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Full Length Article

Fatigue-induced dissociation between rate of force development and maximal force across repeated rapid contractions

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ABSTRACT

We examined whether the presence of fatigue induced by prolonged running influenced the time courses of force generating capacities throughout a series of intermittent rapid contractions. Thirteen male amateur runners performed a set of 15 intermittent isometric rapid contractions of the knee extensor muscles, (3 s/5 s on/off) the day before (PRE) and immediately after (POST) a half marathon. The maximal voluntary contraction force, rate of force development (RFD_{peak}), and their ratio (*relative* RFD_{peak}) were calculated. At POST, considering the first (out of 15) repetition, the maximal force and RFD_{peak} decreased ($p < 0.0001$) at the same extent (by 22 ± 6% and 24 ± 22%, respectively), resulting in unchanged *relative* RFD_{peak} ($p = 0.6$). Conversely, the decline of RFD_{peak} throughout the repetitions was more pronounced at POST ($p = 0.02$), thus the decline of *relative* RFD_{peak} was more pronounced ($p = 0.007$) at POST (−25 ± 13%) than at PRE (−3 ± 13%). The main finding of this study was that the fatigue induced by a half-marathon caused a more pronounced impairment of rapid compared to maximal force in the subsequent intermittent protocol. Thus, the fatigue-induced impairment in rapid muscle contractions may have a greater effect on repeated, rather than on single, attempts of maximal force production.

1. Introduction

Repeated high-force contractions of skeletal muscles cause a decline in force-generating capacity, referred to as muscle fatigue (Bigland-Ritchie & Woods, 1984). During exercise of maximal intensity, fatigue result into a decline of force (Bigland-Ritchie & Woods, 1984) or power (Cheng & Rice, 2005). Research investigating the influence of an exercise-induced fatigue on the neuromuscular function focused mainly on the decline in maximal voluntary contraction force. However, the effect of fatigue on the ability to produce force rapidly, also referred to as explosive strength (Maffiuletti et al., 2016), has received less attention despite its

Abbreviations: ANOVA, analysis of variance; ARV, average rectified value; CV, muscle fiber conduction velocity; EMG, electromyography; MVC, maximal voluntary contraction; RFD, rate of force development

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importance for the production of many movements. Particularly, the rate of force development (RFD) is functionally more informative than maximal force when considering sports in which rapid movements are important, such as running, jumping, or kicking (Aagaard, Simonsen, Andersen, Magnusson, & Dyhre-Poulsen, 2002; de Ruiter, Van Leeuwen, Heijblom, Bobbert, & de Haan, 2006). Muscle fatigue can impair the explosive strength (Buckthorpe, Pain, & Folland, 2014) which in turn can negatively influence explosive sport activities (Krustrup et al., 2006; Mohr, Krustrup, & Bangsbo, 2003; Zoppirolli, Pellegrini, Bortolan, & Schena, 2016). Moreover, maintaining the ability to produce high RFD values is important to limit the risks of injury (Minshull, Gleeson, Walters Edwards, Eston, & Rees, 2007). Therefore, an understanding of how fatigue affects rapid force production would seem important in understanding its influence on athletic performance and injury risk.

Maximal force and RFD should not be used as interchangeable indices when assessing high-intensity muscle fatigue. Indeed, it has recently been demonstrated a more pronounced drop in rapid compared with maximal force production during fatiguing protocols constituted by intermittent explosive isometric contraction (Buckthorpe et al., 2014). Similar disproportionate drop in explosive than maximal torque was recently found also using dynamic contractions (Morel et al., 2015). Particularly, these studies, which was constituted by high-force fatiguing protocols, showed that the early phase (0–50 ms) of explosive muscle contraction seemed to be the most susceptible to muscle fatigue (Buckthorpe et al., 2014; Morel et al., 2015). The relationship between maximal force and RFD decrements also varied among muscles when used to assess muscle fatigue induced by prolonged cross-country skiing (Boccia et al., 2016).

Given the different influence of muscle fatigue on rapid and maximal force production we aimed to determine the influence of muscle conditions at the beginning of the intermittent protocol on the time course of force generating capacities. We compared the time course of maximal force and RFD across a set of 15 intermittent rapid isometric contractions executed in two conditions: before, i.e. *fresh* condition, and after a half-marathon run (21.097 m), i.e. *fatigued* condition. We hypothesized that the ratio between the time course of maximal force and RFD would change in *fatigued* condition.

2. Methods

2.1. Participants

For this specific study 14 amateur male runners were recruited (age 36 ± 8, body weight 74 ± 10 kg, height 173 ± 8 cm) who successfully concluded a half-marathon run (21.097 km). All participants were habitually involved in amateur running with a mean training regimen of 220 min/week. None of them had clinical evidences of cardiovascular, neuromuscular, or joint diseases. Participants were instructed to refrain from performing strenuous physical activity in the 24 h before the first experimental session. All participants provided their written informed consent before participation in the investigation. The study was approved by the local Ethical Committee (Department of Neurological and Movement Sciences, University of Verona) and performed in accordance with the Helsinki Declaration.

2.2. General overview

The study was performed during a specific event called “Run For Science”, held in Verona (Italy) in April 2016. Participants were involved in two measurement sessions: the first was performed the day before the race (PRE), and the second immediately after the race (POST). The neuromuscular test consisted in a set of isometric explosive maximal voluntary contractions (MVCs) of the knee extensors. Force and electromyographic (EMG) measurements were obtained from the rapid (rising) and maximal (plateau) phases of the MVCs. During the PRE session, participants were familiarized with the procedures. For that purpose, they repeated a number of trials of the test procedures until they were able to produce consistent results. In the PRE session participants performed 15-min of a standardised warm-up (details are given below) before neuromuscular testing. In the POST session the neuromuscular assessment started within 10 min after the race. A researcher was positioned at the finishing line to conduct the runners to the testing site, which was located about 50 m from the finishing line. The testing session at POST lasted 3–4 min.

2.3. Procedure

2.3.1. Warm-up

The warm-up at PRE consisted of 15-min of outdoor running at an incremental intensity from 75% to 90% of the maximal heart rate previously determined by an incremental test. The duration of the warm-up was chosen based on previous studies showing that muscle temperature rises rapidly after 5 min and reaches an equilibrium after 15 min (Bishop, 2003).

2.3.2. Force measurement

Participants were seated on a custom-made chair that allowed the assessment of the knee extensors, and straps were fastened across the chest and hips to avoid lateral and frontal displacements. During the testing, participants' knee and hip were flexed at 90° from full extension and they were instructed to maintain the arms crossed on the chest. The knee extensors mechanical response was recorded with a strain gauge load cell (546QD-220 kg; DSEurope, Milan, Italy), fixed with non-compliant straps at the level of the external malleolus. All measurements were taken from the participants' right limbs (which was the dominant limb for 13 out of 14 participants). The force signals were sampled at 2048 Hz together with EMG signals and converted to digital data with a 16-bit A/D converter (EMG-USB2, OT Bioelettronica, Turin, Italy).