Comparing the lactate and EMG thresholds of recreational cyclists during incremental pedaling exercise

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Abstract: The purpose of this study was to determine the validity of using the electromyography (EMG) signal as a non-invasive method of estimating the lactate threshold (LT) power output in recreational cyclists. Using an electromagnetic bicycle ergometer and constant pedaling cadence of 80 rpm, 24 recreational cyclists performed an incremental exercise protocol that consisted of stepwise increases in power output of 25 W every 3 min until exhaustion. The EMG signal was recorded from the right vastus lateralis (VL) and right rectus femoris (RF) throughout the test. Blood samples were taken from the fingertip every 3 min. The LT was determined by examining the relation between the lactate concentration and the power output using a log–log transformation model. The root mean square (RMS) value from the EMG signal was calculated for every 1-second non-superimposing window. Sets of pairs of straight regression lines were plotted and the corresponding determination coefficients ($R^2$) were calculated. The intersection point of the pair of lines with the highest $R^2$ product was chosen to represent the EMG threshold (EMGT). The results showed that the correlation coefficients ($r$) between EMGT and LT were significant ($p < 0.01$) and high for the VL ($r = 0.826$) and RF ($r = 0.872$). The RF and VL muscles showed similar behavior during the maximal incremental test and the EMGT and LT power output were equivalent for both muscles. The validity of using EMG to estimate the LT power output in recreational cyclists was confirmed.

Key words: EMG, lactate, pedaling exercise.

Introduction

The correlation between performance during endurance activities and physiological variables has been widely studied. Classically the maximal oxygen uptake ($V_{O_2max}$) has been used as a performance predictor in such activities. Recently, however, some researchers have suggested that $V_{O_2max}$ is not the best indicator for high-intensity long-duration exercise (Passfield and Doust 2000). It has been noted that among athletes with similar $V_{O_2max}$ levels, the capacity to maintain intense exercise at high $V_{O_2}$ levels in combination with low levels of lactate in the blood and active muscles is what determines success (Lucia et al. 2000). Therefore, as an alternative, the lactate threshold (LT) has been proposed as an efficient predictor of performance in such exercises. Although some authors question the relation between the accumulation of lactate in the blood and inadequate oxygen delivery during exercise (Brooks

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Protocol committee, and all subjects gave signed written consent. Twenty-four male recreational cyclists participated in the study. They had a mean age of 24.9 ± 3.7 years, body mass 72.4 ± 7.5 kg, height 164 ± 1.8 cm, and regularly performed physical activities, including cycling, between 2 and 3 h per week. This study was approved by the university ethics committee, and all subjects gave signed written consent.

Protocol

Before testing, subjects were familiarized with the equipment and procedures used in this investigation. The exercise testing was performed on an electromagnetic bicycle ergometer (model SF, Funbec, Brazil), fitted with competitive clipless pedals, handlebars, and saddle. The incremental exercise protocol consisted of 3 min unloaded pedaling followed by stepwise increases in power output of 25 W every 3 min until exhaustion while the pedaling cadence was kept constant at 80 rpm. The 2 criteria for stopping the test were (i) subjects were no longer able to maintain pedaling cadence at a minimum of 80 rpm, or (ii) subjects voluntarily stopped at exhaustion.

Data acquisition

EMG data and blood samples were obtained before and during exercise testing. Blood samples (25 μL) for the measurement of blood lactate were taken from the fingertip by using an Accusport lactate analyzer (Boehringer Mannheim, Mannheim, Germany) (Baldari and Guinetti 2000). The test protocol was only performed when subjects presented rest-level lactate concentrations before the start of exercise that were lower than 2 mmol/L. Blood samples were taken throughout the exercise testing at the end of every 3 min before the exercise intensity was increased to the next level.

Data processing and analysis

LT was determined by examining the relation between the lactate concentration and power output during the test by using a log–log transformation model (Beaver et al. 1985). In this method, the log of the blood lactate concentration is plotted on the y-axis as a function of the log of the power output on the x-axis. The resulting graph shows a gradual increase immediately interrupted by a sharp increase in the lactate concentration; this breakpoint clearly defines a transition in the relation of lactate versus power output (Fig. 1). Two independent experts identified and confirmed the LT, that is, the point immediately before the curvilinear increase in blood lactate concentration observed with subsequent exercise intensities.

The EMG signal was analyzed using Matlab software.
Raw EMG data were initially submitted to a band-pass filter (Butterworth, 3rd order, 20–400 Hz), after which the RMS value from the EMG signal was calculated for every 1-second non-superimposing window. Each point on the graph corresponds to 1 s of EMG (Fig. 2). The total points were divided into 2 groups. The first 60 points, representing the first 2 min of the test, were arbitrarily included in the first group, with the remaining points representing the second group. A straight regression line was plotted for each set of points and the corresponding determination coefficients ($R^2$) were calculated. The product of the 2 coefficients resulted in an index representing the linearity of the 2 regions. The initial value of the second set of points was included with the first set, increasing the number of points in the first set of points and decreasing the number of points in the second. New regression lines were plotted and the corresponding regression coefficients calculated, resulting in a new index for the 2 new groups. This procedure was repeated until the second set of points was composed of the final 60 points of the file, corresponding to the last 2 min of the test, and consequently the first set of points corresponded to the remainder of the points. The 2 sets of points that together formed the highest index were chosen to represent the EMG threshold (EMGT), that is, the intersection of the 2 straight lines marked the breakpoint at which the EMGT was established. Figure 2 shows the EMGT procedure.

**Statistical analysis**

The data obtained were analyzed with SPSS 10.0 software. The normality of the data (Shapiro–Wilk test) and homogeneity of the variance (Levene’s test) were confirmed. One-way ANOVA was applied to identify possible differences between the EMGT and LT for both the rectus femoris and vastus lateralis muscles. The EMG method was further validated by using the procedures suggested by Bland and Altman (1986). The data were presented graphically by plotting the difference between each method versus its average. The mean differences (bias) and standard deviation (SD) of the differences between the values obtained with the 2 methods, expressed in watts and minutes, were calculated. The limits of agreement were set at bias ± 2 SD. This procedure indicated the degree of precision of the EMG method. Significance was set at $p < 0.01$ for all statistical analyses.

**Results**

The mean lactate concentration at the LT was 4.5 ± 0.7 mmol/L and the mean maximal value of lactate concentration was 9.0 ± 2.2 mmol/L. Of the 24 subjects, the rectus femoris EMGT was not found in 2 subjects, and vastus lateralis EMGT was not found in another 2 subjects. Table 1 shows mean values of power output and time at the EMGT (in both muscles) and LT. There was no significant difference between power output at the EMGT and at the LT ($p = 0.96$). The mean maximal power was 131.3 ± 29.7 W and the mean duration of the test was 19.8 ± 2.9 min.

Figure 3 illustrates the time course of blood lactate concentrations and RMS in the vastus lateralis muscle for one subject. As expected, curvilinear increases in the blood lactate concentration and RMS were observed.

The statistical procedure suggested by Bland and Altman (1986) was used to express the degree of agreement between the threshold values obtained from the lactate curve and the EMG data for both muscles, expressed in both watts (Fig. 4) and minutes (Fig. 5). The bias and the limits of agreement of the EMG method were small for both muscles (rectus femoris and vastus lateralis). For power output, expressed in watts, 100% of the values from both muscles were within the limits of agreement (Fig. 4). For the time to reach the threshold, expressed in minutes, only the rectus femoris
muscle in one subject remained outside the limits of agreement, while all the values for the vastus lateralis were 100% within the limits of agreement (Fig. 5).

Discussion

The purpose of the study was to investigate the validity of the use of EMG in analyzing the power output corresponding to the LT in recreational cyclists. An important finding in this study was that, in contrast to studies involving athletes in which 2 EMG are normally found (Lucia et al. 1999), recreational cyclists presented a single EMGT. Furthermore, the power output of the EMGT corresponded to the power output of the LT. Also, although a difference would be expected because of the 2-minute delay (Svedahl and MacIntosh 2003), there was no statistical difference in the time to reach the threshold between lactate production at the muscle level and the increase of lactate in the blood. This result confirms the validity of using the EMG method in analyzing the LT in recreational cyclists during incremental tests.

As expected, the blood concentrations of lactate gradually increased in response to the increase in power output until the concentrations became exponential, marking the nonlinear behavior of the curve. The multifactorial explanation of the increase in lactate concentration during incremental exercise until exhaustion takes into consideration a number of processes, including increased lactate production, reduced lactate removal, or both (Svedahl and MacIntosh 2003). Thus, when the exercise reaches the intensity corresponding to LT, theoretically the rate of lactate production and transport into the blood will exceed the rate of removal from the blood. This process could be due to redistribution of blood flow away from lactate-removal sites (nonexercising muscle, liver, kidney, heart), or to transformation of lactate-removal sites into lactate-producing sites as the intensity of exercise increases. The consequence of this imbalance between production and removal is the recruitment of additional motor units within an active muscle, since some lactate is liable to diffuse between active and inactive muscle cells within a muscle (Karlsson and Jacobs 1982). In this situation, an accumulation of lactate may occur because, as the pool units become more active, fewer inactive muscle fibers are available to serve as lactate-removal sites (Svedahl and MacIntosh 2003). The tendency for the muscle fibers to produce lactate therefore increases in relation to the pattern of recruitment.

Nonlinear EMG increases similar to those reported in this study have been found in studies assessing neuromuscular fatigue during sustained and dynamic muscular contraction (Moritani et al. 1982; Takaishi et al. 1994), the lactate threshold (Lucia et al. 1999; Seburn et al. 1992), the ventilatory threshold during incremental exercise (Glass et al. 1998; Hug et al. 2003), and the EMG threshold (Hug et al. 2006). Although the abrupt increase in EMG activity is not fully understood, some authors have attributed it to the local accumulation of metabolic by-products such as lactic acid and hydrogen ions (Moritani and Yoshitake 1998; Masuda et al. 1999; Lucia et al. 1999). These changes would in turn affect the muscle excitation–contraction coupling, including the muscle membrane properties and muscle action potential propagation, leading to a subsequent decrease in the developed force and to deficient contractility (Moritani and Yoshitake 1998). Thus there is a consensus that, to compensate for this situation during an incremental exercise, muscle force output must be increased through the recruitment of additional motor units. A relation between the muscle fiber distribution (percentage of type II fibers) and metabolic changes may be expected, since lactate accumulation occurs during fatigue events such as maximal incremental tests, in which at certain intensities a greater twitch rate in fast muscle fibers occurs due to their functional and metabolic properties (Mannon 1999). In addition, lactate formation or associated pH changes in the sarcolemma of the muscle fibers have been thought to be responsible for lowering the mean conduction velocity, one of factors that can cause an increase in EMG signal amplitude (Lindstrom et al. 1970). On the basis of experiments involving the lactate shuttle hypothesis carried out by Brooks (2000), it is apparent that the lactate ion itself has no major role in the fatigue process (Brooks 2001).

Accordingly, a number of studies have sought to show a correlation between the accumulation of lactate and the changes in EMG. Seburn et al. (1992) investigated whether EMG was sensitive to dynamic alterations in the plasma lactate levels during incremental exercise at 90 rpm in 6 trained cyclists. The results showed that lactate and EMG increase in different ways during incremental cycling exercise. The authors speculated that a muscle’s recruitment pattern for incremental exercise would differ between a light load with high cadence and a heavy load with low cadence, despite

<table>
<thead>
<tr>
<th>Variable</th>
<th>Power output, W</th>
<th>Time to reach threshold, s</th>
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<tbody>
<tr>
<td>Lactate threshold</td>
<td>132±30</td>
<td>774±222</td>
</tr>
<tr>
<td>EMGT – VL</td>
<td>134±27</td>
<td>690±192</td>
</tr>
<tr>
<td>EMGT – RF</td>
<td>134±27</td>
<td>690±192</td>
</tr>
</tbody>
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Note: EMGT, electromyography threshold; VL, vastus lateralis; RF, rectus femoris. Values are means ± SD.

Fig. 3. EMG recording of the vastus lateralis muscle of one subject during incremental exercise. Each EMG point represents a root mean square (RMS) value in a 1-second window (small circles). Large circles are the blood lactate concentration (La).
equivalent power outputs. Similarly inconsistent results were reported by Jansen et al. (1997), who found no relation between changes in lactate concentration and median power frequency of the EMG in 12 subjects during cycle ergometer with step-wise increases in exercise intensities up to 100% of $V_{\text{O2max}}$. One of the arguments put forward was that the intensity used was insufficient to cause an accumulation of metabolic by-products and to influence the rate of muscle fiber conduction, thus suggesting the existence of some type of metabolic tolerance at a certain level of exercise.

Inconsistencies in the results reported in the literature may be partly attributable to differences in methodology, which on the one hand make comparisons difficult, but on the other, demonstrate that lactate cannot be considered the only factor influencing changes in EMG. Studies involving patients with myophosphorylase deficiency (McArdle’s disease) (Mills and Edwards 1984) have shown that during fatigue consistent alterations in EMG activity may occur without lactate accumulation. This observation suggests that factors within the central and peripheral nervous system are also involved in the neuromuscular fatigue process. Mateika and Duffin (1994a, 1994b), upon submitting subjects to 2 consecutive tests that induced positive and negative variation in lactate concentration, also showed that such variations do not necessarily occur in accordance with EMG variations. During tests where the load variation was exclusively incremental, however, Mateika and Duffin (1994a, 1994b), like other authors (Nagata et al. 1981; Lucia et al. 1999; Hug et al. 2006; Moritani and Yoshitake 1998), reported correlation between EMG and lactate. Thus, even
though the mechanism by which each of these variables (EMG and lactate) occurs is not fully understood, in a single progressive load test they appear to be correlated.

While some studies have found significant correlation between the changes in lactate and the EMG curves (Lucia et al. 1999), others have not (Seburn et al. 1992; Pringle and Jones 2002; Jansen et al. 1997). Using methodology similar to the present study, Lucia et al. (1999) investigated the validity and reliability of EMG as a new noninvasive determinant of the metabolic response to incremental exercise in 20 elite road cyclists and detected 2 thresholds in EMG that occurred concomitantly with lactate thresholds. The authors reported that these 2 thresholds occurred as a result of a change in the pattern of motor unit recruitment with the possible participation of type IIa and IIb fibers (at the EMGT1 and EMGT2, respectively). This change in recruitment produced larger action potentials, followed by some degree of synchronization as these fibers underwent progressive fatigue. The results of the present study are in overall agreement with Lucia et al. (1999) because the distinct EMGT we observed may have occurred as result of changes in the pattern of motor unit recruitment from a predominantly slow-twitch motor unit to a fast-twitch motor unit. Indeed, the fact that only one EMG threshold was found in recreational cyclists during incremental testing may indicate that only highly trained subjects (such as those selected in the study by Lucia et al. (1999)) are able to effectively recruit a sufficient number of motor units (especially type IIb fibers) at near-maximal intensities during incremental testing (Deschenes and Kraemer 2002) to be able to induce a second EMG breakpoint.

In summary, the results of the present study showed an EMGT that suggests a correlation between the percentage of type II fiber recruitment and the lactate accumulation, since the changes in the pattern of neuromuscular activity during maximal incremental testing appear to be associated with lactate accumulation, independently of the subject’s level of training. The initial speculation that the LT could be identified by using surface EMG was thus confirmed in cases where the EMGT and LT power outputs were equivalent.

We conclude that the rectus femoris and vastus lateralis muscles show similar behavior during maximal incremental testing and that the EMGT and LT power outputs are equivalent for both muscles. The validity of using EMG to measure the power output corresponding to the LT in recreational cyclists was confirmed. Given this finding, EMGT can be considered one more useful tool for coaches and recreational cyclists when designing training programs.

References


Mateika, J.H., and Duffin, J. 1994a. Coincidental changes in ventri-