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Title: Loaded hip thrust-based PAP protocol effects on acceleration and sprint performance of handball players

Running title: Sprint performance related to post-activation potentiation

Original Investigation

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Abstract

This study aimed to investigate the acute effects of two barbell hip thrust-based (BHT) post-activation potentiation (PAP) protocols on subsequent sprint performance. Using a crossover design, eighteen handball athletes performed maximal 15-m sprints before and 15s, 4min and 8min after two experimental protocols consisting of BHT loaded with either 50% or 85% 1RM (50PAP and 85PAP, respectively), in order to profile the transient PAP effects. The resulting sprint performances were significantly impaired at 15s only after the 85PAP protocol, which induced *likely* and *very likely* greater decreases compared to the 50PAP. At 4min and 8min, significant improvements and *very likely* beneficial effects were observed in the 10m and 15m performances following both protocols. Significant differences were found when comparing the two PAPs over time; the results suggested *very likely* greater performance improvements in 10m following the 85PAP after 4min and 8min, and *possible* greater performance improvements in 15m after 4min. Positive correlations between BHT 1RMs values and the greatest individual PAP responses on sprint performance were found. This investigation showed that both moderate and intensive BHT exercises can induce a PAP response, but the effects may differ according to the recovery following the potentiating stimulus and the individual's strength level.

Introduction

Sprinting ability and the underlying mechanical impulse-dependent components represent fundamental prerequisites for successful participation in team sports (Burgess & Naughton, 2010). Resistance exercises and resisted sprints and plyometrics (McBride, Nimphius, & Erickson, 2005; Turner, Bellhouse, Kilduff, & Russell, 2015) are recognised as beneficial training tools for acutely enhancing sprinting tasks, according to the known phenomenon called post-activation potentiation (PAP) (Sale, 2002). PAP refers to the acute enhancement of muscular function as a direct result of its contractile history (Sale, 2002). The literature suggests that PAP effects may be affected by several physiological and training variables, including: the type of exercising muscle fibres (Gullich & Schmidtbleicher, 1996; Sale, 2002); the subject's fitness characteristics; the type, duration, volume and intensity (McBride et al., 2005) of the potentiating conditioning activity (CA) (Seitz & Haff, 2016); the length of the period following the CA (Wilson et al., 2013); and, the type of subsequent activity (Seitz & Haff, 2016). A recent body of research has addressed the effects of specific PAP protocols involving horizontal-oriented CA (Dello Iacono, Martone, & Padulo, 2016; Seitz, Mina, & Haff, 2017) on subsequent sprinting capabilities of elite athletes. Dello Iacono et al. (2016) reported a potentiation effect on 25m sprints and change of direction ability after 8 minutes following a protocol that included horizontal-alternate one-leg drop jumps. Seitz et al. (2017) succeeded to potentiate 15m sprints for up to 12 minutes after a single sled push loaded with 75% body mass. Consequently, such beneficial effects might suggest that the force vector hypothesis (Kawamori, Nosaka, & Newton, 2013; Morin, Edouard, & Samozino, 2011) and the principle of movement specificity between sprinting and the CA must be carefully considered when designing interventions to exploit the PAP response.

Another training exercise often implemented into training programmes for enhancing sprinting capabilities is the barbell hip thrust (BHT) (Contreras et al., 2017; Contreras, Cronin, Schoenfeld, 2011). From a mechanical perspective, the BHT exercise requires consistent hip

extensor muscles' moment development for its execution (Contreras et al., 2011). In addition, the kinetic responses of the BHT highlight the horizontally-loaded nature of this exercise (Contreras et al., 2011). Considering that both the hip muscles' mechanical outputs and the horizontal force application are significantly correlated to increased acceleration and speed capabilities, it seems wise to incorporate BHT training strategies when transfer effects in running sprint performance are sought. Contreras et al. (2017) investigated the effects of six-week front squat and BHT programmes on neuromuscular tasks in adolescent male athletes, and found beneficial effects for the BHT over the front squat in the 10m and 20m sprint times. However, evidence on the effects of BHT-based protocols in terms of acute PAP strategies is still lacking. Moreover, there is no study investigating the acute PAP effects induced by BHT-based protocols on acceleration and sprinting performance amongst adult professional handball players. The current literature (Chiu et al., 2003; Seitz & Haff, 2016) suggests that individuals with prior resistance training experience achieve a considerably larger PAP effect than those with no prior experience. Moreover, individuals with higher strength levels are able to exhibit a greater PAP effect than their weaker counterparts (Jo et al., 2009; Seitz & Haff, 2016). Nevertheless, while there is reason to believe that adult professional athletes represent the ideal target for PAP applications, no data are available regarding either the influence of any BHT protocol or the specific CA load on the magnitude of any PAP response. Finally, it is still unknown whether individuals with higher levels of BHT strength have functional advantages for exhibiting greater PAP responses. Therefore, the primary purpose of the present study was to investigate the effects of BHT-based PAP protocols with either moderate or heavy loads on subsequent sprint performance amongst adult handball players. It was hypothesised that both BHT-based protocols would induce positive acute PAP effects, due to the higher similarity between this CA and the functional sprinting task in terms of the motor patterns and mechanical demands. Finally, assuming that the magnitude of the PAP effect on the subsequent performance is dictated by the individual's strength level, we aimed to verify whether individuals with a higher

BHT strength level are able to express any acute PAP effects to a greater degree, earlier, and for a longer period of time in comparison with teammates presenting lower strength levels.

Methods

Participants

Based on the assumption that within-group difference in sprint performance times of 0.046 ± 0.005 sec for 10m is meaningful in the same population sample (Dello Iacono et al., 2016), we used G*Power Software (G*Power software, v.3.0.10) to determine that a sample size of ≥ 11 athletes would provide maximal chances of 0.5 and 25% of type I and type II errors. Eighteen elite male handball athletes (age 19.8 ± 0.3 years; height 184.3 ± 5.4 cm; body mass 84.2 ± 7.3 kg), members of the U-21 national team and participating at the last European Championship, volunteered to participate in the study. The players had at least six years of high-level practice, four years of specific jumping and sprinting training experience, and three years of resistance training experience. They trained once a day for around 90 minutes, five days per week, undergoing technical, tactical, strength, and speed training. Strength training consisted of ~2 hours a week of resistance exercises for upper and lower limbs. Speed training consisted of two 20min sessions, including athletic drills and sprinting tasks performed both linearly and with multidirectional changes. In addition, the whole sample presented at least two years (2.6 ± 0.8 y) of BHT training background, since this exercise was included and prescribed as a part of the weekly resistance training programme performed twice a week.

Written informed consent was obtained from the athletes after they received an oral explanation of the purpose, benefits, and potential risks of the study. All procedures were conducted in accordance with the Helsinki Declaration and approved by the Institution's Ethics Committee.

Design

A *cross-over design* was used to compare the effects of two (50% 1RM (50PAP) and 85% 1RM (85PAP)) PAP protocols on subsequent 10m and 15m sprint performances. These specific distances were chosen in accordance with current time-motion analyses of official handball matches reporting distances between 10m and 13m as the most relevant and frequently covered during high-intensity sprints (Karcher & Buchheit, 2014). Athletes completed one familiarisation and two experimental sessions, including: a standardised warm-up; baseline sprint assessment; a PAP stimulus based on either 50PAP or 85PAP protocols; and, sprint reassessment after 15s, 4, and 8min of passive recovery (Kilduff et al., 2007), in order to profile the potentiation effects. In addition, in a pilot study administered prior to the experimental sessions, nine participants were required to complete three 15m sprints following the same standardised warm-up and with the same time frame recovery between them. This was done to ensure that any effect observed during the experiment was due to the BHT protocols and not induced by warm-up, fatigue, or potentiation effects from the previous sprint. The order in which the protocols were completed was counter-balanced and determined by block randomisation (www.random.org). The following formula was used to equate the BHT workloads between the two experimental trials:

$$\text{Load volume} = \text{load} \times \text{repetitions} \text{ (Seitz et al., 2017)}$$

A 1 to 1.7 ratio between the 85PAP and 50PAP (Baechle & Earle, 2008) protocols was applied to determine the number of repetitions the athletes had to perform during the potentiation protocols and to approximately equate the volume between conditions.

Procedures

One week before the initiation of the study, the athletes attended a familiarisation session to become acquainted with the experimental procedures. Anthropometric measurements of height and body mass (SECA model 284, Germany) were taken on the same day, and the BHT 1RMs was estimated.

Athletes first performed a 10min general warm-up consisting of various dynamic mobilisation exercises for the lower body musculature. In accordance with Contreras et al. (2011), the BHT exercise was performed by having the participants' upper back rest on a bench. The participants' feet were slightly wider than shoulder-width apart, with the toes pointed forward or slightly outward. The barbell was padded with a thick bar pad and placed over the participants' hips. The participants were instructed to thrust the barbell upwards while maintaining a neutral spine and pelvis. Following this, three specific warm-up sets with progressively heavier barbell loads (subjective 30-50% 1RM) were performed. Finally, each participant performed additional submaximal repetitions, and the individuals' 1RMs were then estimated according to Baechle and Earle (2008).

Following the familiarisation session, the athletes reported to the sport hall on two separate occasions separated by 72 hours. All tests were performed in the same regular indoor court, at the same time of the day (4:00 p.m.-8:00 p.m.), and in similar ambient conditions of temperature ($21.2\pm 0.5^{\circ}\text{C}$) and relative humidity ($61\pm 2.5\%$). In order to prevent an unnecessary fatigue effect, players and coaches were instructed to avoid intense training 24 hours prior to each day of testing. The athletes were also prohibited from consuming any known stimulant (i.e., caffeine) or depressant (i.e., alcohol) substances for 24 hours before testing, and were instructed not to eat for 2-3 hours before each testing session.

15-m Sprint test

The sprints were measured using electronic timing gates (Microgate Photocell, 0.001 sec accuracy, Bolzano, Italy) positioned at the start line and 10 and 15m from the start line, at 0.5m height from the ground. During each experimental session the players performed a standardised warm-up, including athletic drills followed by four bursts of progressive accelerations over 15m and one 15m sprint with maximal effort interspersed by 1min of passive recovery. Two minutes after the end of the warm-up, the athletes completed four maximal (Haugen & Buchheit, 2016) 15m sprints with

2min of recovery in-between. All athletes initiated the sprint, in their own time, from a semi-crouched position with the front foot 20cm from the start line. The athletes received verbal encouragement to sprint at maximal effort. Following the baseline assessment, the athletes performed one of the two experimental PAP protocols, and then were reassessed for a single 15m sprint with maximal effort at 15s, 4min, and 8min. The fastest sprint times recorded over both 10m and 15m were used for baseline-post and between-protocol comparisons. Additionally, the baseline scores were analysed with the aim of assessing the test-retest and the intra-day reliability of the measures.

Post activation potentiation protocols

The participants performed either three sets of six repetitions of 85PAP or three sets of ten repetitions of 50PAP BHT, matched according to the calculation described above. These conditioning protocols were used since they were commonly included as part of weekly conditioning programmes. The rest period between sets was 2min. This rest period was chosen considering that during the familiarisation session it was shown to be sufficiently long enough to prevent execution failure during the concentric phase of the BHT for both PAP protocols. During the exercise execution, the athletes were instructed to assume a position like the one described above for the 1RMs testing procedures. Both protocols were performed at a self-chosen pace, with one researcher and one coach supervising all exercises and providing appropriate motivation. The duration of the protocols, including the rest intervals and duration of the sets, was 5min 39s \pm 4s and 5min 43s \pm 3s for the 50PAP and 85PAP, respectively.

Statistical analysis

All data are presented as means \pm standard deviation (SD) and confidence interval (90%CI). The Shapiro-Wilk test was used to ensure normal distribution of the results. Inter-day test-retest reliability was examined using the Intra-Class Correlation Coefficient (ICC) with 90% CI, while for

the intra-day reliability the spreadsheet of Hopkins (2000) was used to determine the typical error of measurement, expressed as a Coefficient of Variation (CV%) with a 90% CI. A repeated measures one-way Analysis of Variance (ANOVA) was performed to test for significant differences between the sprint performances at baseline and those at each post-PAP point, in order to determine the main effects and interactions for each of the two BHT protocols. A post-hoc Bonferroni test was used when significant differences were detected, to determine which of the post-PAP measures differed significantly to the baseline score. The Cohen's *d* (Cohen, 1992) was used to assess effect size (ES) and the magnitude of difference for each of the two PAP protocols, with respect to the baseline scores at each time point. Accordingly, the magnitudes of ESs were considered small (<0.20), moderate (0.20-0.50) or large (>0.80). In order to provide normative cues for the performance changes, the data were also assessed for clinical significance using the approach based on the magnitudes of change (Hopkins, 2002). Knowledge of the Typical Error of Measurement (TE) allowed the calculation of the smallest worthwhile changes at the 90% confidence interval (SWC₉₀). Quantitative chances of substantial differences were assessed qualitatively, as follows: <1%, most unlikely; 1-5%, very unlikely; 5-25%, unlikely; 25-75%, possible; 75-95%, likely; 95-99%, very likely; and >99%, most likely. When comparing the pre- and post-PAP performances, independently for each of the two BHT protocols, if the chances of having both beneficial and harmful effects were >25% and >0.5%, respectively, the difference was assessed as unclear (Hopkins et al., 2009). For the comparisons of the sprint time change scores at different post-PAP points between the 50PAP and 85PAP, the difference was considered unclear if the chances of having both positive/greater increase and negative/greater decrease were >5%. Correlations between the 1RMs values and the magnitude of each individual greatest PAP effect on sprint performances, separately for 10m and 15m distances, were assessed using Pearson's product-moment correlation coefficients. The qualitative magnitude of associations was reported according to Hopkins (2002). The alpha test level for statistical significance level was set at $P \leq 0.05$. Statistical analysis was performed using SPSS Statistics 21 software (SPSS Inc., Chicago, IL, USA).

Results

All the variables showed highly reliable data at baseline and high agreement between the inter-day measurements (Table 1).

The repeated measures ANOVA indicated that the 10m sprint performances were influenced by recovery duration (time effect: $F_{(3,51)}=257.861$, $P<0.001$) and condition (time x condition interaction: $F_{(3,51)}=30.458$, $P<0.001$). Post-hoc analysis revealed significant improvements relative to baseline after performing the 50PAP at 4min ($-2.44\pm 1.32\%$, $P<0.01$) and 8min ($-3.15\pm 1.36\%$, $P<0.01$) (Figure 1A). Similarly, after performing the 85PAP, the 10m sprint performance results significantly improved at 4min ($-4.42\pm 1.66\%$, $P<0.01$) and 8min ($-4.99\pm 1.72\%$, $P<0.01$) (Figure 1A). The results also indicated that 15m sprint performances were influenced by recovery duration (time effect: $F_{(3,51)}=442.700$, $P<0.001$) and condition (time x condition interaction: $F_{(3,51)}=3.746$, $P=0.001$). Post-hoc analysis revealed significant improvements relative to baseline after performing the 50PAP at 4min ($-3.33\pm 1.21\%$, $P<0.01$) and 8min ($-4.59 \pm 1.33\%$, $P<0.01$). As for the 85PAP, significant improvements in respect to the baseline were observed at 4 min ($-4.17\pm 1.06\%$, $P<0.01$) and 8min ($-4.60\pm 1.07\%$, $P<0.01$) (Figure 1B).

The comparisons between the two PAP protocols identified significant differences in both the 10m and 15m sprint performances at different time points. Specifically, the 85PAP induced greater decrements in the 10m ($F_{(1,17)}=22.735$, $P<0.001$) and 15m performances ($F_{(1,17)}=5.170$, $P=0.03$) at 15s when compared to the 50PAP (Figure 1A-B). At 4min, the 85PAP induced greater increments in both the 10m ($F_{(1,17)}=17.257$, $P<0.001$) and 15m performances ($F_{(1,17)}=4.654$, $P=0.04$) (Figure 1A-B). Finally, at 8min the 85PAP induced greater increments in the 10m performance ($F_{(1,17)}=14.767$, $P<0.001$) in comparison with the 50PAP (Figure 1A).

Meaningful differences following the PAP protocols were also evident, as supported by large ESs and qualitative outcomes (Table 2). In light of the improvement in both 10m and 15m performances at both 4 and 8min time points, there were *likely to very likely* beneficial effects and *very likely* beneficial effects after performing the 50PAP and 85PAP, respectively, (Table 2). The comparison over time between the two PAP protocols suggested that there were *very likely* and *likely* greater decrements in 10m and 15m performances at 15s following the 85PAP (Table 3). Conversely, *very likely* greater performance improvements in 10m were observed following the 85PAP after 4min and 8min and *possibly* greater performance improvements in 15m after 4min (Table 3).

When data from both groups were pooled, the best greatest improvement in sprint performances over 10m ($r=0.738$, $P<0.001$) and 15m ($r=0.720$, $P<0.001$) was significantly correlated to the 1RMs scores (Figure 2A-B).

*****Table 1 about here*****

*****Figure 1 about here*****

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*****Table 3 about here*****

*****Figure 2 about here*****

Discussion

The present study used a controlled design to profile and compare the potentiation effectiveness of two BHT-based PAP protocols on sprinting performance in elite handball athletes. Firstly, as hypothesised, both the 50PAP and 85PAP protocols were effective in inducing improvements on sprint abilities. Compared to the baseline assessment, the optimal recovery time in achieving maximal benefits after both protocols was 8min, despite the fact that significant performance

enhancements were also observed after 4min. A positive correlation between BHT 1RMs values and the greatest individual PAP responses on 10m and 15m sprint performance was found. It appears that either moderate or heavy BHT exercises can induce a PAP response, but the effects may differ according to the recovery time following the potentiating stimulus and the individual's strength level.

The analysis of the main effects induced by the two PAP protocols revealed significant improvements in the 10m and 15m sprint performances following the two potentiation regimens. *Large to extremely large* effect sizes were noted for sprint time changes over 10m ($d=-0.83$ to -1.08 for 50PAP and $d=-0.95$ to -1.27 for 85PAP, respectively) and 15m ($d=-0.95$ to -1.33 for 50PAP and $d=-1.24$ to -1.37 for 85PAP, respectively). The novelty of the present study in using BHT exercises to induce a PAP effect on sprint performance, makes a direct comparison with the literature difficult. Nevertheless, the main findings of this study can be compared with those of other investigations designing different CA, thus accounting for differences due to the used protocols. In the study of McBride et al., (2005), fifteen NCAA football players were able to potentiate their 10m sprint performance at 4min following either heavy-load squats (3 repetitions at 90% of 1RM) or loaded countermovement jumps (3 repetitions with 30% of 1RM in squat exercise). Similarly, Winwood and colleagues (Winwood, Posthumus, Cronin, & Keogh, 2016), highlighted the effectiveness of a sled pull exercise performed by rugby players and loaded with 75% body mass in improving 10m sprint performance at both 4min and 8min following the CA. Turner et al. (2015) reported improved 10m sprint performance of trained males at 4min and 8min after performing plyometric exercises (3 sets of 10 alternate-leg bounds, either with or without an additional load equal to 10% of body mass). It is worth noting that compared to the present study, McBride et al. (2005), Winwood et al. (2016) and Turner et al. (2015) reported smaller effect sizes after the respective conditioning stimulus (ES=0.18 to 0.27 and ES=0.22 to 0.24 ES=0.32 to 0.39, respectively), while in their meta-analysis, Seitz and Haff et al. (2016) found a greater sprint PAP effect (ES= 0.51). These differences may be due to variables influencing both the occurrence and

magnitude of PAP, including the characteristics of the CA (Dello Iacono et al., 2016; Seitz et al., 2017; Wilson et al., 2013) and the individual training experience (McBride et al., 2005; Seitz & Haff, 2016).

Our findings are in line with both the principle of specificity and the force vector hypothesis (Dello Iacono et al., 2016; Dello Iacono, Martone, Milic, Padulo, 2017; Kawamori et al., 2013; Morin et al., 2011). Several authors have previously identified the key mechanical factors for successful performance in short-distance sprints. Kawamori et al. (2013) highlighted that the net horizontal GRF impulse normalised to body mass was the major determining kinetic factor of the change in horizontal velocity of an athlete during ground contacts of sprint tasks. Morin and colleagues (2011) have shown that sprint performance is highly correlated with horizontal force output directed antero-posteriorly, suggesting that both higher amounts of horizontal GRF and an optimal horizontal-to-vertical force ratio may represent the mechanical prerequisites for successful sprinting performance. The physiological explanation of our results relies on the findings of Contreras and colleagues (Contreras, Vigotsky, Schoenfeld, Beardsley, & Cronin, 2015), who showed that the BHT exercise elicits similar knee extensors' and greater hip extensors' EMG amplitude responses compared to the squat exercise. Specifically, the authors reported that the BHT activates the gluteus muscles (mean (69.5 vs. 29.4%) and peak (172 vs. 84.9%)) for upper gluteus maximus, mean ((86.8 vs. 45.4%) and peak (216 vs. 130%) lower gluteus maximus, respectively), and biceps femoris (mean (40.8 vs. 14.9%) and peak (86.9 vs. 37.5%)) to a greater degree than the back squat. Moreover, as stated above, the direction of the resistance force vector relative to the body during CA, addressed to enhance similarly-oriented functional performances, appears to play a key role in transference effects (Dello Iacono et al., 2016; Dello Iacono et al., 2017). In light of this evidence, and considering that the bi-articulate muscles of the lower limbs are well known to be determinants of multi-joint movements such as accelerations and sprinting (Jacobs, Bobbert, van Ingen Schenau, 1993), it is reasonable that both BHT-based PAP protocols may have produced

acute biomechanical adaptations and associated short-term transfer effects which, in turn, led to enhancement in sprinting times.

To the best of our knowledge, there is only one published study reporting BHT 1RM data of an athletic population that investigated the effects of a resistance training programme that included BHT exercises on acceleration and sprint capabilities (Contreras et al., 2017). Specifically, Contreras et al. (2017) found that young athletes (range 14-17 years), with a BHT 1RMs of 113.5 ± 23.6 kg and no previous hip thrusting experience, were able to improve their 10m and 20m sprint performances after 6-weeks of training that included a 3RM BHT protocol. Accordingly, there is clear evidence for the positive chronic effects of BHT training on acceleration and sprint capabilities (Contreras et al., 2017). In the current study, our sample was represented by elite handball players with 1RMs values of 183.4 ± 8.8 kg. Interestingly, we found large correlations between BHT 1RMs levels and the best improvement in sprint performances over 10m and 15m. (Figure 2). These relationships might be explained by the kinematical similarities between the CA and the crouched position both at the start line and for the few initial steps of the sprinting task. In addition, longer contact times in the first steps of the may also represent an advantage for applying greater forces aimed at accelerating the body horizontally. Consequently, as shown in Figure 2, it is clear that higher strength levels in the BHT represent a physical prerequisite providing favorable advantages when performing acceleration and sprint actions.

The temporal profile of PAP effects showed the greatest enhancements were induced after 8min of recovery (Figure 1), despite the fact that significant and meaningful effects were achieved after at least 4min (Table 1). This is in line with the data presented by Wilson et al. (2013), who reported greater levels of potentiation after 3-7 and 7-10min of recovery post CA. In their recent meta-analysis, Seitz and Haff (2016), reporting on the influence of the rest period between the CA and subsequent performance on PAP, highlighted that the greatest PAP effect is elicited after at least 5min post CA following traditional conditioning exercises, performed at high and moderate intensities similar to those used in our study. The same authors also suggested that high-intensity

loads may be more effective than moderate-intensity loads for inducing potentiation, due to the higher recruitment of higher-order (type II) motor units (Gullich & Schmidtbleicher, 1996), which represents one central level mechanism underpinning PAP especially amongst stronger individuals. The results of the current study confirm the aforementioned evidence; significant and meaningful (Table 3) differences between the two PAP protocols (heavy vs. moderate loads) were found for the 10m sprint performances after both 4min and 8min, and for the 15m sprint performance after 4min (Figure 1A-B). Due to the limitation of our study that EMG recordings were not obtained, we cannot draw clear conclusions as to the potential neurophysiological mechanism for the observed improvement in sprint performance following the two PAP regimens at the different time points. Theoretically, given the relationship between fatigue and PAP, moderate-intensity PAP protocol elicits PAP without as much mechanical trauma as a heavier regimen, thus leading to faster effects over time. According to the theory of Banister and colleagues (Banister, Carter, & Zarkadas, 1999), after a heavy conditioning exercise fatigue may occur both as a consequence of biochemical adaptations, like the depletion of available substrates (Dawson et al., 1997), and due to neuromuscular detrimental effects, which negatively affect subsequent twitch contractions (Seitz & Haff, 2016; Tillin & Bishop, 2009; Wilson et al., 2013). In this regard, since the fatigue-PAP relationship is proportional to the previous CA intensity, with greater detrimental effects for progressive higher intensity (Tillin & Bishop, 2009), it could be postulated that a moderate-intensity PAP protocol elicit potentiation without as much neuromuscular impairment and mechanical trauma as a heavier regimen, thus leading to tendential lower but parallel effects over time. This assumption could also explain the *very likely* and *likely* greater decreases in 10m and 15m sprint performance, respectively, when comparing the 85PAP with the 50PAP at the 15s time point. Although the maximal activation of the musculature is the key component in inducing PAP phenomena, the greater intensity of the 85PAP protocol in comparison to the 50PAP may have produced higher mechanical loads and caused the athletes to experience a greater degree of fatigue immediately after the protocol's completion (Sale, 2002). Our results suggest that a cumulative

fatigue occurred due to the fact that the 85PAP inhibited the PAP mechanisms immediately after the its execution, thus impairing the subsequent sprinting performances at 15s time point. Again, considering that no physiological measurements were taken in the current study, the underlying adaptations remain hypothetical and ought to be addressed in future investigations. Another limitation that should be considered is that the adopted research design, including a homogeneous group of elite handball players and the lack of a parallel control group, may limit the opportunity to make broader generalisations to other populations represented by different age groups or athletes of different levels or gender. Still, the data are useful in identifying general trends from the results. Moreover, the lack of a matched control group does not permit exclusion of the possibility that the sprints themselves, performed at the different post-time points, were inducing some form of potentiation effects on subsequent trials. However, in consideration of the theoretical model of the interaction between PAP and fatigue, the current literature (Seitz & Haff, 2016; Wilson et al., 2013) suggests that to induce potentiation, at least one overloading condition must be present with regard to the load volume and intensity of the CA. If both the load volume and intensity of the CA are low, it is likely that a neither an amount of fatigue nor any potentiation effect may be realised. Relying on this evidence and in line with other studies using a similar design (Bevan et al., 2010; Kilduff et al., 2007), we may exclude the idea that a single sprint performed at the post-time points may have affected the subsequent performances. Finally, the lack of within-group strength differences for the BHT 1RMs did not allow for a clear analysis of the theoretical advantages of stronger individuals over weaker ones in likely exhibiting greater levels of PAP (Seitz & Haff, 2016; Wilson et al., 2013). However, the population from which well-trained handball players can be drawn – belonging to the same team and with a common conditioning background – is limited, and therefore the logistical constraints associated with the experimental designs dictated the approach we utilised. Indeed, it is recommended that future studies consider investigating participants with different conditioning backgrounds (e.g. BHT training experience) and strength levels in order to further understand the influence of these factors in modulating the PAP effects.

The findings of the current study present meaningful applications with ecological validity, since both initial acceleration and sprint ability have been found to be athletic discriminators of elite handball players (Povoas et al., 2012). In fact, the distances between 10m and 13m appeared to be the most relevant to be assessed and consequently to be improved, due to the high frequency of short, high-intensity sprints during a handball game (Karcher & Buchheit, 2014). Therefore, the present outcomes offer insights into the possibility of practical applications of training regimens similar to the designed PAP exercises, as either warm-up strategies aiming to acutely improve subsequent functional performances or as part of a complex programme of sprint training.

Conclusions

The present study suggests that both 10 and 15m sprint times in handball players are potentiated after a BHT conditioning activity loaded with either 50% or 85% of 1RM. To note, the significant and meaningful differences between the two protocols observed at the different time points, suggest that the time course of the sprint PAP effect, induced by heavy or moderate loaded BHT exercises, may differ according to the recovery. Another important finding is that the ability to express a sprint PAP effect over 10m and 15m is largely mediated by the individual strength level with greater PAP effects positively correlated with higher BHT 1RM levels.

Strength and conditioning professionals can use either a moderate or heavy BHT conditioning activity to potentiate subsequent 10 and 15m sprint performances. They should provide 4 to 8min of recovery to observe a PAP effect, with 8min providing the greatest effect. In order to optimise the sprint PAP effect, they should consider developing adequate strength levels since stronger individuals are more likely to express a greater sprint PAP response.

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Figure captions

Figure 1. Plot of the time course effects following the two PAP protocols on 10m (A) and 15m (B) sprint performances. * means statistical significance compared to baseline following the 50PAP protocol; # means statistical significance compared to baseline following the 85PAP protocol; § means statistical significance between the two protocols. Data are presented as mean \pm SD.

Figure 2. Correlation plot between the BHT – 1RM (kg) values and the greatest individual PAP effect on 10m (A, black dots) and 15m (B, black triangles) sprint performances.