Journal of Electromyography and Kinesiology 24 (2014) 292–299

Contents lists available at ScienceDirect

Journal of Electromyography and Kinesiology

journal homepage: www.elsevier.com/locate/jelekin

# Relationship between neuromuscular fatigue and spasticity in chronic stroke patients: A pilot study

Julien Boudarham [a,*], Nicolas Roche [a], Mickael Teixeira [a], Sophie Hameau [a], Johanna Robertson [a], Djamel Bensmail [a], Raphael Zory [a,b]

[a] *Groupement de Recherche Clinique et Technologique sur le Handicap (EA 4497), CIC-IT 805, Université de Versailles Saint Quentin, Garches, France*
[b] *Laboratory of Human Motricity, Sport, Education and Health (EA 6309), University of Nice Sophia Antipolis, France*

ARTICLE INFO

*Article history:*
Received 25 April 2013
Received in revised form 10 October 2013
Accepted 26 November 2013

*Keywords:*
Isokinetic
Reflex
Quadriceps
Hemiplegia
Strength

ABSTRACT

*Introduction:* The aim of this study was to assess the effects of neuromuscular fatigue on stretch reflex-related torque and electromyographic activity of spastic knee extensor muscles in hemiplegic patients. The second aim was to characterize the time course of quadriceps muscle fatigue during repetitive concentric contractions.
*Methods:* Eighteen patients performed passive, isometric and concentric isokinetic evaluations before and after a fatigue protocol using an isokinetic dynamometer. Voluntary strength and spasticity were evaluated following the simultaneous recording of torque and electromyographic activity of rectus femoris (RF), vastus lateralis (VL) and biceps femoris (BF).
*Results:* Isometric knee extension torque and the root mean square (RMS) value of VL decreased in the fatigued state. During the fatigue protocol, the normalized peak torque decreased whereas the RMS of RF and BF increased between the first five and last five contractions. There was a linear decrease in the neuromuscular efficiency-repetitions relationships for RF and VL. The peak resistive torque and the normalized RMS of RF and VL during passive stretching movements were not modified by the fatigue protocol for any stretch velocity.
*Discussion:* This study showed that localized quadriceps muscle fatigue caused a decrease in voluntary strength which did not modify spasticity intensity. Changes in the distribution of muscle fiber type, with a greater number of slow fibers on the paretic side, may explain why the stretch reflex was not affected by fatigue.

## 1. Introduction

Spasticity and fatigue are two disabling and persistent symptoms which affect many stroke survivors. Spasticity has been defined by Lance (1980) as “a motor disorder characterized by a velocity-dependent increase in the tonic stretch reflex with exaggerated tendon jerks, resulting from hyper-excitability of the stretch-reflex”. Spasticity may be the result of intrinsic modifications of the muscle and/or altered reflex properties (Mukherjee and Chakravarty, 2010). The reliability of ordinal scales to assess spasticity in adults with central nervous system (CNS) injury has been questioned (Blackburn et al., 2002). As a result, quantitative methods have been developed to investigate spasticity. One such method is based on isokinetic dynamometry. The dynamometer is used to passively move a limb through a defined range of motion while the peak resistive torque is calculated (Perell et al., 1996). This technique, which was initially developed to assess voluntary motor strength, is now considered as the “gold standard” for the evaluation of spasticity in several joints.

Fatigue, which is a common consequence of stroke, has received little attention in clinical rehabilitation research (Knorr et al., 2012). There are different definitions of fatigue in the literature. Neuromuscular fatigue is defined here as any contraction-induced reduction in the ability to generate maximal muscle force or power output (Gandevia, 2001). Muscle fatigue is not an abrupt event, rather it develops gradually from the onset of sustained or repetitive muscle contractions (Enoka and Duchateau, 2008). Neuromuscular fatigue is commonly evaluated by the simultaneous recording of isokinetic and electromyographic (EMG) parameters, during and following a fatiguing task. Following stroke, patients often exhibit a high level of fatigue during daily activities. Central fatigue refers to an activity-induced inability to fully activate a muscle voluntarily, whereas peripheral fatigue implies that the ability of the muscle to produce force is reduced (Nordlund et al.,

---

* Corresponding author. Address: Hôpital Raymond Poincaré, (EA 4497), CIC-IT 805, Garches, 92380 Garches, France. Tel.: +33 1 47 10 79 00.
*E-mail address:* julien.boudarham@rpc.aphp.fr (J. Boudarham).

1050-6411/$ - see front matter © 2014 Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.jelekin.2013.11.006

2004). Central fatigue may be a contributing factor to the increased perception of tiredness which patients report during activities of daily living (Knorr et al., 2012). Some studies which assessed the effect of stroke on neuromuscular fatigability have reported that the paretic side develops a higher level of central fatigue and a lower level of peripheral fatigue than the non-paretic side and healthy subjects after a fatiguing task (Toffola et al., 2001). Loss of voluntary muscle activation, muscle weakness and spasticity could explain the differences between the paretic and non-paretic sides (Rosenfalck and Andreassen, 1980).

Few studies have evaluated the impact of neuromuscular fatigue on the stretch reflex in healthy subjects and the results are often contradictory, preventing any conclusion. Some authors have reported a reduction in intensity of the stretch reflex after a fatiguing protocol (Jackson et al., 2009) whereas others report an increase (Biro et al., 2007). Both a reduction and an increase in muscle spindle (Ia afferent input) sensitivity have been suggested to explain the changes in stretch reflex intensity. It has been suggested that these contradictory results could relate to differences between the fatigue protocols used (Nicol et al., 1996) and that the level of fatigue induced may influence the adaptation of the neuromuscular system (Gollhofer et al., 1987). Since one of the causes of spasticity is an increase in muscle spindle sensitivity (Gracies, 2005), it can be hypothesized that neuromuscular fatigue may influence spasticity in stroke patients. This question is particularly relevant since patients often report that they feel more "spastic" after a rehabilitation session or after walking a long distance (Sibley et al., 2008, 2009; Iosa et al., 2012).

The aims of this pilot study were therefore: (1) to assess the effects of neuromuscular fatigue on stretch reflex–related torque and EMG of spastic knee extensors in hemiplegic patients, and (2) to characterize the time course of quadriceps muscle fatigue during repetitive concentric contractions in spastic stroke patients. To that end, we assessed peak torque and EMG activity of the rectus femoris (RF), vastus lateralis (VL) and biceps femoris (BF) muscles recorded during dynamic and passive isokinetic evaluations, before and after the occurrence of neuromuscular fatigue. We hypothesized that repetitive concentric contractions of the knee extensor muscles and the resulting fatigue would further increase the hyper-excitability of the stretch-reflex.

## 2. Materials and methods

### 2.1. Subjects

Eighteen chronic hemiplegic patients (12 males and 6 females) were included in the present study (Table 1, age: 52 (15) years; height: 170 (8) cm, mass: 71 (18) kg). Inclusion criteria were: over 18 years old, more than 6 months post stroke (chronic-phase), with a score $\geqslant$1+ on modified ashworth scale (MAS) for the quadriceps muscles, ability to walk 10 m without walking aids, no use of anti-spastic medications for 6 months before inclusion and no orthopedic surgery in the last 6 months. This study was approved by the local ethics committee of Ile de France XI and all subjects provided written informed consent prior to participation in any study-specific procedures.

### 2.2. Procedure

#### 2.2.1. Experimental setup

On their arrival at the laboratory, subjects were equipped with surface electrodes for the recording of EMG activity. Subjects performed the passive and dynamic isokinetic evaluations before (PRE) and immediately after (POST) a fatigue protocol. The PRE and POST tests consisted of (i) a passive evaluation, (ii) isometric and (iii) concentric maximal voluntary contractions (MVCs) of the knee extensor muscles, always performed in the same order.

Stretch-reflex related torque was recorded during the passive movements. One set of 5 continuous passive movements of knee flexion was completed at 90, 180, and 240°/s, in a randomized order. Subjects were instructed to relax during the trials and to close their eyes. After the series of passive movements, subjects warmed-up by carrying out concentric sub-maximal contractions of the knee extensor and flexor muscles at 60°/s to familiarize themselves with the procedure and to remove any potential influence of a learning effect. Next, maximal voluntary strength was measured using 2 isometric MVCs of the knee extensor muscles ($\approx$5 s) with the knee fixed at 90° and 3 concentric MVC of the knee extensor muscles at a speed of 30°/s.

The voluntary isokinetic fatigue protocol consisted of 40 maximal concentric contractions of the knee extensor muscles at 60°/s with a passive return to the initial knee position at 30°/s. This protocol has previously shown its effectiveness in creating fatigue of the knee extensor muscles in patients with neurological pathologies (Moreau et al., 2008, 2009). For the dynamic trials, verbal encouragement and visual feedback of the torque generated on the computer monitor were used to ensure that the subjects provided a maximal effort during each contraction. The POST evaluation was carried out immediately after the fatigue protocol. The same tests were carried out (passive movements, at 3 velocities in a randomized order, and isometric and isokinetic concentric contractions). Because the tests were always carried out in the same order, the passive evaluations were performed immediately after the fatigue protocol and the isometric and isokinetic concentric evaluations were performed respectively 1 and 2 min after the fatigue protocol.

#### 2.2.2. Isokinetic evaluation

A ConTrex-MJ isokinetic dynamometer (Contrex, CMV AG, Dübendorf, Switzerland) was used to record instantaneous isokinetic and isometric torques. The paretic lower limb was tested for each subject. They were seated in the chair of the isokinetic dynamometer in a position of 85° hip flexion and the lower legs hanging over the edge of the seat. The trunk and the paretic lower leg were stabilized using straps across the chest, the waist, and upper thigh. The contralateral lower limb was also blocked. The axis of the dynamometer was visually aligned with the knee joint axis, which was defined as a line between the medial and lateral femoral condyles. The lower leg was fixed to the lever of the dynamometer approximately 3 cm above the lateral malleolus. The distance from the force transducer to the axis of rotation was noted. The subject's passive range of motion without inducing pain was determined and used to set the limits of motion. Before the testing sessions, the limb weight was calculated by the dynamometer in order that the gravitational effects on the limb and attachment could be removed from each trial. Gravity correction was performed during the trials using the ConTrex-MJ software (Contrex, CMV AG, Dübendorf, Switzerland).

#### 2.2.3. Electromyography

EMG activity of the RF, VL and BF of the paretic limb was recorded simultaneously during each isokinetic session. Three bipolar surface electrodes with built-in preamplification (SX230 Active EMG Sensor, Biometrics, VA, USA) were placed directly on the skin, according to SENIAM recommendations (Hermens et al., 2000). The EMG sensors were composed of two circular, stainless steel, dry button electrodes with double-differential preamplifiers. The two active electrodes measured 12 mm in diameter and the inter-electrode distance was 17 mm. A ground electrode was placed on the anterior surface of the subject's wrist. All EMG signals were sampled at 1000 Hz and preamplified at the electrode site with a gain