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ORIGINAL ARTICLE

Priming exercise increases Wingate cycling peak power output

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Abstract
Purpose: The aim of the present study was to investigate the effect of priming exercise on Wingate performance and fatigue. Methods: Twelve recreationally active young male volunteers participated in the study (age: 25 ± 5 years; weight: 75.0 ± 7.5 kg; height: 177 ± 6 cm; BMI: 24.0 ± 1.7). During a first visit, participants performed a typical $\dot{V}O_{2max}$ test and a supramaximal assessment of $\dot{V}O_{2max}$ on a cycle ergometer, while during the next three visits, the participants performed in a random order a Wingate test (i) with no priming exercise, (ii) after priming exercise followed by a 15-min recovery (Priming15) and (iii) after priming exercise followed by a 30-min recovery (Priming30). Priming exercise lasted 6 min, at work rate corresponding to the gas exchange threshold (GET) plus 70% of the difference between the GET and $\dot{V}O_{2max}$. Results: The Priming 30 condition exhibited greater peak power output (595 ± 84 W) compared to the control (567 ± 85 W) and the Priming15 condition (569 ± 95 W) ($P < .05$). Regarding fatigue index, a tendency towards increased resistance to fatigue was observed in the Priming30 condition compared to the control and the Priming15 conditions ($P = .072$). Pre-Wingate lactate levels were found to be significantly different between the Priming15 (7.18 ± 3.09 mmol/L) and the Priming30 (4.87 ± 2.11 mmol/L) conditions ($P < .05$). Conclusions: Priming exercise of high intensity followed by a prolonged recovery leads to increased peak power in a subsequent Wingate test. Moreover, our data are consistent with the idea that a priming exercise-induced modest increase in blood lactate concentration at the onset of the following criterion bout is a key factor of performance.

Keywords: *Anaerobic performance, blood lactate, fatigue index, plateau* $\dot{V}O_{2max}$*, recovery*

Highlights
- It is unknown whether high-intensity priming exercise affects performance in a subsequent Wingate exercise test.
- We report that priming exercise increases Wingate cycling peak power output.
- The important parameters that determine the ergogenic effect of priming exercise are: i) the adequate interval (30 min) and ii) the moderately increased blood lactate concentration (≈4.5 mM).

Introduction

Priming (or prior) exercise has been extensively investigated as an acute "warm-up" intervention to study the principal limiting factors to the $\dot{V}O_2$ kinetics during exercise (Grassi et al., 1996; Jones, Koppo, & Burnley, 2003). The vast majority of the literature has focused on the physiological responses during a subsequent exercise bout following priming exercise (i.e. faster overall $\dot{V}O_2$ kinetics) and the contribution of diverse potential underlying mechanisms, such as enhanced muscle oxygen supply due to greater muscle vasodilatation, intramuscular enzyme kinetics, relief of muscle oxidative metabolic inertia and alterations in motor unit recruitment (Behnke, Kindig, Musch, Sexton, & Poole, 2002; Burnley, Doust, Ball, & Jones, 2002; Jones, Berger, Wilkerson, & Roberts, 2006; Jones et al., 2008; Krustrup, Gonzalez-Alonso, Quistorff,

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& Bangsbo, 2001; Lanzi, Borrani, Wolf, Gojanovic, & Malatesta, 2012). Beyond its usefulness as an experimental tool to study the mechanistic barriers of oxidative metabolism, priming exercise is also increasingly considered as a practice to enhance performance (Hajoglou et al., 2005). In fact, some studies have demonstrated that priming exercise increases exercise tolerance and improves performance possibly via increased aerobic (oxidative) contribution to energy turnover at the early stages of exercise coupled with a delay in the attainment of $\dot{V}O_{2peak}$, reducing thereby the magnitude of the muscle oxygen deficit (Burnley, Davison, & Baker, 2011; Burnley, Doust, & Jones, 2005; Gerbino, Ward, & Whipp, 1996; Jones, Wilkerson, Burnley, & Koppo, 2003; Miura et al., 2009; Palmer, Jones, Kennedy, & Cotter, 2009; Raymer, Forbes, Kowalchuk, Thompson, & Marsh, 2007; Silva et al., 2014). However, these findings are not indisputable, since some studies have also reported negative or neutral effects of priming exercise on exercise tolerance and on parameters of the muscular power-duration relationship (Ferguson et al., 2010, 2007; Heubert et al., 2005; Koppo & Bouckaert, 2002).

These contradictory findings can be potentially attributed to several methodological factors. In particular, characteristics related to priming exercise, such as intensity (moderate, high or severe), duration (from a single 30-s sprint up to 10 min) and mode (cycling or running) as well as the duration of the recovery period between the priming and the actual exercise test (from 2 up to 45 min) are key factors for the ergogenic potential of priming. Research during the last twenty years has revealed that using a power output equal to gas exchange threshold (GET) plus 70% of the difference (Δ) between GET and $\dot{V}O_{2max}$ (typically termed "70%Δ") for 6 min, combined with an extended recovery period (i.e. more than 15 min) seems to be the most appropriate protocol to induce a priming effect (Bailey, Vanhatalo, Wilkerson, Dimenna, & Jones, 2009; Ferguson et al., 2007; Vanhatalo & Jones, 2009; Wilkerson, Koppo, Barstow, & Jones, 2004). Interestingly, it has been noted that such a high or severe intensity priming exercise protocol, which initially increases blood lactate concentration with a subsequent reduction due to recovery to 2–3 mmol/L at the onset of the following exercise bout, leads to increased time to exhaustion (Jones, Koppo, et al., 2003; Koppo & Bouckaert, 2002; Palmer et al., 2009; Wilkerson et al., 2004).

Despite the fact that many priming exercise studies have used the upright cycle ergometry as an experimental model, to the best of our knowledge, none of them has evaluated the effect of priming exercise on Wingate peak and mean power outputs (Bearden & Moffatt, 2001; Burnley et al., 2002; Burnley, Jones, Carter, & Doust, 2000; Endo et al., 2004; Gerbino et al., 1996; Koppo & Bouckaert, 2001; Scheuermann, Hoelting, Noble, & Barstow, 2001). In addition, it is currently unknown whether priming exercise can also affect indices of muscle fatigue in a subsequent test. Thus, the aim of the present study was to investigate the effect of a 6-min 70%Δ priming exercise followed by either 15- or 30-min recovery on Wingate performance and fatigue. The two different recovery periods were chosen according to the existing literature, which suggests that recovery has to be extended (i.e. >15 min), while the priming and performance enhancing effects are preserved for at least 30–45 min (Bailey et al., 2009; Burnley, Doust, & Jones, 2006). It was hypothesised that prior exercise will improve peak performance and resistance to fatigue in a following all out supra maximum effort.

Methods

Participants

Twelve ($N = 12$) recreationally active young male volunteers participated in the study (age: 25 ± 5 years; weight: 75.0 ± 7.5 kg; height: 177 ± 6 cm; BMI: 24.0 ± 1.7). Study was limited to males in order to avoid any interference from the hormonal fluctuations during the menstrual cycle. Subjects were excluded from the study if they reported any musculoskeletal injury that would limit their ability to perform the exercise cycling sessions. Participants were asked to recall whether they had participated in regular resistance or aerobic training or in unaccustomed and/or heavy exercise during the week before the study entry. Individuals reporting such activities were precluded from the study. Smoking, coffee drinking and the use of supplements for the final five days prior to initiation of the study were additional exclusion criteria. Participants were instructed to abstain from any strenuous exercise during the study and were advised to refrain from ingesting anti-inflammatory or analgesic medications. A written consent was obtained from all participants, after they were informed of the procedures and risks of the study. The procedures were in accordance with the Helsinki declaration. The overall project was reviewed and approved by the institutional review board and the appropriate state authority (#1113/10-04-2019).

Study design

The participants visited the laboratory on four different occasions. During the first visit, anthropometric

and physiological measurements were performed and, afterwards, participants performed a typical $\dot{V}O_{2max}$ test and a supramaximal assessment of $\dot{V}O_{2max}$ on a cycle ergometer (Monark 827E, Vansbro, Sweden) according to Poole and Jones (2017). During the next three visits (with an interval of one week between each visit), the participants performed in a random order (i) a Wingate test with no priming exercise (control group), (ii) a Wingate test after priming exercise followed by a 15-min recovery (Priming15) and (iii) a Wingate test after priming exercise followed by a 30-min recovery (Priming30) (three-way crossover design). Absolute and relative (body mass-adjusted) peak and mean power outputs were measured during the Wingate test. Blood lactate measurements were performed at baseline, immediately post-priming exercise, before the Wingate test and 3 min after the Wingate test. Blood lactate was measured in capillary blood samples taken from a finger-prick using an automated analyser (Dr. Lange, LP20, Germany). The percent difference (i.e. decrease) of power between the first 5 sec and the last 5 sec during the Wingate test was used as fatigue index.

Exercise protocols

All exercise protocols were performed on cycle ergometers (Monark, Vansbro, Sweden).

Maximal rate of oxygen uptake. The $\dot{V}O_{2max}$ test was performed as follows: after a 5-min warm-up period at 100 W, work rate increased by 50 W every 2.5 min until heart rate reached 160 bpm. Then, work rate increased by 25 W every 2.5 min until exhaustion. The test was terminated either when a subject volitionally reached exhaustion or when the following three criteria were met: (i) a lower than 2 mL/kg/min increase in $\dot{V}O_2$ despite an increase in work rate, (ii) a respiratory exchange ratio greater than or equal to 1.10, (iii) heart rate within 10 bpm of the predicted maximal heart rate (220–age). Respiratory gas variables were measured via a metabolic cart (MedGraphics, CPX-D, Minnesota, USA), which was calibrated before each test using standard gases of known concentration. Fifteen min after the end of the first test, participants performed a constant work rate test at 110% of the peak work rate achieved on the incremental test by each participant individually. Despite the skepticism about the accuracy of this method to confirm the "true" $\dot{V}O_{2max}$ (Murias, Pogliaghi, & Paterson, 2018), it was used as an indirect index that a plateau was achieved during the incremental test to exhaustion. Indeed, the plateau was achieved during each test individually and was verified by the absence of changes in $\dot{V}O_2$ higher than 2.1 mL/kg/min during the last minute of each stage (Taylor, Buskirk, & Henschel, 1955). This approach has been recently described in detail by Poole & Jones (2017) to resolve the classic $\dot{V}O_2$-work rate plateau and has already been successfully conducted by different populations (Astorino, White, & Dalleck, 2009; Nolan, Beaven, & Dalleck, 2014; Sawyer, Tucker, Bhammar, & Gaesser, 2015; Weatherwax, Richardson, Beltz, Nolan, & Dalleck, 2016).

Priming exercise. The GET was determined as described in Beaver, Wasserman, and Whipp (1986) and in Bailey et al. (2009) based on three criteria: (i) the first disproportionate increase in rate of CO_2 production ($\dot{V}CO_2$) from visual inspection of individual plots of VCO_2 versus $\dot{V}O_2$, (ii) an increase in expired ventilation (VE)/$\dot{V}O_2$ with no increase in $\dot{V}E/\dot{V}CO_2$, (iii) the increase in end-tidal PO_2 with no fall in end-tidal PCO_2. The work rate that would require 70%Δ (i.e. GET plus 70% of the difference between the work rate at the GET and $\dot{V}O_{2max}$) was subsequently calculated.

Wingate. The Wingate test was briefly as follows: participants were pedaling with no brake on flywheel as fast as they could and, within three seconds, a load equal to 7.5% of their body weight was dropped instantly on the flywheel and the participants had to maintain maximal pedaling for 30 sec. The peak power and the mean power outputs along with their relative values produced during the Wingate test were used as performance measures.

Statistical analysis

A Student's t-test for paired samples was performed to compare the oxygen consumption values between the $\dot{V}O_{2max}$ test and the constant work rate test at 110% of the peak work rate achieved on the $\dot{V}O_{2max}$ test for the evaluation of plateau achievement. A one-way repeated-measures ANOVA test was performed to compare performance and fatigue in the Wingate test between the three experimental conditions (i.e. control, Priming15 and Priming30). A two-way ANOVA test [condition (control, Priming15 and Priming30) × time (baseline, post-priming, pre-Wingate and post-Wingate)] was used to compare the lactate values between the three experimental conditions. When a significant interaction was obtained, pairwise comparisons were performed through the Sidak test. When sphericity was violated, the Greenhouse-Geisser correction was applied. The statistical power analysis was equal to

0.96 and it was calculated using G*Power 3 (Faul, Erdfelder, Lang, & Buchner, 2007). Data are presented as mean ± standard deviation (SD) and the level of significance was set at $p = 0.05$. The SPSS version 21.0 was used for all analyses (SPSS Inc., Chicago, IL).

Results

No difference in peak rate of oxygen consumption was observed between the incremental and the constant work rate test ($p < 0.05$). A significant difference between conditions was revealed by the one-way repeated-measures ANOVA for the peak power and the relative values of peak power in the Wingate test ($P = 0.009$ and $P = 0.004$, respectively) (Figure 1). In particular, the Priming30 condition exhibited greater values (595 ± 84 W and 7.91 ± 0.74 W/kg) compared to the control (567 ± 85 W and 7.54 ± 0.79 W/kg) and the Priming15 condition (569 ± 95 W and 7.47 ± 0.78 W/kg). No difference was found between the control and the Priming15 condition in peak power. As regards to the mean power output in the Wingate test, the one-way repeated-measures ANOVA revealed a significant difference between conditions both for the mean power ($P = 0.041$) and for the relative values of the mean power ($P = 0.018$). However, the post-hoc analysis showed that no significant differences existed between the three experimental conditions (Figure 1). As regards to the fatigue index, the statistical analysis revealed a tendency towards lower values (i.e. improved resistance to fatigue) in the Priming30 condition (41.2 ± 9.1) compared to the control (47.3 ± 10.5; improved resistance to fatigue by 13%) and the Priming15 (47.7 ± 9.7; improved resistance to fatigue by 14%) conditions ($P = 0.072$) (Figure 2).

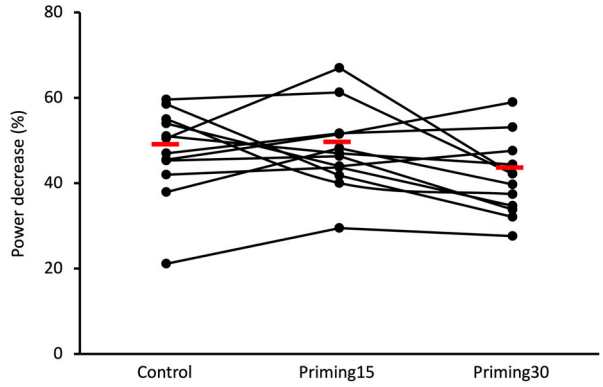

Figure 2. Fatigue index (i.e. percent power output decrease between the first 5 sec and the last 5 sec during the Wingate test) in the three experimental conditions. Red lines indicate the mean value for each condition.

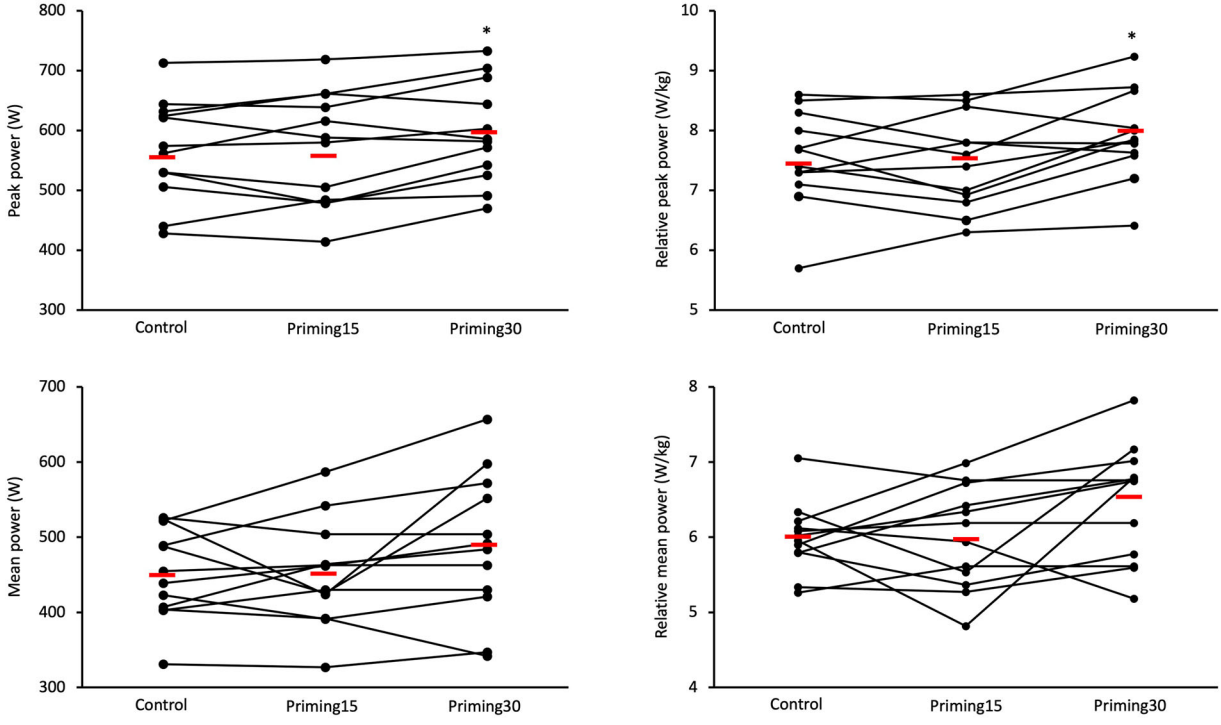

Figure 1. Peak power and the relative values (upper panels) as well as mean power and the relative values (lower panels) in the Wingate test under the three experimental conditions. Red lines indicate the mean value for each condition. (*) indicates significant difference between the Priming30 condition and the control and Priming15 conditions.

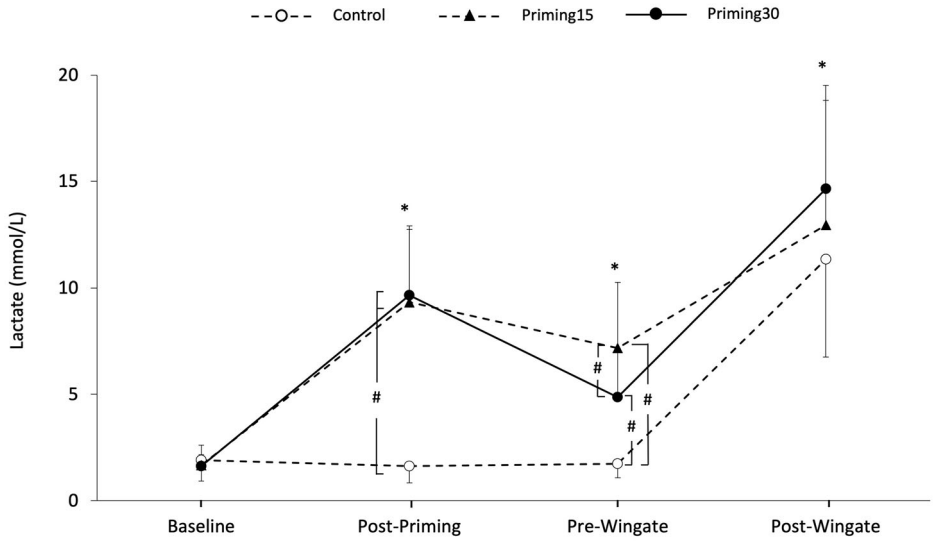

Figure 3. Blood lactate concentration under the three experimental conditions. (*) indicates significant difference compared to baseline in the Priming15 and Priming30 conditions, while at post-Wingate time point indicates significant difference between all conditions compared to baseline; (#) indicates significant difference between groups.

The two-way ANOVA revealed a significant condition × time interaction for blood lactate ($P < 0.001$) (Figure 3). In particular, lactate levels were increased compared to baseline in the Priming15 and Priming30 conditions and remained elevated during the whole intervention (i.e. pre- and post-Wingate). In the control condition, the lactate levels increased compared to baseline as expected only post-Wingate. At the pre-Wingate time point a significant difference was found between the Priming15 (7.18 ± 3.09 mmol/L) and the Priming30 (4.87 ± 2.11 mmol/L) conditions (Figure 3).

Discussion

Oxygen uptake kinetics is regarded a key factor determining performance during severe-intensity exercise (Jones & Burnley, 2009). Thus, speeding the overall $\dot{V}O_2$ kinetics by training manipulations emerged as a means to increase performance. On this notion, priming exercise, which is known to accelerate the overall kinetics of $\dot{V}O_2$ during a second bout of exercise, can exert a major ergogenic effect at work rates in the severe-intensity domain. In general, $\dot{V}O_2$ kinetics after priming exercise are characterised by a reduction of the amplitude of the $\dot{V}O_2$ slow component (Gerbino et al., 1996) and an increase of the amplitude of the primary $\dot{V}O_2$ response during heavy- and severe-intensity exercise (Burnley et al., 2000).

The mechanistic basis of the above-mentioned improvements on $\dot{V}O_2$ kinetics after priming exercise remains a topic of debate (e.g. muscle oxygen supply, intramuscular enzyme kinetics, relief of muscle oxidative metabolic inertia and alterations in motor unit recruitment) (do Nascimento Salvador, Souza, De Lucas, Guglielmo, & Denadai, 2018; Jones, Koppo, et al., 2003; Mattioni Maturana, Peyrard, Temesi, Millet, & Murias, 2018). As regards to ATP turnover during subsequent high-intensity exercise, previous work has demonstrated that priming exercise has the potential to increase oxidative contribution (especially at the initial phase) and to reduce reliance on the finite anaerobic substrate metabolism (expressed as lower decrement in PCr concentration) (Bangsbo, Krustrup, Gonzalez-Alonso, & Saltin, 2001; Krustrup et al., 2001; Rossiter et al., 2001). Moreover, a reduced dependence on anaerobic metabolism is also indicate by the reduced changes in blood lactate concentration at primed compared to unprimed conditions (Bailey, Vanhatalo, Black, DiMenna, & Jones, 2016; Bailey et al., 2009; DiMenna, Wilkerson, Burnley, Bailey, & Jones, 2010; Jones et al., 2008). This phenomenon leads to sparing of the anaerobic reserve, reduction in the oxygen deficit and is therefore thought to result in improved exercise performance. Although this idea could explain our data, in the context of the present study, we focused particularly on the effect of priming exercise on performance rather than on the underlying mechanisms. However, possible mechanisms explaining our findings could be changes in hormones (i.e. epinephrine and glucagon) (Wasserman, 1995; Weise et al., 2004) and changes in post-activation potentiation (PAP) (Sale, 2004). On the other hand, we believe that muscle temperature could not have affected the results, since performance

was greater in the Priming30 condition (Febbraio, Carey, Snow, Stathis, & Hargreaves, 1996).

To the best of our knowledge, this is the first study that aimed to investigate the effect of priming exercise on Wingate performance. According to our data, we report that a 6-min priming exercise bout at 70%Δ (i.e. GET plus 70% of the difference between the work rate at the GET and $\dot{V}O_{2max}$) followed by a 30 min recovery increases absolute and relative peak power, but not mean power during a subsequent Wingate test. Moreover, no effect was observed in peak and mean power outputs in the Wingate test when the same priming exercise protocol was followed by a shorter recovery period of 15 min. The increased performance in the Priming30 condition was also accompanied by a tendency towards increased resistance to fatigue when compared both to the control and the Priming15 conditions. Finally, our blood lactate data verify the idea that a heavy- or severe-intensity priming exercise protocol (like the 70%Δ implemented herein) becomes ergogenic when it is followed by a recovery period that leads to slightly increased lactate values (4.87 ± 2.11 mmol/L herein) at the onset of the subsequent main exercise performance test or time trial (Wingate test herein) (Jones, Wilkerson, et al., 2003; Palmer et al., 2009).

The Wingate test has been extensively used for anaerobic power assessment in power sports in which the ability to develop maximal anaerobic capacity and explosive bursts of activity lasting from a few seconds to 1–2 min is essential for success (Zajac, Jarzabek, & Waskiewicz, 1999) [e.g. American football (Hoffman et al., 2005), tennis (Kovacs, Pritchett, Wickwire, Green, & Bishop, 2007), track and field (Meckel, Atterbom, Grodjinovsky, Ben-Sira, & Rotstein, 1995), and ice-hockey (Hofman, Orie, Hoozemans, Foster, & de Koning, 2017)]. Indeed, during the Wingate test, 28% of the energy relies on ATP-PC pathway, 56% on the glycolytic pathway, and the rest 16% of the energy relies on the aerobic pathway (Smith & Hill, 1991), while, comparable energy contribution was found in a 1500 m cycling simulation study (Foster et al., 2003) and during 800 m running (Spencer & Gastin, 2001). Based on the present data, it could be suggested that after a well-designed priming exercise protocol, an athlete may have an advantage at the start of an event and may preserve this advantage until the end of it (Hofman et al., 2017; Maciejewski et al., 2016).

Our findings are in line with previous studies which demonstrated that short recovery periods (i.e. from 2 up to 15 min) may not be adequate to experience the ergogenic effects of priming exercise, as indicated by the lack of difference between the control and the Priming15 conditions (Ferguson et al., 2007; Heubert et al., 2005; Koppo & Bouckaert, 2002). Noteworthy, the individual data from Figure 1 demonstrate that, although no mean difference was found, almost half of the participants exhibited an impaired performance in peak and mean power outputs under the Priming15 condition compared to the control. In the same vein, the improved peak power output in the Priming30 condition is in agreement with previous reports that highlighted the necessity for longer recovery periods (>15 min) (Bailey et al., 2009; Vanhatalo & Jones, 2009). Considering that in the case of Priming30 only one or two participants exhibited impaired performance in each measured variable (Figure 1) we conclude that the use of 70%Δ proved to be an appropriate intensity to induce a "primed" state to the participants. However, it is likely that this intensity (i.e. ≈9 mmol/l) might prove to be too severe for the participants showed performance deterioration (Black et al., 2017; Burnley et al., 2011).

Previous studies have shown that when priming exercise results in a blood lactate increase higher than 6 mmol/L at the onset of the second bout, neutral or even negative effects may be seen (Burnley et al., 2005; Ferguson et al., 2010, 2007; Koppo & Bouckaert, 2002; Wilkerson et al., 2004). On the other hand, a modest increase in lactate levels (i.e. ≈3 mmol/L) after priming exercise and just before the criterion bout seems to be beneficial for enhancing performance (Bailey et al., 2009; Jones, Wilkerson, et al., 2003; Palmer et al., 2009). Our data on blood lactate, although slightly higher compared to the abovementioned values (i.e. 4.87 ± 2.11 mmol/L), yielded positive effects in the subsequent Wingate test in terms of peak power and the relevant values in the Priming30 condition. Although this phenomenon (i.e. enhanced performance with modestly increased initial lactate levels) seems paradoxical, a possible indirect mechanism has already been proposed. In particular, the presence of lactate in a fatigued muscle preparation improved muscle function via restoration of Na^+-K^+ pumping (Nielsen, de Paoli, & Overgaard, 2001), while acidosis accompanied by lactic acid accumulation does not seem to have a causal relationship with skeletal muscle fatigue (Westerblad, Allen, & Lannergren, 2002). Moreover, the multifaceted role of lactate in muscle energetics (e.g. direct energy fuel and cell signalling) is increasingly acknowledged and can possibly explain this case (Brooks, 2018).

Practical applications/limitations

The assessment of anaerobic power using the Wingate test could be used by coaches and athletes to monitor

progress and to design effective anaerobic training programmes for enhancing performance, given the fact that reference values have been developed for power and fatigue for athletes participating in sports of anaerobic nature (Coppin, Heath, Bressel, & Wagner, 2012; Zupan et al., 2009). While these results are promising, one caveat is that the priming strategy we employed would not be feasible in all sporting activities; for example, there might be an insufficient "window" for its application during sports characterised by repeated efforts that are spread out over an extended period of time. In this regard, dissipation of the ergogenic effect of priming is an important topic for future research. Moreover, when pulmonary $\dot{V}O_2$ is used as a proxy for muscle O_2 consumption, a temporal adjustment must be made to account for the fact that what is measured at the lung will occur later than what happens at the muscle. This is because of (1) the transit delay from lung to muscle; and (2) the finite nature of $\dot{V}O_2$ kinetics (Whipp, Davis, Torres, & Wasserman, 1981). Unfortunately, we did not make this adjustment. However, based on the findings of the present investigation, a properly designed priming exercise protocol in terms of intensity, duration, mode and recovery may become a useful tool in events lasting ≈30 s since an athlete may achieve higher peak power which in turn will not lead to greater fatigue at the end of the effort. Accordingly, it could be suggested that after a well-designed priming exercise protocol, an athlete may have an advantage at the start of an acute short duration/high intensity event and may preserve this advantage until the end of it.

Conclusion

The data presented in this study indicate that priming exercise of heavy to severe intensity followed by a prolonged recovery period leads to increased peak power, but not mean power, in a subsequent Wingate test performed on a cycle ergometer. Moreover, our data are consistent with the idea that a priming exercise-induced modest increase in blood lactate concentration at the onset of the following criterion bout is a key factor of performance. We suggest that a properly designed priming exercise protocol in terms of intensity, duration, mode and recovery may become a useful acute intervention for enhancing performance in events of short duration and very high intensity.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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