

Muscle electrical activity during exercises with and without load executed on dry land and in an aquatic environment

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Abstract Introduction: Muscle activity in the aquatic environment was investigated using electromyographic analyses. The physical properties of water and the resistance used may influence the response of the muscle during exercise. The objective of this study was to evaluate the electrical activity in water and on the floor during flexion and knee extension exercises with and without load and aimed at understanding the muscular response while performing resistance exercises in water. **Methods:** The sample consisted of 14 volunteers between 18 and 35 years old who were subjected to active exercises involving knee flexion and extension with and without load on the floor and in water. Electromyography was performed during the movement. **Results:** A significant increase was found in the electrical activity of the rectus femoris muscle during exercises on the floor. The biceps femoris muscle showed increased electromyographic activity when resistance was used. A significant increase was found in the electrical activity of the rectus femoris muscle compared with exercises with and without load and the moment of rest in immersion. The electrical activity of the rectus and biceps femoris muscles was reduced in exercises with load and without load in a therapy pool compared with on the floor. **Conclusion:** There was a reduction of the electromyographic activity in the aquatic environment compared with that on the ground, which could be attributed to the effects from hot water. Therefore, it is believed that resistance exercises can be performed early in a therapy pool, which will facilitate the prevention and treatment of musculoskeletal disorders.

Keywords: Electromyography, Hydrotherapy, Kinesiotherapy.

Introduction

Immersion treatment programs have been widely recommended because they provide many therapeutic benefits (Rahmann et al., 2009; Roper et al., 2013). The aquatic environment favors exercises that often would be implemented with difficulties on land (Batterham et al., 2011).

The physiological effects from immersion are related to the physical properties of water (Becker, 2009; Kisner and Colby, 2000), including the hydrodynamic principles, hydrostatics and thermodynamics, which are responsible for the differences in the musculoskeletal system response between exercises on land and in a therapy pool.

The muscular work in immersion is directly influenced by the thermodynamic property of water. The heat transfer ability of water is twenty-five times more efficient than that of air, and the heat transfer begins immediately after the immersion. Thus, a water temperature between 32°C and 33°C promotes muscle relaxation (Caromano and Nowotny, 2002).

The muscle endurance when performing floor exercises for therapeutic uses depends on the load and

the action of gravity acting as the liquid medium. The resistance is determined by the hydrostatic pressure, viscosity, buoyancy of the equipment, size and surface area (Müller et al., 2005) and the speed of movement (Harrison et al., 1992; Müller et al., 2005). The viscosity and the hydrodynamic forces acting on the displacer require increased muscle torque compared with those on land (Castillo-Lozano and Cuesta-Vargas, 2013).

The assessment of muscle electrical activity can be performed either on the ground or in a liquid medium by means of electromyography, which allows the elucidation of muscle behavior in different situations in the context of the types of fiber and muscle contraction (Müller et al., 2005; Vodusek, 2007). The quantification of the electromyographic (EMG) activity in immersion is still considered a challenge due to the difficulty in setting the surface electrodes on the skin (Masumoto et al., 2004). When the EMG signal is properly carried out in the aquatic environment, the data integrity is maintained compared with data acquisition on the land (Castillo-Lozano and Cuesta-Vargas, 2013).

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Received: 07 July 2013 / Accepted: 15 January 2015

A study by Pinto et al. (2010) showed no differences in the amplitude of the myoelectric signal for maximum strength exercises performed in water and on land. On the other hand, other studies found a reduction of the muscle electrical activity during exercises in the water compared with on the ground (Cuesta Vargas et al., 2013a; Fujisawa et al., 1998; Kelly et al., 2000; Masumoto et al., 2004; Pöyhönen et al., 1999). Müller et al. (2005) found that when the move occurred at full speed, there was increased electromyographic activity on land and in water. Cuesta-Vargas et al. (2013b) observed the most marked increase in the electrical activity of the trunk muscles in the aquatic environment compared with on land.

There is a need for further studies to quantify the electromyographic signal in the aquatic environment, especially as it concerns the comparison of muscle activity during movement performed with and without resistance from an external force. According to Escamilla et al. (1998), conducting exercises against a certain resistance has implications for rehabilitation, considering the possible existing mechanisms of injury if not carried out properly.

Therefore, this study aimed to evaluate and compare the muscle electrical activity during flexion and knee extension, performed on the ground and in water, with and without load use.

Our hypothesis was that the electromyographic activity during the exercises in the pool with heated water, considered therapeutic, would be lower than on land and that the exercises with resistance would promote increased electromyographic signals in these two environments.

The results of this study may contribute to an improved understanding of the muscle response when performing movements with load in water.

Methods

This was a cross-sectional study, developed in Sensory Motor Rehabilitation Engineering Laboratory and Sector hydrotherapy at the University of Vale do Paraíba (Univap), using a swimming pool with a depth of 1.40 m in the shallow end and a depth of 2.10 m in the deeper side. It is important to note that the latter had a mobile platform, which enabled individual adjustment for each individual. This study was approved by the Research Ethics Committee of the Univap, CAAE: 06708912.8.0000.5503.

The sample consisted of 14 adults (two males and twelve females), sedentary or who did not practice regular physical activity (less than three times a week), aged between 18 and 35 years.

The following exclusion criteria were considered:

- Individuals who had a history of pain, trauma and / or surgery on the knee joint;
- Clinical evidence of meniscal injury or ligament instability;
- Musculoskeletal disorders.

After the selection, all of the volunteers were invited to participate in two exercise protocols performed on the ground and in the heated pool with a minimum interval of 24 hours between each protocol. Data collection was performed only with the dominant member of each volunteer. All of the individuals signed the informed consent and were informed about the measures taken.

Data collection

The acquisition of the muscle electrical signal was performed by an eight channel electromyograph, EMG830 WF model (EMG System do Brasil Ltda®, São José dos Campos/SP/Brasil), with the following technical characteristics: analog-to-digital conversion board (A/D) with 16-bit resolution; bipolar pre-amplified electrode with a differential gain of 20 times, totaling a final amplification of 1000 times; impedance > 10 MOhms, signal-to-noise ratio < 3 μ Volts RMS; common mode rejection ratio > 120 dB; analog band-pass filter of 20-500 Hz; sampling frequency set to 2 kHz per channel.

Before attaching the electrodes, the removal of impurities was performed at the location with 70% ethanol, and the location was shaved to minimize the impedance of the electrode-skin interface. To collect the electromyographic signal Ag/AgCl surface electrodes (Double®) were used, with a contact diameter of 10 mm and a distance of 20 mm between centers.

The surface electrodes were positioned following surface electromyography protocol recommendations for the non-invasive assessment of muscles (SENIAM) under the rectus femoris muscle (50% on the line from the anterior superior iliac spine to the top of the kneecap) and biceps femoris (50% on the line between the ischial tuberosity and the tibial lateral epicondyle).

During the test in the therapeutic pool, we used surface electrodes with preamplifiers and a shielded coaxial extension cable for use in water. We used a waterproof occlusive tape (Tegaderm - 3M) and plastic wrap to avoid getting water on the electrodes. The reference electrode, preacher type, made of a metal plate was placed on the styloid process of the ulna.

Experimental procedure

The experimental procedure consisted of the application of two exercise protocols that were performed with the dominant member of each volunteer on land

and in heated water, which were classified as protocol 1 and protocol 2, respectively, as mentioned below:

Protocol 1

- Heating: 5 min walk on a treadmill at a speed of 2.5 km/h;
- 5 min rest;
- EMG collection at rest in a sitting position for 20 s, during which the knee joint was positioned at 90° flexion.
- Active exercise of knee flexion and extension of the dominant leg without load in the sitting position on the ground during the 20 s EMG collection;
- 3 min rest;
- Active exercise of knee flexion and extension of the dominant leg in a seated position using a load of 2 kgf positioned at the ankle during 20 s EMG collection;
- Stretching of the muscles of the lower limbs, emphasizing the quadriceps and hamstrings (3 repetitions of 15 s for each member).

The volunteers were instructed to carry out the maximum range of knee flexion and extension at a comfortable and harmonic speed.

Protocol 2

We carried out the same procedure as in Step 1; however, the pool heated at 34°C, and the heating was performed on a mat, as described above. The level of immersion to the height of the xiphoid process in the sitting position of each individual was considered. The collection of the electromyographic signal was performed at home and during the exercises with and without load in the water as per the above protocols.

Data analysis

The electromyographic signals were saved in txt format and processed by EMGworks Analysis (Delsys®) software. After obtaining the signals, we calculated the mean square value (root mean square - RMS) of each muscle contraction. Initially, the data were subjected to the D'Agostino normality test. It was found that all of the parameters satisfied the criteria of normality. The data were analyzed using a paired t-test for intra-group analysis and ANOVA with a post criterion Tukey test for intergroup analysis (land and therapy pool) using BioEstat software version 5.0 and considering a significance level of 5%.

Results

To graphically present the RMS values of the electrical activity of the rectus femoris (Figure 1) and biceps femoris (Figure 2) in the different phases of

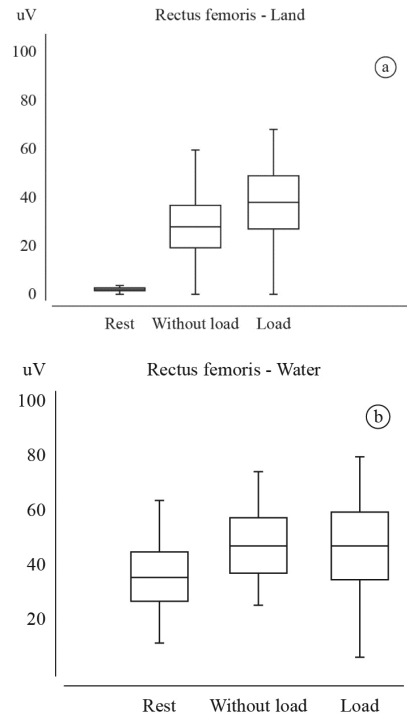


Figure 1. Box plots of the mean and two standard errors of the RMS values of the myoelectric signal of the rectus femoris (a) on the floor and (b) in the therapy pool.

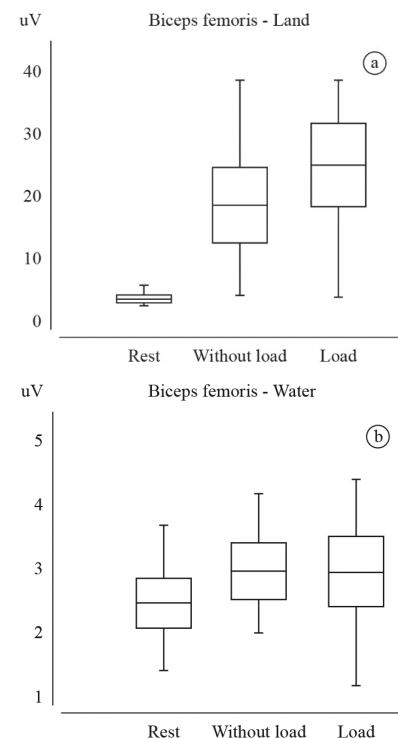


Figure 2. Box plots of the mean and two standard errors of the RMS values of the myoelectric signal of the biceps femoris (a) on the floor and (b) in the therapy pool.

Table 1. Statistical results of electromyography during flexion and knee extension exercises with and without load performed on the floor and in the aquatic environment.

Electromyography - land		
	Rectus femoris	Biceps femoris
Rest x (flexion and extension without load*)	(↑) p < 0.01*	ns
Rest x (flexion and extension without load*)	(↑) p < 0.01*	(↑) p < 0.05*
Flexion and extension: without load* x (with load*)	(↑) p < 0.05*	ns
Electromyography - Aquatic		
	Rectus femoris	Biceps femoris
Rest x (flexion and extension without load*)	(↑) p < 0.01*	ns
Rest x (flexion and extension without load*)	(↑) p < 0.01*	ns
Flexion and extension: No load x With load	ns	ns

*Anova (p < 0.05); ns: not significant; (↑): increase.

Table 2. Statistical results of electromyography during flexion and knee extension exercises with and without load comparing that on the floor with that in the aquatic environment.

Electromyography	Rectus femoris	Biceps femoris
Land rest x (immersion rest*)	(↓) p < 0.001*	(↓) p < 0.001*
Flexion and extension: Land without load x (immersion without load*)	(↓) p < 0.001*	(↓) p < 0.001*
Flexion and extension: Land with load x (immersion with load*)	(↓) p < 0.001*	(↓) p < 0.001*

*t-test (p ≤ 0.05); (↓): decrease.

the protocol, we used the box plot average and two standard errors.

In this study, there was a significant increase in electrical activity of the rectus femoris muscle performed on the ground with and without load compared with the myoelectric signal collected at rest. There was a significant increase in the electrical activity of the rectus femoris muscle analyzed with and without load.

Regarding the biceps femoris muscle, a significant increase was observed when comparing the EMG activity at rest with that with loaded exercise; however, the EMG activity was not significant between rest and movement without load.

During the time in immersion, a significant increase was observed for only the electrical activity of the rectus femoris muscle during movements with and without load for the resting phase. In Table 1, the results obtained after statistical analysis are demonstrated.

There was a significant reduction of the electrical activity of the rectus femoris and biceps femoris at rest with and without load in the therapy pool compared with on land (Table 2).

Discussion

The maintenance and / or improvement of muscle performance are the main objectives set out in the development of exercise programs directed to people with or without changes in the musculoskeletal system.

In this study, we evaluated the muscle electrical activity during flexion and knee extension on land and in the aquatic environment. All of the subjects were instructed to perform the movements at a comfortable and harmonic speed according to procedures adopted in the study by Cardoso and Sousa (2003).

Considering the exercises performed on the ground, there was an increase in the electrical activity of the biceps femoris only compared with the movements performed with load for the resting phase. However, the rectus femoris muscle showed a significantly increased myoelectric signal with load compared with the no-load exercises and both movements relative to the time of rest. This result was justified considering that the knee extension movement was carried out with equipment resistance and was held against gravity. According to Devereux et al. (2005), in a terrestrial environment, movements made in favor of gravity required less force production, thus facilitating muscle contraction. However, the movements performed in the direction opposite to gravity had a higher resistance.

During the movements performed in immersion, there was a significant increase in the electric signal of the rectus femoris muscle with and without the use of load in comparison with the resting phase. The biceps femoris muscle showed an increased myoelectric signal; however, it was not significant. This increase could be attributed to the action of the hydrostatic pressure and the viscosity of the water, in addition to the additional resistance resulting from the load use. In addition, when the member moves in

the aquatic environment, it is subjected to drag forces and turbulence (Becker, 2009)

By comparing the data for the movements performed in water and on land, there was a reduction in the electrical activity of the rectus and biceps femoris with and without load in the aquatic environment. These results were consistent with studies conducted by Sugajima et al. (1996) and Devereux et al. (2005), who found that in water, there was less force production compared with the terrestrial environment due to the buoyant force, which acts in the opposite direction to gravity and reduces the apparent weight (hydrostatic weight). Pöyhönen et al. (1999) found a significant reduction in the amplitude of the electromyographic signal during submaximal and maximal contractions of the knee extensor muscles in immersion compared with on the ground. Masumoto et al. (2004) reported that the individuals walking in the liquid medium showed a decrease in the muscle electrical activity compared with walking on the ground. The authors explained that these results could be attributed to the effect of buoyancy in the water, suggesting that the individuals minimized their efforts to walk in water, which would have resulted in reduced muscular endurance.

According to Pöyhönen et al. (1999) and Kelly et al. (2000), the reduction of muscle electrical activity during immersion exercises can be attributed to the absence of gravity on muscle spindles and proprioceptive receptors in the displacer due to buoyancy.

Another factor that may decrease the electromyographic signal is the water temperature. This study used immersion at 34°C, which is commonly used in therapeutic pools. It is known that the heated water temperature contributes to muscle relaxation (Biasoli and Machado, 2006) and increased blood supply to the skeletal muscle system by peripheral vasodilation (Becker, 2009; Biasoli and Machado, 2006; Rahmann et al., 2009).

Cuesta-Vargas et al. (2013a) found increased electrical activity of some muscles of the legs on the ground compared with in water; however, when evaluating the trunk muscles, there was a larger increase in the electromyographic signal in the aquatic environment. Müller et al. (2005) also found an increase in the electrical activity of the trunk muscles during immersion in water compared with on the ground, both at standard speed and full speed.

In contrast with the results obtained in this study, Pinto et al. (2010) found no significant changes in the electromyographic activity on land or in water during maximal voluntary isometric contractions of

the biceps muscles, triceps brachii, rectus femoris and biceps femoris.

For a study to be comparable on land and in water, playback is needed the same procedure in these two environments, as well as the use of adequate protection to prevent water from entering the electrode during immersion (Castillo-Lozano and Cuesta-Vargas, 2013; Cuesta-Vargas, 2013b). If there is water contact with the electrode during myoelectric evaluation, the myoelectric signal may be decreased (Carvalho et al., 2010; Pöyhönen et al., 1999). In the research conducted, the same procedures on land and in water were made. Furthermore, to evaluate the electromyographic signal in water, water impermeable occlusive tape was used under the electrodes, as well as plastic polyvinyl chloride (PVC) in the region of the body part in question.

Considering the resistance exercises, Pinto et al. (2014) found that when endurance was used before aerobic exercise, there might be optimization of muscle strength and hypertrophy of the lower limbs. Another study investigated the effects of a ten-week training program with progressively increasing resistance in the aquatic environment and evaluated the flexors and knee extensors of twenty-four healthy women. There was a significant increase in the torque, lean mass and neural activation of the muscles, concluding that training in the aquatic environment could be recommended for neuromuscular conditioning (Pöyhönen et al., 2002).

In a therapeutic context, authors report that aquatic therapy allows active movement in the early postoperative period without compromising patient safety (Kelly et al., 2000). According to Bressel et al. (2012), patients with pain symptoms can more easily perform muscle exercises first in an aquatic environment such that they could be subsequently transferred to the terrestrial environment. Orselli and Duarte (2011) observed a significant reduction in the joint torque during marching in water compared with on land, suggesting that the therapeutic pool is a safe environment for the exercise due to the reduction of impact.

The results of this study are in accordance with most of the ongoing research in the literature, although these studies were performed during exercise without load. The heated water may have contributed to the reduction of electromyographic activity. Some studies reported increased electromyographic activity during exercise in immersion compared with on the ground; however, the analysis was performed on trunk muscles. Therefore, it is suggested to compare the electrical signal of muscles from the same body segment.

Knowing that there is a reduction of electrical muscle activity while performing movements in the aquatic environment compared with on land, including load use, it is believed that resistance exercises can be performed early in a therapy pool, which will favor the prevention and treatment of musculoskeletal disorders, considering that the patient can sooner return to their activities of daily living.

Future studies on exercises using different resistance graduations performed in other positions and velocities and in a pool with water lower temperature may be conducted to improve the results obtained in this study in order to determine the influence of all of these factors on the electrical activity muscle.

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