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Impact of Bilateral and Unilateral Post-Activation Potentiation on Immediate Cycling Performance

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ABSTRACT

Post Activation Potentiation (PAP) warm-up strategies are gaining attention for their potential to enhance athletic performance. This study aims to compare the effects of unilateral PAP (UPAP) and bilateral PAP (BPAP) on cycling performance. Using a randomised crossover experimental design, 50 trained recreational male cyclists, aged 18 to 40, participated. Each cyclist's regimen included 4 sets of 5 Repetition Maximum (RM) for back squats (BPAP) and rear leg elevated split squats (UPAP). The exercises were performed on separate occasions, followed by a Power Profile Test developed by the World Cycling Centre (WCC-PTT). Results showed that 85% of 1RM BPAP significantly improved 30-second average power, relative average power, average cadence, and average torque. Conversely, 42.5% 1RM UPAP notably enhanced peak power, peak cadence, and peak torque, with significant improvements in 6-second average power, relative average power, average cadence, and average torque. When the intensity of UPAP was reduced to 42.5%, significant improvements in average power output and average cadence were observed in the 4-minute test. This study highlights the importance of tailoring PAP type and intensity to the specific demands of the sport or event to enhance performance by effectively targeting relevant muscle groups.

INTRODUCTION

Warm-up is crucial for any physical activity of any level (Bishop, D., 2003). In Bishop's 2003 review, the author explores the physiological mechanisms behind warm-up routines and the effects of passive warm-up (heat application without physical activity) on exercise performance. Warm-up activity helps to increase body and muscle temperature, increase readiness to tackle heavy-duty activity, decrease stiffness, increase nerve-conduction rate, anaerobic energy provision and thermoregulatory strain, and reduce risk of injury (Bishop, D., 2003; Racinais et al., 2017). Blagrove et al. (2019) described that warm-up strategy in endurance athletes typically aims to achieve acute metabolic and cardiovascular adjustment which enhances the oxygen uptake, kinetic response, elevation of baseline oxygen consumption and acidaemia, which indirectly produces acute muscle preparedness. A study by Tomaras & MacIntosh (2011) on warm-up techniques indicates that athletes have been using the traditional warming-up method involving a general warm-up followed by a series of brief sprints lasting more than 50 minutes in total. This type of warm-up takes a longer time and gives lesser muscle readiness.

A major concern among coaches and athletes is that post-activation potentiation (PAP) can cause muscle fatigue which affects overall performance. Allen et al., 2008 mentioned that fatigue occurs when the muscle is incapable of generating an expected level of force during a contractile period. Reality-wise, PAP has proven to improve muscle readiness in a short period without causing muscle fatigue or injury to athletes (Chok & Daud., 2024; Wan, J. J. et al., 2017). Appleby et al. (2020) explained that heavy strength exercise improves the lower body strength of an athlete, and the study showed that there are not many significant differences between the usage of unilateral or bilateral strength workouts.

Del Rosso et al. (2016) investigated whether post-activation potentiation (PAP) could influence pacing strategies during a self-paced 30 km trial among half-marathon runners and reported that PAP could give acute muscle preparedness in performance improvement. PAP is the outcome of a voluntary contractile activity in which there is a significant enhancement of muscular twitch force (Mettler & Griffin, 2012). Hodgson et al. (2005) mentioned that the response of muscle groups to electrically induced stimuli is affected by the contractile history. PAP has been widely used in sprint, power and other events or training which require short and explosive movement. For sprinters and jumpers, there is enough evidence that showed improvement in performances after the completion of 5-12 minutes of heavy resistance exercise with more than 85% of 1 Repetition Maximum (Chiu et al., 2003; Maloney et al., 2014; Robin & Thomas, 2017).

However, heavy-strength PAP has not been explored thoroughly enough in the research world. Based on a meta-analysis study by Boullosa et al. (2018), there are only 22 studies done on the effect of PAP on endurance athletes involving distance runners, triathletes, duathletes, rowers, cyclists and cross-country skiers. Out of these studies, only one study done by Silva et al. (2014) focused on heavy-strength PAP for cyclists. Silva et al. (2014) implemented leg press (bilateral movement) as PAP before the 20km Time Trial (TT) for a 4-year experienced cyclist. His study showed the PAP group subjects improved in cycling economy and the time to complete the 20km TT reduced by 6.1%. There are no changes in power output and pedal cadence among the athletes.

On another note, cycling is a unilateral movement exercise (Douglas et al., 2021) that is performed in a unilateral non-weight-bearing phase (Olmedillas et al., 2012). In the form of strength exercise, single leg split squat, which is a unilateral movement, focuses on the primary muscle quadriceps, gluteus muscles, hamstrings, adductors, abductors, and gastrocnemius as well, similar to the leg press (DeForest et al., 2014) but perform unilaterally. Therefore, this study aims to compare the effect of bilateral PAP (BPAP) and unilateral PAP (UPAP) on cyclists' performances. It was hypothesized that 4 sets of 5RM heavy strength exercises would increase the power output and improve the cycling performance of cyclists.

MATERIALS AND METHODS

This is a randomised crossover experimental study design, and this study is approved by the UMS Medical Research Ethics Committee [Code: JKEtika 3/21 (15)].

Subjects

Fifty (n=50) recreationally trained cyclists, with at least two years of recreational racing experience were chosen as subjects. Male cyclists aged 18-40 were selected as they were at the peak of their physiological development, in terms of muscle strength, reaction time, sensory abilities and cardiac functioning. Boundless Psychology (2019) mentioned that most professional athletes gave their best performances during this period. Subjects were those without any history of neurological or orthopaedic dysfunction, surgery or tenderness of the spine and lower extremities. Each subject was provided with a written informed consent form containing the risk factors and their rights to withdraw from the research at any time without reason, as per the University Research Ethics Committee.

Procedure

All subjects were seen five times during the period of study. On day one, subjects who volunteered for this study were first explained regarding the procedure and only those who could commit to the research timeframe (within 11 days) were enrolled into the program. As recommended by Yang et al. (2018), subjects were given 72 72-hour rest periods in between each testing session, 1 Repetition Maximum (RM) testing and World Cycling Centre – Power Profile Test (WCC-PPT) with PAP (Figure 1). Subjects were not allowed to perform any strenuous activities within 24 hours before each testing session. It was made compulsory for all subjects to perform 10 minutes of standardized general warm-up and active stretching before the test.

Figure 1: Subject performing the WCC-PPT with VO2 Max measurement taken during the testing.

On day two, all subjects had their anthropometry measurements (mass, height, body mass index and fat percentage) taken. Fat percentage was measured using the Tanita (UM-050) electronic weighing scale, which has a high accuracy and reliability of r = .934 (Vasold et. al, 2019). Each subject then performed the familiarisation session with the equipment set for the testing.

After 72 hours of rest, on day five, subjects had their 1RM testing for both unilateral (single-leg split squat) (Figure 2) and bilateral (back squat) (Figure 3). Subsequently, they were randomly grouped into Group A and Group B (n = 25 in each group). On day nine of testing, Group A, first performed UPAP followed by WCC-PPT, whereas Group B performed BPAP followed by WCC-PPT. These groups were then swapped after 72 hours rest, on day eleven of testing, with Group A performing BPAP followed by WCC-PPT and were introduced to the bicycle ergometer and explained the WCC-PPT protocol. All subjects were allowed to test the bicycle and run the protocol. The bicycle was fitted with the subject's pedal system and adjusted to each subject's preferred riding position. Subjects were allowed to bring their bicycle to compare

Figure 2, 3 : The Subject is in the starting phase of single leg split squat with 85% of 1RM load. The support box for this movement is measured at the height of the mid-patella of the subject (Figure 2). The subject is performing the single-leg split squat with 85% of 1RM load (Figure 3).

Figure 4, 5 : The subject was in the starting position before performing BPAP with 85% of 1RM load (Figure 4). The subject performed the BPAP with 85% of 1RM load (Figure 5).

Group B performing UPAP followed by WCC-PPT.

Familiarization session

During the explanatory session, all subjects the measurements to the bicycle ergometer. It was made compulsory for subjects to bring their own cycling attire, cycling shoes and cycling preferred pedal.

One Repetition Maximum (1RM)

Before the subject's test session on the bicycle ergometer, subjects obtained their 1RM weight for back squat using free weight barbell and single leg split squat using free weight dumbbell through an indirect method (Niewiadomski et al., 2008). The indirect method was used as the subjects were not from a strength training background and lighter weight was used to prioritize the safety of the subjects. Subjects were given enough rest in between the tests. Wathan's equation will be used to determine the subject's predicted 1RM because the calculated 1RM value using this equation did not differ significantly on average from the achieved 1RM performance (LeSuer et al. (1997).

1RM = (100 x W) / (48.8 + (53.8 x e-0.075 x R))

Bilateral and Unilateral strength test

Subjects were needed to do 4 sets of 5RM of either bilateral or unilateral exercise (according to the assigned group in Chart 1) at 85% of the 1RM obtained previously during the 1RM testing session. 85% of the 1RM was selected as the weight for PAP. van den Tillaar & Saeterbakken (2019) stated that a four to five RM in back squats are used as it is the typical load used to improve maximal strength. Subjects were given 3-5 minutes of rest in between each set (Allen et al., 2008; Rønnestad et al., 2010).

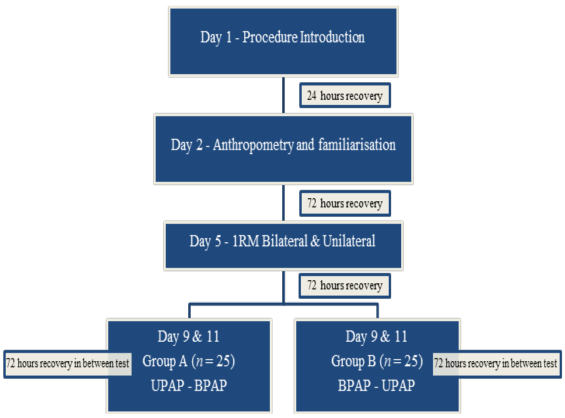

Chart 1: Framework of the study design including recovery time gap in between testing.

DeRenne (2010) recommended that post-PAP recovery time should be between 8-12 minutes. Based on a pilot study that was done using surface electromyography (SEMG) before this research, the results showed that the recovery time for BPAP was 12 minutes and 10 minutes for UPAP. Therefore, for this study, a recovery time of 12 minutes was used for BPAP and 10. minutes for UPAP before the WCC-PPT test.

World Cycling Centre - Power Profile Test (WCC-PPT). The WCC-PPT was developed by the World Cycling Centre (WCC), to provide coaches around the world with relevant information about cyclist potential (Gonzalez-Tablas et al., 2016; Gonzalez-Tablas & Martin-Santana., 2017). WCC-PPT assessed the cyclist's maximum capacity to produce power over duration that was strongly related to the physiological capacity required to perform a specific cycling race (Novak & Dascombe., 2014; Quod et al., 2010). WCC-PPT was conducted using the Lode Excalibur Sport (Lode BV Medical Technology Netherland). The reliability of r = 0.86 to 0.93 on a Lode cycle ergometer was proven by Driller, 2012; Dicks et al., 2016 and Earnest et al., 2005. The WCC-PPT protocol consists of four maximal efforts (6s, 6s, 30s, 4min), with active recovery in between. The 6-second and 30-second timeframe was an all-out effort sprint, whereas, for the 4-minute timeframe, subjects were required to pace their effort (Chart 2). During the active recovery period, subjects were instructed to continue pedalling at a light and comfortable intensity.

Analysis of results for each subject was based on the power, cadence and torque produced during each effort. Raw data produced from each effort were downloaded from the Lode Ergometry Manager (LEM) 10.11.0 software. LEM 10 (Partnumber: 955920) database was exported to Microsoft Excel to extract the raw results (Figure 6). The raw data of power, cadence and torque were then analysed using the SPSS system (IBM

Corp. (2022). IBM SPSS Statistics, Version 29.0).

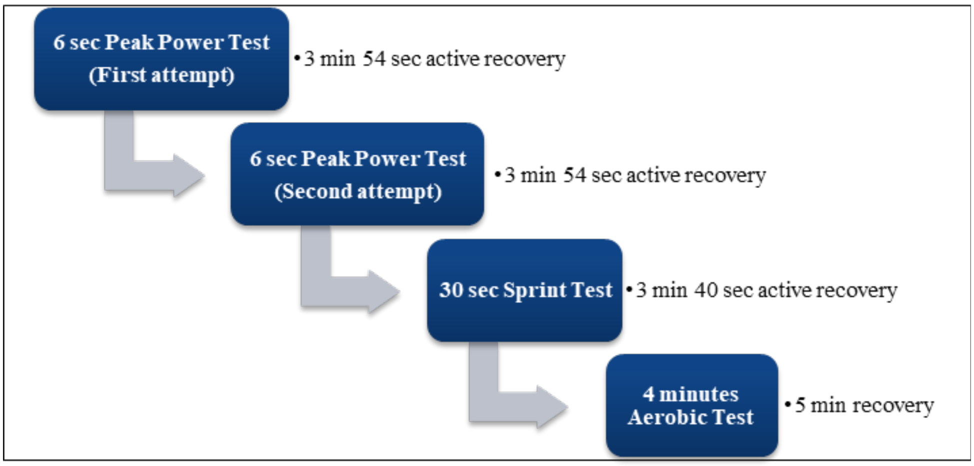

Chart 2 : World Cycling Center – Power Profile Test protocol.

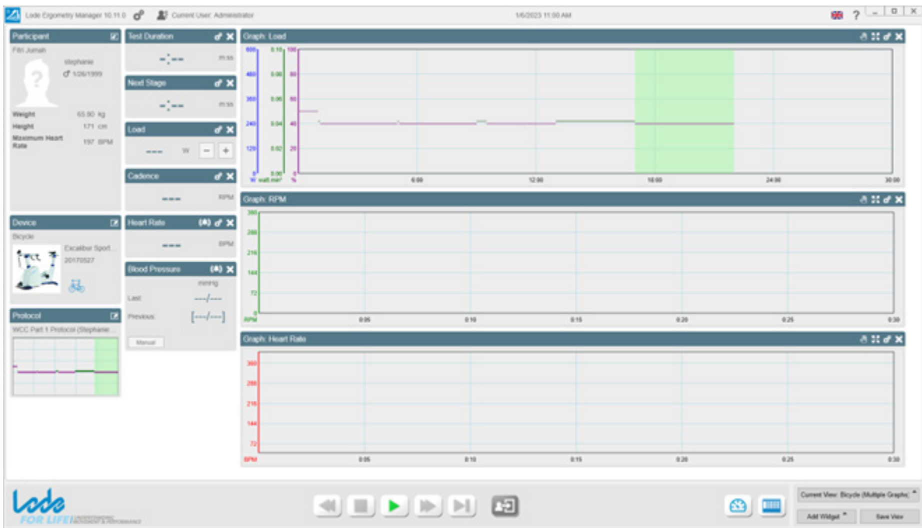

Figure 6 : Software used for the cycling performance test of Lode Ergometry Manager 10.11.1.

Heart Rate.
Measure using an Optical Heart Rate sensor (Model: Polar OH1+). The accuracy and reliability of this wearable heart rate monitor is r=.99 (Hettiarachchi et al., 2019). The data from this heart rate sensor is then immediately extracted into the Polar Beat application to avoid any errors in data collection.

Oxygen Consumption (VO2 Max)
Measured using COSMED K5. The mask can be adjusted according to each's facial built with its adjustable five-point head strap. The accuracy and reliability of this equipment are at r=0.72-0.82 (DeBlois et al., 2021). The data collected was immediately recorded in the COSMED K5 CPET (Cardiopulmonary Exercise Test) Application.

Statistical analysis
A paired sample T-test was used to compare the power output and cadence between the BPAP and UPAP outcomes. A two-way analysis of variance with repeated measures was used to compare changes in physiological capacity between the BPAP and UPAP protocols. The significance level was set at $p < 0.05$. All data

were expressed by mean ± SD.

RESULTS

Subjects. The mean age for the subjects of this study was 29.8 ± 7.7, with a mean BMI of 23.6 ± 3.0. Based on the 1RM we did for all the subjects, the mean 1RM for back squat (bilateral) movement was 83.5kg ± 15.5 and single leg split squat (unilateral) movement was 49.5kg ± 12.7. The mean baseline peak power obtained before the 1RM test was at 1671.3 watts ± 195.1 (Table 1).

Table 1: Subjects' details in mean and SD (n=50)

Variables	Mean ± SD
Age (year)	29.8 ± 7.7
Weight (kg)	66.7 ± 9.8
Height (cm)	168 ± 7.1
BMI	23.6 ± 3.0
Fat (%)	18.5 ± 5.4
1RM Bilateral (kg)	83.5 ± 15.5
1RM Unilateral (kg)	49.5 ± 12.7
Baseline Peak Power Output (watts)	1671.3 ± 195.1

Table 2: Peak Heart Rate, Average heart rate and VO2 Max reading (mean ± SD) during the 4-minute test of WCC-PPT for both BPAP and UPAP.

Variables	BPAP	UPAP	p	F
VO2 Max (ml/kg/min)	50.43 ± 7.82	50.3 ± 8.1	.448	0.93
Peak Heart Rate (bpm)	192.7 ± 7.9	192.4 ± 7.6	.326	1.078
Average Heart Rate (bpm)	174.3 ± 9.5	174.6 ± 8.2	.257	0.745

*The difference is significant at the .05 level.

Table 2 shows the comparison of Peak Heart Rate, Average Heart Rate, and VO2 Max between BPAP and UPAP during the 4-minute WCC-PPT test. The results are reported as mean ± standard deviation (SD) for each variable. There were no statistically significant differences between BPAP and UPAP in any of the measured variables, as indicated by p-values greater than 0.05. The VO2 Max was slightly higher for BPAP (50.43 ± 7.82 ml/kg/min) compared to UPAP (50.3 ± 8.1 ml/kg/min), with a p-value of 0.448 and an F-value of 0.93. Peak Heart Rate was 192.7 ± 7.9 bpm for BPAP and 192.4 ± 7.6 bpm for UPAP (p=0.326, F=1.078). Similarly, the Average Heart Rate was 174.3 ± 9.5 bpm for BPAP and 174.6 ± 8.2 bpm for UPAP (p=0.257, F=0.745). No significant differences were observed at the 0.05 level.

Table 3 compares the cycling performance variables between 85% UPAP and 85% BPAP. The study found significant differences between UPAP and BPAP in the 30-second and 4-minute tests, but not in the 6-second test. In the 30-second test, 85% of 1RM heavy strength BPAP led to a significant increase in Average Power by 13.5 watts (p=0.042, t=1.37), Average Cadence by 2.3 rpm (p=0.025, t=1.43), and Average Relative Power by 0.2 watts/kg (p=0.008, t=-1.43) compared to UPAP. For the 4-minute test, while cyclists showed improvements with BPAP, only the increase in Average Cadence by 1.5 rpm (p=0.031, t=1.45) was statistically significant.

Table 4 compares the cycling performance variables between 42.5% UPAP and 85% BPAP. The results are reported as mean ± standard deviation (SD) for each variable, with percentage differences and values provided. In terms of Peak Power Output, UPAP (42.5%) showed a higher mean (1773.95 ± 243.84 W) compared to BPAP 85% (1624.7 ± 288.33 W), with a percentage difference of 8.41% and a p-value of 0.008. Similarly, Relative Peak Power Output was significantly higher for UPAP (29.39 ± 5.26 W/kg) compared to BPAP (26.76 ± 5.06 W/kg) with a p-value of 0.004. Peak Cadence and Peak Torque were also significantly greater for UPAP (205.8 ± 14.56 rpm, 83.6 ± 5.88 Nm) than BPAP (195.95 ± 17.39 rpm, 78.92 ± 8.36 Nm), with p-values of 0.004. For the 6-second Average Power Output, UPAP exhibited a higher mean (1257 ± 130.3 W) than BPAP (1177 ± 157.62 W), with a p-value of 0.002. Similarly, the 6-second

Relative Average Power Output and 6-second Average Cadence were significantly higher in the UPAP condition (p=0.001 and p=0.015, respectively).

Conversely, for the 4-minute Average Power Output, BPAP (236.15 ± 34.85 W) was slightly higher than UPAP (228.9 ± 35.26 W), with a significant difference (p=0.041). No significant differences were observed in the 4-minute Maximum Heart Rate and 4-minute Average Heart Rate, with p-values of 0.5 and 0.152, respectively. Other non-significant variables included 30-second Peak Power Output, 30-second Average Power Output, and 4-minute VO2 Max, with p-values greater than 0.05, indicating no notable differences between the UPAP and BPAP conditions. Overall, these findings suggest that certain power and torque metrics were significantly improved under the UPAP condition at 42.5%, whereas BPAP at 85% showed better-sustained power output over the 4-minute test.

Based on the data tabulated in Table 3 and Table 4, comparing 42.5% UPAP and 85% UPAP, though no significance was recorded for average power output, 42.5% UPAP gave a greater reading for the 6-second test compared to 85% UPAP. For the 30 seconds and 4 minutes test, 85% UPAP showed a superior analysis compared to the moderate intensity heavy strength PAP. Based on the results acquired for Relative Power Output, 42.5% UPAP gave a greater reading for 6 seconds of Peak Power Output, 6 seconds of Average Power Output, 30 seconds of Average Power Output and 4 minutes of Average Power Output variables. 30 seconds Peak Power Output, on the other hand, displayed similar findings for both 42.5% UPAP and 85% UPAP. On a positive note, there was significance recorded in the Relative Peak Power Output (p=0.0001) and 6 seconds Relative Peak Power Output (0.0001) of the 42.5% of UPAP compared to 85% UPAP, as depicted in Table 3 and Table 4.

DISCUSSION

PAP can be integrated into training regimens due to its feasibility and accessibility, requiring no additional facilities or equipment beyond the standard gym or weight room resources (Lorenz, 2011). This makes PAP a practical and cost-effective strategy for enhancing athletic performance, as athletes and coaches can incorporate it into existing training programs without significant modifications or investments.

Effective scheduling and exercise selection are crucial for maximizing the benefits of PAP. Timing the PAP exercises correctly within a training session or warm-up routine ensures that athletes experience the potentiating effects at the most beneficial moments, such as just before a performance or competition. Additionally, selecting the appropriate exercises is essential to target the specific muscles and movements relevant to the athlete's sport or activity. This tailored approach helps optimize the performance-enhancing effects of PAP.

This study has established a dependable protocol for integrating heavy-strength PAP into warm-up routines. The protocol includes guidelines for appropriate loading, exercise selection, and rest intervals, tailored to accommodate athletes of varying experience levels and physical capabilities. By following this protocol, coaches and trainers can effectively incorporate PAP into their training programs, enhancing performance while minimizing the risk of injury. This approach ensures that athletes can safely and efficiently reap the benefits of PAP, leading to improved performance outcomes and overall athletic development.

The randomised crossover experimental study was conducted using a sample size of 50 athletes being tested in two different groups. The first group was tested using 85% of 1RM of UPAP and BPAP before their 6-second, 30-second, and 4-minute tests. The second

Table 3: Cycling performance variables results on 85% UPAP Vs 85% BPAP.

Variables	UPAP 85% Vs. BPAP 85%						
	UPAP (85%) Mean ± SD	BPAP (85%) Mean ± SD	Diff. (%)	Diff. (Value)	Repeated Measures ANOVA (p)	t value	F
Peak Power Output (W)	1631.8 ± 243	1652.6 ± 231.8	-1.27	-20.8	.475	-1.288	0.525
Relative Peak Power Output (W/kg)	24.53 ± 4.26	24.85 ± 4.43	-1.30	-0.32	.097	-3.77	1.137
Peak Cadence (rpm)	196.5 ± 15.3	196.6 ± 16.2	-0.05	-0.1	.924	-1.35	0.009
Peak Torque (Nm)	80.38 ± 6.46	80.83 ± 5.84	-0.56	-0.45	.281	-1.03	0.819
6sec Average Power Output (W)	1178.3 ± 136.1	1192.6 ± 129.2	-1.21	-14.3	.363	-1.36	0.853
6sec Relative Average Power Output (W/kg)	17.8 ± 2.63	18 ± 2.93	-1.12	-0.2	.527	-3.84	0.41
6sec Average Cadence (rpm)	162.6 ± 8.24	163.4 ± 9.8	-0.49	-0.8	.637	-1.10	0.227
6sec Average Torque (Nm)	69.27 ± 4.03	69.64 ± 3.88	-0.53	-0.37	.43	-0.92	0.642
30sec Peak Power Output (W)	930.17 ± 225.48	978.43 ± 153.36	-5.19	-48.26	.089	0.29	0.463
30sec Relative Peak Power Output (W/kg)	14.05 ± 3.85	14.57 ± 2.7	-3.70	-0.52	.106	-1.03	0.491
30sec Average Power Output (W)	567 ± 65.3	580.5 ± 59.4	-2.38	-13.5	*.042	1.37	4.537
30sec Relative Average Power Output (W/kg)	8.5 ± 1.03	8.7 ± 1.04	-2.35	-0.2	*.008	-1.43	8.244
30sec Average Cadence (rpm)	114.3 ± 6.9	116 ± 5.9	-1.49	-1.7	*.025	1.43	5.62
30sec Average Torque (Nm)	46.39 ± 2.67	47.26 ± 2.42	-1.88	-0.87	*.002	1.34	11.56
4min Average Power Output (W)	234.2 ± 35.25	240 ± 34.9	-2.48	-5.8	.106	1.66	2.784
4min Relative Average Power Output (W/kg)	3.5 ± 0.6	3.6 ± 0.5	-2.86	-0.1	.209	-0.53	1.651
4min Average Cadence (rpm)	73.6 ± 5.5	75.1 ± 6.2	-2.04	-1.5	*.031	1.45	5.146
4min Average Torque (Nm)	29.57 ± 2.28	30.14 ± 2.23	-1.93	-0.57	*.015	1.42	6.653
4min Maximum Heart Rate (bpm)	181.17 ± 8	181.67 ± 6.63	-0.28	-0.5	.239	-5.39	0.687
4min Average Heart Rate (bpm)	174.6 ± 8.21	174.27 ± 9.52	0.19	0.33	.373	-0.39	1.343
4min Average VO2 Max (mL/kg/min)	50.3 ± 8.1	50.43 ± 7.82	-0.26	-0.13	.448	40.53	0.931

Table 3: Cycling performance variables results on 85% UPAP Vs 85% BPAP.

Variables	UPAP 85% Vs. BPAP 85%						
	UPAP (85%) Mean ± SD	BPAP (85%) Mean ± SD	Diff. (%)	Diff. (Value)	Repeated Measures ANOVA (p)	t value	F
Peak Power Output (W)	1773.95 ± 243.84	1624.7 ± 288.33	8.41	149.25	*.008	-1.288	8.722
Relative Peak Power Output (W/kg)	29.39 ± 5.26	26.76 ± 5.06	8.95	2.63	*.004	-3.77	10.518
Peak Cadence (rpm)	205.8 ± 14.56	195.95 ± 17.39	4.79	9.85	*.004	-1.35	10.978
Peak Torque (Nm)	83.6 ± 5.88	78.92 ± 8.36	5.60	4.68	*.004	-1.03	10.557
6sec Average Power Output (W)	1257 ± 130.3	1177 ± 157.62	6.36	80	*.002	-1.36	12.725
6-sec Relative Average Power Output (W/kg)	20.83 ± 3.35	19.42 ± 3.07	6.77	1.41	*.001	-3.84	14.737
6sec Average Cadence (rpm)	166.65 ± 7.91	162.35 ± 9.52	2.58	4.3	*.015	-1.10	7.11
6sec Average Torque (Nm)	71.16 ± 4.22	68.66 ± 4.32	3.51	2.5	*.001	-0.92	15.69
30sec Peak Power Output (W)	860.75 ± 247.06	785.4 ± 166.62	8.75	75.35	.172	0.29	2.015
30sec Relative Peak Power Output (W/kg)	14.05 ± 3.79	12.9 ± 2.68	8.19	1.15	.202	-1.03	1.74
30sec Average Power Output (W)	540.6 ± 97.25	531.54 ± 74.9	1.68	9.06	.505	1.37	0.461
30sec Relative Average Power Output (W/kg)	8.86 ± 1.48	8.74 ± 1.24	1.35	0.12	.556	-1.43	0.36
30sec Average Cadence (rpm)	111.75 ± 9.84	111.15 ± 7.98	0.54	0.6	.684	1.43	0.171
30sec Average Torque (Nm)	45.43 ± 4.03	45.75 ± 4.08	-0.70	-0.32	.721	1.34	0.131
4min Average Power Output (W)	228.9 ± 35.26	236.15 ± 34.85	-3.17	-7.25	*.041	1.66	4.792
4min Relative Average Power Output (W/kg)	3.78 ± 0.644	3.89 ± 0.605	-2.91	-0.11	.051	-0.53	4.334
4min Average Cadence (rpm)	73.1 ± 5.59	74.3 ± 5.43	-1.64	-1.2	*.030	1.45	5.516
4min Average Torque (Nm)	29.37 ± 2.23	29.58 ± 2.35	-0.72	-0.21	.602	1.42	0.282
4min Maximum Heart Rate (bpm)	191.75 ± 8.06	191.75 ± 8.06	0	0	.5	-5.39	0.997
4min Average Heart Rate (bpm)	183.6 ± 7.79	184.4 ± 7.48	-0.44	-0.8	.152	-0.39	2.227
4min Average VO2 Max (mL/kg/min)	63.31 ± 9.04	61.59 ± 8.24	2.72	1.72	.288	40.53	1.197

group was tested using 85% of 1RM for BPAP and 42.5% of 1RM for UPAP (which was half the load) before their 6-second, 30-second, and 4-minute tests. This is further supported by studies done by Van Den Tillaar et al. (2019) and Schoenfeld et al. (2021) which stated that 40-60% of 1RM of unilateral heavy strength PAP is sufficient to obtain the maximum potential result of an athlete. The weight of 42.5% of 1RM is used for this study as it is exactly 50% of the 85% of 1RM and falls within the category of 40-60% of 1RM. The fast-twitch muscular fibres, which are essential for power output and speed, are activated to a sufficient degree without being too fatigued when 40–60% of 1RM is used. This range is not too high to cause premature tiredness, but it is high enough to prime the muscles and enhance motor unit recruitment (Hegedus et al., 2020).

A 6-second effort can be classified as an extremely short and explosive burst of activity (Sahlin, 2014). It falls within the realm of high-intensity, anaerobic performance. Activities that involve a 6-second effort typically include explosive movements, quick sprints, or rapid power-based exercises (Davies et al., 2015). In this study, subjects were tested for average power output, relative average power output, average cadence, and average torque during the 6-second test after performing 85% of 1RM of BPAP and UPAP. Based on the results obtained, there was no significance recorded for all the variables mentioned above.

Having said the above, there were significant differences in the average power output, relative average power output, average cadence, and average torque produced in 6 seconds following two different PAP loads: 85% of 1RM BPAP and 42.5% of 1RM for UPAP. Average power output, relative average power output, average cadence, and average torque following UPAP are higher compared to BPAP, which indicates that lightweight PAP has a significant effect on short-interval performance. 42.5% of 1RM is a lightweight PAP, which is also known as a "submaximal" PAP. This finding is consistent with a previous study done by Penichet-Tomas et al. (2020), who used 50% of 1RM load for half squat among elite male rowers, which resulted in subjects reaching a greater number of strokes ($p=0.049$) and strokes per minute ($p=0.046$).

The UPAP with 42.5% of 1RM produced higher peak power output, peak cadence, and peak torque compared to BPAP. Lightweight PAP protocols emphasize high-velocity movements that closely mimic the speed requirements of sprinting in cycling. Sprinting involves rapid force production and high cadence (Douglas et al., 2021). By training with lighter weights and focusing on explosive movements, cyclists can improve their ability to generate power quickly and efficiently during sprints. The speed specificity of lightweight PAP allows for better transfer of training adaptations to the demands of sprint-based cycling events (Vikmoen & Rønnestad, 2021).

A 30-second effort can be categorized as a brief, high-intensity burst of activity rather than a measure of endurance (Atakan et al., 2021). It falls into the realm of anaerobic metabolism, which is characterized by short-duration, intense efforts that rely on energy sources that do not require oxygen (Chamari & Padulo., 2015). During a 30-second effort, the body primarily utilizes the phosphocreatine system and anaerobic glycolysis to generate energy (Tortu et al., 2024). These energy systems can supply the body with quick bursts of power and strength but are not sustainable for longer durations due to the accumulation of metabolic by-products, such as lactic acid (Sahlin, 2014).

During the analysis of data for this 30-second test, it was discovered that there was a significant effect of 85% of 1RM of BPAP on the cyclists' average power output, relative average power output, average cadence, and average torque, compared to 85% of 1RM of UPAP. In a study done by Song et al. (2023), the author explained that performing BPAP training with 85% of 1RM can lead to an increased neural activation of the muscles involved. The heavy load stimulates the nervous system, resulting in enhanced recruitment and activation of motor units, leading to greater force production. However, when the test was repeated in the second phase using 42.5% of 1RM for UPAP and 85% of 1RM for BPAP, there were no significant differences between UPAP and BPAP.

When comparing 85% of Unilateral PAP and 42.5% of Unilateral PAP using the independent t-test, despite the variation in results in the 6 seconds, 30 seconds, and 4 minutes, much to our surprise, 42.5% showed better results for Relative Peak Power Output and 6 seconds' Relative Average Power Output. As discussed, lighter-weight PAP protocols involve performing high-velocity movements or exercises with lower loads. These movements can prime the neural system, enhancing the activation and coordination of muscle fibres without inducing significant fatigue (Schmid et al., 2006). By targeting the activation of these muscle fibres, lighter-weight PAP can help improve the cyclist's ability to generate power output repeatedly over a long duration, such as during a long-distance cycling event (Poole et al., 2016). This can enhance endurance capabilities and maintain performance throughout the race.

Heavy-strength PAP protocols can potentially improve the average power output of cyclists by temporarily enhancing their force-generating capacity (Beato et al., 2019). Heavy strength exercises, such as squats or deadlifts, can activate a larger number of motor units and increase neural recruitment (Elgueta-Cancino et al., 2022). This increased neural drive can enhance the ability of cyclists to generate force during subsequent cycling efforts (Douglas et al., 2021). By recruiting more motor units, the muscles are better prepared to produce force and generate power during the cycling activity.

This justifies that for the 30-second test, 85% of 1RM of BPAP will provide crucial improvement in an athlete's performance. By incorporating BPAP using a high intensity, an athlete can directly target the specific muscle groups involved in their sport. This specificity can lead to improved performance in sport-specific movements and actions (Song et al., 2023).

A 4-minute test can be considered a measure of endurance, especially if it involves sustained physical or mental effort (Raghuveer et al., 2020). While it may not be classified as a long-duration endurance activity, it can still provide valuable insights into an individual's ability to maintain performance over a moderate duration (Nystoriak & Bhatnagar., 2018). It's important to note that the classification of endurance can vary depending on the specific activity and the perspective of the individual or field of study. While longer-duration activities typically come to mind when discussing endurance, shorter tests or tasks that require sustained effort can still provide valuable information about an individual's endurance capacity within that specific context (Thiel et al., 2018).

On the other hand, after analysing the data collected for the 4-minute test, it was concluded that 85% of 1RM of BPAP showed a significant difference in the average power output, torque, and cadence. 85% of 1RM of BPAP produced higher average power output, average torque and average cadence compared to 42.5% of 1RM of UPAP. This denotes that 85% of 1RM of BPAP gave a significant acute effect on the average cadence, power output, and torque of cyclists in a 4-minute testing. This can be compared with a study done by Silva et al. (2014), whereby the author used a similar weight of 75% to 85% for leg press as bilateral heavy strength PAP which showed an improvement of 6.1% in the duration to complete a 20km TT. In this study, usage of 85% of 1RM of BPAP showed an increase in power output of 3.2% among cyclists in the 4-minute test.

Long-distance cycling events often involve intermittent bursts of high-intensity efforts (Etxebarria et al., 2019). Heavy-strength PAP can enhance recovery between these bursts by promoting better muscle recruitment, energy transfer, and overall efficiency (Ciocca et al., 2021). This improved recovery can help long-distance cyclists sustain the quality and power output of their short bursts throughout the race, even when fatigued.

CONCLUSION

In conclusion, this study demonstrates that heavy-strength PAP significantly impacts cycling performance in athletes, whether through bilateral or unilateral exercises. Significant differences were observed in the 6-second, 30-second and 4-minute WCC-PPT test. The results obtained show that lightweight PAP would benefit short interval performance whereas heavyweight PAP will be of advantage for long interval performance. This research highlights the benefits of heavy-strength PAP as a warm-up, offering evidence-based recommendations for training and injury prevention, beneficial for athletes and coaches. Proper application of the study's protocols can minimize injury risks across various age groups and weight classes. Sports associations and institutions can leverage these findings to enhance safety protocols, training programs, and talent identification processes, ultimately improving athlete performance and competition outcomes.

CONFLICT INTEREST

The author declared no conflict of interest regarding the publication of this manuscript.

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