Assessment of Muscle Fatigue, Strength and Muscle Activation During Exercises with the Usage of Robot Luna EMG, Among Patients with Multiple Sclerosis

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Abstract. Objective measurement of fatigability in patients with neurological diseases remains a problem rarely described in the research. The quick and easy assessment of muscle fatigue among patients with multiple sclerosis (MS) is a needed tool, which could be implemented as a standard test among those patients, to better plan and conduct physiotherapy. New devices, such as Luna EMG, allows to create precise environment, to carry out objective assessment and providing data based on strength and electromyography (EMG) measurement, especially median frequency (MDF), which is the standard parameter to indicate fatigue. The experiment was performed among 25 MS patients. Subjects were asked to perform 5 minutes isokinetic exercise of elbow flexion and extension and 2 minutes of isokinetic exercise of the same joint, with a 2 min break between. RMS value, median of frequency and its slope during exercise, was assessed for biceps and triceps brachii. The mean strength of both muscles were measured at the same time, accompanied by the automated counting of repetition. The correlation concerning triceps brachii has been found, between the amount of repetition in first exercise, with the slope of frequency in the first exercise (5 minutes isokinetic exercise). The same correlation for triceps brachii has been found for the second isokinetic exercise (2 minutes isokinetic exercise). For biceps brachii different correlation has occurred. The correlation between amount of repetition in 5 minutes isokinetic exercise and the slope in second (2 minutes) exercise has been noted. The mean strength during flexion for 5 minutes exercise was 11.20 Nm and 9.5 for extension. During 2 minutes exercise the mean values were 11.53 Nm and 10.18 Nm respectively. Assessment of MS patients performed with the usage of newest devices allows us to observe muscle fatigue, strength, muscle activation and relations between them among patients with MS. This quick test, accompanied by functional assessment can be a base for patient objective evaluation and a good foundation for planning and controlling training, in terms of muscle fatigue, applied force, muscle activation and coordination.

Keywords: sclerosis multiplex (MS), fatigue, exercise, sEMG

1 Introduction

Multiple sclerosis is a chronic autoimmune, inflammatory neurological disease of the central nervous system. This is an autoimmune disease, mounted by CD4+ T cells reactive against central nervous system (CNS) antigens. These T cells are, ostensibly, primed in peripheral lymphoid tissues and cross the blood-brain barrier to initiate inflammatory demyelination. MS attacks the myelinated axons in the CNS, destroying the myelin and the axons to varying degrees.The course of MS is highly varied and unpredictable. In most patients, the disease is characterized initially by episodes of reversible neurological deficits, which is often followed by progressive neurological deterioration overtime [1].

The diagnosis of MS is typically made on the basis of a set of objective clinical criteria, which may be supplemented with other data obtained from MRI scans and CSF (cerebrospinal fluid) analysis. The clinical presentation of MS is highly variable, relying on patient reported or objectively observed sensory, visual, or motor signs and symptoms that reflect neurological damage and that have been documented by a neurological exam and findings from visual evoked potential testing or MRI.

Fatigue is one of the most disabling multiple sclerosis symptoms, significantly impacting on patients' daily life activities and quality of life and affecting up to 80% of MS patients [2–6]. It is present even in early stages of the disease, it can precede other MS symptoms or predicts disease progression. The main characteristics of MS-related fatigue are enhanced perception of effort and limited endurance of sustained physical and mental activities. The pathophysiology of fatigue is still unclear. Damage of specific brain structures and strategic localization of MS lesions have been related to fatigue in MS patients [7].

The rehabilitation of patients with multiple sclerosis can not lead to overheating and excessive fatigue of the body. Exercise helps maintain muscle length and flexibility and lead to increase their strength, mass and endurance. Research on the effectiveness of rehabilitation interventions is crucial for people with multiple sclerosis. The content of rehabilitation programmes should be individualised and based on an assessment of the patient's unique needs [8–11].

Technologies can provide valid, reliable and sensitive assessment tools that, when used alongside clinical measures, can inform clinical decision-making and provide richer data on patient outcomes [12]. There is now a clear need for guidelines for clinicians and researchers to optimise technology-based assessment and application of clinical measures and procedures [13].

2 Material and Methods

The main goal of the study was to create and test a special protocol, using innovative device, such as Luna EMG, to assess fatigue and other related factors among patients with multiple sclerosis.

2.1 Luna EMG

Luna EMG is a rehabilitation robot manufactured by EGZOTech, with assessment and training options, especially useful in rehabilitation of neurological and orthopaedic patients (Fig. 1). It allows physiotherapists to measure muscle force, muscle activity (EMG), stiffness, coordination and proprioception during the exercises. The system allows to work with neurological patients in all stages of rehabilitation, starting from patients, with no muscle force and no muscle activity, through patients with muscle activity, without muscle force, to patients with muscle activity and muscle force. Luna EMG includes motor and extensions-exchangeable mechanical parts, that are connected to the patient by straps or by grip. The movement can be preprogramed based on sensors including: a position sensor, a torque sensor, a 6 channel electromyograph and column height position sensor. It is controlled by a Windows Application from a tablet, through User Interface (UI). Luna EMG is able of facilitating the following basic control algorithms: Isokinetic movement, Isotonic movement, Isometric exercises. To measure the muscle activity and muscle force of the patient, therapist can apply a special protocol of repetitive movements, using isokinetic mode. With surface EMG electrodes, attached to the muscle, the root mean square (RMS) signal can be reported as a representation of muscle activity during the movement. On the other hand we can use EMG median frequency (MDF), which is the standard parameter to indicate fatigue, due to theory that muscle fatigue results in a downward shift of frequency spectrum of the EMG signal. Especially due to the fact, that if the fatigue is increasing sharply, this can cause damage in the muscles and influence the motoric functions of the patient. For that reason this can be a useful tool for therapist working with MS patients on daily basis.

Fig. 1. Neurorehabilitation robot Luna EMG

2.2 Subjects

The experiment was performed among 25 patients, assessed with Expanded Disability Status Scale (EDSS) scale as 6 points or less (patient should have walked independently) [14]. Patients were included regardless of the form of multiple sclerosis or medication, but with understanding of the exercise protocol, therefore the patients with cognitive problems were excluded. In order to perform isokinetic training, biceps and triceps brachii had to be rated on a Lovett scale as 3 degree or higher. Lovett scale is commonly used method of muscle strength assessment, with the scale of 0–5, where 0 – no visible or palpable muscle contraction, 1 – visible or palpable contraction but no range of motion, 2 – moves full range of motion, gravity is eliminated, 3 – moves full range of motion against gravity, 4 – moves full range of motion against gravity and moderate resistance, 5 – moves full range of motion against gravity and has maximal resistance [15]. Patients had to understand training with usage of Luna EMG robot and had to follow the instructions.

2.3 Experiment

Subjects were asked to perform 5 minutes isokinetic exercise of elbow flexion and extension, followed by 2 minutes break and finished with 2 minutes of isokinetic exercise of the same joint. The exercise was preceded with 2 minutes of passive motion exercise. Surface EMG electrodes were placed on the biceps brachii and triceps brachii, to assess the RMS value, median of frequency and its slope during exercise. The mean strength of both muscles were measured at the same time, accompanied by the automated counting of repetition. Setting of the patient is presented on Fig. 2.

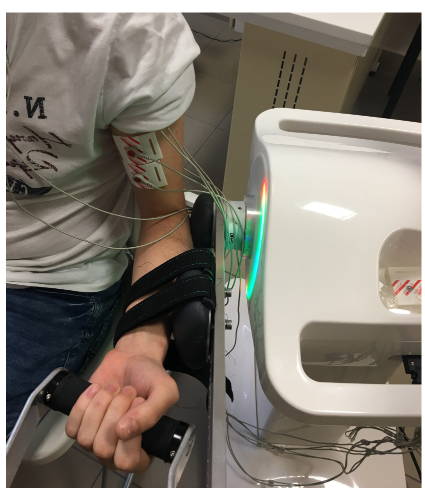

Fig. 2. Patient setting in Luna EMG

2.4 Data Processing

Acquired signals from Luna EMG – EMG signals from biceps brachii and triceps brachii, torque and position, were analysed by algorithm written in Python 3.7.0. The all readings were partitioned into sections responding to movement up (flexion) and down (extension) based on the extension's position measurement. EMG signals were filtered using bandpass filter and notch filter. After filtration, RMS values of electromyography signal were computed with window 100 ms (Fig. 3). Median power frequency is frequency value at which the EMG power spectrum is divided into two regions with an equal integrated power. It can be expressed as:

$$\sum_{j=1}^{MDF} P_j = \sum_{j=MDF}^{M} P_j = \frac{1}{2}\sum_{j=1}^{M} P_j \tag{1}$$

where P_j is the EMG power spectrum at a frequency bin j and M is the length of the frequency bin. Median frequency was computed for each second of the signal (Fig. 4). Then the line is fitted to these results using linear regression.

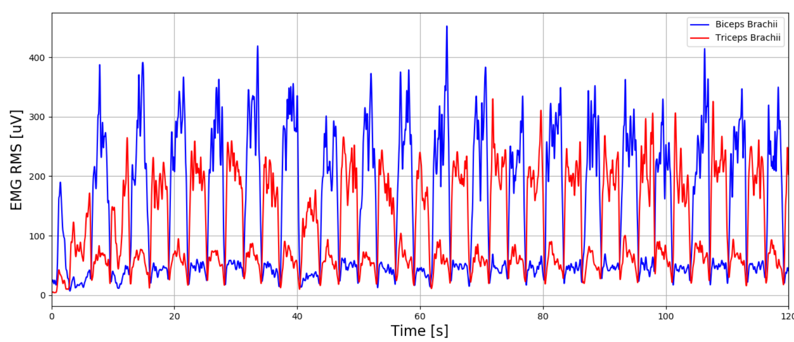

Fig. 3. EMG RMS signal from biceps brachii and triceps brachii during 2 minutes exercise

2.5 Statistical Analysis

The tables present descriptive statistics: mean, standard error, median, standard deviation, minimum and maximum value, and confidence level (95.00%). In order to check the relationship between variables, Pearson's correlation coefficient was applied. The following scale was used to assess the correlation coefficient:

r = 0 variables are not correlated;
0 <r <0.1 slender correlation;
0.1 ≤ r <0.3 weak correlation;

$0.3 \leq$ r <0.5 average correlation;
$0.5 \leq$ r <0.7 high correlation;
$0.7 \leq$ r <0.9 very high correlation;
$0.9 \leq$ r <1 nearly full correlation.

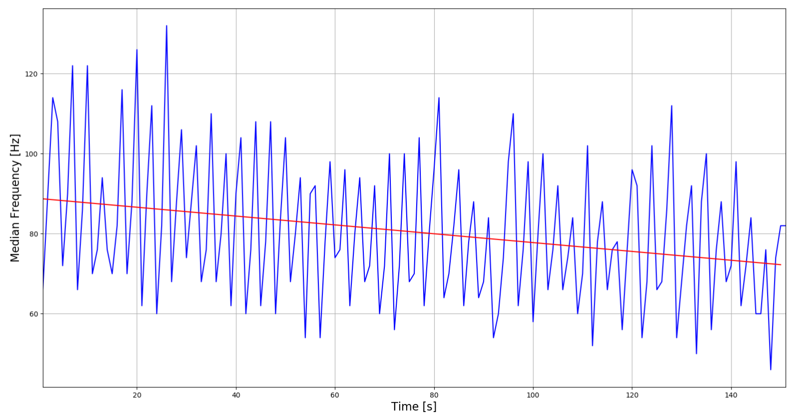

Fig. 4. Triceps Brachii EMG Median frequency showing fatigue during extension in 5 minute exercise

The direction of correlation refers to the order of the value of one variable in relation to the value of the other variable. In the case when the correlation is positive, this means that high values of one variable correspond to the high values of the second variable. Correlation is negative, when one variable takes high values and the other low values. All the hypotheses considered in the study were verified at the significance level of $\alpha = 0.05$. The test results with a significance level of p <0.05 were considered statistically significant.

3 Results

The basic values of RMS for biceps brachii and triceps brachii, amount of repetitions and mean torque of both muscles are shown in Table 1. The mean strength during flexion for 5 min exercise was 11.20 Nm and 9.5 for extension. During 2 min exercise the mean values were 11.53 Nm and 10.18 Nm respectively. Values of the median frequency and frequency slope among experimental group are presented in the Table 2. Data shows extensors are slightly weaker muscle group, than flexors, in those patients, in both exercises. The correlation concerning triceps brachii has been found, between the amount of repetition in first exercise, with the slope of frequency in the first exercise (5 minutes isokinetic exercise). The same correlation for triceps brachii has been found for the second isokinetic exercise (2 minutes isokinetic exercise). For biceps brachii different correlation has occurred – between amount of repetition in 5 minutes isokinetic exercise and the slope in second 2 minutes exercise (Table 3). Beside the correlation between mean torque in flexion and MDF slope of biceps brachii during the 2 minutes exercise, when if patients applied more force, they were getting more tired, no other correlation between strength and fatigue was found (Table 4).

Table 1. EMG RMS and torque values among the group of multiple sclerosis patients

	Isokinetic exercise (5min) Flexion			**Isokinetic exercise (2min) Flexion**		
	EMG Biceps [uV]	**EMG Tricpes [uV]**	**Torque [Nm]**	**EMG Biceps [uV]**	**EMG Tricpes [uV]**	**Torque [Nm]**
Mean	136.77	59.62	-11.20	139.54	60.52	-11.53
SE	24.31	7.38	0.76	23.49	7.99	0.89
Median	87.30	50.67	10.84	97.63	49.27	-10.68
SD	121.55	36.92	3.78	117.44	39.93	4.44
Minimum	6.26	5.06	-19.16	4.82	21.95	-19.56
Maximum	427.94	147.02	-4.90	407.28	170.70	-4.48
Confidence level	50.17	15.24	1.56	48.48	16.48	1.83
	Isokinetic exercise (5min) Extension			**Isokinetic exercise (2min) Extension**		
Mean	72.76	135.69	9.53	76.86	140.24	10.18
SE	8.17	23.17	0.96	12.23	23.32	0.87
Median	66.18	113.27	7.20	61.30	111.16	8.96
SD	40.83	115.84	4.81	61.13	116.61	4.37
Minimum	16.47	5.21	5.10	10.24	16.21	5.02
Maximum	174.51	437.16	20.29	273.63	457.26	20.57
Confidence level	16.86	47.81	1.98	25.23	48.13	1.80

4 Discussion

Prevention of disability progression in patients with neurodegenerative diseases such as multiple sclerosis is crucial. In the scientific literature, fatigability is described as one of the symptoms of multiple sclerosis. Fatigue can be characterized as a form of general fatigue, drowsiness, lack of energy, mental and physical fatigue, increasing of the muscle fatigue, and tiredness at rest. This symptom affects 30-50% of patients with MS. The accumulation of symptoms of multiple sclerosis is observed during the first 10 years after diagnosis. Focused rehabilitation introduced, when first syndromes occurs, creates an opportunity for normal functioning. Rehabilitation in MS is extremely difficult. It is associated with a variable prognosis, depending on the course of the disease, the form,

Table 2. Mean frequency and frequency slope among experimental group

	Exercise		**Exercise**	
	(5min)	**(2min)**	**(5min)**	**(2min)**
	Mean Frequency [Hz]		**MDF Slope [%]**	
Biceps Brachii				
Mean	46.37	48.13	-1.94	-1.29
SE	1.28	1.33	0.36	0.93
Median	49.02	48.55	-1.61	-0.37
SD	6.41	6.66	1.82	4.64
Minimum	24.76	23.63	-6.34	-12.58
Maximum	53.31	58.80	0.21	7.08
Confidence level 95.0%	2.65	2.75	0.75	1.92
Triceps Brachii				
Mean	54.32	56.99	-5.36	0.39
SE	1.84	1.82	1.65	2.91
Median	52.58	53.57	-2.34	0.08
SD	9.18	9.10	8.26	14.53
Minimum	35.85	45.60	-28.84	-25.81
Maximum	80.54	82.67	4.49	34.62
Confidence level 95.0%	3.79	3.76	3.41	6.00

Table 3. Correlation between mean torque and MDF slope for biceps and triceps (in flexion and extension)

		Amount of repetition in	
		5 min exercise	**2 min exercise**
Biceps Brachii	MDF Slope in 5 min exercise	p=0.6110	p=0.6742
	MDF Slope in 2 min exercise	**p=0.0269 (r=0.4419)**	p=0.8428
Triceps Brachii	MDF Slope in 5 min exercise	**p=0.0198 (r=0.4625)**	p=0.8158
	MDF Slope in 2 min exercise	p=0.6932	**p=0.0246 (r=0.4481)**

Table 4. Correlation between mean torque and MDF slope for Biceps Brachii and Triceps in flexion and extension

	MDF Slope [%] corr Mean torque [NM]			
Muscle	Biceps Brachii	Triceps Brachii	Biceps Brachii	Triceps Brachii
Type of exercise	Flexion	Extension	Flexion	Extension
Duration	5 min	5 min	2 min	2 min
Corr	p=0.8776	p=0.1433	**p=0.000193 (r=0.6784)**	p=0.2632

degree and location of the lesions. Due to the variety of forms of rehabilitation, both in the field of kinesiotherapy and physical procedures, there is a need to objectify the results of rehabilitation [8–11].

Objective measurement of fatigability in patients with neurological diseases remains a problem rarely described in the research. Many authors emphasize the need for further research to determine the possibility of reliable, repeatable measurements of muscle fatigue in neurodegenerative diseases [13, 16].

According to Hughes et al. "There is an urgent need for agreed guidelines on measurement tools and assessment protocols. Furthermore, new technology-based measurement tools have the potential to be used alongside clinical measures of impairment, activity and participation, but need to be rigorously tested for usability, validity, reliability and responsiveness. Technologies can provide valid, reliable and sensitive assessment tools that, when used alongside clinical measures, can inform clinical decision-making and provide richer data on patient outcomes. There is now a clear need for guidelines for clinicians and researchers to optimise technology-based assessment and application of clinical measures and procedures" [17]. Motor fatigability is, however, important to consider in patients with MS because it affects the ability to perform sustained activities of daily living. Furthermore, it will have an impact on the exercise capacity of patients with MS, limiting the possibility to exercise regularly. The assessment of muscle weakness is routinely performed, but muscle weakness and motor fatigability are different concepts. Patients with MS might not show muscle weakness on a single assessment of muscle strength, but they might show increased motor fatigability with a fast decline in muscle strength during longer or repeated test protocols [18]. Physical activity which is tailored to the individual patient's needs can bring a lot of beneficial effects. The individualized and supervised exercise program should be designed to patient to improve strength, endurance, balance, coordination, fatigue, etc. It should consider a patient's baseline impairments and capabilities, should be safe and effective. The prescription should include all the necessary components, such as frequency, duration, intensity, modalities to be used, and precautions to be observed [19].

Consequently, it is important to quantify (pathological) motor fatigability applying objective, valid, reliable, and responsive outcomes. To unravel the relation between motor fatigability and activities of daily living, it is, furthermore, important to include outcome measures on both the body function level and the activity level of the International Classification of Functioning, Disability and Health (ICF), when assessing fatigability [18].

There is need of to objective evaluate the effects of neurorehabilitation, standardized assessment protocols and outcome measures. Use of rehabilitation robots during the process of improvement patients with neurological disease could be useful not only for physiotherapist but also for the patients as a objective biofeedback and for treatment plan [20]. Among sclerosis multiplex patients overloading with exercises is not allowed, but therapists goal is need to slow down the weakness and disability progress. Due to information about fatigability, therapist can plan intensity and duration of training adapted to the patient individually. During training with the use of the rehabilitation robot Luna EMG patients show high motivation to perform exercises due to very good cooperation and biofeedback with the therapist. New technologies allows us to better objectively assess and understand relations between muscle fatigue and other factors, like eg. amount of repetition, in context of applied force and muscle activation. Data from the experiment shows, that there is a average correlation between triceps muscle fatigue and amount of repetition, both for 5 minutes and 2 minutes exercise. This was not the case for biceps brachii, where the slope in second exercise was rather correlated with the amount of repetition in the first one. This could indicated that biceps brachii, got more tired in the second training, being followed by the exhausting first one. High correlation between mean torque in flexion and MDF slope of biceps brachii during the 2 minutes exercise was noted, higher mean force, correlated with higher fatigue. No other correlation between strength and fatigue was found. According to study of Schwid and et. [13] fatigue is greater in MS patients, comparing to control group, even in muscles that were not clearly weak. They have not found significant associations between strength and fatigue in any of the muscles tested in their research, so they conclude that motor fatigue appears to be distinct from weakness because the degree of fatigue was not associated with the degree of weakness. In addition comparing with healthy control subjects, MS patients were weak in lower extremity muscles, but upper extremity strength was relatively preserved. Since fatigue of MS patients seems like a complex topic, our first results are the beginning and a first step for the further research, to develop exercises and right protocols for MS rehabilitation. New technologies can be useful in applying right amount of repetitions, accurate force and at the same time to monitor muscle fatigue. Through objective measurements and understanding of the muscles conditions, we can create evidence based exercise protocols, which can be used in precise exercise devices, like Luna EMG.

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