The influence of upper limb immobilization on lower limb muscular activity during the sit-to-stand task

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Abstract.

PURPOSE: The aim of this study was to compare the magnitude and pattern of lower limb muscular activity during the sit-to-stand (STS) task with and without upper limb immobilization.

METHODS: The activity of six muscles from each lower limb (Rectus Femoris, Vastus Medialis, Biceps Femoris, Tibialis Anterior, Gastrocnemius Medialis and Soleus) were recorded while 19 young healthy participants performed the STS task with and without an arm sling on their dominant side. Myoelectric signals were collected using BioPlux Research device, and two Bertec force platforms were used to determine different phases of the STS task. The peak of muscular activity and muscle onset times were calculated, two general linear models with an alpha of 0.05 were used between the conditions with and without upper limb immobilization.

RESULTS: We found no statistically significant differences in the onset of lower limb muscular activity, and we observed decreased peak of muscular activity in the Rectus Femoris at the immobilized side and an increased peak in the Vastus Medialis at the side opposite to the upper limb immobilized compared to the control condition.

CONCLUSIONS: We did observe differences in the magnitude of ipsilateral Rectus Femoris and contralateral Vastus Medialis as a consequence of upper limb immobilization.

Keywords: Upper limb, immobilization, muscular activity, sit-to-stand task

1. Introduction

The upper limb immobilization maintained for more than 12 hours temporarily interfere the sensory-motor system and change motor recruitment patterns of the upper limb muscles [1, 2]. Several studies assessed the effects of upper limb immobilization on structural properties or muscular activity in the immobilized upper limb. Short-term immobilization affects primarily elbow flexion strength and ballistic movements, resulting in weakness and loss of normal neuromuscular control of the upper limb

[3, 4]. Usually, the upper limb is immobilized with the shoulder in medial rotation and adduction, and 90° of elbow flexion. Presumably this immobilization induces changes in the alignment of the segments and consequently influence the pattern of muscular activity not only in the index segments, but also in distant body segments [3, 5].

All areas of the body are synergistically involved to improve efficiency in the daily motor tasks [6]. For example, patients with lower limb disorders commonly use their upper limbs to compensate deficits in strength on lower limbs in order to improve the stand task [7]. Functional and structural changes in the upper limbs may affect motor skills in other parts of the body. When upper limb function is compromised by immobilization, changes on lower limb muscular activity are expected during daily life tasks [8]. However, studies exploring how upper limb immobilization influences lower limb muscular activity during daily life activities are yet to be conducted.

During daily life activities, such as the sit-to-stand (STS) task, the movement of the upper limbs is considered an important part of the task by promoting horizontal and vertical impulse of the body [4]. The STS strategy involves the coordinated interaction between lower and upper limbs [9, 10]. According to Carr and Gentile, restrictions on upper limb function affect postural stability and lower limb kinematics during the STS task [8]. It is unclear whether or not changes on lower limbs' muscular recruitment are mediating such altered kinematic patterns. The knowledge of how the lower limb muscles' recruitment pattern is influenced by upper limb immobilization would help to better understand the interconnections between lower and upper limbs. Such information might help clinicians to determine whether or not specific strategies for enhancing balance, postural control or muscular strength are necessary for patients with upper limb immobilization.

Therefore, the aim of this study was to compare the magnitude and pattern of lower limb muscular activity during the STS task with and without upper limb immobilization. We hypothesized that the magnitude of lower limb muscles would be larger when the STS task is performed with upper limb immobilization compared to the control non-immobilized condition. We also hypothesized that lower limb muscle onset would be later during the STS task with upper limb immobilization compared to the control condition.

2. Materials and methods

2.1. Study design

This is a laboratory-based, repeated measures study with a sample of convenience. Activity of six lower limb muscles (Rectus Femoris, Vastus Medialis, Biceps Femoris, Tibialis Anterior, Gastrocnemius Medialis and Soleus) were recorded bilaterally while the participants performed the STS task with upper limb immobilization and without (referred as control condition) a sling on their dominant upper limb.

2.2. Participants

Asymptomatic individuals were recruited from the local community. The inclusion criteria were having a body mass index between 18 and 24.9 Kg/m^2 and ages between 18 and 25 years. Exclusion criteria were history of neurological or musculoskeletal disorder, any kind of pain at the day of data collection, and being high competition athletes.

According with the protocol of the World Medic Association's Declaration of Helsinki, all participants were entirely informed of all study circumstances and it was given the opportunity of consent, refuse or interrupt their participation at any moment. The local ethical committee approved this study (School of Health Sciences, Polytechnic Institute of Porto, Porto, Portugal).

2.3. Instruments

Myoelectric signals were recorded using two six-channels wireless BioPlux Research devices (Plux, Covilhã, Portugal) at a 1000 Hz sampling frequency with a gain of 1000. Bipolar configuration with 20 mm of distance between electrodes was used. The ground electrode was placed over the lateral malleolus of the fibula [11].

Disposable silver chloride (AgCl) Dahlausen 505 electrodes, 10 mm circular shape, were connected to two devices with an impedance of 100MΩ and 100 dB (Common Mode Rejection Ratio) and 12bit analog collection channels with Bluetooth connection to two portable computers. The skin impedance was measured by a Noraxon® impedance meter (Noraxon, Scottdale, Arizona).

Aiming to determine different phases of the STS task, two force platforms (FP4060-07-1000 and FP4060-1000, Bertec Corporation, Columbus, OH,

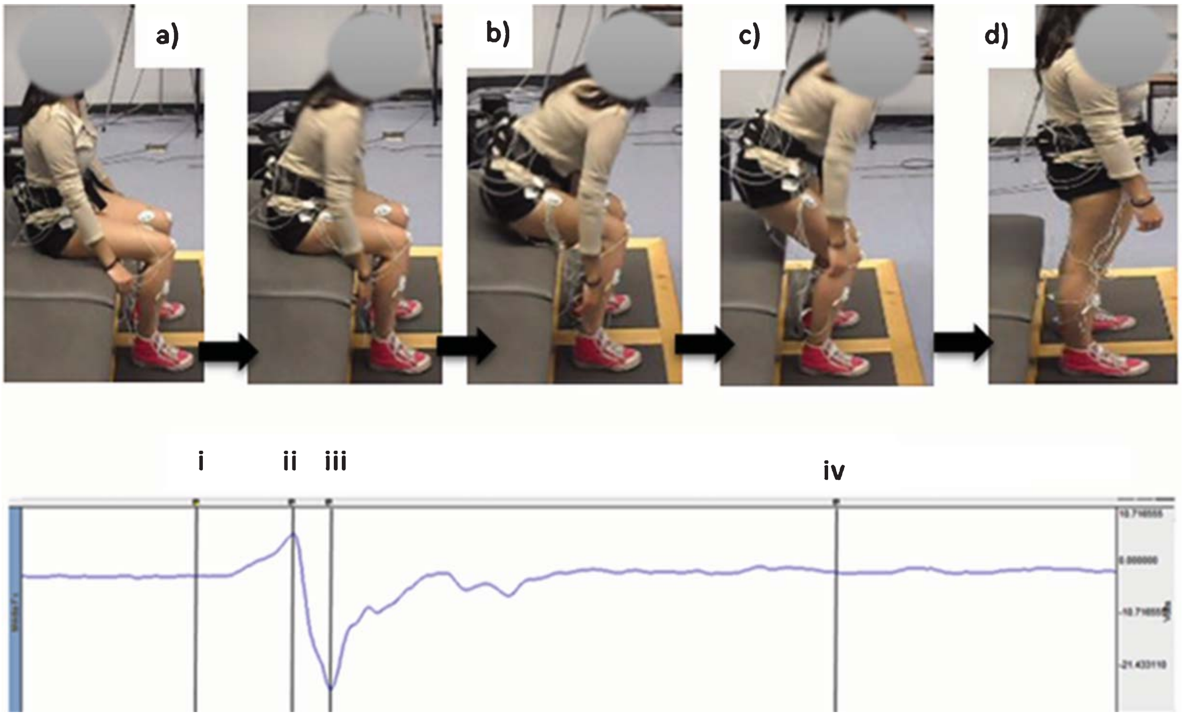

Fig. 1. Phases of the STS task. Example from one participant: a) Start of movement; b) Seat-off; c) Trunk extension; and d) Final stabilization. Phase 1 – trunk flexion: between “i” and “ii”; Phase 2 – transference: between “ii” and “iii”; Phase 3 – extension and stabilization: between “iii” and “iv”.

USA) were used to record the ground reaction forces while participants performed the STS task. The anterior-posterior component (Fx) of the ground reaction forces was used to determine different stages of the STS task [12]. Both force platforms were connected to a Bertec AM6300 amplifier to convert the analog signal into digital. Qualisys Track Manager® software (Motion Capture system, Gothenburg, Sweden) was used to record and synchronize EMG and ground reaction force data. All data were processed and analysed through AcqKnowledge® software, version 3.9 (BIOPAC Systems Inc., Goleta, CA, USA).

Universal goniometer was used to determine hip, knee and ankle joint amplitudes on the sitting postural set.

2.4. *Protocol*

For skin preparation and placing of electrodes, the Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) guidelines were adopted [11]. For the soleus muscle, the instructions proposed by Palmieri et al. [13] were followed. Participants performed a maximal isometric voluntary contraction for each monitored muscle. Manual resistance was provided by the researcher, and the participants sustained the position for 5 seconds. Maximal isometric voluntary contractions were used for normalizing EMG data collected during the trials [11].

Universal arm sling was used since it is the most common aid in medical practice for shoulder disorders, and it is the most comfortable approach to restrict the upper limb movement [14].

Before performing the STS task, the participants were sat on a hydraulic gurney with 90° of hip, knee and ankle joint flexion, and with parallel feet over the force platforms (Fig. 1). Each participant was instructed to perform each condition at a comfortable self-selected speed and looking forward. After a verbal command “stand up, please”, participants started randomly with upper limb immobilization condition or control condition. After standing, participants remained still for 60 seconds and then came back to start position. Three trials were performed for each condition, with an interval of a minute between each trial [11].

2.5. *Data analysis*

The EMG signal and Fx were digitally filtered using an IIR type filter, Low-pass 6 Hz, for the Fx [15, 16] and a IIR type filter, Band-pass 20–500 Hz, for the EMG signal [17–19]. Finally, the EMG was transformed by the root mean square (RMS) calculation into 100 samples [20].

STS task was divided into three stages (Fig. 1) according to the kinematic model proposed by Bishop et al. [12], the phases were identified based on the variation of the magnitude or direction of Fx:

> Phase 1 – trunk flexion: This phase started at the movement onset, which was considered the mean plus or minus two standard deviations within the baseline amplitude over a period greater than 50 ms. This phase ended at the peak of Fx, which corresponds to the moment of seat-off.
>
> Phase 2 – transference: This phase represents body's center of mass moving forward and upwards, occurring maximal ankle dorsiflexion. It began after phase 1 and ended at Fx valley.
>
> Phase 3 – extension and stabilization: It corresponds to a coordinated activation of the lower limb extensor muscles, allowing to reach a standing position. This phase began after phase 2 and ended with a fluctuation smoothing – the mean plus or minus two standard deviations within the baseline amplitude over a period greater than 50 ms [15].

Muscle onsets were calculated for each muscle. Muscle onset was defined considering the periods in which the amplitude of EMG signal exceeded the average of the basal activity (–500 to –450 ms relative to the beginning of the movement) in the order of three times the standard deviation of this same period [21], at a period equal or greater than 50 ms [15, 18, 22].

The average RMS values of each muscle for each STS phase were normalized by the maximal isometric voluntary contraction and expressed as a percentage of the maximal isometric voluntary contraction [18].

The lower limb muscles at the immobilized (right) side are referred to as "ipsilateral muscles" and the lower limb muscles from the non-immobilized side (left) as "contralateral muscles".

2.6. *Outcome measures*

The primary outcome measures were (i) muscle onset: the onset of each muscle, expressed as "ms" relative to the movement onset; and (ii) magnitude of muscle activity: the average of activity for each of the 12 monitored muscles for each STS phase, expressed as percentage of the maximal isometric voluntary contraction.

2.7. *Statistical analysis*

Statistic software version 8 (Statfoft, Tulsa, OK) was used for statistical analysis. Two general linear models with an alpha of 0.05 were used: (i) a repeated measures ANOVA with conditions (control and upper limb immobilization) and muscles (ipsilateral and contralateral Rectus Femoris, Vastus Medialis, Biceps Femoris, Tibialis Anterior, Gastrocnemius Medialis and Soleus) as within-subject factors, and muscle onsets as dependent variable; and (ii) a repeated measures ANOVA with conditions (control and upper limb immobilization), STS phases (phase 1, phase 2, and phase 3) and muscles (ipsilateral and contralateral Rectus Femoris, Vastus Medialis, Biceps Femoris, Tibialis Anterior, Gastrocnemius Medialis and Soleus) as within-subject factors, and magnitude of muscle activities as dependent variable. Where significant interactions were found, the Fisher's least significant difference was calculated. The partial eta-squared (η^2) was used to measure effect size, considering η^2 lower than 0.061 as small, between 0.061 and 0.14 as medium, and above 0.14 as large effect sizes.

3. Results

The final sample consisted of 19 participants (5 males) with age of 20.74 (SD 1.24) years old and body mass index of 21.33 (SD 1.66) Kg/m^2. All participants were right-handed and seventeen said that their dominant lower limb was the right one.

There were no statistically significant interactions between conditions (controls and upper limb immobilization) and muscles in the muscle onsets ($F(11, 198) = 0.865, p = 0.576$, power = 47% – Fig. 2), and there was no main effects of condition on muscle onsets ($F(1, 18) = 1.338$, $p = 0.263$, power = 20%).

There were no statistically significant interactions among the three factors condition, STS phases and muscles in the magnitude of muscle activity ($F(22, 396) = 1.189$, $p = 0.253$, power = 87%). There were statistically significant interactions between conditions and muscles in the magnitude of muscular

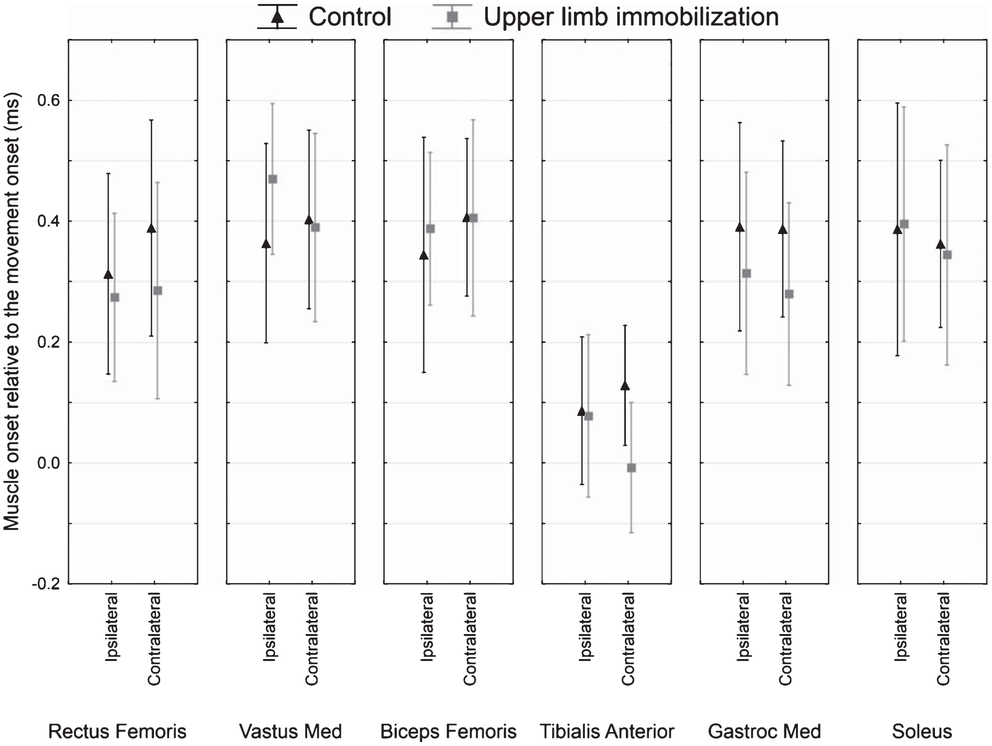

Fig. 2. Descriptive statistic for muscle onsets (mean and 95% confidence intervals).

activity (F(11, 198) = 1.859, $p = 0.047$, $\eta^2 = 0.093$ – Fig. 3). During the upper limb immobilization condition the magnitude of the ipsilateral Rectus Femoris muscle was lower, whereas the magnitude of the contralateral Vastus Medialis was greater compared to the control condition. No statistically significant differences were observed for the remaining ten muscles (Table 1 and Fig. 3).

4. Discussion

The aim of this study was to compare muscle onset and magnitude of lower limb muscles during the STS task performed with and without upper limb immobilization. Our two hypotheses were not satisfied. We found no differences in muscle onsets between conditions (control and upper limb immobilization). We also observed no differences in magnitude of muscular activity in ten of the 12 muscles assessed. We observed changes in the magnitude of activity in two muscles. These changes were irrespective to the STS phase – since no interactions were observed between conditions, STS phases and muscles. During the STS task, the magnitude of (i) ipsilateral Rectus Femoris was lower and (ii) contralateral Vastus Medialis was larger for the upper limb immobilization compared to the control condition. These changes were statistically significant and showed a moderate effect size, suggesting practical relevance.

Based on our findings, it was verified that most EMG parameters showed similar values between conditions. These findings were unexpected since the qualitative performance of the STS is compromised in individuals with their upper limb injured and immobilized. [6]. In addition, a previous study showed that restrictions on upper limb movement cause larger energy consumption of the lower limb muscles [7]. Thus our data suggest that these changes in energy consumption and the quality of movement are minimal influenced by changes in lower limb pattern and magnitude of activation.

According to Goulart and Valls-Solé [17], when the initial posture on STS is modified changes in the pattern of recruitment of postural lower limb muscles, such as the Tibialis Anterior, Gastrocnemius Medialis and Soleus are expected to occur. Considering the upper limb immobilization as a change in the initial condition of the task, it would be expected to find

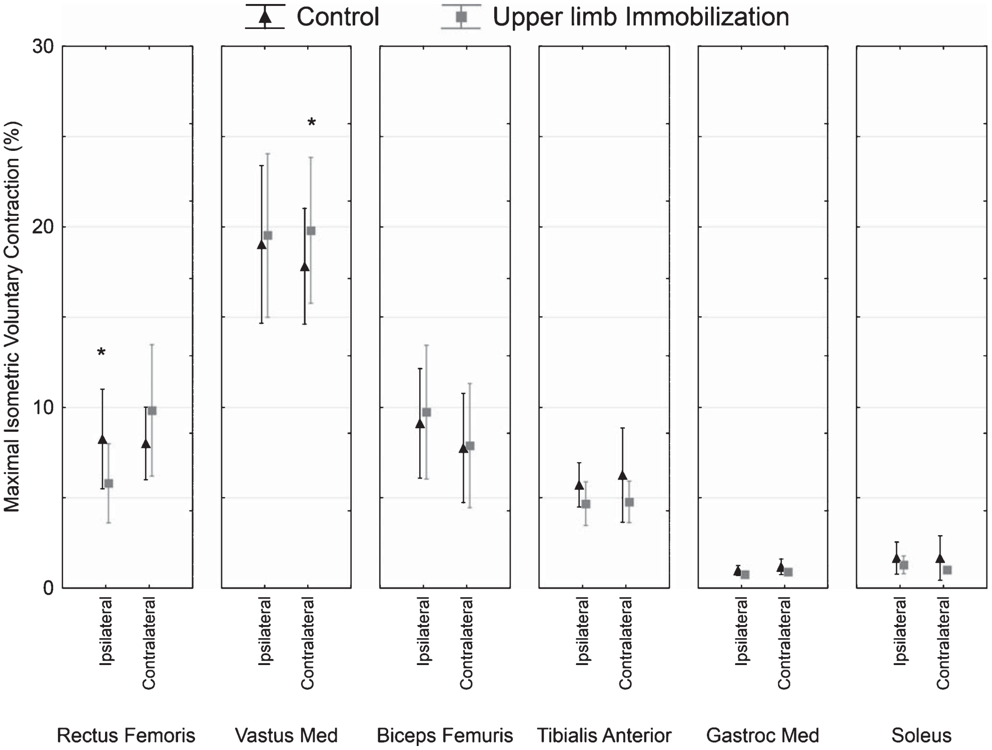

Fig. 3. Interactions between conditions and muscles in magnitude of muscle activity (mean and 95% confidence intervals). *statistical significant difference with $p < 0.005$.

Table 1
Magnitude of muscle activity: mean difference, 95% confidence limits and *p*-values.

Muscles	Mean difference (%MIVC)	95% confidence limits		*p*-value
		lower	upper	
Ipsilateral Rectus Femoris	2.44	0.60	4.28	0.009*
Contralateral Rectus Femoris	–1.84	–3.68	0.00	0.050
Ipsilateral Vastus Med	–0.50	–2.34	1.34	0.591
Contralateral Vastus Med	–1.99	–3.83	–0.15	0.034*
Ipsilateral Biceps Femoris	–0.63	–2.47	1.21	0.500
Contralateral Biceps Femoris	–0.14	–1.98	1.70	0.881
Ipsilateral Tibialis Anterior	1.04	–0.80	2.88	0.265
Contralateral Tibialis Anterior	1.48	–0.36	3.32	0.114
Ipsilateral Gastroc Med	0.21	–1.63	2.05	0.823
Contralateral Gastroc Med	0.28	–1.56	2.11	0.768
Ipsilateral Soleus	0.37	–1.47	2.21	0.689
Contralateral Soleus	0.66	–1.18	2.50	0.480

*Statistically significant difference.

significant changes in these postural muscles. However, our findings did not support changes in lower limb muscle onset as a consequence of upper limb immobilization. It is important to consider that the present study assessed young healthy participants. Thus the similar pattern of muscle activity observed between conditions may reflect a good capacity of the central nervous system coping with constraints.

Regarding the magnitude of muscle activity our results from the control group are according with reports in the literature under unconstrained conditions [20, 21]. The main novelty of this study was the identification of asymmetric changes in the recruitment of two lower limb muscles. The ipsilateral Rectus Femoris was lower and the contralateral Vastus Medialis was larger in the upper limb immobilization condition compared to the control condition. It is unclear the impact of increases of 2% of maximal isometric voluntary contraction in the activity of the Vastus Medialis on the knee joint. Although this is not a large change, possibly it will be often present during daily activities where load bearing is required, such as the STS task. Increased activity in the Vastus Medialis might promote additional load on the knee and influence patellar tracking. Clinicians might consider closely observe the knee contra-lateral to the immobilized upper limb to prevent eventual overload injury.

The present study has some limitations. Our sample size is small and thus the study might be unpowered to sustain the lack of differences between conditions. We did not assess the non-immobilized upper limb; then, we might have missed mechanisms of movement compensation performed by the upper body. We assessed the acute effect of upper limb immobilization, and thus changes in the magnitude and pattern of muscle activity may occur only after longer periods of immobilization. Although we found statistically significant differences between conditions in the magnitude of the ipsilateral Rectus Femoris and contralateral Vastus Medialis, they were relatively small (2.44 and –1.99 % maximal isometric voluntary contraction, respectively). Finally, we included in this studies young health participants. It is unclear whether we would observe the same pattern of muscle activity in populations of patients with upper limb immobilization.

Most between-group comparisons performed in this study did not show statistically significant differences. Even though, we found differences in the magnitude of muscle activation in two tight muscles, and the subjective analysis of the results (Fig. 2 and 3) along with the visual analyses of the participants performing the tasks during the experimental protocol suggest that functional changes in one segment might be capable of interfere in the motor pattern in distal segments. It shows the importance of considering a holistic view of the individual. Thus this study builds on the literature demonstrating the presence of changes in the magnitude of thigh muscles activation in additional of the previous described changes in kinematics during the STS task [8].

5. Conclusion

We found no differences in the pattern of lower limb muscular activity, and in the magnitude of ten out of twelve muscles assessed during the STS task performed with and without upper limb immobilization in healthy subjects. We did observe differences in the magnitude of ipsilateral Rectus Femoris and contralateral Vastus Medialis as a consequence of upper limb immobilization.

References

[1] Moisello C, Bove M, Huber R, Abbruzzese G, Battaglia F, Tononi G, et al. Short-term limb immobilization affects motor performance. J Mot Behav 2008;40(2):165-76.

[2] Langer N, Hänggi J, Müller NA, Simmen HP, Jäncke L. Effects of limb immobilization on brain plasticity. Neurology 2012;78(3):182-8.

[3] Seki K, Taniguchi Y, Narusawa M. Effects of joint immobilization on firing rate modulation of human motor units. J Physiol 2001;530(3):507-19.

[4] Zanette G, Manganotti P, Fiaschi A, Tamburin S. Modulation of motor cortex excitability after upper limb immobilization. Clin Neurophysiol 2004;115(6):1264-75.

[5] Raine S, Meadows L, Lynch-Ellerington M. The Bobath concept: Theory and clinical practice in neurological rehabilitation. Chichester: Wiley-Blackwell; 2009.

[6] Vaughan VG. Effects of upper limb immobilization on isometric muscle strength, movement time, and triphasic electromyographic characteristics. Phys Ther 1989;69(2): 119-29.

[7] Alenabi T, Jackson M, Tétreault P, Begon M. Electromyographic activity in the shoulder musculature during resistance training exercises of the ipsilateral upper limb while wearing a shoulder orthosis. J Shoulder Elbow Surg 2014;23(6):e140-8.

[8] Carr JH, Gentile AM. The effect of arm movement on the biomechanic of standing up. Human Movement Science 1994;13:175-93.

[9] Dehail P, Bestaven E, Muller F, Mallet A, Robert B, Bourdel-Marchasson I, et al. Kinematic and electromyographic analysis of rising from a chair during a "Sit-to-Walk" task in elderly subjects: Role of strength. Clin Biomech 2007;22(10):1096-103.

[10] Chen HB, Wei TS, Chang LW. Postural influence on Stand-to-Sit leg load sharing strategies and sitting impact forces in stroke patients. Gait Posture 2010;32(4): 576-80.

[11] Hermens HJ, Freriks B, Disselhorst-Klug C, Rau G. Development of recommendations for SEMG sensors and sensor placement procedures. J Electromyogr Kinesiol 2000;10(5):361-74.

[12] Bishop M, Brunt D, Pathare N, Ko M, Marjama-Lyons J. Changes in distal muscle timing may contribute to slowness during sit to stand in Parkinsons disease. Clin Biomech 2005;20(1):112-7.

[13] Palmieri RM, Ingersoll CD, Hoffman MA. The hoffmann reflex: Methodologic considerations and applications for use in sports medicine and athletic training research. J Athl Train 2004;39(3):268-77.

[14] Magnus CR, Barss TS, Lanovaz JL, Farthing JP. Effects of cross-education on the muscle after a period of unilateral limb immobilization using a shoulder sling and swathe. J Appl Physiol 2010;109(6):1887-94.

[15] Akram SB, McIlroy WE. Challenging horizontal movement of the body during sit-to-stand: Impact on stability in the young and elderly. J Mot Behav 2011;43(2):147-53.

[16] Roy G, Nadeau S, Gravel D, Malouin F, McFadyen BJ, Piotte F. The effect of foot position and chair height on the asymmetry of vertical forces during sit-to-stand and stand-to-sit tasks in individuals with hemiparesis. Clin Biomech 2006;21(6):585-93.

[17] Goulart FR, Valls-Solé J. Patterned electromyographic activity in the sit-to-stand movement. Clin Neurophysiol 1999;110(9):1634-40.

[18] Camargos AC, Rodrigues-de-Paula-Goulart F, Teixeira-Salmela LF. The effects of foot position on the performance of the sit-to-stand movement with chronic stroke subjects. Arch Phys Med Rehabil 2009;90(2):314-9.

[19] Kollmitzer J, Ebenbichler GR, Kopf A. Reliability of surface electromyographic measurements. Clin Neurophysiol 1999;110(4):725-34.

[20] Ashford S, De Souza L. A comparison of the timing of muscle activity during sitting down compared to standing up. Physiother Res Int 2000;5(2):111-28.

[21] Cheng PT, Chen CL, Wang CM, Hong WH. Leg muscle activation patterns of sit-to-stand movement in stroke patients. Am J Phys Med Rehabil 2004;83(1):10-6.

[22] Brunt D, Greenberg B, Wankadia S, Trimble MA, Shechtman O. The effect of foot placement on sit to stand in healthy young subjects and patients with hemiplegia. Arch Phys Med Rehabil 2002;83(7):924-9.