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Mechanical and electromyographic responses during the 3-min all-out test in competitive cyclists

Andrea Nicolò, Ilenia Bazzucchi, Francesco Felici, Federica Patrizio, Massimo Sacchetti *

Department of Movement, Human and Health Sciences, "Foro Italico" University of Rome, Piazza Lauro De Bosis 6, Rome 00135, Italy

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ABSTRACT

While the 3-min all-out test is an ideal exercise paradigm to study muscle fatigue during dynamic whole-body exercise, so far it has been used mainly to provide insight into the bioenergetic determinants of performance. To shed some light into the development of peripheral muscle fatigue during the 3-min all-out test, we investigated the time course of muscle-fibre conduction velocity (MFCV). Twelve well-trained cyclists (23 ± 3 yrs) performed an incremental test, a 3-min all-out familiarization trial and a 3-min all-out test. Surface electromyographic signals were detected from the vastus lateralis muscle of the dominant limb. MFCV decreased with power output, though with a somewhat different time course, and the two parameters were strongly correlated ($r = 0.87$; $P < 0.001$). A modest decrease in MFCV (17.7 ± 4.8%), probably due to the endurance characteristics of the subjects, may help explain why a relatively high power output (79 ± 8% of the peak power output of the incremental test; 60 ± 14% of the difference between this peak value and the gas exchange threshold) was still maintained at the end of the test. These findings suggest that muscle fatigue substantially affects performance in the 3-min all-out test, expanding on the traditional bioenergetic explanation that performance is limited by rate and capacity of energy supply.

1. Introduction

Muscle fatigue is commonly defined as a loss in maximal force- or power-generating capacity (Kent-Braun et al., 2012). It follows that muscle fatigue has been classically studied by means of sustained or intermittent maximal voluntary contractions, mainly during isometric exercise (Bigland-Ritchie et al., 1981; Bigland-Ritchie and Woods, 1984; Kent-Braun, 1999; Komi and Tesch, 1979; Merton, 1954; Schillings et al., 2003). A typical curvilinear decrease in force is observed during such effort in a variety of muscle groups (Bigland-Ritchie and Woods, 1984; Kent-Braun, 1999; Komi and Tesch, 1979; Merton, 1954; Schillings et al., 2003). The decrease in force is generally accompanied by myoelectric manifestations of fatigue, i.e. changes in surface electromyographic (sEMG) parameters (Bigland-Ritchie et al., 1981; Komi and Tesch, 1979; Schillings et al., 2003). While most of the parameters extracted from the sEMG signal are not related to any physiological quantity, muscle-fibre conduction velocity (MFCV) represents the propagation velocity of muscle-fibre action potentials (Farina, 2011). Since MFCV largely depends on the polarization state of the sarcolemma (Farina, 2011), it has been extensively used as a measure of peripheral fatigue (Mesin et al., 2009; Schillings et al., 2003).

In view of the analogy with sustained or intermittent maximal voluntary isometric contractions, all-out cycling exercise is an ideal paradigm to investigate muscle fatigue during dynamic whole-body exercise (James and Green, 2012). However, so far, all-out cycling protocols have been classically developed and used mainly to provide insight into the bioenergetic determinants of performance. For instance, the popular 30-s all-out Wingate test was developed to infer on anaerobic power and capacity (Bar-Or, 1987). Since anaerobic capacity is not fully expended in 30 s, longer exercise protocols lasting up to 90 s were later proposed (Withers et al., 1993). More recently, the observation that power output stabilizes in the last part of a 3-min all-out test led some authors to suggest that maximal lactate steady state (Burnley et al., 2006) or critical power (CP) (Vanhatalo et al., 2007) (i.e. the intensity defining the boundary between the heavy and severe intensity domain) could be successfully estimated by measuring the end-test power output (EP) of a 3-min all-out test.

While it has been pointed out that all-out cycling performance is largely determined by neuromuscular factors (Bundle and Weyand, 2012; James and Green, 2012), there is a paucity of

* Corresponding author. Tel.: +39 0636733281; fax: +39 0636733214.
E-mail address: massimo.sacchetti@uniroma4.it (M. Sacchetti).

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neuromuscular data on all-out dynamic whole-body exercise. Specifically, although MFCV has been successfully estimated during a variety of cycling-based exercise paradigms (Duffy et al., 2012; Farina et al., 2004; Nicolò et al., 2014b; Sbriccoli et al., 2009; Stewart et al., 2011), we are not aware of any study investigating the behaviour of MFCV during all-out cycling performances longer than 30 s (Stewart et al., 2011). To provide some insight into the development of peripheral muscle fatigue during the 3-min all-out test, in the present study we have investigated the time course of MFCV, together with that of other sEMG variables and power output. Based on previous findings during sustained maximal voluntary isometric exercise (Schillings et al., 2003) and 30-s all-out cycling performance (Stewart et al., 2011), we expected that the decrease in power output would be accompanied by a decrease in MFCV.

2. Methods

2.1. Subjects

Twelve male participants (mean ± SD: age 23 ± 3 years, stature 1.77 ± 0.04 m, body mass 68 ± 7 kg) volunteered to participate in this study. All participants gave their written informed consent according to the declaration of Helsinki. The experimental protocols were approved by the Ethics Committee of the University of Rome "Sapienza". All the participants were well-trained competitive cyclists with a minimum of 4 years' cycling experience and 250 km training per week. They were asked to refrain from strenuous exercise, consumption of alcohol and caffeine for at least 24 h before each test.

2.2. Experimental overview

All testing was completed in the laboratory with a room temperature of 19–21 °C and at the same time of day (±2 h). Participants reported to the laboratory on 3 separate occasions over a two-week period, with visits separated by at least 48 h. In the first visit, participants performed a preliminary ramp incremental exercise test. In the second and third visits they performed a 3-min all-out familiarization trial and a 3-min all-out test, respectively. All the protocols were performed on an electromagnetically-braked cycle ergometer (Lode Excalibur Sport, Groningen, the Netherlands), whose setting was adjusted and recorded for each participant during the first visit to be reproduced in the following visits.

2.3. Incremental ramp test

The ramp incremental test to exhaustion was preceded by a 5-min warm-up at 100 W, 3 min of rest and 3 min pedalling at 20 W. The test consisted of a continuous ramped increase in work rate of 30 W min^{-1}, starting from 20 W. Preferred pedalling cadence (92 ± 2 rpm) was selected by each participant and was kept constant throughout the test, which terminated when cadence fell by more than 10 rpm, despite strong verbal encouragement. The peak power output (PPO) of the test was defined as the highest power output achieved at exhaustion, registered to the nearest 1 W. Breath-by breath pulmonary gas exchange data were averaged over 10 s and the gas exchange threshold (GET) was determined from a cluster of measures including (1) the first disproportionate increase in carbon dioxide output (VCO_2) from visual inspection of individual plots of VCO_2 versus VO_2, (2) an increase in V_E/VO_2 (V_E, minute ventilation) with no increase in V_E/VCO_2, and (3) an increase in end-tidal O_2 tension with no fall in end-tidal CO_2 tension (Whipp, 2007). The power output value corresponding to the GET was estimated with account taken of the mean response time of the VO_2 response, which was assumed to approximate 40 s (Whipp, 2007). Specifically, the 2/3rd (40 s/60 s) of the 30 W/min ramp increase in power output (i.e. 20 W) was deducted from the power output corresponding to VO_2 at GET.

2.4. 3-min all-out test

The subjects performed two tests in total, the first of which served as familiarization trial and was not included in subsequent data analysis. A warm up consisting of 3 min at 100 W, 6 min at 50% of PPO, 1 min at 60% of PPO, and 1 min at 100 W was performed. Three minutes of rest and 3 min pedalling at 20 W immediately preceded the test. The test was performed complying scrupulously with original recommendations (Burnley et al., 2006). The ergometer was set in linear mode, and the α linear factor (indicating the slope of the linear relationship between torque and cadence) was set according to the formula: α = 50% Δ/preferred cadence^2. The 50% Δ represents the power output halfway between PPO and GET, while the cadence was selected according to the preferred cadence adopted in the ramp incremental test. The subjects were asked to increase their cadence to approximately 120 rpm during the last 5 s of the 20 W phase, and subsequently to provide an all-out effort for the entire duration of the trial. Strong verbal encouragement was given throughout the test, and subjects were instructed and strongly encouraged to maintain the cadence as high as possible at all times throughout the test. Importantly, subjects were not informed of the elapsed time so that pacing might be prevented.

The end-test power output (EP) was determined as the average power output during the final 30 s of the test. The work performed above the EP (WEP), which is considered to be analogous to the work performed above critical power (W′), was calculated as the power output-time integral above the EP (Burnley et al., 2006). Pulmonary gas exchange and ventilatory parameters were measured to verify correct execution of the test. Indeed, in well conducted tests, VO_2 increases rapidly towards VO_{2peak}, and a plateau is commonly observed for the remaining of the 3-min all-out test (Burnley et al., 2006). In addition, similar VO_{2peak} values are commonly observed for the ramp incremental test and the 3-min all-out test (Burnley et al., 2006). We also measured respiratory frequency (f_R) as a valid measure of effort during exercise (Nicolò et al., 2014a). Furthermore, we recruited well trained competitive cyclists because the 3-min all-out test requires extremely high levels of motivation.

2.5. Gas exchange and ventilatory parameters

Pulmonary gas exchange, V_E, f_R and tidal volume (V_T) were measured breath-by-breath using open-circuit indirect calorimetry (Quark b2, Cosmed, Rome, Italy). Appropriate calibration procedures were performed following the manufacturer's instructions. The VO_{2peak} and the f_{Rpeak} for both the ramp incremental test and the 3-min all-out test were calculated as the higher 30 s value of a 10-s moving average.

2.6. sEMG recording

Surface electromyographic (sEMG) signals were recorded during the 3-min all-out cycling test using a portable wi-fi transmission EMG amplifier (BTS POCKETEMG, BTS SpA, Italy). The sEMG signals were sampled at 2 kHz and A/D converted with a 16-bit resolution (amplitude range ±5 V; band pass filtered 10–500 Hz). Before electrodes' positioning, the skin was properly abraded with sandpaper and cleaned with ethyl alcohol. sEMG signals were recorded with a linear array of four electrodes (silver bars 5 mm