Human Movement Science 45 (2016) 161–171

Contents lists available at ScienceDirect

Human Movement Science

journal homepage: www.elsevier.com/locate/humov

Local muscle oxygen consumption related to external and joint specific power

Knut Skovereng *, Gertjan Ettema, Mireille van Beekvelt

Centre for Elite Sports Research, Department of Neuroscience, Norwegian University of Science and Technology, Trondheim, Norway

ARTICLE INFO

Article history:
Received 21 May 2015
Revised 13 November 2015
Accepted 17 November 2015
Available online 1 December 2015

Keywords:
Near-infrared spectroscopy
Inverse dynamics
Cycling
Work rate
Joint specific power

ABSTRACT

The purpose of the present study was to examine the effects of external work rate on joint specific power and the relationship between knee extension power and vastus lateralis muscle oxygen consumption (mVO_2). We measured kinematics and pedal forces and used inverse dynamics to calculate joint power for the hip, knee and ankle joints during an incremental cycling protocol performed by 21 recreational cyclists. Vastus lateralis mVO_2 was estimated using near-infrared spectroscopy with an arterial occlusion. The main finding was a non-linear relationship between vastus lateralis mVO_2 and external work rate that was characterised by an increase followed by a tendency for a levelling off ($R^2 = 0.99$ and 0.94 for the quadratic and linear models respectively, $p < 0.05$). When comparing 100 W and 225 W, there was a ~43 W increase in knee extension but still a ~9% decrease in relative contribution of knee extension to external work rate resulting from a ~47 W increase in hip extension. When vastus lateralis mVO_2 was related to knee extension power, the relationship was still non-linear ($R^2 = 0.99$ and 0.97 for the quadratic and linear models respectively, $p < 0.05$). These results demonstrate a non-linear response in mVO_2 relative to a change in external work rate. Relating vastus lateralis mVO_2 to knee extension power showed a better fit to a linear equation compared to external work rate, but it is not a straight line.

1. Introduction

During aerobic steady-state cycling exercise, the change in external work rate shows a linear relationship with the corresponding change in whole body oxygen consumption (pVO_2) (di Prampero, 2000; Ettema & Loras, 2009). Also, when looking at the entire leg as a whole during a multi-joint exercise such as cycling, a linear relationship is found between the increase in external work rate and leg VO_2 (Calbet et al., 2007). However, in multi-joint exercise, a change in external work rate does not necessarily lead to a homogeneous change in all active tissues with regard to their contribution in producing work (Dorel, Guilhem, Couturier, & Hug, 2012).

From cycling kinematics and pedal forces, inverse dynamics can be used to quantify joint specific contribution to the external work rate. In cycling exercise, power is mainly produced by the hip, knee and ankle joints (Ericson, 1988; Ettema, Loras, & Leirdal, 2009), and several studies have investigated the effect of work rate on the contribution of these joints (Elmer, Barratt, Korff, & Martin, 2011; Ericson, 1988). Using external work rates ranging from 250 W to ~1100 W (maximal), Elmer et al. (2011) reported decreasing relative contribution from knee extension while Ericson reported

* Corresponding author at: Department of Neuroscience, Centre for Elite Sports Research, Norwegian University of Science and Technology, Trondheim N-7491, Norway.

E-mail address: knut.skovereng@ntnu.no (K. Skovereng).

http://dx.doi.org/10.1016/j.humov.2015.11.009
0167-9457/© 2015 The Authors. Published by Elsevier B.V.

increasing contribution of knee extension at 0 compared to 240 W, but 240 W did not differ from 120 W in relative contribution (Ericson, 1988). Although there appears to be no complete consensus, the knee extension contribution to external work rate during a multi-joint task may differ from that reported during isolated knee extension (Andersen, Adams, Sjogaard, Thorboe, & Saltin, 1985).

Alteration in the contribution of a joint to external work rate will likely influence the metabolic demands of the active tissues spanning the respective joints, but if we want to investigate this, we need to assess the muscle directly. In vivo determination of muscle VO_2 (mVO_2) is difficult to accomplish during exercise without invasive techniques, but recent advances in near-infrared spectroscopy (NIRS) have enabled the measurement of mVO_2 in vivo. NIRS is a non-invasive, continuous method that can be used to study the balance between O_2 delivery and O_2 extraction at the muscle level by measuring concentration changes in oxygenated and deoxygenated haemoglobin and myoglobin (similarities in absorption spectra result in an inability to differentiate between haemoglobin and myoglobin). Changes in deoxyhaemoglobin (HHb) have been regarded to represent changes in the oxygen extraction of the microvasculature (DeLorey, Kowalchuk, & Paterson, 2003). Total haemoglobin (tHb) is calculated as the summation of HHb and oxyhaemoglobin (O_2Hb) and is used to evaluate changes in blood volume within the active tissue. In addition, by the application of an arterial occlusion, one can calculate mVO_2 and thus obtain a non-invasive estimate of local muscle energy expenditure (Van Beekvelt, Colier, Wevers, & Van Engelen, 2001). The use of the arterial occlusion method to calculate mVO_2 provides a more direct evaluative tool/measure of the metabolic demands of the individual muscles. A lack of studies measuring mVO_2 during exercise exists despite the reports showing NIRS to be a reliable method (Ryan, Brophy, Lin, Hickner, & Neufer, 2014; Van Beekvelt et al., 2001).

Several recent studies have investigated changes in HHb and/or tHb in relation to increasing external work rate (Bellotti, Calabria, Capelli, & Pogliaghi, 2013; Boone, Barstow, Celie, Prieur, & Bourgois, 2014; Boone, Koppo, Barstow, & Bouckaert, 2009; Ferreira, Koga, & Barstow, 2007; Ferreira, Lutjemeier, Townsend, & Barstow, 2006; Murias, Spencer, Keir, & Paterson, 2013; Spencer, Murias, & Paterson, 2012). Indeed with regard to HHB, these studies show that individual muscles show a non-linear response to a change in cycling exercise intensity, with a tendency to level off as intensity increases above ~82% of peak external work rate (Bellotti et al., 2013; Boone et al., 2009; Ferreira et al., 2007; Murias et al., 2013; Nagasawa, 2008; Spencer et al., 2012). Blood volume has been reported to plateau at ~80% of peak external work rate during incremental cycling exercise (Boone et al., 2014) and also to be similar at lactate threshold compared to maximal exercise (Ferreira et al., 2006). The results on cycling exercise again seem to be in contrast to the findings on isolated knee extension tasks, where a linear relationship has been reported between external work rate and knee extensor VO_2 (Andersen & Saltin, 1985) and leg VO_2 (Richardson et al., 1995). To the best of our knowledge only one study has used NIRS to investigate mVO_2 in cycling exercise and this study reported no increase in vastus lateralis mVO_2 from an intensity increase of 50–70% of VO_{2peak} (Nagasawa, 2008).

A non-linear mVO_2 response to an increase in external work rate would be in line with the findings of a changing relative joint contribution with increasing external work rate. In addition, it would be a clear indication that a change in cycling exercise intensity is not characterised by just "pressing harder" on the pedals, but rather a change in technique. A change in technique seen through a change in muscle recruitment pattern (Dorel et al., 2012) and a shift towards larger contribution from hip extension and knee flexion (Elmer et al., 2011). Simultaneous quantification of vastus lateralis oxygen consumption and joint powers in relation to external work rate will further our knowledge regarding metabolic demands in the active tissues in response to exercise. With the classical findings on isolated muscle (Fenn, 1924), the findings from studies on local muscles and the previously mentioned findings on joint powers and the effect of external work rate, it would be reasonable to expect that mVO_2 is more closely related to joint specific power than to external work rate.

Thus, the purpose of the present study was to investigate how increasing external work rate influences the absolute and relative power contribution different joints and the relationship between knee extension power and mVO_2 of the vastus lateralis. We expect a non-linear relationship for vastus lateralis mVO_2 with external work rate, as well as a decreasing relative knee extension contribution when external work rate increases. In addition, we expect a linear relationship between the vastus lateralis mVO_2 and knee extension power in line with isolated knee extension models and the Fenn-effect.

2. Methods

2.1. Participants

Twenty-one recreationally trained level 3 cyclists (age; 40 ± 5.6 yrs; body mass, 83.1 ± 5.5 kg; height, 183.4 ± 5.0 cm pVO_{2peak}; 53.8 ± 5.7 ml/kg/min, maximum aerobic power; 371.5 ± 23.4 W and vastus lateralis adipose tissue thickness; 5.3 ± 1.8 mm) participated in the study (Ansley & Cangley, 2009). Permission to conduct the study was given by the regional ethical committee and a signed written informed consent was obtained from all participants prior to their participation in the study.

2.2. Protocol

The participants came to the laboratory on two days. The first day started with the measurement of the height and body mass of the participants. This was followed by an arterial occlusion test consisting of a 10-min occlusion. The occlusions