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1 **The effect of ballistic potentiation protocols on elite sprint swimming: Optimizing**  
2 **performance.**

3

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26 **ABSTRACT**

27 Warming up prior to an athletic event is important for performance, however in some  
28 competition scenarios there is a long wait between completing the warm up and the event. Thus  
29 potentiation protocols are becoming increasingly popular in a competition environment. The  
30 aim of the study was to determine the effects of practical potentiation protocols on 15m start  
31 performance in national level swimmers. Eleven national level swimmers participated in the  
32 study. Using a randomized cross over design participants completed a 15m swimming start  
33 following 4 different experimental conditions (swim specific control, resisted band squat,  
34 weighted counter movement jumps, drop jumps from a 45cm box) each separated by at least  
35 48h. A repeated measures ANOVA showed a significant difference in 15-m swimming start  
36 performance following different warm-up protocols ( $F_{(1.646, 14.810)}=6.968, p=0.01$ ) A Post hoc  
37 Bonferroni test indicated that 15-m start time was significantly quicker with the band squat  
38 protocol compared to the swim specific protocol ( $6.65 \pm 0.43$  v  $6.78 \pm 0.43$  s respectively,  $p =$   
39  $0.04$ ). The results conclude that practical potentiation protocols are able to enhance 15-m swim  
40 start performance when combined with a swim specific warm-up and supports the use of post  
41 activation potentiation (PAP) during competitive swimming environments.

42

43 **KEY WORDS** – Post-activation Potentiation, Swimming, PUSH™ Band.

44

45 **INTRODUCTION**

46 Warming up prior to an athletic event is considered important for optimal performance (3).  
47 Warm-up protocols are generally classified as either active or passive. Passive strategies focus  
48 on increasing core temperature with the use of external means such as a hot shower or sauna,  
49 whilst active protocols focus on the use of exercise (3). Active warm-ups have been considered  
50 the norm to enhance physiological mechanisms prior to competition. These mechanisms  
51 include an increase in oxygen delivery to the muscles, anaerobic metabolism and nerve  
52 conduction rate all of which have been attributed to an increase in body temperature (3). The  
53 use of active warm-ups has been used extensively in the sport of swimming and has  
54 demonstrated performance benefits over several distances (11).

55

56 The competitive swimming environment poses many issues which may cause disruptions to  
57 the use of active warm-ups. These issues include delays in competition schedule, lack of pool  
58 warm-up facilities, time required for clothing changes and long marshaling periods.  
59 Disruptions can result in longer periods between warm-up and competition which can  
60 negatively affect performance (37). Therefore additional preconditioning / warm-up strategies  
61 may be required to maximize performance. Kilduff et al. (23) identified several alternative  
62 preconditioning strategies which may offset the negative effects of the time between warm-up  
63 and performance. These strategies include passive heat maintenance (8) hormonal priming (9),  
64 and post-activation potentiation (PAP).

65

66 PAP has been defined as an acute enhancement of muscle function following an intense muscle  
67 activity occurring as a result of the contractile history of the muscle (19). Performance increases  
68 have been shown in jumping (15), sprinting (27) and throwing (2). Increased performance  
69 following a potentiation stimulus has been attributed to increases in force production in

70 subsequent muscle contractions which occur due to a higher rate of cross bridge formation  
71 resulting from influx of calcium into the muscle following muscle contractions (3,13,16,30).  
72 Other mechanisms proposed include an increase in neuromuscular activation and motor unit  
73 recruitment contributing to greater force production (19).

74

75 PAP protocols commonly utilise heavy resistance training (HRT), yet despite the depth of  
76 research supporting the positive effects HRT has on subsequent explosive movements (6, 15,  
77 21, 22, 27) it has limited practicality in a competition environment. As such alternative  
78 protocols within competitions may need to be considered. Recent research has focused on  
79 varying potentiation protocols including ballistic exercise (30) utilising a variety of bench  
80 throws (36), loaded jumps (27), and plyometric exercises (25). Protocols involving jumps have  
81 been used within various research studies (26, 32) showing mixed results yet heavier loads in  
82 the form of bar loaded squat jumps (27) or weighted vests (12) have increased their  
83 effectiveness. Plyometric exercises have also been used during potentiation protocols but with  
84 no substantial conclusions made (25). However, there is a significant amount of research which  
85 supports the use of drop jumps inducing a performance increase (18, 25, 33) suggesting that  
86 the increased eccentric pre-loading may facilitate greater neural excitation (33). It also appears  
87 that multiple sets of plyometric activities have a greater effect on subsequent performance (33).  
88 Finally, the use of resisted band squats has predominately been used within complex training  
89 methods (1) but a single study has shown its use as a potentiation stimulus with similar  
90 performance enhancements to HRT (4).

91

92 PAP appears to have very little benefit on increasing maximum force production but has been  
93 shown to enhance the rate at which force is produced at a given velocity (30). The dive start in  
94 swimming is a time restraint activity which requires rapid force production in as little as 0.79

95 s (24). Alongside this, the start (time to 15-m) has been shown to be an important factor in  
96 overall sprint performance contributing to 30% of 50-m swim time and also been significantly  
97 correlated to jump height and peak power output (38). PAP therefore would be a plausible  
98 preconditioning strategy to enhance power production in swimmers (10).

99

100 Previous research looking into the effect of PAP on swimming performance has focused on  
101 using dynamic resisted sprints in the water prior to performance (17). Even though positive  
102 improvements have been found over 50m swimming performance this method of inducing PAP  
103 may not be practical in a swimming competition due to poor availability of the training pool in  
104 the lead up to competition. If PAP was to be utilised to its full potential during swimming  
105 competitions, land based activities would be required. In addition to this the role of fatigue  
106 from the contractile history of the muscle has been well established with muscle fatigue and  
107 potentiation co-existing and the relationship dictating performance (31). Despite this, there  
108 has been limited research identifying optimal recovery time following a potentiation stimulus  
109 (20, 21) with previous research showing performance using recovery times from 15 seconds to  
110 12 minutes (7 20, 21).

111

112 Therefore the aim of the current research study is to determine the optimal recovery time  
113 following three ballistic warm-up protocols to optimise performance in a CMJ and to explore  
114 how practical potential protocols effect 15m start performance.

115

116

## 117 ***METHODS***

### 118 **Experimental Approach to the Problem**

119 The research protocol followed a randomised, crossover design where each participant was

120 required to report for testing on 7 separate occasions. The first 3 sessions were used to  
121 determine optimal recovery time following each separate potentiation protocol. Recovery time  
122 was determined by counter movement jump (CMJ) height to determine the subject's peak  
123 power output. The following 4 sessions required participants completing four 15-m dive starts  
124 following a potentiation or control protocol separated by 48 hours.

125

### 126 **Participants**

127 Eleven national level swimmers (8 men and 3 female) volunteered to participate in this study  
128 which was approved by St Mary's University Ethics Committee in accordance with the  
129 Declaration of Helsinki. All participants were informed of the risks and benefits of taking part  
130 in the study prior to completing a health screening questionnaire and giving written informed  
131 consent in order to participate. Participant characteristics can be found in Table 1. Throughout  
132 the study participants were asked to maintain their usual training regime and were asked not to  
133 consume alcohol or caffeine 24 hours prior to testing days. In order to participate in the current  
134 study, participants were required to have at least 2 years of resistance training experience.

135

136 *Table 1 about here.*

137

138

139

### 140 **Procedures**

141 Six weeks prior to the experimental trials, participants were familiarised with the potentiation  
142 protocols, which were added to their weekly programmes. The first 3 testing sessions were  
143 used to identify participants optimal recovery time following the potentiation protocols, and  
144 took place at the same time every day, separated by 24 hours. On arrival participants

145 anthropometric measurements of mass (kg) and height (cm) were taken and a standardised  
146 warm-up consisting of a 5-minute ergometer row (Concept 2 Ltd, Wilford, Nottingham, UK)  
147 and a series of dynamic mobility exercises were conducted. Participants were given a 10 minute  
148 recovery period before a baseline CMJ was conducted to measure subject's peak power output  
149 using an inertia sensor (PUSH™, PUSH, Inc. Canada) validated to provide key metrics of jump  
150 performance (35). In order to measure peak power output the PUSH™ App (Apple, San  
151 Francisco, CA USA) was downloaded to a smartphone and 1 PUSH Band was positioned on  
152 the sacrum of the subject using a PUSH Waist Belt. Participants were instructed to place their  
153 hands on their hips, drop to a depth they felt comfortable with and jump vertically in an attempt  
154 to gain maximum jump height. Participants then completed a 20-minute recovery period before  
155 completing 1 of the 3 potentiation protocols. Following each potentiation protocol participants  
156 completed a single CMJ at 15 s and 3, 6, 9 and 12 min post. The optimal recovery times from  
157 these results were used to establish the recovery time during the experimental conditions.

158

159 *Figure 1 about here.*

160

161 During the experimental conditions (Figure 1), participants completed 4 additional  
162 testing sessions separated by 48 hours. Each testing session required participants to  
163 complete a dive 15-m start following a swim specific warm-up and a 20-min wait period  
164 used to simulate time spent in call room before a race (Table 2). During 3 of the testing  
165 sessions participants completed a potentiation protocol (Table 3) during the 20-minute  
166 wait. Recovery time between the potentiation protocol and the 15m dive start was set as  
167 the optimal recovery time observed for the group during the preliminary tests.

168



169 The 15 m freestyle starts were conducted under race conditionings and FINA rules and  
170 regulations. All 15 m starts were recorded using a Sony DCR-HC51E (Sony UK Headquarters,  
171 Surrey, UK) situated at the 15 m mark for video analysis through Dartfish Pro Analysis –  
172 version 7.0 (Dartfish, Fribourg 5, CH). Participants were instructed to swim as fast as they  
173 could to a distance further than 15 m. Reliability of 15 m sprint swim starts have previously  
174 been reported with an ICC of 0.987 (22)

175

176 *Table 2 about here.*

177

### 178 **Potential protocols**

179 The resisted band squat protocol was performed using 2 resistance bands (My Protein, UK).  
180 Participants completed 3 sets of 3 repetitions of band resisted squats with a 2-minute recovery  
181 period between sets. Each resistance band provided 60 to 150lbs of resistance (4). The  
182 resistance bands were placed over each subject shoulders and anchored to the opposite foot.  
183 The weighted jump protocol consisted of 3 sets of 3 repetitions of CMJs with an additional  
184 load of 15% of bodyweight using a weighted vest (4). Participants set themselves in  
185 comfortable jumping positions then lowered themselves to a predetermined height and rapidly  
186 accelerated themselves vertically to reach maximum jumping height. During the drop jump  
187 protocol participants completed 2 sets of 5 repetitions of drop jumps from a height of 45cm.  
188 Ten seconds rest was given to participants between repetitions to set themselves up on the box  
189 and 3 minutes rest between sets (25).

190

191 During the potential protocols, participants completed the protocols wearing athletic  
192 footwear and gym clothing. During the band squats and weighted jump protocol, participants  
193 lowered themselves to the same depth as a swimming start with their knee angle at between

194 135° to 145°. This was measured prior to completion of the protocol and observed by a member  
195 of the research team to ensure the correct depth was met. All participants were given verbal  
196 encouragement throughout the protocols.

197

198 *Table 3 about here.*

199

## 200 **Statistical Analysis**

201 Statistical analysis was performed using SPSS 22.0 (SPSS Inc., Chicago, IL, USA). Data is  
202 presented as mean  $\pm$  SD and significance level was selected at  $p \leq 0.05$ . A repeated measures  
203 1-way ANOVA with a Bonferroni post hoc test was carried out to determine if peak power  
204 output changed following the potentiation protocols and to assess the differences between 15-  
205 m start time between the swim specific warm-up and potentiation protocols. Effect sizes (ES)  
206 were calculated using Cohens D.

207

208

## 209 **RESULTS**

210 Ten out of the 11 participants completed all experimental trials fully. One female participant  
211 was unable to complete one of the 15-m trials as video analysis showed that the participant  
212 slowed down prior to the timing mark. For this reason this participant has been excluded from  
213 the results.

214

215 *Figure 2 about here.*

216

217 A repeated measures ANOVA indicated no significant differences between baseline CMJ  
218 and subsequent time points following the band squats, ( $F_{(2.06, 18.56)} = 2.515, p = 0.107$ ),

219 weighted jump, ( $F_{(2.12, 19.079)} = 1.363, p = 0.281$ ), and drop jump ( $F_{(3.36, 30.25)} = 0.636, p =$   
220  $0.615$ ) (Figure 2). However notable increases in peak power output of 6.9%, 7.8% and 2.9%  
221 were observed during the band squats, weighted jump and drop jump protocols respectively  
222 following 6min, 3min and 15s.

223

224 The group mean for peak power in the band squat protocol was 6 minutes with 5 participants  
225 achieving their highest peak power at that time (3min N=2, 6min N=5, 9min, N=2, 12min  
226 N=2). The group mean for the weighted jump protocol was 3 minutes with 5 participants  
227 observing their highest peak power at that time (15s N=2, 3min N=5, 6min N=4). The mean  
228 for the drop jump protocol was 15 seconds with 5 participants observing their highest peak  
229 power at that time (15s N=5, 3min N=2, 6min N=2, 9min, N=1, 12min N=1).

230

231 *Table 4 about here.*

232

233 A significant difference was observed between 15-m start performance and different warm-up  
234 potentiation protocols ( $F_{(1.646, 14.810)} = 6.968, p = 0.01$ ). Post hoc tests using the Bonferroni  
235 correction revealed that 15-m start times were significantly quicker in the band squats protocol  
236 ( $6.70 \pm 0.45$ s) compared with the sport specific warm up condition ( $6.81 \pm 0.42$  s) ( $p =$   
237  $0.04, ES = 0.30$ ). A significant difference was also observed between the band squats  
238 protocol and the weighted jump protocol ( $6.86 \pm 0.42$  s) ( $p = 0.003, ES = 0.40$  ). There  
239 was no significant difference between the weighted jump and drop jump protocol ( $6.84$   
240  $\pm 0.44$  s) ( $p = 0.857, ES = 0.09$ ), nor was there a significant difference between the swim  
241 specific warm up and the drop jump protocol ( $p = 1.000, ES = 0.04$ ).

242

243 **DISCUSSION**

244 The results of the present study indicate that PAP can be utilised alongside traditional warm-  
245 ups, by including 3 sets of 3 repetitions of resisted band squats in a race timeline, to enhance  
246 swim start performance following 6 minutes recovery. Previous research has been inconsistent  
247 with studies supporting the use of PAP (17) and others finding that potentiation protocols  
248 produce similar performance times compared to standard warm-up protocols (22).

249

250 Although the current study is unable to identify the cause of the increase in start performance  
251 it is most likely due to an increase in peak power output produced during the block phase of  
252 the start, possibly arising from myosin light chain phosphorylation (14). The use of resistance  
253 bands has been well documented in research surrounding power development (1) and more  
254 specifically the use of contrast training methods. Modifying traditional strength exercises, such  
255 as the back squat, with resistance bands alters the kinetics of the movement to allow the user  
256 to produce higher power output at the start of the movement and continue to apply high levels  
257 of force throughout (1). During low-volume and high-velocity movements, a greater force and  
258 power output have been observed (28), allowing for greater muscle activation during the  
259 concentric phase of the movement which is also believed to enhance PAP protocols.

260

261 No significant differences were seen on 15-m start performance during the weighted jump and  
262 drop jump protocol which are contradictory to previous research (18, 25, 32) which have shown  
263 to be the most effective ballistic methods in enhancing short duration athletic performance (26).

264 Differences in protocols between studies may be one reason why differences in performance  
265 outcomes have been found. Previous research using drop jumps have implemented similar  
266 protocols (5) but with the current study using a much lower drop height. The height at which  
267 drop jumps are performed change parameters such as power and velocity (34) which may alter  
268 the effect it has on subsequent movements. As volume of the potentiating exercise is a known

269 factor to influence subsequent performance, differences between studies volume of  
270 potentiation protocols need to be considered. The current study used a total volume of 10 CMJs  
271 whereas Tahayori (32) used a total volume of 15 CMJs. Individual differences can play large  
272 role in the effect PAP has on performance and as a result, protocols need to be highly specific.  
273 In the aforementioned studies, both sets of participants took part in sports with a high reliance  
274 of plyometric capabilities. Both sets of participant's may have a far greater training age  
275 compared to swimmers who rarely utilise the stretch shortening cycle (SSC) to its full capacity.  
276 Therefore, the utilisation of PAP through the use of plyometric activity may be dependent on  
277 the participant's ability to utilise their SSC. It is also interesting to note, previous research into  
278 plyometrics and PAP has shown only increases in performance where sprinting or CMJs have  
279 been used as the performance test, which relies greatly on plyometric capability (18, 25).

280

281 The secondary aim of the study was to find the optimal recovery time required from a  
282 potentiating stimulus to increase CMJ performance and despite the coexistence of potentiation  
283 and fatigue being the prominent reason for varied recovery time. This is the first study to show  
284 the effects recovery has on CMJs following ballistic potentiation protocols. Preliminary tests  
285 showed no significant time effect was found within any of the potentiation protocols however  
286 notable increases of peak power output were seen. Major championships are not won by  
287 significant differences. Thus, small improvements in performance measures, such as peak  
288 power, may be sufficient to enhance performance. However a limitation of the current study  
289 was that recovery times set for each condition were based upon the group average, not for each  
290 individual.

291

292 The current findings support the growing volume of evidence to support the view that shorter  
293 recovery times are necessary between ballistic potentiation protocols and subsequent

294 performance in comparison to HRT (26). Optimal recovery times following HRT have been  
295 recommended between 8 to 12 minutes when using loads up to 87% of 1RM (21) whereas the  
296 longest recovery time shown in the current study was 6 minutes supporting previous findings  
297 (5). Intensity of potentiation protocols will directly impact recovery times as higher loads  
298 during HRT will produce both greater potentiation within the skeletal muscle but also a greater  
299 amount of fatigue which will require longer recovery periods. The reduced external loading  
300 placed on individuals during ballistic exercises may be a credible reason to why optimal  
301 recovery times are far less than HRT and also between the potentiation protocols in the current  
302 study. Resisted band squats provide greater external loading than 15% of BW used during a  
303 CMJ. However, there is contradicting research which suggests recovery periods following  
304 ballistic exercises are similar to those of HRT (4, 28).

305

306 The magnitude at which the potentiating protocols increased participants power values were  
307 lower in the current study compared with earlier studies which found 12% increase in mean  
308 power output following a 5-minute recovery using the same three recovery protocols used  
309 within this study (4). The present study measured peak rather than mean power output which  
310 may be one reason for the differences in results. It is also well established that individual  
311 differences have a contributing factor into the effects of PAP and resistance-training  
312 backgrounds may affect the result. Shorter recovery times have shown to be more beneficial in  
313 trained individuals. It is thought that this is because trained athletes are more sensitive to PAP  
314 protocols (6), which may explain why larger increases in performance have been previously  
315 seen. However, with both studies showing increases in performance, it suggests the use of  
316 resisted band squats may be a practical alternative to HRT when attempting to enhance  
317 explosive power. With these two studies being the only studies to have used resistance band to  
318 elicit a PAP response, further research is required to understand its use.

319

320 With the current research supporting the use of potentiation protocols on start performance  
321 more research is required to assess the effects PAP has on 50-m swimming performance. It  
322 would be reasonable to assume that faster times to 15-m would produce faster 50-m as 30% of  
323 the swim is attributed to the start (10). However, due to the body being buoyant in the water,  
324 no ground reaction forces are applied, therefore land based protocols arguably will have limited  
325 effect on swimming speed. There is limited research investigating the use of PAP over 50m  
326 performance. Tahayori (32) observed no significant difference between a traditional race-  
327 specific warm-up and a lower body PAP protocol over 50m. Adding to this research, Hancock  
328 (17) investigated the use of a PAP protocol compared to a swim specific warm up on 100m  
329 performance. While there was no significant difference observed between groups, there was a  
330 trend towards a significant improvement in performance over the first ( $p=0.51$ ) and second  
331 ( $p=0.058$ ) 50m split times in the PAP trial. This equated to an improvement of 0.26 and 0.27  
332 seconds in the first and second 50m, respectively. Given that sprint swimming races are often  
333 won by narrow margins, this is a considerable improvement.

334

335 The current research has only investigated a potentiation protocol with the use of a single  
336 exercise and as it is common in many warm-up protocols to include a combination of exercises.  
337 It may be plausible that including band resisted squats within a prolonged warm-up protocol  
338 could enhance performance further. Further research in implementing race times which  
339 incorporate a number of preconditioning strategies is required. With any PAP protocol, there  
340 is always a recovery period following the potentiating stimulus and research should look into  
341 what can be done during this period to either maintain muscle potentiation without the onset  
342 of fatigue or even increase muscle potentiation. In addition future research could also consider  
343 using individualized recovery durations rather than using times based upon the group average.

344

345 In summary the current study clearly supports the use of practical potentiation protocols to  
346 enhance start performance, specifically implementing 3 sets of 3 repetitions of resisted band  
347 squats following a traditional warm-up.

348

349

### 350 ***PRACTICAL APPLICATIONS***

351 The findings will benefit strength and conditioning practitioners who are implementing  
352 preconditioning strategies on a pre-race timeline. The current findings suggest that practical  
353 protocols are likely to enhance 15m swim start performance when used with a traditional  
354 swimming warm-up in comparison to the use of a traditional swimming warm up alone. Due  
355 to its use of simple equipment, the band squats would be the most practical method to be used  
356 within a competition environment.

357

358

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#### 464 **ACKNOWLEDGMENTS**

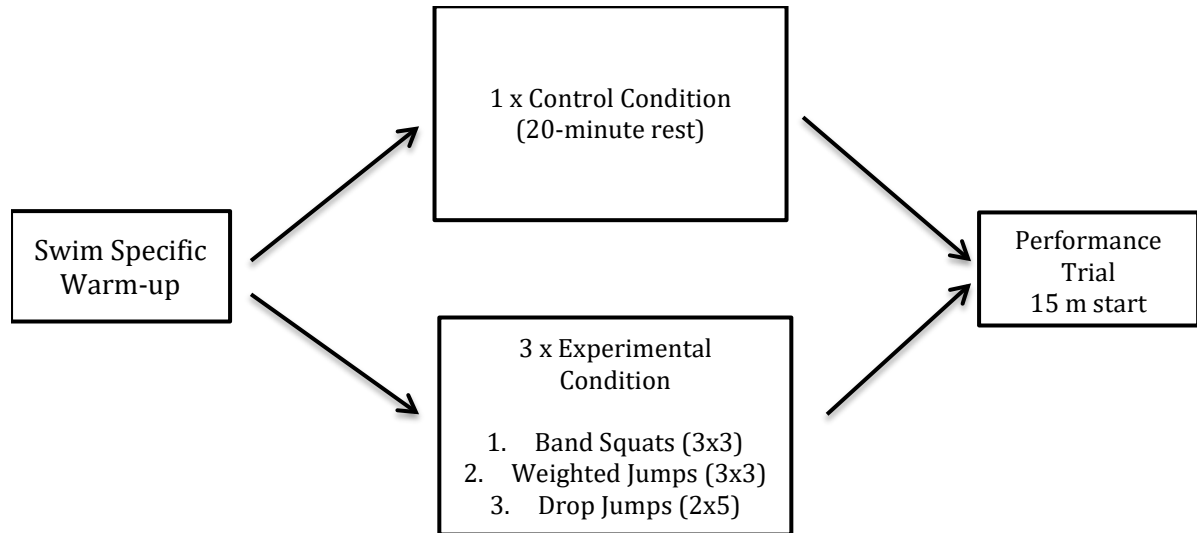
465 This research investigation was carried out in compliance with the ethical laws of Great Britain  
466 and the authors have no conflicts of interest that are relevant to the content of this article. The  
467 results of the present study do not constitute endorsement of the product by the authors or the  
468 NSCA.

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471 **FIGURES**

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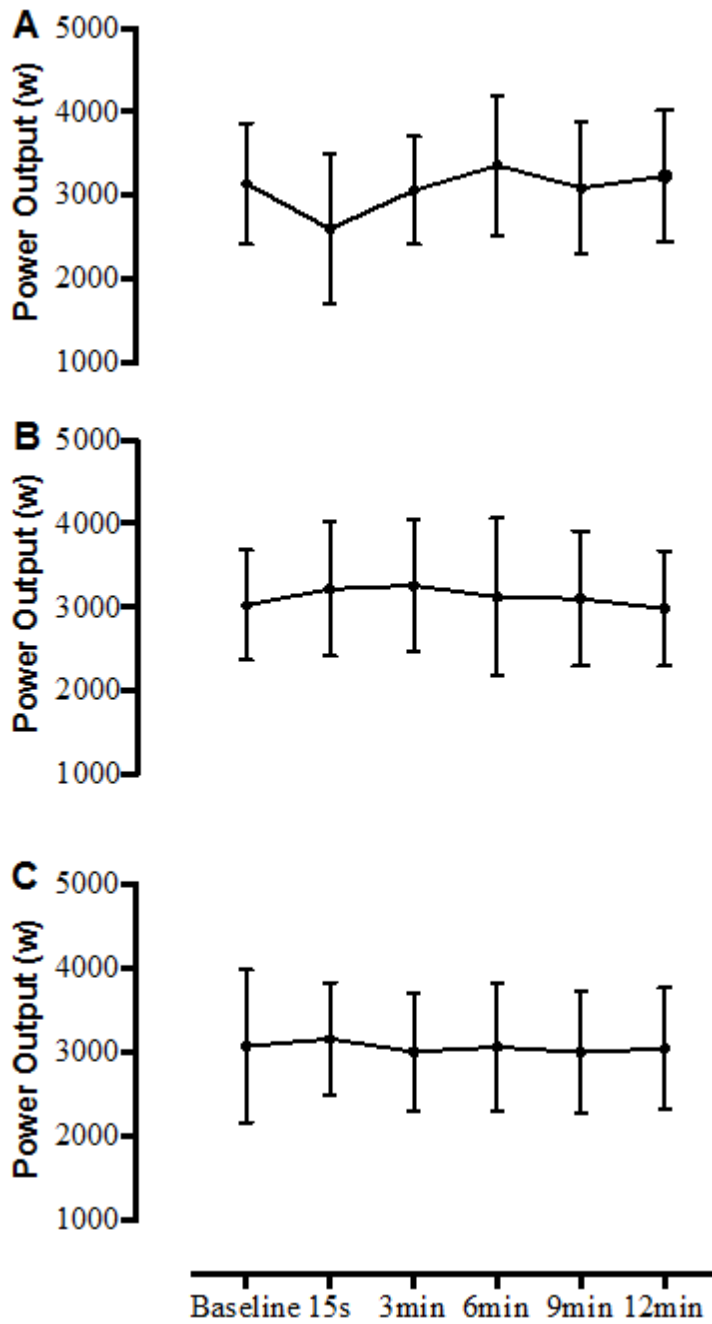
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474 **Figure 1.** Experimental design of the main trials

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479 **Figure 2.** Absolute Peak power output from countermovement jumps at baseline and 15s, 3

480 min, 6 min, 9 min and 12 min following the A – Band Squat, B - Weighted Jump, C - Drop

481 Jump potentiation protocols. Values are reported as mean  $\pm$  SD.

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485 **TABLES**486 **Table 1.** Participant's baseline characteristics during the first testing session (n=11)

Characteristics	Mean $\pm$ SD
Mass (kg)	78.97 $\pm$ 12.80
Height (cm)	182.13 $\pm$ 10.27
Age (yrs)	19.00 $\pm$ 1.25
15m swim (s)	6.81 $\pm$ 0.42

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490 **Table 2.** Standardized swimming warm-up

Warm-Up	Exercises
<b>Dynamic Mobility</b>	<ol style="list-style-type: none"> <li>1. 5 mins Myofascial release</li> <li>2. Spideram x10</li> <li>3. Inchworms x10</li> <li>4. Glute Bridge x10</li> <li>5. OH Lunges x 6ea</li> <li>6. Arabesques x6</li> <li>7. Dynamic Squats x6</li> </ol>
<b>Swim specific warm-up</b>	<ol style="list-style-type: none"> <li>1. 400 swim</li> <li>2. 4x50 as kick/drill</li> <li>3. 4x50 Freestyle, Rest 15s (<i>1- build, 2-25 fast/25 easy, 3-easy, 4-pace</i>)</li> <li>4. 2x15m Starts (<i>At race speed</i>)</li> </ol>

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493 **Table 3.** Sets and repetitions for exercises within each protocol.

Protocol	Exercise	Sets	Reps	Optimal Recovery
Band Squat	Band Resisted Squat	3	3	6 minutes
Weighted Jump	Weighted Jump Squat	3	3	3 minutes
Drop Jump	Drop Jump (45cm)	2	5	15 seconds

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498 **Table 4.** Percentage change of peak power output (PPO) in countermovement jumps

499 from baseline to peak during each potentiation protocol including coefficient of variation

500 (CV).

Potentiation Protocol	PPO at baseline (w)	PPO change to peak (%)	CV %
Band Squat	3142 ± 724	6.9	13.4
Weighted Jump	3024 ± 662	7.8	10.2
Drop Jump	3071 ± 912	2.7	19.0

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