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Hip thrust-based PAP effects on sprint performance of soccer players: heavy-loaded versus optimum-power development protocols

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ABSTRACT
This study aimed to investigate the acute effects of two barbell hip thrust-based post-activation potentiation (PAP) protocols on subsequent sprint performance. Using a crossover design, eighteen soccer athletes performed 5 m, 10 m, and 20 m sprints before and 15 s, 4 min, and 8 min after two PAP protocols. The PAP conditioning activities consisted of hip thrust exercises loaded with either 85% 1RM or a load for optimum power development. The resulting 5 m and 10 m sprint performances were impaired at 15 s following both protocols. At 4 min and 8 min, meaningful improvements were observed for the three sprint distances following both of the protocols. Meaningful differences were found when comparing the two PAPs over time: greater impairments in 5 m and 10 m following the 85% of 1 RM protocol after 15 s, and greater improvements in all sprint distances after 4 min and 8 min following the optimum power development protocol. Positive correlations between the hip thrust's 1RM and power values and the overall individual PAP responses were found. This investigation showed that both heavy-loaded and optimum-power hip thrust exercises can induce a PAP response, with the optimum-power development protocol preferred due its higher efficiency.

ARTICLE HISTORY
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KEYWORDS
Musculoskeletal; strength; team sport; training

Introduction

The ability to develop high levels of muscular force and power has been extensively considered as an essential neuromuscular component of key tasks (Dello Iacono, Martone, & Padulo, 2016; Morin, Edouard, & Samozino, 2011), such as acceleration and sprinting commonly performed in team sports like soccer. In light of the intermittent high-intensity profile of the soccer practice (Stolen, Chamari, Castagna, & Wisloff, 2005), and the growing physicality required for participating at elite levels of soccer competitions (Barnes, Archer, Hogg, Bush, & Bradley, 2014), acceleration and sprint-type activities are considered to be crucial prerequisites for successful performance (Carling, Le Gall, & Dupont, 2012). Barnes and colleagues (Barnes et al., 2014) have recently reported on longitudinal changes of the soccer match's physical demands in the English Premier League, highlighting a substantial increase of short, explosive (i.e., acceleration) and leading sprints from the 2006–2007 to the 2012–2013 seasons. These activities account for only 3–5% of the total distance covered during in a soccer match (Carling et al., 2012; Dello Iacono, Martone, Cular, Milic, & Padulo, 2017), but despite their infrequent nature they commonly take place during significant moments like goal situations by both the scoring and the assisting players (Faude, Koch, & Meyer, 2012). Therefore, if soccer players are required to perform a greater number of shorter explosive sprints and also attain higher maximal speeds (Barnes et al., 2014), then their acceleration capabiliy should be adequately developed, and practitioners must design and implement appropriate conditioning exercises. Consequently, training methods aimed at improving an athlete's neuromuscular capabilites, and in turn inducing chronic adaptations of the neuro-musculoskeletal system, have received significant attention in the sport science literature (Loturco, Pereira, Kobal, Zanetti, Kitamura, et al., 2015; Markovic & Mikulic, 2010; Ramirez-Campillo et al., 2015). Furthermore, according to the known phenomenon called post-activation potentiation (PAP) (Sale, 2002), training methods employing resistance exercises should also be used for acutely enhancing sprinting tasks. The practical applications of PAP-based training regimens have implications for either warm-up strategies aiming to improve subsequent functional performances, or for serving as part of a complex programme of sprint training (Kotzamanidis, Chatzopoulos, Michailidis, Papaiakovou, & Patikas, 2005).

Besides the physiological (Tillin & Bishop, 2009) and training (Seitz & Haff, 2016; Wilson et al., 2013) variables influencing the PAP responses, a recent body of research (Dello Iacono et al., 2016; Seitz, Mina, & Haff, 2017) confirmed both the relevance of the force vector theory and the principle of movement specificity (Kawamori, Nosaka, & Newton, 2013; Morin et al., 2011) between the conditioning activity (CA) and the subsequent functional performance. Very recently, Dello Iacono, Padulo, and Seitz (2017) reported a potentiation effect on both 10 and 15 m sprint times in handball players after a barbell hip thrust (BHT) conditioning activity with either moderate (50% of one-repetition maximum (1RM)) or heavy (85% of 1RM) loads. The authors, confirming the existing literature (Chiu et al., 2003; Seitz & Haff, 2016), concluded that heavy-loaded consitioning activities are recommended for optimizing the PAP effects, and that individuals with higher

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strength levels were able to exhibit a greater PAP effect. Therefore, traditional PAP protocols – those using external loads – imply the need to first assess an athlete`s 1RM and then to determine the effective load for enhancing the subsequent functional performance. However, this procedure is not common in soccer training routines; it would probably be very time-consuming for large groups of individuals, and in addition may expose those being tested to increased risk of injury (Loturco, Nakamura, et al., 2016).

In practical terms, an optimum load for power development can be easily determined and used for conditioning purposes (Cormie, McGuigan, & Newton, 2011; Morin & Samozino, 2016). Accordingly, it determines the optimum range of loads by measuring the bar velocities during the movements through the use of portable and cost-effective linear position transducers (Cronin, Hing, & McNair, 2004; Loturco, Pereira, Kobal, Zanetti, Gil, et al., 2015, Loturco, Pereira, Kobal, Zanetti, Kitamura, et al., 2015). To date, soccer practitioners have a good understanding of the exact procedures required to induce enhanced performance using the optimum power zone approach during half-squats, jump-squats, or resisted sprints (Loturco, Pereira, Kobal, Zanetti, Kitamura et al., 2015; Morin & Samozino, 2016). In summary, soccer players can achieve performance improvements by slightly manipulating the training load within the optimum power zone (Loturco, Nakamura, et al., 2016, Loturco, Pereira, et al., 2016; Loturco, Ugrinowitsch, Tricoli, Pivetti, & Roschel, 2013).

However, research still needs to be carried out to verify whether the same approach could be applied to the BHT exercise. The BHT is a bridging exercise used to target the hip extensors' and knee flexors' musculature, and it is growing in popularity among applied practitioners and exercise scientists (Contreras, Vigotsky, Schoenfeld, Beardsley, & Cronin, 2016; Dello Iacono, Padulo, et al., 2017). Hip extensors' and knee flexors' strength and power capabilities are well known to be determinants of multi-joint athletic movements that involve acceleration and sprinting (Jacobs, Bobbert, & van Ingen Schenau, 1993). Accordingly, confirming evidence of the applicability of BHT exercise for acutely enhancing acceleration and sprinting tasks among soccer players may support its valid and alternative use as a training intervention for soccer coaches and conditioning trainers.

Moreover, while the evidence suggests that a heavy preload stimulus represents the ideal loading condition for PAP applications, no data are available regarding either the influence of optimum-power-based BHT protocols or comparisons between heavy- load BHT and optimum-power-based BHT on the magnitude of any PAP response. Finally, the hypothesis that individuals with higher power outcomes are able to exhibit a greater PAP effect has yet to be tested under experimental conditions (Cormie et al., 2011; Morin et al., 2011).

Therefore, the primary purpose of the present study was to investigate the effects of BHT-based PAP protocols with either optimum-power or heavy loads on subsequent sprint performance amongst young soccer players. It was hypothesised that both of these BHT-based protocols would induce positive acute PAP effects, due to the high similarity between this conditioning activity and the functional sprinting task. Finally, we aimed to verify whether individuals with higher BHT strength and power levels are able to express any PAP effects to a greater degree over time in comparison with teammates presenting lower mechanical capabilities.

Methods

Participants

The sample size was determined *a priori* by G*Power Software (G*Power software, v.3.0.10), assuming maximal chances of 0.5 and 25% of type I and type II errors and based on similar studies performed with top-level soccer players (Loturco, Nakamura, et al., 2016, Loturco, Pereira, Kobal, Zanetti, Gil, et al., 2015) using 5 m, 10 m, and 20 m sprint performance changes as the main outcomes. Hence, 18 elite male soccer athletes (age 19.3 ± 0.2 years; height 178.3 ± 3.2 cm; body mass 76.2 ± 3.1 kg; BHT 1RM 181.4 ± 9.6 kg), members of the U-19 football team, volunteered to participate in the study. The players had at least four years of high-level soccer practice and at least three years of resistance training experience. They trained once a day for about 75–90 min, five days per week, undergoing technical, tactical, strength, and speed training. In addition, the whole sample presented at least two years (2.1 ± 0.3 y) of BHT training background, since this exercise was included and prescribed as a part of the weekly resistance training programme. Written informed consent was obtained from the athletes after they received an oral explanation of the purposes, 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 (PPAP and 85PAP) PAP protocols on subsequent 5 m, 10 m, and 20 m sprint performances. The athletes completed: two familiarisation and two experimental sessions, including a standardised warm-up; baseline sprint assessment; a PAP stimulus based on either the PPAP or 85PAP protocol; and, sprint reassessment after 15 s, 4 min, and 8 min of passive recovery (Kilduff et al., 2007), in order to profile the potentiation effects. The order in which the protocols were completed was counterbalanced and determined by block randomisation (www.random.org). The following formula was used to equate the BHT workloads between the two experimental trials:

Load volume = load × repetitions (Dello Iacono, Padulo, et al., 2017)

In detail, the coefficient ratio $\left(\frac{85PAP}{PPAP}\right)$ between the two loads, calculated for the 85PAP and PPAP protocols, was used to determine the number of repetitions the athletes had to perform during the potentiation protocols, and to approximately equate the volume between conditions. For example, considering a given subject with a BHT 1RM equal to 160 kg and nominal loads for the 85PAP and PPAP of 136 kg and 100 kg, respectively, the load volumes between the two protocols were equated as follow:

Coefficient ratio: 136/100 = 1.36;

85PAP protocol: three sets of six repetitions with a load of 136 kg (3 × 6 × 136 = 2448 kg);

- PPAP protocol: three sets of eight (six × coefficient ratio) repetitions with a load of 100 kg (3 × 8 × 100 = 2400 kg).

All tests were performed on the same regular field, at the same time of the day (4:00 p.m.–8:00 p.m.), and in similar ambient conditions of temperature (22.2 ± 0.5°C) and relative humidity (60 ± 3.5%). In order to prevent an unnecessary fatigue effect, players were instructed to avoid intense training 24 h prior to each day of testing, were prohibited from consuming any known stimulant or depressant substances for 24 h before testing, and were instructed not to eat for 2–3 h before each testing session.

Procedures

Two weeks and one week before the initiation of the study, the athletes attended two familiarisation sessions in order to become acquainted with the experimental procedures and to assess the reliability of the measures. On the same occasions, both the BHT 1RMs and optimum BHT power load were estimated. At each session, the athletes first performed a 10-min general warm-up consisting of various dynamic mobilisation exercises for the lower body musculature. Then, three specific warm-up sets with progressively heavier barbell loads were performed. Finally, each participant performed additional submaximal repetitions, and the individuals' 1RMs were then estimated according to Baechle and Earle (2008).

BHT assessments and PAP protocols

The optimum BHT power load was assessed through the BHT exercise performed on a Smith machine (Technogym Equipment, Italy). In accordance with Contreras, Cronin, and Schoenfeld (2011), the BHT exercise was performed by having the participant's upper back rest on a bench, as recently described by Dello Iacono et al. (2017). The athletes were instructed to execute three repetitions at maximal velocity with progressive loads, starting at 50% of their body mass. Prior to each power assessment, a test administrator instructed the participant to maintain constant downward pressure on the barbell throughout the execution, to prevent the bar from moving independently of the body (Cormie, McBride, & McCaulley, 2007). An additional load of 20% of body mass was gradually added in each set until a decrease in BHT mean propulsive power was recorded. This was observed after five to six sets on average. A 5-min interval was provided between sets. To determine BHT power measures, a linear transducer (T-Force, Dynamic Measurement System; Ergotech Consulting S.L., Murcia, Spain) was attached to the bar on the Smith machine and the method for determining the optimum BHT power load, as previosly described by Loturco, Pereira, Kobal, Zanetti, Gil, et al. (2015), was followed. Specifically, the optimum BHT power load was determined considering the maximum value of MPP collected during the assessment trials with incremental loads. We considered the BHT mean propulsive power and the correspondent optimum load for the PPAP used in the experimental procedures. In addition, we also considered the BHT peak power, calculated as the product between the instantaneous force and the vertical velocity of the moving bar (Sanchez-Medina & Gonzalez-Badillo, 2011). These measures were calculated using the commercial software provided by the manufacturer in conjunction with the device. In order to avoid misinterpretation of the power outputs, and taking into consideration the influence of body mass on its calculation, we normalized both the BHT mean propulsive power and the peak power values by dividing the absolute power value by the body mass (BHT relative power = $W{\cdot}kg^{-1}$) for data analysis purposes. Test-retest reliability for BHT 1RMs, BHT mean propulsive power, peak power, and optimum power load outputs, as measured by the coefficient of variation, were all <5%. Following the familiarisation session, the athletes reported to the sport hall for the PAP trials on two separate occasions separated by 72 h. As for the BHT PAP protocols, the participants performed either three sets of six repetitions of 85PAP (154.2 ± 8.2 kg) or three sets of eight repetitions (range: 7–9) of PPAP (118.2 ± 13.6 kg), based on their individual BHT assessment outcomes, for matching the total load volume according to the calculation described above. The rest period between sets was 2 min (Dello Iacono, Padulo et al., 2017). One researcher and one coach supervised all exercises and provided appropriate motivation.

20-m sprint test

The sprints were measured using electronic timing gates (Microgate Photocell, 0.001 s accuracy, Bolzano, Italy) positioned at the start line and 5 m, 10 m, and 20 m from the start line. The sensors were positioned 0.5 m above the ground. During each experimental session the players performed a standardised warm-up, including athletic drills followed by four bursts of progressive accelerations over 20 m, and one 20 m sprint with maximal effort interspersed by 1 min of passive recovery. Two minutes after the end of the warm-up, the athletes completed four maximal 20 m sprints with 2 min of recovery in-between. All athletes initiated the sprint in their own time, from a semi-crouched position with the front foot 20 cm 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 20 m sprint with maximal effort at 15 s, 4 min, and 8 min. The fastest sprint times recorded 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.

Statistical analysis

All data are presented as means ± 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), while the intra-day reliability was expressed as a Coefficient of Variation (CV%) (Hopkins, 2000). The Cohen's *d* was used to assess effect size (ES), and the magnitude of differences were considered as trivial (<0.20), small (0.20–0.49), moderate (0.50–0.79), or large (>0.80). In order to provide normative cues for the performance changes, the data were analysed using the approach based on the magnitudes of changes (Hopkins, 2000).

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, Marshall, Batterham, & Hanin, 2009). For the comparisons of the sprint time change scores at different post-PAP time points between the PPAP and 85PAP, the difference was considered unclear if the chances of having both positive/greater increase and negative/greater decrease were >5% according to the mechanistic interpretation of the magnitudine based inference approach (Hopkins et al., 2009). Correlations between either the BHT 1RMs or peak power values and the individual overall changes of sprint performances, separately for 5 m, 10 m, and 20 m distances, were assessed using Pearson's product-moment correlation coefficients. The qualitative magnitude of associations was reported according to Hopkins et al. (2009). The alpha test level for statistical significance level was set at $P \leq 0.05$. Statistical analysis was performed using SPSS Statistics 24 software (SPSS Inc., Chicago, IL, USA).

Results

At baseline all the sprint scores showed highly reliable inter-day and intra-day data, with the ICC ranging from 0.863 and 0.982, and CVs ranging from 2.28% to 4.12%, respectively. Moderate to large ESs were noted for sprint time changes over all the three distances with $d = -1.77$ to -2.19 for PPAP and $d = -1.22$ to -1.59 for 85PAP over 5 m; $d = -2.09$ to -2.66 for PPAP and $d = -1.01$ to -1.39 for 85PAP over 10 m; and, $d = -0.98$ to -1.34 for PPAP and $d = -0.54$ to -0.73 for 85PAP over 20 m. Meaningful differences following the PAP protocols were evident, as supported by the qualitative outcomes reported in Table 1. In light of the improvement in 5 m, 10 m, and 20 m performances at both the 4 min and 8 min time points (Figure 1), there were *likely* to *most likely* beneficial effects and *possibly* to *most likely* beneficial effects after performing the PPAP and 85PAP, respectively. The comparison over time between the two PAP protocols suggested that there were *most likely* greater decrements in 5 m and 10 m performaces at 15 s following the 85PAP (Figure 1). Conversely, *most likely* greater performance improvements in 5 m and 10 m were observed following the PPAP after 4 min and 8 min, and *likely* to *very likely* greater performance improvements in 20 m after 4 min and 8 min, respectively (Figure 1).

When data were pooled for each individual athlete, the overall changes in sprint performances over 5 m (r = 0.453, P = 0.04), 10 m (r = 0.329, P = 0.05), and 20 m (r = 0.306, P = 0.05) were significantly moderately correlated to the BHT-1RMs scores (Figure 2(a–c). Finally, the BHT-relative peak power scores were highly and very highly correlated to the same overall changes in performances over 5 m (r = 0.735, P < 0.01), 10 m (r = 0.535, P = 0.02) and 20 m (r = 0.549, P = 0.02) (Figure 3(a–c)).

Discussion

The present study aimed to compare the effects of two BHT-based PAP protocols on sprinting performance in young soccer athletes. According to our main hypothesis, both protocols were effective in inducing improvements in sprint abilities, with the PPAP achieving meaningfully greater effects than the 85PAP. Compared to the baseline assessment, the profile of the potentiation effects showed enhancements after 4 min, while the optimal recovery time in achieving maximal benefits after both protocols was 8 min. Positive moderate to large correlations were found between the overall individual PAP responses in 5 m, 10 m, and 20 m sprint performance and between the BHT mechanical outputs.

Table 1. Effect sizes (ESs), and qualitative inferences between baseline and different time points following the PPAP and 85PAP protocols.

		ES			Qualitative Inference		
		Post-15s	Post-4min	Post-8min			
Protocol	Variable	Mean; 90% CI			Post-15s	Post-4min	Post-8min
PPAP	5 m	*Small* 0.29 0.27;0.83	*Large* −1.77 −1.09;−2.38	*Large* −2.19 −1.45;−2.82	*Possibly Harmful* 3.8/48.6/47.6	*Likely Beneficial* 82.1/17.9/0	*Very Likely Beneficial* 95.4/4.6/0
	10 m	*Small* 0.35 0.21;0.89	*Large* −2.09 −1.37;−2.72	*Large* −2.66 −1.85;−3.34	*Possibly Harmful* 1.2/59/39.8	*Most Likely Beneficial* 99.6/0.4/0	*Most Likely Beneficial* 99.8/0.2/0
	20 m	*Trivial* 0.12 0.43;0.67	*Large* −0.98 −0.38;−1.54	*Large* −1.34 −0.71;−1.92	*Unlikely Harmful* 6.7/73.8/19.5	*Most Likely Beneficial* 95.9/4.1/0	*Most Likely Beneficial* 99.7/0.3/0
85PAP	5 m	*Large* 1.59 0.93;2.18	*Large* −1.22 −0.60;−1.79	*Large* −1.59 −0.93;−2.18	*Most Likely Harmful* 0/0/100	*Most Likely Beneficial* 99.8/0.2/0	*Most Likely Beneficial* 99.9/0.1/0
	10 m	*Large* 1.53 0.87;2.11	*Large* −1.01 −0.41;−1.57	*Large* −1.39 −0.75;−1.97	*Most Likely Harmful* 0/0.1/99.9	*Most Likely Beneficial* 99.5/0.5/0	*Most Likely Beneficial* 100/0/0
	20 m	*Trivial* 0.18 −0.38;0.72	*Moderate* −0.54 −1.09;0.03	*Moderate* −0.73 −0.15;−1.28	*Unlikely Harmful* 4.5/70.7/24.8	*Possibly Beneficial* 66/33.5/0.5	*Likely Beneficial* 83.5/16.5/0

Note: Negative values represent positive changes to sprint time (i.e., faster sprint time) compared to baseline value; PPAP: experimental post activation potentiation protocol with optimum power load; 85PAP: experimental post activation potentiation protocol with a load of 85% 1RM; ES: effect size; CI: confidence interval.

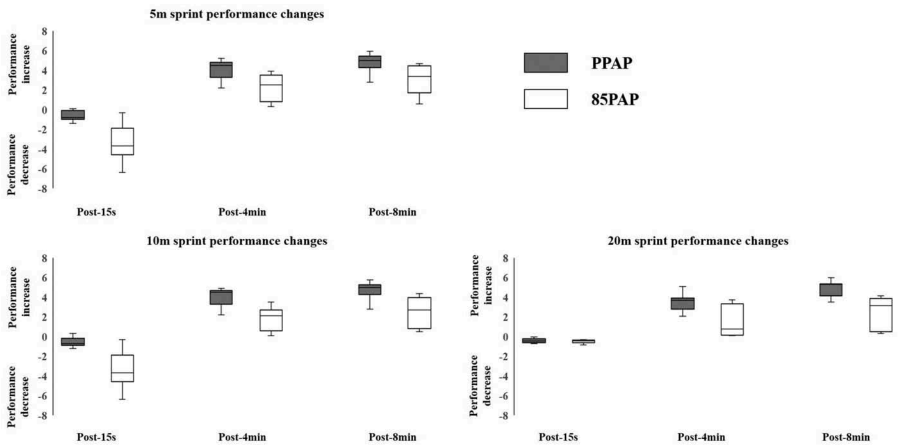

Figure 1. Box-and-whisker plot of the performance changes following the two PAP protocols at each post-intervention point.

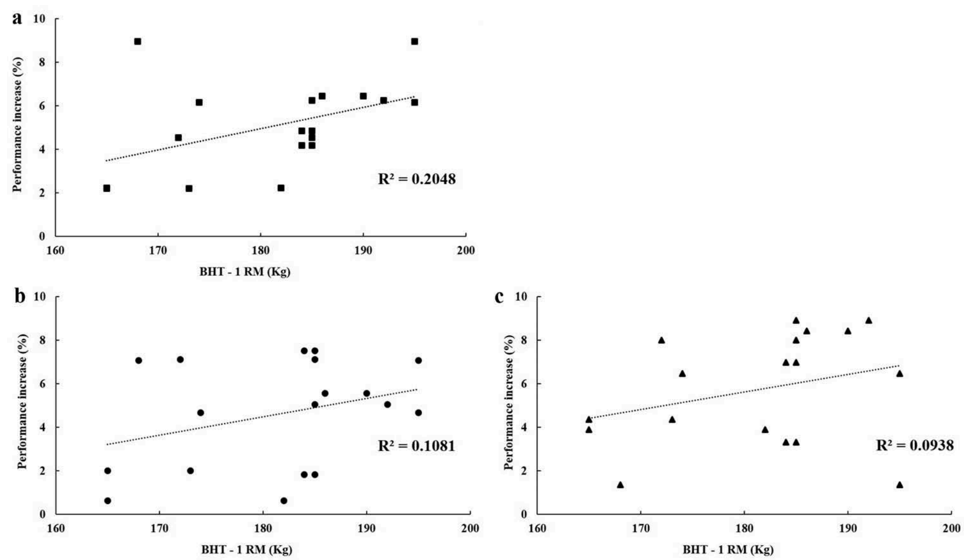

Figure 2. Correlation plot between the BHT – 1RM (kg) values and the individual PAP effect on 5 m (A, black squares), 10 m (B, black dots), and 20 m (C, black triangles) sprint performances.

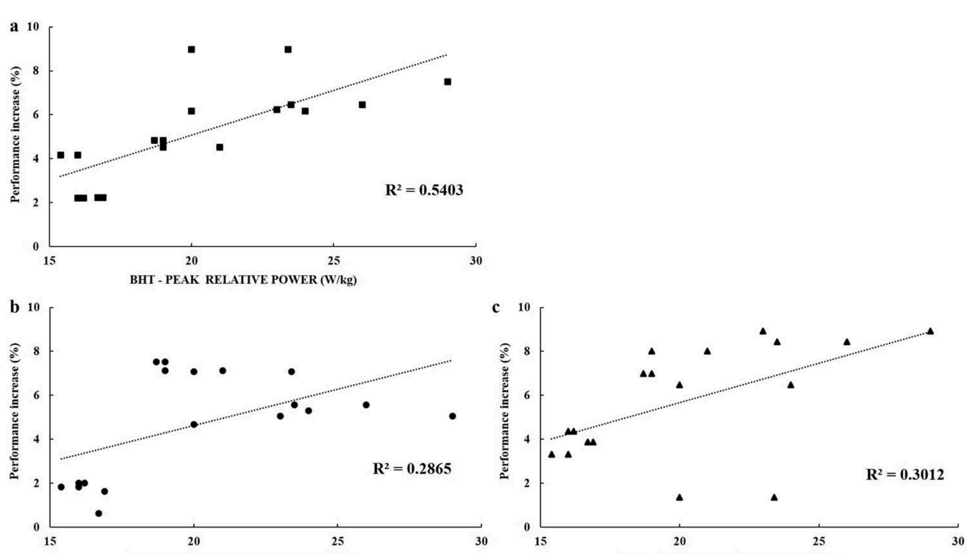

Figure 3. Correlation plot between the BHT – Relative Peak Power (W/kg) values and the individual PAP effect on 5 m (A, black squares), 10 m (B, black dots), and 20 m (C, black triangles) sprint performances.

The analysis of the main effects induced by the two PAP protocols revealed improvements in the 5 m, 10 m, and 20 m sprint performances following the two regimens after at least 4 min of recovery (Figure 1). In addition, moderate to large ESs were noted for sprint time changes over all three distances (Table 1). These results are in line with the recent findings of Dello Iacono et al. (2017), who reported similar ESs on sprint performance of handball players following either moderate or heavy-loaded BHT PAP protocols. The current findings seem to confirm both the principle of specificity and the force vector theory (Dello Iacono, Martone, Milic, & Padulo, 2017; Dello Iacono et al., 2016; Kawamori et al., 2013; Morin et al., 2011), which have previously identified the net horizontal ground reaction force (GRF) impulse normalised to body mass and the optimal horizontal-to-vertical force ratio as key mechanical prerequisites for successful performance in short-distance sprints. From a mechanical perspective, the bi-articulate muscles of the lower limbs (e.g., knee extensors and hip extensors), well known to be determinants of multi-joint movements such as accelerations and sprinting (Jacobs et al., 1993), may be highly recruited and involved throughout BHT exercises (Contreras et al., 2016). Indeed, the combination of a high neuromuscular recruitment of the relevant muscles involved in sprint tasks and a proper direction of the resistance force vector relative to the body during conditioning activity, may have produced acute beneficial biomechanical adaptations. These short-term adaptations then combined to make a high similarity between the conditioning activity and subsequent functional performances, and may have possibly induced transfer effects which, in turn, led to enhancement of sprinting times (Dello Iacono et al., 2016, Dello Iacono, Padulo et al., 2017).

The novelty of the present study was the use of a PPAP protocol based on the optimum training load (Loturco, Nakamura, et al., 2016) of the BHT exercise. Although direct comparisons with the literature are difficult, the findings of this study concerning the effectiveness of the PPAP can be compared with those of other investigations using different conditioning activities, thus accounting for differences due to the protocols used. In general, the use of the BHT exercise using the optimum power load approach appears to be preferebale over other PAP protocols. This consideration is justified by the relatively lower ESs (all ESs < 0.51) induced by a variety of conditioning activities commonly implemented to potentiate sprinting tasks, such as heavy-load squats (Bevan et al., 2010; McBride, Nimphius, & Erickson, 2005), loaded countermovement jumps (McBride et al., 2005), loaded sled-pull exercise (Winwood, Posthumus, Cronin, & Keogh, 2016), and either loaded or non-loaded plyometric exercises (Dello Iacono et al., 2016; Turner, Bellhouse, Kilduff, & Russell, 2015). However, this conclusion should be made with caution, given that such differences may be due to other variables influencing the magnitude of PAP, such as the subject`s fitness characteristics, the individual training experience (McBride et al., 2005), and strength levels (Seitz & Haff, 2016). Nevertheless, our outcomes support recent evidence about the advantageous effects of BHT PAP protocols in improving sprint tasks (Dello Iacono, Padulo et al., 2017).

Interstingly, meaningful differences between the two PAP protocols were found for the three sprint performances after both 4 min and 8 min, with the PPAP resulting in *likely* to *most likely* greater performance improvements in comparison to the 85PAP (Figure 1). Current research has reported that when perfoming shorter sprints (i.e., acceleration-only phases up to 10–20 m), the shorter the distance considered, the greater the relationship between sprint performance and maximal mechanical outputs development (Markovic & Mikulic, 2010; Morin et al., 2012, 2011). Thus, training programs designed to improve sprint-acceleration performance should focus on increasing power development by improving its force and velocity components. Considering this background, the most practical finding arising from this study is the possibility of applying the optimum-power approach for determining the optimum load that may be used for BHT PAP protocols aiming to enhance sprint performance. Accordingly, the training interventions could be individualized for pursuing optimal training outcomes and possibly limiting nonfunctional overloading, thus making this approach more efficient than those which consider percentages of the 1RM (Loturco, Pereira, Kobal, Zanetti, Gil, et al., 2015). The results of the current study confirm the last consideration; in addition to the differences between the two PAP protocols found for the 5 m, 10 m, and 20 m sprint performances after both 4 min and 8 min (Figure 1), *most likely* greater decreases in 5 m and 10 m sprint performance were observed when comparing the 85PAP with the PPAP at the 15 s time point. In this regard, since the fatigue-PAP relationship has proven to be proportional to the previous conditioning activity intensity, with greater detrimental effects for progressively higher intensity (Tillin & Bishop, 2009), it could be postulated that the PPAP protocol maximised potentiation, thus leading to transient lower fatigue and greater potentiation effects over time (Banister, Carter, & Zarkadas, 1999; Tillin & Bishop, 2009; Wilson et al., 2013).

The results highlight moderate and large correlations between the best improvement in sprint performances and the BHT 1RMs and BHT peak power levels, respectively (Figures 2 and 3). These relationships might be explained by the similar biomechanics between the conditioning activity and the crouched position, both at the start line and for the few initial steps of the sprinting task, when the ability to apply greater mechanical outputs aimed at accelerating the body horizontally represent an advantage. As shown in Figures 2 and 3, it is clear that higher strength and power levels in the BHT represent an individual physical prerequisite, providing a favorable advantage when performing acceleration and sprint actions. These results are in agreement with previous findings (Kilduff et al., 2007; Seitz, de Villarreal, & Haff, 2014) highlighting significant correlations between strength levels and PAP effects. Collectively, the current literature (Chiu et al., 2003; Jo, Judelson, Brown, Coburn, & Dabbs, 2010) conforms with the fact that the magnitude and the temporal profile of PAP are related to the individual's relative strength levels and to the ability to express fatigue resistance to heavier loads. In our study, more interestingly, the correlations between the sprint performance improvements and the BHT peak power were higher than those with the BHT 1RMs (Figures 2 and 3). This finding is not completely unexpected, and is in agreement with those biomechanical analyses of sprinting which report that short-distance sprint is highly dependent on the subject´s ability to generate powerful actions of the lower limb muscles (Mero, Komi, & Gregor, 1992). The underlying physiological explanation may depend on the nature of the skeletal muscle fiber characteristics. Specifically, it is well documented that individuals with greater muscle power levels display elevated myosin light chain phosphorylation, and also tend to have larger and stronger type II muscle fibers (Hamada, Sale, MacDougall, & Tarnopolsky, 2000; Tillin & Bishop, 2009). Additionally, type II muscle fibers exhibit a greater neural excitation in response to high-intensity resistance training exercises, such as those typically used as conditioning activity in potentiation complexes. Therefore, the present study suggests that when designing PAP strategies, it is important to consider not only the athletes' strength levels, but also and mainly the power capabilities that may play a role in determining the magnitude and profile of the PAP effects.

As the first limitation of this study, it is worth mentioning that the adopted research design, including a homogeneous group of elite soccer 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 by athletes of different levels or gender. Still, the data are useful in identifying general trends from the results. In addition, the population from which well-trained soccer 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. 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 effect 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 conditioning activity. If both the load volume and intensity of the conditioning activity are low, it is unlikely that an amount of fatigue or any potentiation effect will 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 eliminate the idea that a single sprint perfomed at the post-time points may have affected the subsequent performances.

In conclusion, it appears that either heavy-loaded BHT or optimum-power exercises can induce a PAP response leading to sprint performance improvements among soccer players. The meaningful differences between the two protocols observed at the different time points, suggest that the profile of the PAP effect may differ according to the protocol used and the recovery time. Another novel finding is that the ability to express PAP response is largely mediated by the individual strength and power levels, with greater PAP effects on sprinting tasks positively correlated with higher BHT 1RM and peak power scores.

Soccer practitioners can use either a moderate or optimum-power BHT conditioning activity to potentiate subsequent 5 m, 10 m, and 20 m sprint performances, but the optimum-power approach should be considered as the preferred protocol due its higher efficiency. They should provide 4–8 min of recovery to observe a PAP response; and in order to optimise the sprint PAP effect they should consider developing adequate strength and power levels, since stronger and more powerful individuals are more likely to express a greater sprint PAP response.

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