HEART RATE AND LOWER LIMB MUSCLE ACTIVITY ON CYCLE ERGOMETER

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ABSTRACT

Introduction: Muscle activity in the pedal stroke movement on a cycle ergometer can be measured by surface electromyography, as an effective and improved method for studying muscle action and objectively determining the different action potentials of the muscles involved in specific movements. Heart rate behavior is an important factor during exercise with load. Objective: To identify heart rate behavior and pattern of muscle activity of the rectus femoris and vastus medialis in healthy subjects in the pedaling dynamic at different loads, submaximal test, on an instrumented cycle ergometer. Methods: 20 healthy adults were evaluated. Heart rate measurement was performed, together with electromyographic analysis, in the time domain, of the rectus femoris and vastus medialis muscles during incremental exercise of the lower limbs on the cycle ergometer. Results: Heart rate behavior presented significant difference for p≥0.05 in relation to increased loads. The EMG signal intensity from the vastus medialis muscle (normalized RMS value) in each quadrant of the pedaling cycle showed significant difference for p≥0.05 in relation to quadrants I, II and IV and significant difference for p≤0.05 in relation to quadrants III and IV. In the rectus femoris (RF) muscle, there was significant difference for p≤0.05 in relation to quadrants I, II and IV and significant difference for p≤0.05 in relation to quadrants I, II and III. Conclusion: An increase in heart rate proportional to the increase in load was observed, as well as an increase in the amplitude of the electromyographic signal proportional to the increase in load. It was possible to identify the pattern of muscle activation in the studied quadrants during pedal stroke movements, independent of load.

Level of evidence III; Study of non-consecutive patients; without uniform application of the “gold” standard reference.

Keywords: Heart rate; Surface electromyography; Rectus femoris; Vastus medialis.

RESUMO

Introdução: A atividade muscular no gesto motor da pedalada no cicloergômetro pode ser mensurada por meio da eletromiografia de superfície. A eletromiografia de superfície tem sido um método efetivo e aprimorado para estudar a ação muscular, determinando com objetividade os diferentes potenciais de ação dos músculos empenhados em movimentos específicos. O comportamento da frequência cardíaca tem relação importante durante o exercício com carga. Objetivo: Identificar o comportamento da frequência cardíaca e o padrão da atividade muscular do reto femoral e vasto medial em indivíduos saudáveis na dinâmica da pedalada em diferentes cargas, teste submáximo, no cicloergômetro instrumentado. Métodos: Foram avaliados 20 adultos saudáveis, realizando-se a mensuração da frequência cardíaca e a análise eletromiográfica no(s) segmento(s) do(s) músculo(s) reto femoral e vasto medial durante o exercício incremental dos membros inferiores em cicloergômetro. Resultados: O comportamento da frequência cardíaca apresentou diferença significante para p<0,05 em relação ao incremento das cargas. A intensidade do sinal EMG do músculo vasto medial (valor RMS normalizado) em cada quadrante do ciclo da pedalada mostrou diferença significativa para p<0,05 em relação aos quadrantes I, II e IV e diferença significativa para p<0,05 com relação aos quadrantes III e IV. No músculo reto femoral (RF) verificou-se diferença significativa para p<0,05 em relação aos quadrantes III e IV. No músculo reto femoral (RF) verificou-se diferença significativa para p<0,05 em relação aos quadrantes I, II e IV e diferença significativa para p<0,05 em relação aos quadrantes I, II e III. Conclusão: Houve aumento da frequência cardíaca proporcional ao incremento das diferentes cargas e também se evidenciou um aumento na amplitude do sinal eletromiográfico proporcional ao incremento da carga. Foi possível identificar o padrão da ativação dos músculos com relação ao ciclo da pedalada nos quadrantes estudados, independentemente do nível da carga. Nível de evidência III; Estudo de pacientes não consecutivos; sem padrão de referência "ouro" aplicado uniformemente.

Descritores: Frequência cardíaca; Eletromiografia; Reto femoral; Vasto medial.

RESUMEN

Introducción: La actividad muscular en el gesto motor de la pedalada en el cicloergómetro se puede medir por medio de la electromiografía de superficie. La electromiografía de superficie ha sido un método efectivo y mejorado para estudiar la acción muscular, determinando con objetividad los diferentes potenciales de acción de los músculos empeñados en movimientos específicos. El comportamiento de la frecuencia cardíaca tiene relación importante durante el ejercicio con carga. Objetivo: Identificar el comportamiento de la frecuencia cardíaca y el patrón de la actividad muscular del recto femoral y vasto medial en individuos en la dinámica de la pedalada en el cicloergómetro.
INTRODUCTION

Scientific evidence points out that exercising physical activity and also physical fitness exercises are factors that contribute to the improvement and / or maintenance of human health, indicating that its regularity and adequate dosage provide benefits for physical and mental health, for people in all the ages. It is also an important and determining factor in physical and psychological health. Recovery processes in pathological interventions in individuals are also accelerated with the proper practice of these activities, as well as being adequate means for disease prevention, improving health and well-being, promoting social interaction and integration. The performance of physical exercise also depends on the functional status of the respiratory, cardiovascular and muscle skeletal system.

For aerobic exercise, studies prove the effectiveness and benefits of suggestions from the American College of Sports Medicine (ACSM) and the American Heart Association (AHA) that recommend at least 30 minutes of moderate physical activity, five days a week or 20 minutes of vigorous activity three days a week.

Cycling is an activity that requires synchronized movements of multiple joints to generate propulsion by transferring the force produced by the lower limbs during the pedaling cycle to the pedal. The exercise bike is generally used as a form of aerobic exercise for weight loss, cardiac rehabilitation and exercise testing.

In cycling kinetics, you can divide the pedal cycle into two phases: propulsion and recovery, shown in Figure 01. The propulsion phase, where the cyclist applies the greatest force on the pedal, occurs from 0° to 180°, from 180° to 360° the recovery phase of the rotation of the sailfoot takes place, that is, when the left pedal is in the propulsive phase, the right pedal is in the recovery phase.

The quality of the pedaling depends on the different settings of the bicycle (saddle height, sailboat size, frame size, etc.), the position adopted by the cyclist, the gear ratio and the pedaling technique. The workload and pedaling cadence also have a direct influence on muscle activity.

Surface electromyography (EMGs) is an important technique for analyzing the structure and functioning of motor units, the electrical behavior in a musculature, identifying the activation of muscles in certain movements and also assessing muscle fatigue.

The electromyographic signal is the capture of the action potential of the muscle produced during muscle contraction, making it possible to observe the recruitment of motor units. The signals are captured and shown as graph records.

Detailed biomechanical analyzes of the lower limb during cycling were performed, demonstrating the intense activity of the rectus femoris muscle during the process, making it an indicator of muscle activity in cycling.

The objective of the present study was to identify the heart rate behavior and pattern of muscle activity of the rectus femoris and vastus medialis muscles in healthy individuals in the pedaling dynamics at different loads, submaximal test, in the instrumented ergometer cycle, with the hypothesis of increasing the amplitude of the electromyographic signal of the vastus medialis and rectus femoris muscles, proportional to the increase in load.

METHODS

Design

This is an observational cross-sectional study, in which heart rate and electromyographic signals from the rectus femoris and vastus medialis muscles of the dominant lower limb of healthy individuals were evaluated during the cycle of pedaling at different loads. It was carried out at the Movement Analysis Laboratory of the Universidade de São Paulo - UNICID.

All signals have already been collected following all ethical principles for research with humans as established by the Declaration of Helsinki, in accordance with the study “Behavior of the Electrical Activity of the Muscles of the Lower Limbs involved in the dynamics of pedaling on a cycloergometer”, approved by the ethics committee of Universidade de São Paulo – UNICID, registry #910041.
The sampling size calculation applied a two-tailed T test for independent samples, with type I error of 5%, type II error of 20%, power of 80% and effect size of 30%, thus obtaining a calculated sample of 25 individuals.

After completing and signing the Informed Consent Form, the selected individuals, according to the eligibility criteria, underwent anthropometric assessments, and measurements of heart rate, respiratory rate, oxygen saturation and blood pressure.

Personal information was noted and the Physical Activity Readiness Questionnaire (Par-Q)\textsuperscript{22}, 2 e Baeeke\textsuperscript{18,20}, were filled out to classify the individual as sedentary or physically active.\textsuperscript{21}

Data from twenty individuals from a previous study were analyzed and divided into two groups. A physically active group (10 individuals) and a sedentary group (10 individuals).

The eligibility criteria were a young, healthy adult, of both sexes, aged between 18 and 36 years, with no previous history of any musculoskeletal disorder.

Individuals diagnosed with musculoskeletal disorders that could interfere with electromyographic assessment, individuals with cognitive impairment preventing the understanding of the procedures and those who for some reason are unable to perform incremental exercise on the lower limbs cycloergometer were excluded.

Procedures

All participants underwent physical evaluation, heart rate analysis, electromyographic analysis of the rectus femoris and vastus medialis muscle and incremental exercise on the lower limbs cycloergometer. They were also submitted to physical examination to check vital signs, a necessary condition for performing the exercises.

An anamnesis form was filled out containing personal information and demographic data (Table 1).

The data from the electromyographic signals of the rectus femoris and vastus muscles were collected in the region of greatest electrical activity, following the recommendations of the International Society of Electrophysiology and Kinesiology (ISEK) and SENIAN, regarding the size of the contact area of the electrodes, positioning on the muscles and the distance between the pairs of electrodes\textsuperscript{22}.

In addition to the evaluation of the lower limb muscles, the heart rate synchronized to the EMG signals of the intensity of the imposed load, speed and cadence of the pedaling was recorded, to observe the behavior of the latter, in relation to the different loads during the incremental exercise.

After evaluating the maximum voluntary contraction, an incremental exercise was performed following the Billat Protocol (2001), where the speed was kept constant for 3 minutes and the load was increased so that the power was increased by 25 Watts.

All signals were collected simultaneously and analyzed using the software EMGlab V1.1 - EMG System do Brasil\textsuperscript{23}.

The system was implemented in order to follow the trace related to the cycloergometer load, making it possible to carry out the increments in the load accurately.

The data were analyzed using the quantitative method in the domain of amplitude. The values of the electrical activities of the muscles (µV RMS) were individually normalized by the maximum voluntary contraction (CVM).

To obtain the RMS averages of the evaluated muscles, mobile windows were used every 200ms, in the studied loads. The results were expressed as mean and standard deviation.

The load imposed on the pedal of the cycloergometer was measured through a force transducer and the measurements of load increase were synchronized to the other collected signals.

### Assessment of Maximum Voluntary Contraction

Due to the known variability of the signal, not only between people, but also between attempts, different standardization techniques have been developed to reduce this variability, being the maximum voluntary contraction (CVM), one of the known ways, which uses the highest value found in a contraction maximum voluntary, for the muscles in question correlating with the signals measured during the data extraction\textsuperscript{14,24,25}.

### Incremental Exercise Protocol

The protocol applied during the exercise test should consider the purpose of the assessment, the specific expected results, and the characteristics of the individual being assessed, such as age and symptoms.

Larger increments protocols, such as Bruce, Billat and Ellestad, are more suitable for research with young individuals and/or physically active.\textsuperscript{26}

After the evaluation of the maximum voluntary contraction, the participant already positioned on the exercise bike, previously adjusted, with the electrodes positioned, performed the incremental exercise following the Billat Protocol (2001).

The choice of this protocol was based on a study by Azevedo (2010) that recommends that the stages that make up the incremental test must be long enough for stabilization of blood lactate concentrations to occur after each new load increase, that is, the dynamic balance between blood and muscle lactate. It is suggested that each stage lasts between 3 and 10 minutes\textsuperscript{26}.

The authors indicate the following loads and increment times: 10 Watts (W) and duration of 2 minutes for each stage; 20 W every 3 minutes; 30 W every 4 minutes; 40 W every 4 and 45 seconds; 50 W every 5 minutes\textsuperscript{26}.

Therefore, the choice of the Billat protocol is more appropriate in relation to other incremental protocols, since it performs a 25W increment in the load of the cycloergometer, every 3 minutes, maintaining a constant speed, on average 22.5 Km / h, until the subjective fatigue reported by the individual under evaluation.

Taking into account that the Billat Protocol is performed until subjective fatigue, for the classification of the subjective perception of effort, 30 seconds before the increase in the load, a Borg\textsuperscript{22,24,26} was answered by each individual, peripheral oxygenation was measured by a pulse oximeter, and the heart rate was recorded. Symptom recommendations for test interruption according to American College Sports Medicine (2007) were also followed.

### Table 1. Characteristics and demographic variables of the participants.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group Physically Active</th>
<th>Group Sedentary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>5(50)</td>
<td>5(50)</td>
</tr>
<tr>
<td>Male</td>
<td>5(50)</td>
<td>5(50)</td>
</tr>
<tr>
<td>Age (year)</td>
<td>27.5±5.29</td>
<td>23±4.23</td>
</tr>
<tr>
<td>Height (meter)</td>
<td>1.73±0.11</td>
<td>1.70±0.09</td>
</tr>
<tr>
<td>Body weight (kg)</td>
<td>74.75±(13.03)</td>
<td>75.78±(21.77)</td>
</tr>
<tr>
<td>IMC</td>
<td>25.08±(3.65)</td>
<td>25.99±(6.63)</td>
</tr>
<tr>
<td>Smoker</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>1(10)</td>
<td>1(10)</td>
</tr>
<tr>
<td>No</td>
<td>9(90)</td>
<td>9(90)</td>
</tr>
<tr>
<td>Par-Q</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Apt</td>
<td>10(100)</td>
<td>10(100)</td>
</tr>
<tr>
<td>Inapt</td>
<td>0(0)</td>
<td>0(0)</td>
</tr>
<tr>
<td>Baeeke</td>
<td>9.90±(7.71)</td>
<td>7.37±(8.81)</td>
</tr>
</tbody>
</table>
After performing the incremental protocol, the vital signs: heart rate, respiratory rate, oxygen saturation and blood pressure were measured and recorded again only as feedback on the volunteer’s physical situation (Table 2).

### Statistical Analysis

Continuous variables are expressed as means, standard deviation (SD) and RMS (Root Mean Square) and the data were subjected to a normality test. Through the analysis of variance ANOVA (one-way), it was possible to observe that the VM Muscle (vast medial) presents significant difference for $p < 0.05$ in relation to quadrants I, II and IV. It also presents a significant difference for $p < 0.05$ in relation to quadrants III and IV (Table 3). For the RF muscle (rectus femoris), a significant difference can be observed for $p < 0.05$ in relation to quadrants I, II and IV. It also presents a significant difference for $p < 0.05$ in relation to quadrants I, II and III (Table 4). Heart rates showed a significant difference for $p < 0.05$ in relation to the different loads (Table 5).

### RESULTS

Table 3 shows that the heart rate is dependent on the increased load imposed during pedaling.

The behavior of the heart rate as a function of the imposed loads, is depicted in Figures 2 and 3, indicating the direct relationship between them.

#### Table 2. Clinical signs during the test.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group Physically Active</th>
<th>Group Sedentary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial HR (bpm)</td>
<td>76.8 (7.35)</td>
<td>75 (11.42)</td>
</tr>
<tr>
<td>RR inicial (bpm)</td>
<td>163 (9.25)</td>
<td>173 (2.75)</td>
</tr>
<tr>
<td>SpO2 inicial (%)</td>
<td>96.4 (0.7)</td>
<td>96.5 (1.08)</td>
</tr>
<tr>
<td>Final HR (bpm)</td>
<td>143.3 (20.97)</td>
<td>137.6 (20.94)</td>
</tr>
<tr>
<td>Final RR (bpm)</td>
<td>23.3 (3.59)</td>
<td>24.8 (3.68)</td>
</tr>
<tr>
<td>SpO2 final (%)</td>
<td>96.2 (0.79)</td>
<td>96.4 (1.17)</td>
</tr>
</tbody>
</table>

Continuous variables are expressed as mean and standard deviation (SD), Heart Rate (HR), Respiratory Rate (RR), and SpO2 (Oxygen Saturation).

#### Table 3. Average heart rate (MFC) during the cycle of pedaling at different loads.

<table>
<thead>
<tr>
<th>P valor</th>
<th>MFC 1C (bpm)</th>
<th>MFC 2C (bpm)</th>
<th>MFC 3C (bpm)</th>
<th>MFC 4C (bpm)</th>
<th>Effect size</th>
</tr>
</thead>
<tbody>
<tr>
<td>$p &lt; 0.05$</td>
<td>78 ± 7.74</td>
<td>108 ± 13.54</td>
<td>127 ± 17.76</td>
<td>140 ± 18.02</td>
<td>0.435</td>
</tr>
</tbody>
</table>

Continuous variables are expressed as mean and standard deviation (SD), Heart Rate (HR) for the loads (1C, 2C, 3C, 4C). Statistical significant difference for $p < 0.05$ in relation to the four loads.

#### Table 4. Electrical activity of the vastus medial muscle (MV) during the four quadrants of pedaling at different loads.

<table>
<thead>
<tr>
<th>Quadrant</th>
<th>VM1C (µV)</th>
<th>VM2C (µV)</th>
<th>VM3C (µV)</th>
<th>VM4C (µV)</th>
<th>Effect size</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>113.78 ± 9.04</td>
<td>122.87 ± 9.82</td>
<td>147.04 ± 11.76</td>
<td>147.09 ± 11.76</td>
<td>0.427</td>
</tr>
<tr>
<td>II</td>
<td>79.69 ± 6.57</td>
<td>100.90 ± 8.07</td>
<td>103.26 ± 8.26</td>
<td>67.82 ± 5.42</td>
<td>-</td>
</tr>
<tr>
<td>III</td>
<td>5.96 ± 0.47</td>
<td>5.89 ± 0.47</td>
<td>6.44 ± 0.51</td>
<td>6.99 ± 0.55</td>
<td>0.309</td>
</tr>
<tr>
<td>IV</td>
<td>49.83 ± 3.98</td>
<td>56.33 ± 4.50</td>
<td>56.52 ± 29.11</td>
<td>63.95 ± 5.11</td>
<td>-</td>
</tr>
</tbody>
</table>

Continuous variables are expressed as mean and standard deviation (SD). RMS (Root Mean Square) VM (vast medial). A significant difference for $p < 0.05$ in relation to quadrants I and IV. Significantly significant difference for $p < 0.05$ in relation to quadrants II and III.

#### Table 5. Electrical activity of the rectus femoris (RF) muscle during the four quadrants of pedaling at different loads.

<table>
<thead>
<tr>
<th>Quadrant</th>
<th>RF1C (µV)</th>
<th>RF2C (µV)</th>
<th>RF3C (µV)</th>
<th>RF4C (µV)</th>
<th>Effect size</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>19.96 ± 1.59</td>
<td>15.57 ± 1.24</td>
<td>24.40 ± 1.94</td>
<td>26.95 ± 2.15</td>
<td>-</td>
</tr>
<tr>
<td>II</td>
<td>11.33 ± 0.90</td>
<td>14.53 ± 1.16</td>
<td>18.86 ± 1.50</td>
<td>17.75 ± 1.42</td>
<td>-</td>
</tr>
<tr>
<td>III</td>
<td>4.68 ± 0.37</td>
<td>4.41 ± 0.33</td>
<td>4.67 ± 0.37</td>
<td>5.21 ± 0.41</td>
<td>0.148</td>
</tr>
<tr>
<td>IV</td>
<td>22.20 ± 1.77</td>
<td>27.28 ± 2.18</td>
<td>37.35 ± 2.98</td>
<td>46.00 ± 3.68</td>
<td>0.475</td>
</tr>
</tbody>
</table>

Continuous variables are expressed as mean and standard deviation (SD). RMS (Root Mean Square) RF (rectus femoris). Significant difference for $p < 0.05$ in relation to quadrants I, II and IV. A significant difference for $p < 0.05$ in relation to quadrants I, II and III.

In Table 4, it can be seen that there was a more significant activation of the vastus medialis muscle during the first quadrant of the pedaling in the four load increments. Table 5 shows that there was a greater activation of the rectus femoris muscle during the fourth quadrant of pedaling in the four load increments.

### DISCUSSION

This study, being performed on an instrumented cycloergometer, allowed total control of the participant’s movement through heart rate, electrical activity (EMG) of the vastus medialis and rectus femoris muscles in contraction during movement at different loads. All signals were effectively synchronized from the control of imposed loads, pedal cadence, speed, EMG muscle contraction, according to the Billat Protocol. This minimizes the influence of the mechanical effect of the movement, as in the conventional cycloergometer there may be some difficulty in maintaining the pedaling cadence throughout the exercise and speed control, especially with the progressive increases in the load imposed on the movement of the pedals.

The use of surface electromyography in the time domain allowed to monitor the muscle activation of the rectus femoris and vastus medialis during the cycle of pedaling. Understanding that each muscle has an important function in the pedaling movement, acting in a different phase of the same, it was decided to analyze the magnitude of the EMG signal (normalized RMS value) in each quadrant of the pedaling cycle.

Hug e Dorel²⁹, in the comparison between groups, it showed significant differences for the magnitude of the EMG signal (normalized RMS value), when compared by quadrants of the pedal. This data could be observed for $p < 0.05$ in relation to quadrants I, II and IV, indicating the direct relationship between them.
also be observed in this study, since the vastus medialis muscle had a greater activity in the first quadrant and the rectus femoris, had a greater activity in the fourth quadrant of the pedal.

In Candotti study, in the first quadrant, the RMS value between the groups was significantly different for the RF and VL muscles at a rate of 90 rpm. In the third quadrant, there was no significant difference between muscle groups. In this study, there was also no significant difference in the third quadrant.

According to Gregor (2000), the activity of the monoarticular muscles is more consistent when compared to the activity of the biarticular muscles, in the sense of the amount of muscle activation. It can be observed that the RF, a muscle with biarticular function that acts on both the hip and the knee, showed greater activity in the propulsion phase, acting as a knee extensor, together with the VL, in this same phase of the cycle. However, the RF also showed a certain degree of activation in the pedal recovery phase, acting as a hip flexor.

Table 5 shows that the rectus femoris showed greater activity in the recovery phase, together with less activation of the vastus medialis (Table 4). However, there was an activation of this muscle in the recovery phase, more specifically during the fourth quadrant of the pedaling cycle (Figure 4) and also shown in Figure 5 which depicts the RMS and normalized averages.

With this, it can be said that the RF (rectus femoris) has an important function in the knee extensor torque, developed in the propulsion phase of the pedal cycle.

The VM and RF muscles are crucial for generating pedal forces. The vast medialis produces 55% of the total power during the propulsion phase.

Limitations
Aiming at a reliable data collection, the study performed a quality instrumentation through a force transducer that, synchronized to the acquisition module, allowed perfect adjustments for the load increase. The biological signals of the research subjects were also synchronized.

The speed control and pedaling cadence were also implemented using an electronic device designed for this purpose. In addition, to reduce the risks of physical exercise, measures were taken to find out if the participants were really able to perform the type of effort proposed.

On the other hand, no analysis of RR intervals was performed, which could provide greater power of comparison with studies found in the literature. During the collections, it was possible to notice that other muscles such as the vastus lateralis, biceps femoris, gastrocnemius and anterior tibialis play an important role in pedaling and for the study of this type of activity.

CONCLUSIONS
It was possible to identify the behavior of heart rate and its relationship with different loads imposed in an effective, instrumented and synchronized way, and the activation pattern of the vastus medialis and rectus femoris muscles, showing an increase in the amplitude of the electromyographic signal proportional to the increase in the load. The pattern of muscle activation in relation to the pedaling cycle, regardless of the level of the imposed load, was also demonstrated.

Heart rate exhibits a behavior directly proportional to the increase in the load imposed on the cycloergometer.

Such characterizations have innumerable contributions to the health area, regarding their primary prevention, assisting the professional in the choice and direction of evaluations and/or training with different loads.

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All authors declare no potential conflict of interest related to this article.

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