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original article

Analysis of localized muscle fatigue in elderly women with and without a history of falls using electromyographic signal frequency parameters

Análise da fadiga muscular localizada em idosas caidoras e não caidoras através de parâmetros de frequência do sinal eletromiográfico

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Abstract – One of the problems that most concerns the elderly population is the falling, which can be caused by muscle fatigue. The objective of this study was to compare median electromyographic frequency values for the vastus lateralis muscle and the lateral portion of the gastrocnemius muscle (as parameters of electromyographic fatigue) in elderly people with and without a history of falls. A total of 20 healthy, physically active, elderly women who had or had not suffered falls were enrolled on the study. Median electromyographic signal frequencies were analyzed for the vastus lateralis muscle and the lateral portion of the gastrocnemius muscle in isometric contraction. ANOVA and Student's t test were used for comparisons, to a cutoff of $p \leq 0.05$. Median frequencies for the gastrocnemius and vastus lateralis muscles were both higher in the group with a history of falling, but without statistical significance. It was also observed that the rate of decline in median frequency was greater in the group with a history of falling. It can be concluded that elderly people with a history of falling have a greater tendency to fatigue of the gastrocnemius and vastus lateralis muscles than their peers with no history of falling.

Key words: Electromyography; Elderly; Balance; Muscle fatigue; Postural equilibrium; Seniors.

Resumo – *Um dos problemas que mais preocupam a população idosa são as quedas, que podem ser causadas pela fadiga muscular. O objetivo do estudo foi comparar os valores de frequência mediana, como um parâmetro de fadiga eletromiográfica, dos músculos vasto lateral e porção lateral do gastrocnêmio em idosos com e sem história de quedas. Participaram do estudo 20 idosas saudáveis, ativas fisicamente (que sofreram e não sofreram quedas). Analisou-se a frequência mediana do sinal eletromiográfico dos músculos vasto lateral e porção lateral do gastrocnêmio em isometria. As comparações foram feitas pela ANOVA e teste t de Student, considerando $p \leq 0,05$. O músculo grastrocnêmio apresentou maiores Fmed no grupo caidor do que no não caidor, o mesmo acontecendo com o vasto lateral, sem significância estatística. Também foi possível observar que a taxa de queda dos valores da frequência foi maior no grupo caidor do que no não caidor. Pode-se concluir que há maior tendência de fadiga dos músculos gastrocnêmio e vasto lateral de idosos caidores.*

Palavras-chave: *Eletromiografia; Equilíbrio; Equilíbrio postural; Fadiga muscular; Idoso; Senior.*

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INTRODUCTION

The number of people over the age of 60 is predicted to double over the next 20 years. Demographic data indicate that there will be 33 million Brazilians over the age of 60 in 2025, making Brazil's elderly population the sixth-largest in the world[1].

One of the complications of aging is the emergence of chronic degenerative conditions. It can be observed that functional capacity goes into decline during aging and that this is associated with a significant reduction in physical activity, meaning that elderly people are ever more limited in terms of their daily activities, resulting in a compromised musculoskeletal system, problems with balance, reduced resistance and frequent falls[2-5].

It has been observed that muscle strength is reduced by 20% at 60 years of age, which is caused by changes in the number and size of muscle fibers, loss of motor units and changes to motor end plates[6]. This reduction in strength increases the probability of falls, which are the most serious consequences of disorders of postural control. Around 29% of the elderly fall at least once a year and 13% fall repeatedly[7].

One factor that is associated with falls is muscle fatigue, which can be defined as the point at which a given muscle or muscle group is no longer able to maintain a given level of force[8,9]. Muscle fatigue involves disturbances in the neuromuscular system involving changes in muscle strength and control, altering amplitude and velocity of movements[8]. Muscle fatigue affects both the proprioceptive and peripheral systems, and also processing of sensory information[10], leading to attenuation of capacities and of precision, reducing motor control, impacting negatively on balance and predisposing to falls[11], which in turn cause physical, psychological and social problems[2].

There is a lack in the literature of studies that have compared electromyographic fatigue among elderly people with and without a history of falling. The hypothesis raised here is that elderly people with a history of falling could be differentiated from elderly people without a history of falling on the basis of electromyographic median frequency values, which would therefore be an indicator of differences in myoelectric conduction during the tasks assessed.

The objective of this study was therefore to compare median frequency values as a parameter of electromyographic fatigue of the vastus lateralis muscle and the lateral portion of the gastrocnemius muscle in elderly people with and without a history of falling.

METHODOLOGICAL PROCEDURES

Sample

This was a cross-sectional study of elderly women living in the city of Marília, SP, who were recruited at activity centers for the elderly and classified as elderly women who had suffered falls (n = 10) or had not suffered falls (n = 10).

All of the participants were informed about the study objectives and signed free and informed consent forms. The study was approved by the local Research Ethics Committee under protocol number 0047/2011.

A questionnaire was used to acquire data for inclusion in the sample and personal details were then recorded. In order to meet the inclusion criteria, individuals had to be 60 or older, be defined as active according to the Brazilian Society for Sports Medicine criterion (SBME - Sociedade Brasileira de Medicina do Esporte), which requires activity at least three times per week with a minimum duration of 30 minutes[13], be able to walk unaided and to understand the verbal commands used during the procedures, this last assessed against a cutoff of ≥ 18 on the Mini Mental State Examination, duly adjusted for educational level[14].

Individuals were excluded if they had clinical conditions that interfered with motor performance and/or balance, such as sequelae of neuromusculoskeletal diseases or labyrinthine disorders, uncorrected visual problems or postural hypotension on continuous sedative, antidepressant or hypnotic drugs.

Occurrence of falls was measured using the responses to a dedicated questionnaire, with participants who reported suffering two or more falls during the previous year defined as having a history of falling[15]. The same questionnaire also investigated fear of falling using a verbal response item.

Instruments

Participants' vital signs (arterial blood pressure, heart rate and respiratory rate) were recorded at the start and end of procedures by the researchers.

Electrical muscle activity was detected using a portable 8-channel Myosystem Br1_P84® Electromyograph (Datahominis, Uberlândia, Brazil), with analog band-pass filters for cutoff frequencies of 10-1000Hz, digitization to a sample frequency of 4KHz, 12-bit resolution and simultaneous signal sampling.

Simple differential active surface electrodes by Datahominis Ltda. (model DHT-easd) were used. These were made of two parallel pure silver bars, were 1mm thick and 10mm long, with a 10 mm gap between electrodes, and had input impedance of 10 GW, 130 dB CMRR and 100 times gain. Electromyographic signals were viewed using the Myosystem-Br1 software, version 3.5, which was also used for digital processing. Signals were analyzed in terms of their Median Frequencies (Fmed) and a Butterworth 15-500Hz band-pass filter was used.

Procedures

The reference electrode was smeared with gel and attached at the lateral malleolus and active differential electrodes were placed over the muscle bellies after procedures to reduce the impedance of skin, trichotomy and cleaning of the skin with 70% alcohol[16]. All equipment was running on batteries during data collection.

Electrical activity was captured from the lateral part of the gastrocnemius muscle and from the vastus lateralis muscle on the dominant side using electrodes positioned in accordance with recommendations made by the International Society of Electrophysiology and Kinesiology (ISEK) and found in Surface Electromyography for the Non-Invasive Assessment of Muscles[17,18]. The gastrocnemius muscle (lateral part) was monitored in the proximal third between the head of the fibula and the ankle and the vastus lateralis muscle was monitored in the distal third along a line joining the anterior superior iliac spine to the superior lateral edge of the patella.

Electrical activity of the gastrocnemius muscle was recorded with the participant in a standing position performing a closed kinetic chain plantar flexion until standing on tiptoes, starting from a position at which neutral isometric contraction was registered.

For the vastus lateralis muscle, the electromyographic signal was recorded while the participant performed a squat to 40 degrees of knee flexion. The participant was requested to stand on a squat platform and perform a wall slide exercise with the lumbar region supported by a Swiss ball against the wall, with feet shoulder-width apart and the lower extremities in semi-flexion and away from the wall. Participants were also requested to keep their heads erect and cross each arm across their chest in the direction of the contralateral shoulder, while maintaining light pressure between back and Swiss ball throughout the squat, in order to allow the greatest possible proportion of body weight to load the lower extremities bilaterally[19].

The isometric contraction was held for 30 seconds, since this is the minimum duration suggested by the International Society of Electrophysiology and Kinesiology - ISEK for fatigue analyses[17].

Statistical analysis

The Kolmogorov-Smirnov test was used to confirm that the distributions of median frequency values were normal for both groups. ANOVA was used to conduct intragroup comparisons of median frequency values for 3-second time windows. Each time window was compared between groups using Student's t test for unpaired observations. GraphPad InStat 3® software was used for data analysis. The cutoff for significance was set at $p \leq 0.05$. The minimum sample size (interactions method with stabilization at n=9 individuals)[20], was estimated at $n_{minimum}$= 10 individuals, for a significance level of 5% (a=0.05) and a type II error of 20% (1 – b= 80%). The values for vastus lateralis muscle activity (which resulted in the largest $n_{minimum}$) used to calculate $n_{minimum}$ were obtained from the results of a pilot study in which the means of median frequencies for the three windows were 60.0 Hz (SD=11.1 Hz) for the group with no history of falling and 75.0 Hz (SD=7.6 Hz) for the group with a history of falling.

All procedures used for recording and analysis of electromyographic signals were in accordance with the Standards for Reporting EMG Data. [17] The median electromyographic signal frequency was obtained from the power spectral density data for the isometric contraction. Three time windows were sampled from within the initial 30-second window: 0 to 2.951 seconds, 11.988 to 15 seconds and 26.988 to 30 seconds, thereby obtaining median frequencies for three windows for each participant (MedFqW1, MedFqW2 and MedFqW3).

RESULTS

Twenty elderly women were enrolled who had or had not suffered falls during the 12 months preceding the tests and with mean ages of 68.7 ± 5.7 and 67.5 ± 6.0, respectively. Eighty-eight percent of the volunteers had studied for 7 years or more and 20% had spent from 4 to 7 years in education. Eighty-eight percent of the study population reported fear of falling (Table 1). The sample was selected by convenience, according to the inclusion and exclusion criteria.

Table 1. Characteristics of the sample: age, educational level, fear of falling and cognitive status.

	Faller group	Non-faller group	p
Age*	68.7 ± 5.7	67.5 ± 6.0	0.6
Years in education			
1 to 3 years	---	---	
4 to 7 years	3	1	
More than 7 years	7	9	
Fear of falling	8	8	
MMSE*	28.2 ± 1.4	28.8 ± 0.9	0.3

*Figures shown are Mean ± Standard Deviation, MMSE: Mini Mental State Examination.

Tables 2 and 3 list means for MedFqW1 and MedFqW3 for the groups of elderly people with and without history of falling and their respective results after statistical analysis of the data. It was found that only the falling group had significantly lower results for MedFqW1 than for MedFqW3 for both muscles assessed.

Table 2. Comparison of means of normalized values for median frequencies for the gastrocnemius muscle for first and third analysis windows.

Moments	Groups		
	Faller group	Non-faller group	p
MedFqW1	1.043	1.038	0.70
MedFqW3	0.953	0,987	0.42
Rate of loss	8.60%	4.90%	
p	0.02	0.08	

MedFqW1 - means of median frequencies for window 1, MedFqW3 - means of median frequencies for window 3.

Table 3. Comparison of means of normalized values for median frequencies for the vastus lateralis muscle for first and third analysis windows.

Moments	Groups		
	Faller group	Non-faller group	p
MedFqW1	1.02	1.01	0.87
MedFqW3	0.97	0.99	0.31
Rate of loss	4.5%	1.8%	
p	0.02	0.66	

MedFqW1 - means of median frequencies for window 1, MedFqW3 - means of median frequencies for window 3

It was also observed that the rate of loss of motor unit firing was greater in the group with a history of falling for both the gastrocnemius muscle

(8.6% versus 4.9%, respectively), and for the vastus lateralis muscle (4.5% versus 1.8%, respectively).

Figures 1 and 2 illustrate the behavior of Fmed during the data capture windows, for the groups with and without history of falling. The reduction in Fmed, which indicates fatigue, was greater among elderly people with a history of falling.

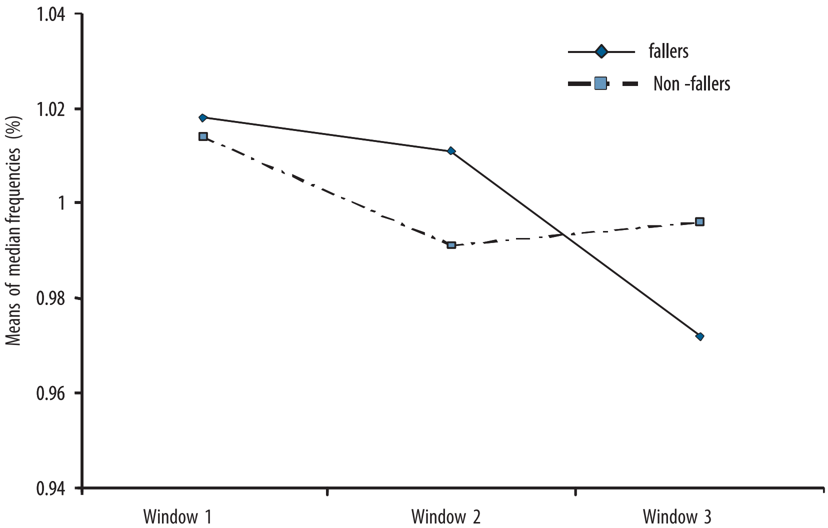

Figure 1. Means of normalized values of median frequency for the vastus lateralis muscle for fallers (n = 10) and non-fallers (n = 10).

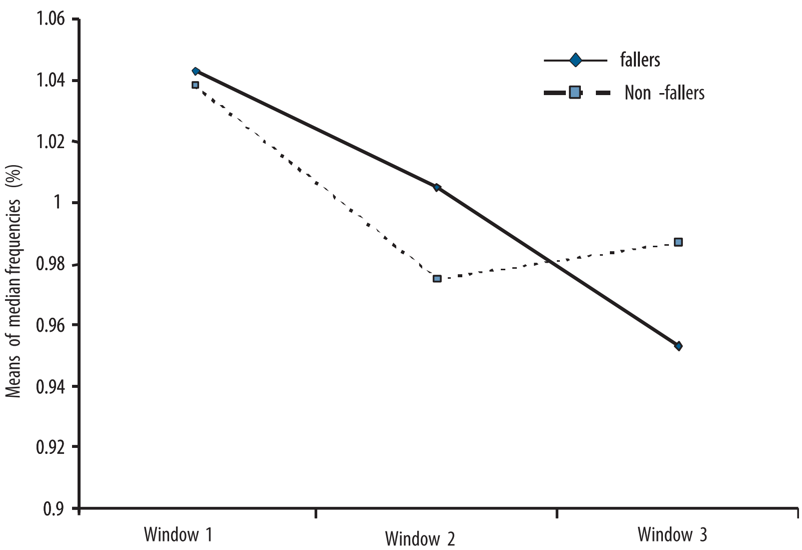

Figure 2. Means of normalized values of median frequency for the gastrocnemius muscle for fallers (n = 10) and non-fallers (n = 10).

DISCUSSION

If falls are to be avoided after loss of postural stability, the central nervous system and the musculoskeletal system must both react accordingly[21,22]. Identifying mechanisms that are linked with deficits of stability and falling among the elderly population is therefore an important step in development of effective interventions designed to prevent falls.

In this study we opted to use a submaximal contraction lasting 30 seconds[17] to test for muscle fatigue. With regard to this protocol, we observed that holding the position for 30 seconds was sufficient to induce localized muscle fatigue in the muscles being tested. This claim is supported by the observation that initial and final Fmed values reduced in both groups. This behavior is widely reported in the literature as an indication that a muscle is working in a fatigued state[23,24].

Muscle fatigue can be defined as a reduction in the neuromuscular system's capacity to generate force during a sustained effort, leading to reduced muscle performance[25]**.** In electromyographic fatigue, the median frequency can be observed to reduce, indicating a lower frequency of muscle motor unit firing. During the tasks undertaken in this study, the group with a history of falling had lower median frequencies than the group without a history of falling in both muscles tested, indicating a lower motor unit firing rate, which translates into a greater tendency to fatigue, and this decline could be a primary factor in the incidence of falls among the elderly[26].

Muscle fatigue causes changes in the neuromuscular system, resulting in reduced muscle performance. Mian et al.[27] claim that an increase in co-contraction of the musculature needed to maintain balance increases metabolic costs for elderly people, which may explain the higher levels of fatigue among elderly people with a history of falling. The elderly develop adaptive muscle mechanisms to provide increased stability when walking, with or without obstacles in their path, which generates higher levels of muscle activity than are observed in young adults[28,29], increasing the likelihood of fatigue and, consequently, of falling.

When the rate of loss of median frequency was compared across groups the history of falling group had a higher rate of loss, indicating greater fatigue and greater risk of falling. There are two physiological consequences related to fatigue: peripheral disorders of muscle activation and failures of the central nervous system to adequately activate motor neurons[25]. These disturbances involve changes in muscle strength and neuromuscular control, impacting on amplitude and velocity of movements[8]. Postural control is therefore inevitably affected, increasing the risk of falling.

One limitation to this study is the number of participants in each group. This was the result of the difficulties we encountered in trying to identify elderly people with a diagnosis of falling, since falls are not seen as diagnoses, but as the causes of, for example, fractures. Another possible limitation is the fact that both groups were considered physically active, which may have contributed to the absence of statistical differences between them.

CONCLUSIONS

The data reported here allow for the conclusion that analysis of median frequencies in surface electromyography can provide a parameter for muscle fatigue in elderly people with a history of falls.

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