Neuromuscular fatigue during prolonged pedalling exercise at different pedalling rates

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Abstract. The purpose of this study was to estimate the differences in neuromuscular fatigue among prolonged pedalling exercises performed at different pedalling rates at a given exercise intensity. The integrated electromyogram (iEMG) slope defined by the changes in iEMG as a function of time during exercise was adopted as the measurement for estimating neuromuscular fatigue. The results of this experiment showed that the relationship between pedalling rate and the means of the iEMG slopes for eight subjects was a quadratic curve and the mean value at 70 rpm [1.56 (SD 0.65) μV·min⁻¹] was significantly smaller (P<0.01) than that at 50 and 60 rpm [2.25 (SD 0.54), and 2.22 (SD 0.68), respectively]. On the other hand, the mean value of oxygen consumption obtained simultaneously showed a tendency to increase linearly with the increase in pedalling rate, and the values at 70 and 80 rpm were significantly higher than those at 40 and 50 rpm. In conclusion, it was demonstrated that the degree of neuromuscular fatigue estimated by the iEMG changes for five periods of prolonged pedalling exercise at a given exercise intensity was different among the different pedalling rates, and that the pedalling rate at which minimal neuromuscular fatigue was obtained was not coincident with the rate at which the minimal oxygen consumption was obtained, but was coincident with the rate which most subjects preferred. These findings would suggest that the reason why most people prefer a relative higher pedalling rate, even though higher oxygen consumption is required, is closely related to the development of neuromuscular fatigue in the working muscles.

Key words: Neuromuscular fatigue – Optimal pedalling rate – Integrated electromyogram

Introduction

Many studies have reported that the most efficient (economical) pedalling rate for trained and/or untrained people is between 40 and 80 rpm (Boning et al. 1984; Coast and Welch 1985; Gaesser and Brooks 1975; Jordan and Merrill 1979; Pandolf and Noble 1973; Seabury et al. 1977) despite the fact that most cyclists prefer a rate of 90 rpm (Hagberg et al. 1981; Patterson and Moreno 1990). This finding indicates that the most economical pedalling rate is not necessarily coincident with the pedalling rate most preferred in actual prolonged exercise.

Patterson and Moreno (1990) have reported that the efficiency for the transmitting of force output by the legs to a crank might be an effective measurement for determining the optimal pedalling rate, and suggested that the optimal pedalling rate was closely related to peripheral muscle fatigue. Theoretically there should exist a close inverse relationship between pedalling rate and the pedalling torque during a constant power output. Although it has been shown that the pedalling torque is not coincident with actual force output exerted by the legs (Sjøgaard 1978), it would be expected that pedalling at a higher rate may lead to a lowering of the pedalling force for each thrust and reduction of neuromuscular fatigue in the leg muscles.

It is known that surface electromyography (EMG) may be used to quantify the total activity of working muscles. Previous studies have reported that a progressive increase in integrated EMG (iEMG) occurs when static (Maton 1981; Moritani et al. 1982; Petrofsky et al. 1982) or dynamic (Nilsson et al. 1977; Petrofsky 1979) muscle contractions are sustained at a constant force output. It has generally been speculated that a progressive recruitment of additional motor units (MU) and/or an increase of firing rates of already recruited MU might take place to compensate for the deficit in contractility due to some impairment of fatigued MU. In some studies, it has been shown by recordings of intramuscular spikes with fine wire electrodes that some additional MU with larger spike ampli-
tudes are recruited and the firing rate of MU are increased when a fatiguing static exercise (Maton 1981) or dynamic exercise (Moritani et al. 1993) is sustained. Thus, the iEMG has been widely accepted as a means of assessing muscle fatigue and in some studies the rate of iEMG changes with time, i.e. "the iEMG slope" has been applied to estimate the development of neuromuscular fatigue (DeVries 1968; DeVries et al. 1982; Moritani et al. 1993).

The purpose of this study was to determine the extent of neuromuscular fatigue during prolonged pedalling exercise against a given exercise intensity at different pedalling rates using the iEMG slope as determined by the EMG voltage-time relationship. This study was intended to produce a means of interpreting the discrepancy between the most efficient pedalling rate and the most preferred (optimal) pedalling rate.

**Methods**

**Subjects.** Eight healthy male subjects who were not trained cyclists volunteered for this study. Mean height, body mass and age were 173.0 (SD 4.2) cm, 64.0 (SD 2.8) kg, 21.9 (SD 4.2) years, respectively. All experimental procedures were explained in detail to each subject who then signed a statement of informed consent.

**Protocol.** Each subject performed a ramp exercise test to the point of exhaustion as well as five sessions of prolonged pedalling exercise on an electromagnetically braked ergometer. Following the warm-up exercise, the ramp test was started with 2 min unloaded exercise at 60 rpm. The intensity was then increased by 20 W min⁻¹. For the prolonged exercise, the intensity for each individual was decided as that at which approximately 75% maximal oxygen uptake (VO₂max) was elicited while pedalling at 60 rpm. Five sessions of exercise at a given intensity were performed in random order at pedalling rates of 40, 50, 60, 70, and 80 rpm. During the main exercise session the subjects pedalled for 15 min at the previously decided intensity for individuals. Prior to the main session, 2 min of unloaded pedalling and 3 min of pedalling at 60 W were performed continuously as sub-exercise. In principle, the subjects should have exercised once each experimental day; however, three of the eight subjects exercised twice in one day. In the latter cases, more than 3 h of rest was allowed between the sessions. The sub-exercise prior to each session was employed to avoid muscle fatigue due to anaerobic metabolism derived from an abrupt increase in exercise intensity.

**Measurement of EMG.** Myoelectric signals during five sessions of exercise were recorded by the surface EMG technique. The EMG instrumentation used in this experiment has been fully described in our previous study (Takaishi et al. 1992). Briefly, two miniature electrodes (Nihon Koden, Ag-AgCl, 6-mm contact diameter, 4-cm interelectrode distance) were placed over the belly of the vastus lateralis muscle and a reference electrode was placed over the anterior superior spine of the iliac crest. All electrode placements were preceded by abrasion of the skin so as to reduce the source impedance to less than 3 kΩ. Myoelectric signals were amplified (Nihon Koden, AM-601G) with band pass filtering (5–500 Hz), and recorded on a digital recorder (TEAC, RD-101T). The recorded data were digitized at a sampling rate of 1 kHz, and the iEMG was calculated every 20-s interval by the use of a Hewlett-Packard 9858OC desk-top computer.

**Measurement of oxygen uptake.** Measurements of oxygen uptake (VO₂) were taken in all subjects for the ramp test and in five of the eight subjects for prolonged exercise. During the ramp test and five sessions of prolonged exercises, respiratory measurements were taken by our on-line computer system which consisted of a mass spectrometer (Westron) and a pneumotachograph connected to a respiratory flow transducer. The analogue signals of fractional concentrations of O₂, CO₂, and N₂ from the mass spectrometer and those from the flow transducer were continuously digitized at 100 Hz by the computer system (NEC PC-9801 III). The VO₂, carbon dioxide production and expired ventilation were calculated every 20 s and those data were stored on a floppy disk for subsequent analysis. As for the determination of VO₂ during the main exercise for each subject, the mean VO₂ after the initial 3 min was obtained because it would have taken at least 2 min to reach a steady state of VO₂ at the given intensity. In addition, the mean value of VO₂ during unloaded exercise at each session was also obtained as a reference and called here the reference VO₂.

**Data analysis.** The iEMG data for the main exercise during each session of prolonged exercise was fitted mathematically to a straight line by linear regression and the coefficient was defined as "the iEMG slope".

**Statistics.** Paired Student's t-tests were performed to compare the means of VO₂ and the means of the iEMG slope among the respective pedalling rate treatments. In all analyses, differences were considered significant at P<0.05.

**Results**

The mean value of VO₂max was 2.97 (SD 0.33) l min⁻¹. The exercise intensity of prolonged exercise for the individuals, which was decided at the intensity corresponding to 75% VO₂max, ranged from 140 to 210 W. Figure 1 shows a typical set of data indicating the changes in iEMG as a function of time in one subject to show the differences of the iEMG slope in each pedalling rate treatment. With each period of exercise, the iEMG increased linearly. The iEMG slope tended to become smaller with the increase in pedalling rate.