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Spectral analysis of the electromyograph of the erector spinae muscle before and after a dynamic manual load-lifting test

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Abstract

The aim of the present study was to assess the spectral behavior of the erector spinae muscle during isometric contractions performed before and after a dynamic manual load-lifting test carried out by the trunk in order to determine the capacity of muscle to perform this task. Nine healthy female students participated in the experiment. Their average age, height, and body mass (± SD) were 20 ± 1 years, 1.6 ± 0.03 m, and 53 ± 4 kg, respectively. The development of muscle fatigue was assessed by spectral analysis (median frequency) and root mean square with time. The test consisted of repeated bending movements from the trunk, starting from a 45º angle of flexion, with the application of approximately 15, 25 and 50% of maximum individual load, to the stand up position. The protocol used proved to be more reliable with loads exceeding 50% of the maximum for the identification of muscle fatigue by electromyography as a function of time. Most of the volunteers showed an increase in root mean square versus time on both the right (N = 7) and the left (N = 6) side, indicating a tendency to become fatigued. With respect to the changes in median frequency of the electromyographic signal, the loads used in this study had no significant effect on either the right or the left side of the erector spinae muscle at this frequency, suggesting that a higher amount and percentage of loads would produce more substantial results in the study of isotonic contractions.

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Key words
- Electromyography
- Spectral analysis
- Root mean square
- Load lifting
- Fatigue

Introduction

Manual load lifting continues to be a concern in everyday activities, particularly in occupational ones. Many variables interfere with the action of manual load lifting (1), hindering the establishment of definitive rules. Several researchers have attempted to develop testing protocols that would permit the assessment of muscle behavior in this extremely demanding activity (1-7).

Overload-related lumbar lesions caused by manual load lifting can be prevented by tests specifically developed to identify muscular activity patterns characteristic of a state of fatigue. Because fatigue results from the repetition of tasks and overloads, it is one of the major causes of musculoskeletal injuries of the spine.

The literature contains several proposals for test protocols, some of which include the use of manual load-lifting accessories such as pelvic belts (4), which have been found to reduce electromyographic activity but not to interfere with the development of the fatigue process (3).

Among the protocols developed for the identification of muscular fatigue, most of those based on the methodology of deVries et al. (8) show a steadily stronger electromyography (EMG) signal along time through the root mean square (RMS) of the signal (4,9-12).

Another tool for the analysis of muscular fatigue is spectral analysis (5), which is used to interpret the behavior of motor units in response to repetitive tasks, particularly those involving isometric contractions. One of the main characteristics of this behavior is the reduction of firing frequency, which can be represented by the mean power frequency (13-15) and more clearly by the median frequency (2).

The determination of the evolution of median frequency may be applied clinically (16) in studies in which spectral analysis is used to help monitor the rehabilitation of patients with lower back pain (7).

Other factors possibly related to fatigue are accumulation of hydrogen and metabolic ions (17,18), as well as a deviation of sodium and potassium concentrations. Thus, biomechanics together with physiology of exercise seek to quantify the muscular effort required for given workloads over a given period of time. The EMG signal is an index of the energy expended in performing the task and fatigue is an important factor in the characterization of this pattern of movement and its efficiency (19). The RMS of this signal indicates variations in the firing frequency and amplitude of muscular activity (20), variables that are normally affected in the fatigue process.

In an attempt to identify more reliable protocols based on the use of EMG, the objective of the present study was to assess the spectral behavior of the erector spinae muscle during isometric contractions performed before and after a dynamic manual load-lifting test of the trunk in order to diagnose the capacity to carry out the task.

Material and Methods

Subjects

Nine healthy female students participated in the experiment. Their average age, height, and body mass (± SD) were 20 ± 1 years, 1.6 ± 0.03 m, and 53 ± 4 kg, respectively. The protocol was approved by the local Ethics Committee, and all subjects signed informed consent forms prior to the experiment. None of the subjects reported any history of lower back pain.

Instrumentation

For the experiment, the subjects stood up straight, hips leaning on a horizontal support rod, knees stretched straight, and the trunk supported on a mobile rod. In this position, the trunk performed bending movements, from its initial position to a 45° angle, in both isometric and isotonic contractions.

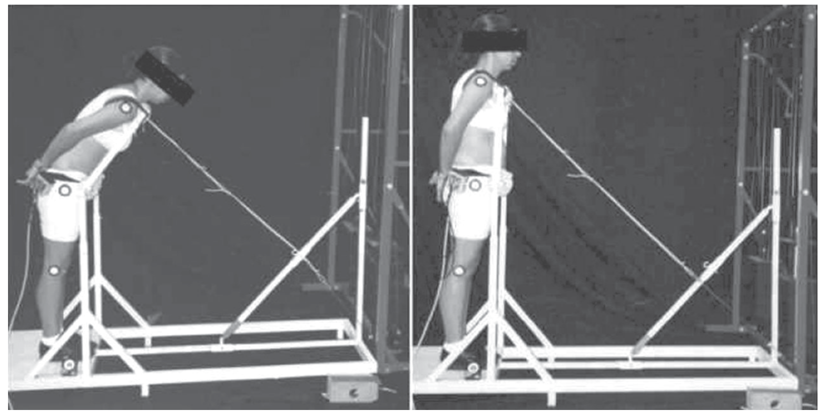
A videocamera (JVC 30 Hz) was used in order to ensure that the subjects maintained the correct posture during manual load lifting and to identify the beginning and the end of the manual load-lifting movement. The image recorded by the camera was displayed in real time to the subject as the test was performed, serving as a feedback of the initial and final limits of the extent of the movement allowed. A metronome (Qwik Time) was used to ensure that all subjects performed the exercise at the same pace (20 bpm).

To synchronize the acquisition of the electromyographic data and the corresponding posture during the movement, a photoelectronic system (21) was used to activate an incandescent bulb, which emitted a common signal to the EMG apparatus (Lynx - Tecnologia Eletrônica Ltda.) and to the videocamera.

Procedure

Prior to the experiment, the maximum load of the erector spinae muscle was determined based on the protocol proposed by Bittencourt (22).

The experiment consisted of performing a maximum voluntary contraction (MVC) of 3 s before and after the isotonic contractions (manual load lifting and lowering with the trunk), using an M.A. ISOSTATION 2000 device (Rio Claro, SP, Brazil) (Figure 1). The isotonic contractions lasted 1 min and were performed using a cable coupled to a system of double pulleys (Riguetto) using 50% of the maximum load obtained by each subject.



A B

Figure 1. M.A. ISOSTATION 2000 device. *A*, Isometric contractions and initial position in the 1-min test; *B*, final position in the 1-min test.

Data analysis

A biological signal acquisition module (Lynx) was used, with four channels connected to monopolar (differential way) passive surface electrodes (Ag/AgCl) measuring 1 cm in diameter. The electrodes were positioned along the muscle at a distance of 4 cm from one another bilaterally to the subject's back after cleaning and gentle abrasion of the skin. The EMG signals were recorded from the portions of the erector spinae muscle (spinal process L1) where the electrodes were attached, according to the procedure described by Kumar (6).

The EMG signals were sampled at a rate of 1000 Hz, with filters at 20 and 500 Hz and were amplified 1000 times. The conversion from analog-to-digital signals was performed by an A/D circuit board with an input range of -5 to +5 volts (CAD 1026 - Lynx). The common mode rejection ratio was 80 dB. A specific software program (Aqdados - Lynx) was used to capture the signals.

The RMS obtained for the concentric phase was calculated and correlated with the number of data recorded during the 1-min test. The spectral analysis was based on the isometric contractions (3 s).

Results and Discussion

Table 1 reports the median frequency before and after the 1-min test and Table 2

Table 1. Median frequency (MF in Hz) before and after the 1-min test on both the right and left sides with the application of 15, 25 and 50% of maximum load.

Subject	Load	Right side		Left side	
		MF before	MF after	MF before	MF after
1	15%	72.26	74.21	56.64	66.40
	25%	74.21	76.17	69.33	65.42
	50%	65.42	68.35	57.61	53.71
2	15%	82.03	83.98	75.19	74.21
	25%	59.57	67.38	73.24	71.28
	50%	62.50	55.66	69.33	68.35
3	15%	67.38	62.50	63.47	71.28
	25%	85.93	75.19	59.57	68.35
	50%	61.52	61.52	62.50	69.33
4	15%	77.14	69.33	65.42	64.45
	25%	71.28	72.26	62.50	63.47
	50%	76.17	61.52	73.24	59.57
5	15%	66.40	58.59	68.35	70.31
	25%	75.19	76.17	66.40	70.31
	50%	73.24	75.19	65.42	66.40
6	15%	70.31	69.33	65.42	63.47
	25%	70.31	69.33	78.12	64.45
	50%	61.52	57.61	65.42	62.50
7	15%	64.45	67.38	73.24	71.28
	25%	75.19	66.40	115.23	83.00
	50%	65.42	63.47	71.28	63.47
8	15%	73.24	74.21	73.26	62.50
	25%	76.17	73.24	66.40	69.33
	50%	69.33	63.47	66.40	60.54
9	15%	81.05	77.14	73.24	83.00
	25%	83.00	68.35	83.00	73.24
	50%	63.47	57.61	70.31	69.33
Mean ± SD	15%	72.70 ± 6.31	70.74 ± 7.67	68.25 ± 6.09	69.66 ± 6.44
	25%	74.54 ± 7.56	71.61 ± 3.85	74.87 ± 16.84	69.87 ± 5.90
	50%	66.71 ± 5.29	62.71 ± 6.05	66.83 ± 4.84	63.69 ± 5.25

No significant differences were observed (Wilcoxon test).

reports the RMS value during the test. Table 1 shows that there were no significant differences in median frequency before and after the 1-min test. However, most of the subjects showed a slight decrease in median frequency (before and after the exercise) on both the right (N = 5) and the left side (N = 5) with the application of 15 and 25% of maximum load, while the application of 50% of maximum load also resulted in a slight decrease on the right (N = 6) and the left side (N = 7). These data characterize the development of fatigue, as reported by Elfving et al. (23) and Seidel et al. (24), who studied muscular fatigue in isometric contractions of the erector spinae muscle in the lumbar area using spectral analysis and identifying fatigue by the evident drop in median frequency.

Table 2. Correlation between root mean square (RMS) and time during the 1-min test on both the right and left sides with the application of 15, 25 and 50% of maximum load.

Subject	Load	RMS (µV) *vs* time (s)	
		Right side	Left side
1	15%	r = 0.081	r = -0.782
	25%	r = -0.225	r = -0.073
	50%	r = -0.059	r = -0.498
2	15%	r = -0.408	r = 0.351
	25%	r = 0.419	r = 0.617
	50%	r = 0.877*	r = 0.780
3	15%	r = -0.054	r = -0.307
	25%	r = 0.410	r = 0.266
	50%	r = 0.370	r = 0.613
4	15%	r = -0.491	r = -0.022
	25%	r = 0.631	r = 0.432
	50%	r = 0.825*	r = 0.154
5	15%	r = 0.082	r = -0.071
	25%	r = -0.003	r = -0.595
	50%	r = 0.856*	r = 0.554
6	15%	r = 0.257	r = -0.212
	25%	r = -0.702	r = -0.425
	50%	r = 0.553	r = 0.504
7	15%	r = -0.518	r = -0.536
	25%	r = -0.388	r = -0.604
	50%	r = -0.169	r = -0.224
8	15%	r = -0.886*	r = 0.096
	25%	r = -0.044	r = 0.604
	50%	r = 0.738	r = 0.716
9	15%	r = 0.486	r = 0.082
	25%	r = -0.248	r = 0.664
	50%	r = 0.236	r = -0.261

*P < 0.05, correlation of RMS *vs* time (linear regression test).

Since surface electrodes were used in the present study, the reduction of median frequency is consistent with the findings of Bigland-Ritchie et al. (25) and Moritani et al. (26), who highlighted the presence of low frequency components associated with an increase in the amplitude of the EMG signal in their study of sustained contractions. This can be explained by the shape of the motor unit action potential wave, which showed a longer duration and lower conduction speed for a longer time lapse to cross the electrode.

Because the present protocol failed to present the results expected regarding the fatigue process, we suggest that adjustments should be made in order to use it to assess individuals that usually subject this muscle to overloads.

No marked increase in RMS versus time was found on either the right (N = 4) or the left (N = 3) side during the load-lifting phase using 15% of the maximum load (Table 2). With 25% of the maximum load, however, although no predominant increase of RMS versus time was observed on the right side (N = 3), a slight increase did occur on the left side (N = 5). Last, with 50% of maximum load, most of the volunteers showed an increase in RMS versus time on both the right (N = 7) and the left (N = 6) side, indicating a tendency to become fatigued. These findings are consistent with those reported by Bigland-Ritchie et al. (27) and Wittekopf et al. (18), who observed that, when the muscle displays localized fatigue after repeated contractions, the EMG signals increase. This is even more explicitly reported in the study by Sparto and Parnianpour (28), whose evaluations of erector spinae muscle fatigue revealed a 75% increase of EMG activity with decreased loads.

The protocol tested here proved to be more reliable with the use of loads exceeding 50% of the maximum for the identification of muscle fatigue by EMG as a function of time. The loads used in this study had no significant effect on the identification of fatigue related to alterations in median frequency in the erector spinae muscle on either the right or the left side, leading us to conclude that the number and percentage of loads for isotonic contractions should be increased to provide a reliable identification of the development of fatigue.

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