Effects of the exercise-induced muscular fatigue on the time of muscular reaction of the fibularis in healthy individuals

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ABSTRACT

The muscular fatigue (MF) is a common phenomenon in the daily sports activities that results in a worsening of the motor performance. It is considered one of the major factors for muscle-skeletal damages, such as the ankle sprain, when the MF would affect both the afferent and the efferent systems. Several studies have been analyzing the influence of the MF on the neuromuscular control (NMC). Nevertheless, there are few researches comprising that influence on the velocity of the muscular reaction. The purpose of this study was to check the effects of the MF on the time of the muscular reaction (TMR) in the fibularis muscles, which are the first to respond to an inversion stress of the ankle. Fourteen healthy male individuals (age: 20-35 years) were studied, who had their TMR assessed by means of the surface electromyography (EMG). The beginning of the muscular activity was defined as the mean resting value +3x the standard deviation (SD). The TMR of the fibularis was measured after a sudden 20º inversion performed on a platform. The sudden inversion was performed before and after the muscular fatigue, which was induced through localized exercises of the fibularis up to the exhaustion. The results have shown a significant increase in the time of the muscular reaction after the fatigue ($p < 0.01$). While performing prolonged sportive activities and during the rehabilitation process, there must be caution to perform tasks that require extremely fast muscular responses.

Keywords: Muscular fatigue. Time of the muscular reaction. Fibularis.

INTRODUCTION

The muscular fatigue (MF) that is defined as any reduction in the neuromuscular ability to produce strength[1,2] is a usual phenomenon in resistance sports, and is a common experience in the daily activities[3]. The beginning of the voluntary muscular activity involves several processes that start with the cortical control in the brain, and end with the cross-bridges inside the muscular fiber. Therefore, the muscular fatigue can be the result of a failure in any process involved in the muscular contraction[4].

Historically, the potential factors involved in the fatigue development are divided in two categories: the central factors that should provoke the fatigue by a disorder in the neuromuscular transmission between the CNS and the muscular membrane, and peripheral factors that would cause an alteration inside the muscle[5-7]. Another characteristic of the fatigue is the fact that it depends on the task, that is, its causes vary in a very wide way, and it behaves according to the way it is induced[4,8]. The muscular fatigue is considered a predisposing factor to the appearance of injuries[9,10], such as the ankle sprain. In the majority of cases upon the occurrence of such type of injury, the originator mechanism is an inversion movement of the ankle[11,12]. The responsible by the obstruction in that harmful stress to the joint is the structure that statically (fascia, capsule, ligament) and dynamically (muscles)[13] restricts the joint. The short and *longus* fibular muscles are the first and more important muscular structures that actuate in the prevention of that type of sprain[14].

Several authors have been studying the effects of the muscular fatigue on the neuromuscular control (NMC)[9,15-17], which is related to the proprioceptive afferents that are taken by the peripheral receptors to the upper centers, and to the efferent (motor) responses generated with the purpose to keep the dynamic muscular stability[18]. Studies have shown that the muscular fatigue causes an adverse change in the proprioception[16,19] (a sensorial modality comprising the sensations of the joint movement and positioning[13]), as well as the postural control[9,15,17,20]. However, few studies analyzed the changes that the muscular fatigue generates in the time of the muscular reaction (TMR)[3,21,22].

Due to the high incidence of the ankle sprain caused by the inversion[23,24] and the great amount of occurrences of the muscular fatigue both in the sportive and daily activities, and being aware of the major importance that the effective and fast motor control have to prevent muscle-skeletal injuries[4], this study had as main purpose to analyze the effects of the muscular fatigue induced by active-resisted exercises in the TMR of the fibularis in healthy individuals by means of surface electromyography (EMG), and to verify if there is any difference in the EMG activity of the resting fibularis before and after the muscular fatigue. The fibular reaction was tested by utilizing a sudden inversion platform.

METHODOLOGY

The research was developed at the Laboratory of the Exercise Research (LAPEX) of the Rio Grande do Sul Federal University

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(UFRGS). Before participating in the study, each individual granted his formal consent to participate in the research signing a Free and Clarified Consent Term elaborated following ethic standards previously approved by the Ethics Committee in Research of the Rede Metodista de Educação in March, 2004.

Population and sampling

It participated in the study 14 male individual practitioners of regular physical activity (at least twice a week) with no previous history of injuries in the lower limbs, and without compromise in the joint stability of the ankle. All participants were not performing any physical activity at least 24 hours prior to the data collection. It was chosen not to use individuals from both genders because some authors have shown differences between men and women as to the fatigue[25,26].

Procedures to the data collection

The data collection was performed in three steps: 1) assessment of the time of the pre-fatigue muscular reaction, 2) fatigue induction, and 3) assessment of the time of the post-fatigue muscular reaction. The right lower limb was chosen to perform the test, regardless the individual's dominance.

To measure the time of the muscular reaction, it was used a Bortec® electromyograph (EMG) (Bortec Electronics Incorporation Calgary, Canadá). The EMG had a 10 cm away from the electrodes preamp, and it was used two channels where the amplified signal was converted through a digital-analogical board. In order to record the electromyographic signal, it was used disposable Kendall® surface electrodes with a 3 cm diameter stick (Meditrace – 100; Ag/AgCl) in the bipolar configuration. To attain the adequate electrode positioning, each participant was asked to perform a voluntary contraction of the fibular muscles against manual resistance, in order to allow the identification of the muscular abdomen, when the electrodes were placed 1/3 below the fibula's head to fix the electrodes.

Ground electrodes were placed on the tibialis tuberosity of the left leg, and the skin was shaved using a disposable razor, in order to reduce the electrical impedance and by scraping the skin with alcohol-soaked cotton to remove dead cells and the oiliness at the spot where the electrodes were positioned[27]. Next, the electrodes were fixed on the skin through a mild pressure in order to increase the contact area between the electrode's gel and the skin[28].

It was used a 20º sudden ankle inversion platform with a synchronism system connected to a computer, which was able to inform the precise moment when the platform would tumble against the board's base, thus signalizing the end of the inversion spinning. With no previous warning, the board device was manually triggered, simulating a sprain by ankle inversion. At that moment, the computer collected the muscular response from the fibularis, as well as the moment when it occurred. The same procedure was performed in two different periods: in the beginning that is, before the muscular fatigue, and in the end, after the fatigue. The individual was in orthostatic position on the board, with his arms interlaced on the thorax, and next, he was oriented to stare a fixed point at the height of his eyes, in a way they could not see when the researcher was triggering the mechanical device of the board. At that moment, the computer was already collecting the (resting) muscular electrical activity.

The muscular fatigue was induced through active localized resisted exercises. The muscular fatigue is defined in the literature as a failure in the neuromuscular system in its ability to generate a required or expected strength[10]. When performing voluntary strengths, such failure can result from several central or peripheral mechanisms[5].

Thus, the fatigue induction was performed through ankle eversion exercises against the resistance. The individual was seat on a little mattress with his backs supported by the wall, his knees and left hip inflected. The right lower limb was positioned in a 90º flexion of the hips with extended knees and the ankle in a neutral position. He was barefoot. By using a green Theraband® brand elastic band, the researcher was on the left side of the individual, and he positioned the elastic band on the external side of the foot, thus creating a resistance against the eversion movement. The individuals were instructed to perform the higher amount of eversions possible, and they always received oral stimuli. Such Theraband® band was used because it supplies a medium resistance[30] due to the heterogeneity of the sampling, and the fact that the electrical capability of the participants was not previously known. The test was performed in every individual with the same researcher. Even with the whole methodological criterion used, it cannot be asserted that every participant reached the same fatigue level; it can only be asserted that they achieved some fatigability level that made them unable to go on performing the task.

After the fatigue induction, the individual was once again positioned on the board (located 1 meter away the place where the exercises were performed), and the TMR was measured once again through a sudden inversion. The post-fatigue measurement occurred in less than 10 seconds after the muscular fatigue of the fibularis.

Analysis and filtering of the electromyographic signals

Initially, a 3-order Butterworth filter was used at a 20-600 Hz frequency. The resting period was considered the prior 2 seconds to the stimulus, from which the mean and the standard deviation of the resting EMG signal were obtained. From these data, it was possible to determine the threshold to detect the muscular activity. This means that the EMG signal that it would surpass that threshold would be the muscular activation above the resting. The criterion for the muscular activation was based on the following calculation: Threshold = mean + (3x SD). Whenever using three deviations above the mean, the result attained was 99.7% chance to consider a different activity from the resting[30]. To set the time for the reaction of the fibularis muscles, it was set the moment when the first muscular activation peak occurred (post-stimulus), when the threshold would be surpassed. The difference between the moment when the external stimulus occurred and the activation peak was set as the time of the muscular reaction, or the time of the electromyographic response.

Statistical analysis

It was used the *t* Student test for paired sampling to compare the resting activity of the fibular muscles before and after the fatigue, as well as to check the differences in the time of the pre- and post-fatigue muscular reaction. The significance level used was $p < 0.05$.

RESULTS

The characteristics of the 14 participants are presented on table 1. The mean age was 25 ± 3.94 years; height: 1.75 ± 0.06 meters; weight: 72.71 ± 11.71 kg; the amount of days they performed physical activities per week was 4.10 ± 1.60, and the amount of eversion repetitions performed along the fatigue induction was 113.40 ± 34.60.

The resting electrical signal (v) (defined as the 2 seconds period before the stimulus) of the fibularis was higher than in the post-fatigue period (0.031 ± 0.020) compared to the pre-fatigue values (0.025 ± 0.013). Nevertheless, there was no statistically significant difference ($p > 0.05$). Table 2 presents the values related to each participant.

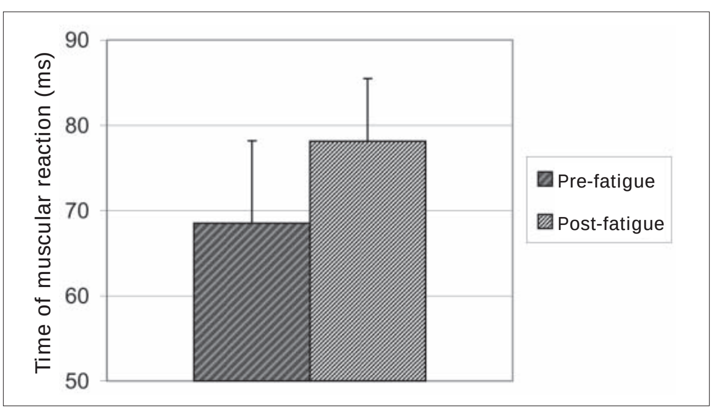
The comparison between the fibular TMR in the pre- (68 ± 9.7 ms) and post-fatigue (78 ± 7.4 ms) period has shown a statistically significant increase in the TMR in the post-fatigue period ($p < 0.001$), as shown on graphic 1.

TABLE 1
Characteristics of the participants

Individuals	Age (years)	Height (cm)	Weight (kg)	Amount of activities/ week (days)	Repetitions
1	21	168	70	5	110
2	25	175	70	7	140
3	23	170	62	3	64
4	34	187	84	5	140
5	25	172	60	5	90
6	33	183	89	0	140
7	22	187	63	5	96
8	25	174	80	2	100
9	23	169	63	3	80
10	24	182	98	5	80
11	22	166	61	0	170
12	27	172	69	6	100
13	22	175	80	5	178
14	24	175	69	3	100
Mean	25	175.35	72.71	3.85	113.42
Standard deviation	3.94	6.84	11.71	2.1	34.6

TABLE 2
Comparison of the pre- and post-fatigue values during the resting

Individuals	Pre-fatigue resting activity (v)	Post-fatigue resting activity (v)
1	0.0091	0.0101
2	0.0386	0.0587
3	0.027	0.0235
4	0.0318	0.0262
5	0.0330	0.0823
6	0.0293	0.0313
7	0.0532	0.0445
8	0.0116	0.0213
9	0.0084	0.0117
10	0.0310	0.0240
11	0.0349	0.0377
12	0.0089	0.0095
13	0.0129	0.0479
14	0.0206	0.0175
Mean	0.02511	0.0319
Standard deviation	0.0135	0.02071



Graphic 1 *– Description of averages and standard error in the muscular reaction time in the two studied periods*

DISCUSSION

This study aimed to analyze the influence of the muscular fatigue in the fibular TMR. The sampling was composed by 14 male individuals. It was chosen not to use individuals from both genders as some authors have shown differences between men and women as to the fatigue[25,26]. The majority of the studies performed show that women have higher resistance to the fatigue during submaximal contractions. One of the goals of the present study was to check whether there is a difference in the EMG activity of the resting fibular muscles in the postural controlling and/or balance[9,15,17,20,32], and in only one of the studies the muscular fatigue did not cause an adverse postural change [15]. As the postural control is kept through some afferences that come from the visual, vestibular, and somatosensory systems that stimulate the continuous muscular contractions[15,17,20], and as the muscular fatigue changes the muscular contractile effectiveness and proprioceptive information[15,16,32,42], these results are not surprising.

In order to keep the balance in the orthostatic positioning according to the individuals' positioning along the data collection, it is necessary constant corrective contractions as a response to the small disturbances in the joint[20]. Due to the fact the muscular fatigue decreases the neural transmission velocity[21], maybe the ability in creating efficient compensatory contractions around the joint is reduced, resulting in a loss of the NMC and higher changes in the joint positioning. But this is only a speculative statement, as the aim of the study was not to analyze any difference in the balance and posture of the individuals.

The present study has identified a significant increase in the TMR in individuals after inducing the muscular fatigue. The latency period of the fibularis muscles was similar to those found in the literature. Some authors[14,35] have presented studies assessing the TMR of the fibularis on sudden inversion boards in individuals with stable and unstable ankles, and the values found had a significant variation. The time of the fibular reaction may be influenced by some factors. Studies testing the reliability of those measurements assessed 30 individuals, and it was verified that the time of the fibular reaction did not present a statistically different result between both genders and the left and right limbs, and it was found no influence of the body weight; there was a decrease in the pre-warming period and an increase after the fatigue, and it decreased with a 15º plantar flexion. The tests performed in different days and times did not show any difference; so, the authors have concluded that the time of the fibular reaction is a reliable measurement[35]. In the present study, it was chosen the right limb, and the tests were performed in three days in the same hour.

Other factors that have influenced the results of such type of measurement were: the platform angle and the criterion for the muscular activation (CMA). The angle used on the platform in this study was 20º[29]; nevertheless, other studies used 18º to 35º angles[14,35,36]. It is quite probable that the different angles lead to different afferences, and this would cause different motor responses.

As to the beginning of the muscular activation, normally, it is used criteria such as: to consider the first electrical activity of the muscle[29,35], or to calculate the mean of the resting signal plus *n* times more the SD[14,22,30].

The works using as criterion the activation of the first muscular response after the stimulus have shown lower reaction times. As to the other criterion used, it varied from 2 to 10x of the SD[22] between authors. That difference may led some researchers to consider the mean latency signal or even the long latency as the first response of the muscle[14]. This may have occurred in the present study because it has used a CMA of: [mean + (3xSD)]. When it is used three deviations above the mean, it presents a 99.7% chance to consider a different activity than the resting[31].

It is a consensus that the intact afferent nervous system is important to provide the necessary feedback for an effective motor control[11]. Parallel to this, studies have shown that the human proprioception is deteriorated by the fatigue[16,18,19,33,34], and theoretically, this would be one of the causes for the worsening in the motor responses. According to the present study, it is known that the proprioception contributes for the muscular reflection, thus providing the dynamic joint stability[18]. So, some authors have suggested that the muscular fatigue would not have apparent effects on the sense of the joint movement (kinesthesia)[18]. Despite the importance of the feedback that comes from mechanoreceptors and the proprioception[11,14], it is probable that the muscular receptors have a major interference on the TMR, since it was measured under a sudden perturbation and high velocity condition, when the responsible by the defense mechanism was the muscular fuse activated by the straining reflection[8,37]. In another study[14], it was performed an anesthetic blockage of the ligament receptors of the ankle, and it was seen that the fibular reaction to the sudden inversion did not change (80/83 ms). These findings suggest that the afferent information to the sensor-motor capabilities were mediated by the receptors in the myotendinous system.

Another process that may be involved is the recurrent inhibition[38]. The recurrent inhibition is a local feedback circuit that can modify the reflective responses by means of an interneuron known as Renshaw cell. This cell can be activated by a supraspinal impulse, by the group III and IV muscular afferents, and by a collateral branch of the axon of the alpha-motoneuron (MN). The activation of the recurrent inhibition results in a decrease in the excitability of the MN that can be increased during the contractions in the fatigue state. Besides the effects on the alpha-MN, such inhibition also generates potential post-synaptics in the gamma-MN. This connection means that the recurrent inhibition can modulate the muscular fuse excitability and influence the relationship between the afference and efference to the straining reflection[8]. Some authors[39] assessed the M1 and the muscular rigidity interaction with their influences in the pre- and post-performance in a marathon. The test protocol included several jumping in an ergonometer. The interpretation in the sensitivity of the reflection was based on measurements of the patellar reflections and the M1. The fatigue has provoked a considerable worsening of the neuromuscular function. The results have shown a clear deterioration in the reflection sensitivity after the fatigue, and they suggest that the modulation of the neural input to the muscle has at least partial reflective origin in the contracted muscles, and the decreasing muscular rigidity that followed the decreasing reflection sensitivity, and such lower rigidity may have been partially responsible by the weaker muscular performance, due to the worse utilization of the elastic power[39]. According to the results found in the present paper, the neuromuscular control is partially compromised with the fatigue onset, and this can be a predisposing factor to injuries. There are few available studies in the literature aiming the relationship between the fatigue and TMR[3,21,22].

CONCLUSION

The results attained in the present study must be carefully interpreted. The conclusions must be accepted in the environment in which the data was collected rather than in a generic way. Thus, the muscular fatigue induced through resisted active exercises did not influence the resting electrical signal of the fibularis. There was a statistically significant increase in the time of the muscular reaction after induction the fatigue, showing that there is a neuromuscular compromise.

FUTURE GUIDANCE

It is necessary to be very careful both in the sports and in the daily activities for the muscular fatigue not be a possible cause for injuries. To avoid tasks that demand extremely fast muscular responses when the body presents signals it is tired could be the ideal situation to prevent injuries. Along the rehabilitation process, the precaution must be even higher, because individuals who are in such situation probably present proprioceptive and/or muscular deficits. Along the rehabilitation sessions, it would be advisable to perform tasks that would need an accurate neuromuscular control before exercising the required muscles in order to prevent an injury worsening or recurrence. Therefore, the training aiming the muscular resistance is very important both to athletes and patients, since those muscles with an increased resistance to the fatigue would expose in a lower level individuals to muscle-skeletal injuries. Future studies, besides of analyzing the time of the muscle reaction, must check the effects of the muscular fatigue in the magnitude of its strength and the duration of these effects.

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