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Hill, Victoria, Patterson, Stephen, Buckthorpe, Matthew and Legg, Hayley S ORCID logoORCID: https://orcid.org/0000-0002-4995-2091 (2024) The Acute Effects of a Preload Upper-Body Power Exercise on 50-m Freestyle Performance in Youth Swimmers. Journal of Strength and Conditioning Research, 38 (7). pp. 1295-1299. doi:10.1519/JSC.0000000000004792

This is a non-final version of an article published in final form in Journal of Strength and Conditioning Research 38(7):pp. 1295-1299, July 2024. DOI: 10.1519/JSC.0000000000004792

Official URL: http://doi.org/10.1519/JSC.0000000000004792
DOI: http://dx.doi.org/10.1519/JSC.0000000000004792
EPrint URI: https://eprints.glos.ac.uk/id/eprint/14194

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Accepted 2 Feb 2024
DOI: 10.1519/JSC.0000000000004792

Citation: Hill V, Patterson S, Buckthorpe M, Legg HS. The Acute Effects of a Preload Upper-Body Power Exercise on 50-m Freestyle Performance in Youth Swimmers. J Strength Cond Res. 2024 Jul 1;38(7):1295-1299. doi: 10.1519/JSC.0000000000004792. PMID: 38900175.

Original Article Submission

The Acute Effects of a Preload Upper Body Power Exercise on 50-m Freestyle Swimming Performance in Youth Swimmers

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Conflicts of interest: Authors declare no conflicts of interest.

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ABSTRACT

This study aimed to investigate the acute effects of a medicine ball slam, and the optimal recovery time required to induce a post-activation performance enhancement (PAPE) response on 50-meter freestyle swimming performance. Twenty-four (13 females, 11 males) competitive, adolescent swimmers (mean ± SD: age, 16.7 ± 1.2 years; height, 173.3 ± 6.7 cm; mass, 63.1 ± 6.4 kg) participated in a randomized crossover study. Following the PAPE intervention (3 x 5 medicine ball slams), subjects had a 1, 4 and 8 minute recovery period prior to a 50-m maximal freestyle swim. A one-way repeated-measures ANOVA revealed that different recovery times, elicited changes in 50-m performance ($F = 12.12$, $p < .0005$). After 4 minutes of recovery, 50-m performance was 1.6% (0.47 seconds) faster (95% CI (0.17, 0.77), $p < .001$). When the data were split by sex, after 4 minutes of recovery, 50-m performance was 2% (0.64 seconds) faster for females (95% CI (0.279, 0.998), $p < .001$). In conclusion, an upper body power exercise, prior to performance, can induce a PAPE response and enhance 50-m freestyle performance following a 4-minute recovery time period.

KEY WORDS post-activation performance enhancement, adolescent athletes

INTRODUCTION

Post-activation performance enhancement (PAPE) refers to the phenomena by which an athlete's performance is enhanced due to an increase in acute muscular performance following a near maximal pre-loading conditioning exercise (9). Athletes commonly utilise PAPE through the repeated pairing of a heavy load resistance exercise (greater than 85% of 1 repetition maximum [RM]) with an explosive (e.g., plyometric, ballistic) exercise, with the aim to improve their explosive force capabilities (4, 17, 34). The conditioning exercise causes excitation of the neuromuscular system which primes the nervous system to produce more force, and / or force at a faster rate (12). Two recognised theories regarding the PAPE response, are improved connections in phosphorylation of myosin regulatory light chains and recruitment of higher threshold motor units, following the conditioning exercise (27).

Whilst the majority of research advocates the use of a high-load conditioning stimulus as a method to induce PAPE (1, 14, 15, 17), studies show that the intensity and volume of the conditioning exercise, as well as the rest interval between the preload and the subsequent exercise, will provide the greatest influence on the PAPE response (25). Bevan et al. (5) found that athletes performing a heavy loaded bench press (3 sets of 3 repetitions at 87% 1RM), prior to a ballistic bench press throw, displayed potentiation of muscular power in the upper body, evidenced by improvements in peak power output during the bench throw (4.2 ± 11%) following an 8 minute recovery time between the two exercises. Kilduff et al. (18) followed a similar testing protocol to Bevan et al. (5) and demonstrated peak power output was significantly enhanced (5.3 ± 4.5%) 12 minutes after performing a preload stimulus in rugby players. Baker (1), interestingly found a significant increase of 4.5% in bench press throw performance after 3 minutes of rest, following a lighter set of 6 repetitions at 65% 1RM, showing that a lower intensity conditioning activity requires less recovery time to have a PAPE effect.

There is a growing body of literature (13, 24, 35) supporting the use of lighter explosive exercises (e.g., plyometrics) which may also produce a similar PAPE effect to that following a heavy load conditioning stimulus. This is thought due to the explosive conditioning task recruiting type II muscle fibres, with high levels of motor unit firing frequency, which are key mechanisms to induce a PAPE response (12). It is noteworthy that both fatigue and PAPE occur concurrently after contractile activity, so the balance between the two will determine the extent of the increase in muscle performance (5, 14). It is commonly supported that explosive activities cause less fatigue than heavy loaded traditional resistance exercises, and can therefore lead to a PAPE response with less recovery time. West et al. (35) compared athletes' upper body peak power output after performing a ballistic bench throw and a traditional bench press. Both protocols increased peak power output compared to baseline scores (bench throw, – 3.6%, bench press, – 4.3%, $p < 0.001$), suggesting that a ballistic conditioning activity is just as effective as a heavy resistance preload stimulus to induce a short term improvement in upper body power. Logistically, it is not always practical for athletes to use heavy resistance exercises prior to competition due to the equipment required. Therefore, more practical strategies to bring about the same effect of PAPE need to be explored for pre-competition and training warm-ups.

There is a lack of literature in both the effects of PAPE amongst adolescent athletes and the influence of PAPE in competitive swimmers. The objective of competitive swimming is to cover a set distance within the rules of the stroke in a faster time than other competitors (18). Swim speed is determined largely from the power exerted by the upper limbs during the arm pull, compared to that of the lower limbs when kicking (3). With the leg kick contributing 10% of locomotion in the water during sprint freestyle, whilst the arm pull generates 90% of the total propulsive force (8). Early research by Sharp et al. (25) found a close relationship between arm

power and freestyle sprint speed (r = 0.90), further suggesting the leg kick is of less importance during this event. During swimming competitions, the time between races can often be short and the space for a warm-up in the pool is often limited.

As sprint freestyle requires maximum power, and the arms are the main contributor to overall propulsion (8), it is justifiable to assume that an upper body power exercise could induce a PAPE effect in competitive swimmers. Researchers (2, 19, 23) have found mixed results amongst swimming populations using upper, lower and a combination of upper and lower body PAPE protocols. With PAPE protocols producing similar race times to performances following a traditional warm-up (23), or a slight increase in performance (2, 19), there is basis for further investigation on utilizing a PAPE protocol in sprint swimming. As small improvements in performance are considered of great importance in this event, a 1% increase in a race that takes 30 seconds to complete, equates to a faster time of 0.3 seconds, which is a meaningful improvement in time amongst elite swimmers.

The aim of the present investigation was to determine the effect of using medicine ball slams on subsequent 50-m freestyle performance in a group of trained adolescent swimmers. It was hypothesised that preparation involving a PAPE intervention will result in faster freestyle 50-m performance than those without the PAPE intervention.

METHODS

Experimental approach to the problem

A randomized, crossover design study took place to compare the effect of a PAPE stimulus, on the performance of 50-m freestyle after a 1, 4 and 8-minute recovery window among trained adolescent swimmers. Subjects visited the pool for a familiarization session and then a further 4

randomized testing sessions (control, 1, 4 and 8-minute recovery), spaced 1 week apart. In each testing session, subjects performed a 50-m freestyle swim following the race specific 1500-m warm-up and PAPE intervention, with a 1, 4 or 8-minute recovery between the preload stimulus and the swim. The recovery interval was based on previous studies (24, 28, 29), where 1–8 minutes of recovery was found to elicit potentiation on a subsequent exercise after a conditioning activity.

Subjects

Twenty-four trained, competitive swimmers (13 females, mean ± SD: age, 16.3 ± 1.1 years; height, 170.8 ± 6.8 cm; mass, 59.1 ± 5.6 kg and 11 males, mean ± SD: age, 17.2 ± 1.3 years; height, 176.2 ± 5.5 cm; mass, 67.8 ± 3.3 kg), volunteered to take part in this study. The purpose and experimental risks of the study were explained to both parents and subjects, with written informed consent gathered prior to testing and parental and/or guardian's consent was obtained for subjects under 18 years of age. The study was approved by BLINDED University Ethics Board. The inclusion criteria to take part was as follows: (i) male or female between 15 and 18 years of age; (ii) competitive swimmers competing at local or national level; (iii) healthy and injury free; (iv) had taken part in weight room training over the past year; (v) completed 12–15 hours of swim training each week, for the past year. Exclusion criteria comprised: (i) non-competitive swimmers; (ii) unable to commit to all 5 planned experimental sessions; (iii) injury or sickness that would have affected their ability to exercise in the past three months or at any time during the experimental study. All subjects met the national age-grade qualification times. Three subjects had to withdraw from the study after the familiarization session, and one subject withdrew after the first testing session, due to Covid-19 illness. None of their data is included in the study.

Procedures

The current study took place during the swimmers' pre-season phase using an outdoor 50-m pool with a water temperature of 28 degrees. To avoid any order bias, subjects were randomly placed in 4 groups (A, B, C & D). Each group was given a subject number for identification (e. g. A1, A2). Subjects were given the same time slot each week for their testing session and they rotated through each of the 4 conditions over 4 testing days, scheduled 1 hour apart over 4 weeks (Figure 1) in a randomized order. For the experimental trials at the pool, swimmers were instructed to refrain from caffeine, alcohol and any strenuous activity 48 hours prior to the testing days but to maintain their normal nutrition in the morning before testing. During the familiarisation session, that took place prior to the testing sessions, subjects' anthropometric measurements were recorded by the researcher, and following a standardized warm-up (5 minutes on a rowing ergometer and dynamic stretching) led by the swim team's strength and conditioning (S&C) coach (UKSCA Accredited S&C Coach), the subjects practised medicine ball slams. The S&C coach ensured that the correct technique was executed and instructed the subjects to complete the medicine ball slams (5-kg for females, 9-kg for males) by placing their feet shoulder-width apart, pressing the ball above their heads with straight arms and squatting towards the ground as they slam the ball downwards. They were required to perform the slam with a countermovement to ensure they involve a stretch-shortening cycle and to execute it with maximum effort. The load used was based on previous studies (31, 32), that found maximal throwing velocity decreased with an increase in ball weight.

For each of the testing sessions at the pool, the subjects completed the same race swim warm-up in order to manage the effects of performance from this activity. The warm-up was led by the

swim team's coach (American Swimming Coaches Association Level 5 certification). The total distance for the warm-up was 1500-m consisting of 300-m easy, 6 x 100-m (3 pull, 3 kick), 10 x 50-m freestyle (25-m fast, 25-m easy x 2, 50-m build, 2 x 50-m at 200-m race pace x repeat), 100-m easy. For the baseline 50-m performance, that acted as the control, swimmers had a 10 minute rest between the warm-up and their 50-m freestyle swim. For the experimental sessions involving the PAPE stimulus, the swimmers underwent the standardised 1500-m warm-up along with a 10 minute rest, followed by 3x5 medicine ball slams (supervised by the S&C coach) with a 2 minute recovery between sets. Once the slams were completed, the researcher timed the sitting recovery period (1, 4 or 8 minutes) that preceded the 50-m time trial.

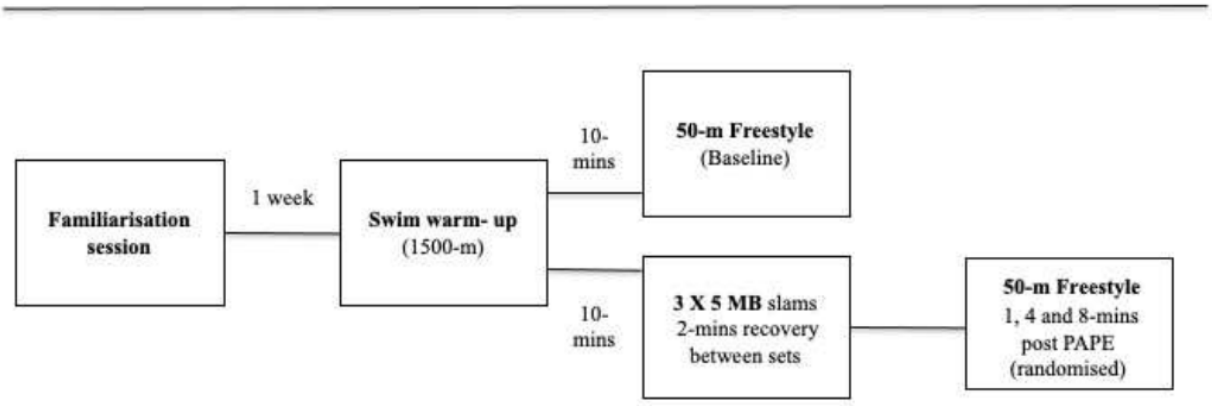

Figure 1. Schematic diagram of the experimental procedures.

50-m Freestyle Testing

During all experimental trials, swimmers performed a 50-m freestyle swim under race conditions from a dive start and were instructed before commencement of each 50-m, to swim at maximal effort. In each trial, 6 swimmers mounted the blocks and the commands "take your marks" were said from the test administrator, followed shortly after by a starting signal. A 50-m swimming

pool was set up with an OMEGA electronic timing system and touch pads (Swiss Timing Ltd, Switzerland with software Quantum Swimming Version 1.4, Swiss Timing Ltd, Switzerland). The 6 central lanes were used for testing and within their testing cohort swimmers were assigned to the same lane each time.

Statistical analyses

All statistical analyses were performed using SPSS software version 28.0.0 (SPSS, Inc, Chicago, IL, USA). Data are presented as mean and standard deviation (± SD). The Shapiro-Wilk test was carried out to ascertain whether the 50-m times were normally distributed at each time point. A one-way repeated measures analysis (ANOVA) was used to compare 50-m sprint performance after different recovery times (1, 4 and 8 minutes) following the PAPE intervention. Subjects' times were analysed as a whole group, but as the effect of PAPE may be affected by the sex of the subject (22), the data was also split into male and female, to be analysed. As the assumption of sphericity was violated in the whole group data, Greenhouse-Geisser modified values were applied for this data set only. There were no outliers in the female and combined sex specific group data, as inspected by a box plot. However, one outlier was observed in the male group during the 8-minute PAPE swim, based on the participant's time being greater than one and a half box lengths (± 3 seconds) from the edge of the box. Significant F-values were followed up using the Bonferroni post hoc test to determine significant differences between the recovery times. An alpha level of $P < 0.05$ was used to determine statistical significance. The individual PAPE response for each subject was also investigated, and the percentage of subjects who displayed a change in time from baseline to each of the recovery time points was recorded.

RESULTS

50-m performance

The combined male and female specific results reveal that different recovery times following a PAPE stimulus, elicited changes in 50-m performance (ANOVA: $F = 12.12$, partial eta $^2 = .35$, $p < .005$). Post-hoc analysis identified a significantly slower 50-m swim time at 1-minute recovery, compared to the control and 4-minute recovery time swims. The 4-minute recovery time produced significantly faster swim times compared to control and all other times. There were no significant changes following 8 minutes (Table 1).

Table 1

Mean times and standard deviations (seconds) for 50-m Freestyle and percentage (%) change from baseline, before and after each PAPE intervention

	N	Pre *	Post 1-min *	Post 4-min *	Post 8-min *
Whole Group	24	30.24 ± 2.31	30.47 ± 2.40 † (+0.8%)	29.77 ± 2.10 † (-1.6%)	30.24 ± 2.29 (0.0%)
Female	13	31.77 ± 1.40	32.03 ± 1.55 (+0.8%)	31.13 ± 1.27 † (-2.0%)	31.70 ± 1.62 (-0.2%)
Male	11	28.44 ±1.82	28.62 ± 1.86 (+0.6%)	28.17 ± 1.72 (-0.9%)	28.50 ± 1.67 (+0.2%)

Note. * Values are mean ± SD

† Significantly different from baseline (0.0005)

When separated by sex the PAPE intervention elicited a change in 50-m performance times amongst females (ANOVA: $F = 12.26$, partial eta $^2 = .51$, $p < .05$) but not amongst the males (ANOVA: $F = 2.21$, partial eta $^2 = .18$, $p = .108$). Post-hoc analysis revealed significantly faster swim times for females at 4 minutes compared to all other swim conditions (-0.64 seconds, 95% CI (.279, .998), $p < .001$).

Individual responses

Examination of individual responses revealed that two subjects (8%) showed performance enhancements at one minute, 21 (88%) at four minutes and 11 (46%) at 8 minutes post intervention. With regards to the best performance, nineteen participants (79.1 %) achieved their fastest 50-m performance after 4 minutes of recovery (Table 1), with a mean decrease in time of 0.47 seconds (95% CI (0.17, 0.77), $p < .001$). Three subjects (12.5%) had their best performance following 8 minutes recovery. One athlete (4.2%) improved at 4 minutes, with the same improved time at 8 minutes recovery. One athlete (4.2%) did not show any improvements in time following the PAPE intervention, however their 8-minute recovery performance matched their baseline time.

DISCUSSION

The key findings of this paper are that medicine ball slams produce an acute PAPE effect after 4 minutes of recovery, as evidenced by the significant decrease in 50-m freestyle times (-0.47 seconds, 1.6 % change). In agreement with our hypothesis, swim preparation involving a pool-side PAPE intervention can enhance freestyle 50-m performance. We found a significantly diminished swim performance following a one minute recovery period after the PAPE intervention. This PAPE benefit was found to be sex-specific, when separated by sex, females produced a 2% improvement in swim time (-0.64 seconds) following a 4 minute recovery period after the ballistic medicine ball PAPE intervention.

Previous literature (20, 22, 23) exploring the effects of PAPE between sexes has found mixed results. Rixon et al. (22) found a significant increase in male vertical jump height only, following a PAPE intervention. Likewise, Sarramian et al. (23) found an improvement in 50-m freestyle

amongst the male participants after PAPE protocols, whilst the performance of the female participants did not change. O'Leary et al. (20), on the other hand, found no difference in performance in either sex following a PAPE intervention. In contrast, the findings of this paper are that there was a greater PAPE effect amongst the female participants. However, whilst the findings from these prior studies found significant improvements in the male subjects only, none of them used a high velocity PAPE intervention like the current study.

Our work supports a greater PAPE effect for females, which could be due to the modality of the exercise used in this study being better suited them. Much of the literature revealing positive effects of PAPE on the upper body has concentrated on pushing movements, such as the bench press throw (1, 4, 14, 35), as a throwing action is commonly prescribed to develop power output (26). The findings of this paper are in accordance with the research by Ulrich and Parstorfer (30), that a low load, high velocity upper body exercise (plyometric push-up) can enhance power-performance. The medicine ball slam was selected as the upper body exercise for the current study as it is a recognised modality for power training (33). It's pool-side practicality and the ability to execute immediately before a competitive race or in a training environment provides high accessibility and feasibility for athletes and coaches. Performing 3 sets of 5 repetitions of the medicine ball slam in the current study provided sufficient intensity and volume to improve performance following 4-minutes recovery, it could be assumed to have increased the motor-unit recruitment pattern and rapid neural stimulation which, in succession improved upper-body power performance (16). It is believed that this type of exercise would potentiate muscles effectively with less fatigue than a heavy resistance modality (24), which subsequently increased the 50-m swim performances.

Whilst the majority of the swimmers had their best performance after 4 minutes, some subjects' produced their best performances following an 8 minute recovery period, showing that some individuals may require longer rest interval. Supporting previous jumping literature (7), it is suggested that the rest interval between stimulus and subsequent exercise should be determined individually. The strength of an athlete has been found to play a key role in the effect of PAPE on performance, with stronger athletes eliciting a higher PAPE response (24). Although the strength of the swimmers was not measured for this study, speculatively, for some, fatigue may have outweighed potentiation. The findings from the current study suggest that the PAPE intervention can be advantageous to 50-m freestyle performance but it is dependent on the recovery interval given. The improvement window appears to differ between subjects and therefore it is recommended, within the training environment, that the recovery period should be decided, based upon the individual.

Our results demonstrated that a 4-minute recovery between the preload medicine ball stimulus and the 50-m freestyle sprint produced the fastest times for the majority of swimmers. This supports the work of Seitz and Haff (24), that following a plyometric stimulus, a PAPE effect can be noticed between 0.3 – 4 minutes, as opposed to a loaded traditional resistance exercise which would require a longer rest period. In line with the findings of our study, Ulrich and Parstorfer (30) also reported improvements in PPO after 4- and 8-minutes recovery, similarly, with a decrease in performance after 1-minute when compared to baseline scores. Further supporting previous research in the area that after 1 minute, subjects are still fatigued from the intervention stimulus and require a longer recovery period to elicit potentiation after a plyometric or power type stimulus (14, 24).

The findings of the present study contradict previous research using adolescent populations (21, 23), which show no performance improvements following a PAPE intervention. Likely, the protocols used, including the intensity of the intervention and the recovery time points may not have been suitable to induce a PAPE response. Of interest, after the upper body PAPE condition (1 x 3RM pull up) executed in the study by Sarramian et al. (23), the swim times slowed down by 1.2%, when compared to baseline performance. This could be due to their study using a pulling exercise, as opposed to a push exercise used in this study, with the authors speculating the pull up my not be kinematically similar to the swim stroke (23). In addition, the pull up may not be an appropriate sport specific movement to elicit activation of the tricep brachii, which is responsible for the upsweep phase of the freestyle arm action (10).

A limitation of the current study is that the subjects' 50-m times were quite varied which could suggest they were of a mixed strength and performance levels. Whilst a heterogenous sample is not a limitation in itself, PAPE response (at least following a high load conditioning stimulus) is impacted by strength and power levels and training history of the athletes, with power athletes reported to benefit more from a conditioning stimulus than recreational trained athletes (6). The heterogenous sample could explain the wide response in performance benefits found in our study. The fact we did not assess the strength profiles of the athletes means we have no way of explaining our results with mechanistic insight. It is possible that superior swimmers were stronger, as a correlation ($r = 0.60$) between strength and swim speed has been reported (11). However, given the discrepancy between sexes reported in our study, the use of a power as opposed to heavy resistance conditioning stimulus and the lack of strength and power data, such analysis would be highly speculative. Additionally, the findings of the current study are only relevant to 50-m freestyle, but offer avenues for further research to explore pool-side PAPE interventions for alternative strokes and other freestyle distances.

The major conclusion of this investigation, is that the utilisation of an upper body pool-side power exercise induces a PAPE response and provides an effective strategy to increase 50-m freestyle performance by 0.47 seconds (1.6 %), in adolescent swimmers, provided that an adequate recovery time is given between the conditioning activity and sprint performance. A 1.6% improvement is a small percentage increase in performance, however, this small improvement in time, is pivotal in a 50-m freestyle event. The majority of swimmers in the current study saw their biggest advancement in performance after 4 minutes of recovery. Some subjects saw an improvement after 8 minutes, whilst most of the subjects performed their slowest time, after only 1 minute of recovery between the 2 activities.

PRACTICAL APPLICATIONS

The current findings of this study suggest that pool-side medicine ball slams can be used as part of a warm-up to enhance upper body power in adolescent swimmers, which will ultimately increase speed over 50-m freestyle swimming. Due to the practicability of the exercise, it can easily be performed on the pool-side and during competitions, when warm-up space and time in the water is limited. However, it is essential to determine the recovery time that activates the most potentiation in individual swimmers. Practitioners and coaches can use a medicine ball PAPE as an effective tool, to enhance upper body swim power, which will give swimmers a competitive edge and increase their speed over 50-m freestyle. Using the results from the present study, 4 minutes of recovery, between the conditioning activity and sprint, produced significantly faster times for the female swimmers.

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