, single sets of FW squats or DJs completed before sport-specific training sessions (or even competitions) do not impair or reduce their athletic performance (e.g., micro-dosing strength–power training). Coaches and practitioners working in rugby (and other team sports) are advised to individualize and tailor the CAs for their athletes, keeping in mind that, as revealed by the true-changes analysis, athletes may exhibit very different responses to similar PAPE protocols.

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