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Original investigation

Are the oxygen uptake and heart rate off-kinetics influenced by the intensity of prior exercise?

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ABSTRACT

The aim of this study was to investigate the effect of prior exercise on the heart rate (HR) and oxygen uptake (VO_2) off-kinetics after a subsequent high-intensity running exercise. Thirteen male futsal players (age 22.8 ± 6.1 years) performed a series of high-intensity bouts without prior exercise (control), preceded by a prior same intensity continuous exercise (CE_{+CE}) and a prior sprint exercise (SE_{+CE}). The magnitude of excess post-exercise oxygen consumption ($EPOC_m - 4.25 \pm 0.19$ vs. $3.69 \pm 0.20\,L\,min^{-1}$ in CE_{+CE} and $3.62 \pm 0.18\,L\,min^{-1}$ in control; $p < 0.05$) and the parasympathetic reactivation ($HRR_{60s} - 33 \pm 3$ vs. 37 ± 3 bpm in CE_{+CE} and 42 ± 3 bpm in control; $p < 0.05$) in the SE_{+CE} were higher and slower, compared with another two conditions. The EPOCτ (time to attain 63% of total response; 53 ± 2 s) and the heart rate time-course (HR$\tau - 86 \pm 5$ s) were significantly longer after the SE_{+CE} condition than control transition (48 ± 2 s and 69 ± 5 s, respectively; $p < 0.05$). The SE_{+CE} induce greater stress on the metabolic function, respiratory system and autonomic nervous system regulation during post-exercise recovery than CE, highlighting that the inclusion of sprint-based exercises can be an effective strategy to increase the total energy expenditure following an exercise session.

1. Introduction

The dynamic recovery of resting homeostasis upon cessation of exercise is widely investigated in exercise physiology, with oxygen uptake (VO_2) and heart rate (HR) responses as the two most commonly used variables to investigate the post-exercise recovery process (Poole and Jones, 2012). The magnitude of excess post-exercise oxygen consumption ($EPOC_m$) seems to be mediated by the extent of phosphocreatine (PCr) breakdown, replenishment of O_2 stores in blood and muscle, metabolites removal (e.g., lactate), increased body temperature and circulating catecholamines (Bahr and Sejersted 1991; Børsheim and Bahr 2003; Townsend et al., 2013). On the other hand, the post-exercise autonomic nervous system activity, measured indirectly through HR recovery, is modulated by complex interactions of factors related to sympathetic withdrawal and parasympathetic reactivation (Imai et al., 1994; Buchheit et al., 2007).

Some previous studies have shown that the VO_2 recovery pattern after a square-wave transition is strikingly influenced by exercise intensity, supporting the notion of a curvilinear relationship between the $EPOC_m$ and exercise intensity (Børsheim and Bahr, 2003; Jones and Carter, 2000; Mann et al., 2014; Ozyener et al., 2001). Regarding the HR recovery kinetics, Mann et al. (2014) showed that the time constant of HR off-kinetics (HRτ) was greater when the exercise intensity was increased from 60% to 80% of

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maximal VO_2 (VO_{2max}). However, to our knowledge, the effect of prior exercise on the VO_2 and HR recovery curves after subsequent exercise remains to be investigated, mainly comparing the prior exercise performed at different intensities (e.g., submaximal vs. supramaximal) and patterns (e.g., continuous vs. intermittent).

Repeated sprints training may be considered as a time-efficient strategy for inducing important muscle metabolic adaptations (Bailey et al., 2009). The sprints exercise (SE) could be adopted as a training model to improve some physiological functions and performance. According to previous studies, sprints-based training might promote improvement in the ability to repeat high intensity exercise, glycolytic and oxidative enzymes activity, muscle buffering capacity and increases in aerobic fitness in humans (Bailey et al., 2009; Gibala et al., 2006). Moreover, intermittent repeated or single sprints have been used as a viable alternative to the traditional submaximal warm-up, aiming to accelerate the "overall" VO_2 on-kinetics response (i.e., mean response time—MRT) (Burnley et al., 2002; do Nascimento et al., 2015; Lanzi et al., 2012; Wilkerson et al., 2004). Several studies have reported that prior exercise performed above the gas exchange threshold (GET) normally accelerates the MRT, either increasing the amplitude of the VO_2 primary component and/or decreasing the amplitude of the VO_2 slow component, without changes to the time constant (i.e., τ) of both (Burnley et al., 2002, 2006; Jones et al., 2003; Bailey et al., 2009; Lanzi et al., 2012).

Sprints exercise are characterized by a greater anaerobic energy contribution (i.e., PCr hydrolysis and glycolysis) and higher levels of muscle power output than submaximal continuous running exercise (Buchheit et al., 2007). Furthermore, high-intensity runs with changes of direction may elicit greater HR, blood lactate concentration ([La]) and rating of perceived exertion (RPE) values compared with straight-line high-intensity efforts (Dellal et al., 2010). Despite these differences in the metabolic and neuromuscular requirements during running bouts of different activity patterns (continuous vs. intermittent or straight-line vs. shuttle run), it has been shown that both prior repeated sprints and straight-line submaximal continuous exercise had a similar effect on VO_2 on-kinetics parameters (do Nascimento et al., 2015). However, to date, the literature is still sparse regarding the physiological stress imposed by a bout of square-wave exercise preceded by SE on the post-exercise autonomic cardiac activity and respiratory responses.

The balance between training stimulus and recovery after different combinations of exercise is considered as a key component to induce performance gains (Stanley et al., 2013). Understanding the impact of prior exercise intensity and type on post-exercise autonomic cardiac activity can be an interesting approach to detect the recovery profile according to different types of tasks typically incorporated into exercise programs. In addition, if the difference on the $EPOC_m$ caused by the prior exercise intensity and type (i.e., SE_{+CE} vs. CE_{+CE}) is physiologically significant, then this may have implications for the design of exercise protocols which aim at weight loss or maintenance. The resulting information will be of great interest not only for the assessment of the exercise load and for the monitoring fatigue but also for individualized training prescription and establishing adequate recovery periods according to different types of tasks (Cunha et al., 2016; Del Rosso et al., 2016; Stanley et al., 2013).

Thus, the aim of the present study was to investigate how prior exercise of different intensities and patterns (i.e., SE_{+CE} vs. CE_{+CE}) affects post-exercise autonomic control and VO_2 off-kinetics parameters following a high-intensity exercise bout in trained subjects. Since the VO_2 and HR off-kinetics are stimulus dependent, our hypothesis was that high-intensity running preceded by a prior SE would induce a higher $EPOC_m$ and would elicit slower metabolic and cardiac responses than when preceded by a CE.

2. Materials and methods

2.1. Participants

Thirteen male amateur futsal players (age 22.8 ± 6.1 years; body mass 76.0 ± 10.2 kg; height 178.7 ± 6.6 cm; VO_2max 58.1 ± 4.5 mL kg^{-1} min^{-1}) volunteered to participate in the present study. At the time of study, the participants had at least four years experience in futsal training. Participants performed three to five regular training sessions per week (6.7 ± 1.9 h) and participated in games on weekends (74.6 ± 18.5 min). After being fully informed of the risks and stresses associated with the study, the participants gave their written informed consent to participate. The experimental protocol was approved by the local Ethics Committee of the University and was performed according to the Declaration of Helsinki.

2.2. Experimental design

The participants were required to report to the laboratory on three separate occasions over a two-week period. On the first visit, they performed a maximal incremental running test for the determination of the GET and VO_{2max} in order to determine the exercise intensities used during the main experimental protocol. Following this preliminary test session, the subsequent visits were used to evaluate the HR and VO_2 off-kinetics. During the second visit, the participants completed a CE without prior exercise (control) at 50% Δ (running speed corresponding to 50% of the difference between the VO_2 at GET and VO_{2max}), followed by another CE performed at the same intensity (with prior exercise—CE_{+CE}), each lasting 6 min and separated by 6 min of recovery. After 60 min of rest (Burnley et al., 2006), the participants performed a prior SE, followed 6 min later by a 6-min CE at 50% Δ (SE_{+CE}) and 6 min of recovery. The third visit was identical to the second. Therefore, the 6-min square-wave transient was performed twice in each condition (see Fig. 1). The SE was performed on an outdoor futsal court and composed by six sprints of 40 m, with 60 s of passive recovery between each sprint. Each sprint was designed with three changes of direction of 180°, one every 10 m. Each participant was verbally encouraged to complete all sprints as fast as possible. All tests were separated by at least 48 h and were performed at the same time of day in controlled environmental laboratory conditions (19–22 °C; 50–60% RH) to minimize the effects of diurnal biological variation on the results (Carter et al., 2002). The participants were instructed to avoid any intake of alcohol and strenuous exercise in the 24 h preceding each test session and to arrive at the laboratory in a rested and fully hydrated state, at least 2 h postprandial.

2.3. Measurement of GET and VO_{2max}

The participants completed a ramp incremental test on the motorized treadmill (Millenium Super Atl 10.200, Inbramed, Brazil) to volitional exhaustion in order to determine the GET and VO_{2max}. The test started with the participants walking at 6.0 km h^{-1} and 1% gradient (Jones and Doust, 1996) followed by an increase of 0.5 km h^{-1} every 30 s thereafter until exhaustion. Capillary blood samples (25 μL) were obtained from the ear lobe of each participant at the beginning and at the end of the test and the [La] was measured using an electrochemical analyzer (YSL 2700 STAT, Yellow Springs, Ohio, USA). The analyzer was calibrated in accordance with the manufacturer's recommended procedures. Each participant was verbally encouraged to perform a maximal effort. The VO_2 and HR responses were recorded continuously throughout the test and subsequently averaged over 15-s intervals (Quark PFTergo, Cosmed, Rome, Italy). The VO_{2max} was considered as the highest 15-s average obtained during the test, or, in the presence of a plateau