Comparing the Effect of Voluntary and Electrical Fatigue of Quadriceps on Postural Control

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Submitted: 2015-11-04; **Accepted**: 2016-02-16

Introduction: Postural control is necessary for conducting all activities and is the result of corporation of somatosensory, visual and vestibular systems. Impairment in each of these systems leads to disturbance of postural control and increases the risk of falling and injury. Fatigue is one of the common conditions that can affect postural control. The aim of this study was to elucidate different effects of Electrical Stimulation (ES) and Voluntary (Vol) quadriceps fatigues on postural control. **Methods and Materials:** This cross-sectional randomized order of testing study was performed at Biomechanics Laboratory of Iran University of Medical Sciences, Tehran, Iran from December 2014 to May 2015. Sixteen healthy active males (24.5±1.36 yr; height: 155.37±53.79 cm and body weight: 70.93±4.5 kg) participated. All the participants underwent two fatigue protocols: ES and VOL contractions. Each fatigue procedure contains isometric contraction with five seconds holding contraction, two seconds rest between each contraction and intensity of voluntary contraction was 20% of Maximal Voluntary Contraction (MVC). In each fatigue protocols, muscles MVC decreased to 30% in both ES and VOL protocols. MVC and postural control measured by using a digital dynamometer and a force plate that registered the Canter of Pressure (COP). Data collected before and after completion of each fatigue protocol. Monopedal postural control was recorded in eyes closed condition. **Results:** Results did not show significance effect of fatigue on area and mean velocity while showed significant effect on the anterior-posterior (Y-axis) and on the mediolateral direction (X-axis). **Conclusion:** Thirty percent loss of MVC in quadriceps muscle did not impair postural control.

Keywords: Postural Control, Quadriceps Muscle Fatigue, Voluntary Contraction, Electrical Stimulation

Please cite this paper as: Mostafa M, Akbari M, Dadgoo M, Teymuri Z. Comparing the Effect of Voluntary and Electrical Fatigue of Quadriceps on Postural Control. JCPR. 2017; 1(1): 12-16.

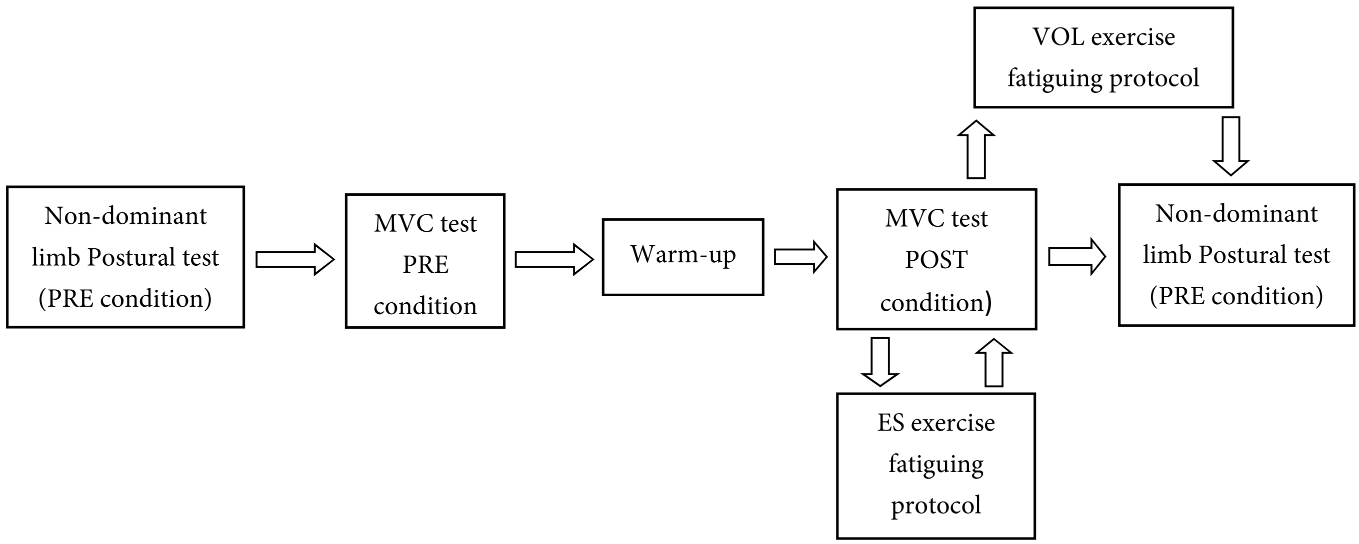
Introduction

Postural control is a complex function that maintains the whole body projection or centre of gravity (COG) within the base of support (1) and it requires the integrated information of sensory and motor system.

Manipulation and impairment in information of these two systems and impairment of different sensory system receptors (involving cutaneous, musculo-tendinous, temperature, visual and vestibular receptors) may influence integrated information and then lead to postural control disturbance (2-4). Postural control can be measured by centre of foot pressure (COP) displacements (5). Body always has a constants sway in erect standing, which is the result of neuromuscular system inability in maintaining of constant tension in the body (6).

Excessive repetitive submaximal contractions with low intensity can disturb postural control, which originates from the impaired motor system pathways or fatigue (7, 8).

Localized muscle fatigue causes metabolic and/or neurological changes in motor system pathways and disturbs postural control (9). Fatigue has an adverse effect on neuromuscular control (10-12). Muscle fatigue can increase the discharge of muscle spindle threshold; afferent feedback disturbance and alteration of joint conscious, which lead to joint's proprioception deficits and change in kinaesthesia properties (12, 13), resulted to postural control disturbance (14). Fatigue defines as two types, central and peripheral, the former is a progressive contraction-induced reduction in the level of voluntary activation of the muscle (13) whereas, decrease in force generation capacity of the muscle at the level of or distal to the neuromuscular junction is related to latter (14). Magnitude of muscle strength loss with repetitive



contractions can influence level of postural control disturbance after fatigue (15). For an equal force generation intensity and duration in each contraction of fatigue protocols, the magnitude of muscle strength loss induced by ES is greater in relation to VOL fatigue while VOL fatigue lead to more disturbances in postural control (1, 16, 17).

Based on review of previous studies and lack of study that compare the effects of VOL and ES fatigue with equal decreasing in muscle strength on postural control, present study attempt to check the effect of these two different natures of muscle fatigues (ES and VOL fatigue of non-dominant quadriceps muscle) with equal amount of losing in muscle strength on postural control.

Methods and Materials

This study was a cross-sectional randomized order of testing study conducted at Iran University of Medical Sciences, Tehran, Iran from December 2014 to May 2015. Sixteen healthy, active male volunteers after taking informed consent participated in this study. Left limb was as non-dominant limb in all participants. Subjects were excluded from entry to the trial if they had a documented postural control disorder or a medical condition that might affect postural control, a neurological or a musculoskeletal impairment in the past two years, any mal-alignment in the lower limb (pronated or supinated foot, knee hyper-extension), participant´s disinclination during the test and any problem that affect the result during the test (ankle sprain, knee trauma). Participants were notified that they should avoid any strenuous activity two hours before the data collection.

This experiment consisted of examination of the possible modifications of postural control induced by two different fatigue protocols on Non-dominant quadriceps muscle: VOL and ES contractions. To measure MVC asked subjects to sit on the table with a 90◦ of hip and knee flexion, arms crossed on the chest and then perform quadriceps maximum voluntary contraction. Three MVC tests with five seconds holding and thirty seconds rest between each test had considered. The best MVC performance (peak force in$_{Kg}$) recorded. Five min later fatigue protocols begun and were assigned in a randomized order. In the beginning, method of study explained for participants and then non-dominant limb determined. Participants took part in a 15 min warm up with low intensity by a cycle ergometer. All participants were be able to stand 30 sec on force plate and theirs pre fatigue postural control test was taken. MVC was measured with the digital dynamometer and at least 10 min later, one of the fatigue protocols was performed and immediately after protocol completion, post fatigue postural control test was taken. At least two hours later, second protocol performed similar as first one. The workload of each muscle contraction during VOL and ES protocols was adjusted to 20% of MVC by the digital dynamometer (18).

Voluntary fatigue protocol

Isometric voluntary contractions of quadriceps muscle were used in VOL fatigue protocol. Each contraction included of five seconds holding and two seconds rest. The workload of each contraction was controlled by verbal feedback from the examiner and the screen surface of the Dynamometer (Commander Power Track II HHD, J Tech Medical, USA). The force plate placed nearby (3-meter distance) the subjects. After 15 or 20 contractions a MVC test was taken and if muscle strength loss was about 30% of MVC (1) the examiner stopped the fatigue protocol and took post fatigue postural control test (18, 19).

Table 1. Comparison of before and after VOL fatigue data

Variables \ Indices	Mean (SD)	T	*P*-value
Area	-3.62 (9.80 mm^{2})	-1.47	0.16
Mean velocity	1.61 (8.74 mm/s)	0.73	0.47
Ant-post displacement	-50.33 (46.60 mm)	-4.32	0.001
Medio-lateral displacement	-14.91 (18.06 mm)	-3.30	0.05

Table 2. Comparison of before and after ES fatigue data

Variables \ Indices	Mean (SD)	T	*P*-value
Area	-3.75 (10.61 mm^{2})	-1.41	0.17
Mean velocity	-2.11 (11.57 m/s)	-0.72	0.47
Ant-post displacement	-30.54 (33.47 mm)	-3.64	0.002
Medio-lateral displacement	-14.46 (19.09 mm)	-3.03	0.008

Table 3. Comparison of difference between VOL and ES fatigue data

Variables \ Indices	Mean (SD)	T	*P*-value
Area	-0.14 (13.01 mm^{2})	-0.04	0.96
Mean velocity	-3.72 (6.84 mm/s)	-2.17	0.08
Ant-post displacement	19.79 (39.63 mm)	1.99	0.06
Medio-lateral displacement	0.45 (15.96)	0.11	0.91

Electrically stimulation fatigue protocol

In this protocol, quadriceps muscle was stimulated electrically by a portable stimulator. Four circular self-adhesive conducting electrodes (Stimrode®, diameter 50mm, Sweden) were placed over the four parts of the non-dominant quadriceps muscle. The two electrodes were placed over the distal parts of the vastus medialis and vastus lateralise and two other electrodes one on the middle part of rectus femuris and the other on the crossing area of vastus medialis and vastus lateralis in proximal part of the thigh (with at least 5cm distance between upper and lower electrodes). A biphasic symmetrical rectangular wave (continuous pulse 350μs, frequency 80 Hz) was used. The intensity of stimulation in each contraction was adjusted to 20% of MVC by the digital dynamometer. ES contractions were similar to VOL contractions with five seconds holding and two seconds rest between each contraction. Similar to VOL protocol after fifteen or twenty contractions, stimulation current was paused and a MVC test was taken, if muscle strength loss was about 30% of MVC the examiner stopped the fatigue protocol and took post fatigue postural control test (18, 19).

Measurements

Postural control was recorded for all participants in three conditions: 1-baseline, 2-after VOL fatigue 3- after ES fatigue. At baseline condition, no intervention was done on participants. Postural control parameters included sway area and mean velocity recorded by force plate (Kistler-9260AA6) 4th order, 10 Hz low-pass Butterworth filter). Reliability of the postural control sway when assessed by force plate (kistler) has been proven (20). Signals from the force plate were sampled at 100 Hz, amplified and converted from analog to digital form through an A/D converter. We asked the subjects to stand on the force plate for 30 sec, as possible as with their arms along the body, barefooted and immobile as possible as on non-dominant limb. The foot was placing according to precise landmarks with respect to the X and Y-axes on the force plate. The other foot was lifted so that the participant's big toe touched the medial malleolus of the supporting limb. Participant's eyes were closed with an eye cover to prevent vision contribution in regulation of postural behaviours. Once this state achieved by subject, the COP displacements was recorded.

Data analysis:

Data were analyzed using SPSS software version 22 (Chicago, IL, USA). Normal distribution was assessed using the Kolmogorov Smirnov analysis. Because of normal distribution of data, the One-Way ANOVA and Pair *t*-test were used to determine the effect of muscle fatigue (VOL and ES) on the postural control parameters in unilateral stance and to compare these parameters between PRE and POST conditions. Statistical significance for all tests was accepted below the 0.05 level.

Results

The mean age, height and weight of participant was 24.5±1.36 yr; height: 155.37±53.79 cm and bodyweight: 70.93±4.5 kg, respectively.

There was no significant effect on sway area (*P*=0.39, F=1.20) and mean velocity (*P*=0.24, F=1.44) of quadriceps muscle fatigue on unilateral postural control whereas there was a significant effect of fatigue (VOL and ES) on Y-axis (*P*=0.00, F=6.12) and X-axis (*P*=0.03, F=3.60) displacement.

There was not any significant effect of VOL and ES fatigue on sway area and mean velocity in unilateral postural control (Table 1 and 2).

There was not any significant difference between VOL and ES fatigue on sway area and mean velocity in postural control (Table 3).

Discussion

The present study investigated the effect of quadriceps voluntary and electrical fatigue on postural control. The first hypothesis was that fatigue lead to impairment of postural control and the second hypothesis was that VOL fatigue impairs postural control more than ES fatigue. Quadriceps muscle fatigue did not impair monopedal postural control. High levels of muscle fatigue impairs postural control while low levels of fatigue does not impair postural control effectively actually and 40% MVC decrease in muscle strength lead to increase in mean velocity whereas a decrease of 27% was not increased it (18). Muscle fatigue lead to change in central mapping representation of limb (21). In present study, fatigue had not sufficient effect on limb central mapping representation and did not lead postural control disturbance. Knee muscles fatigue does not impair COP displacement (22). Muscle fatigue lead to decrease in muscle force generation capabilities (23-25) and proprioceptive deficits (26-27). Little decrease in muscle strength does not lead sufficient effect on force generation and proprioception deficits in muscle. Thirty percent MVC loss in ankle or knee muscles lead to postural control disturbance (22). After quadriceps muscle fatigue impairs monopedal postural control but in these studies amount of muscle strength loss is not equal (7, 14, 28). In physiological aspect, ES fatigue acidifies the cellular cytoplasm and reduces the intracellular pH more than VOL fatigue (16, 28).

Concerning to nature of muscle contraction the VOL contraction as a voluntary activation of muscle is generate by central drive while the ES contraction as an artificial activation of muscle is not generated by central drive (17). After prolong VOL contractions the influence of corticospinal output can decrease and lead to synaptic dysfunction (9, 30-32). This phenomenon can affect the descending drives require for activation of motor neurons and influence the control of movement (32). Concerning to 20% of MVC intensity contractions VOL contractions first activate the small motor units located in the depth of muscle (32) whereas the ES contractions first activate large motor units located on the surface of the quadriceps muscle (33). Thus VOL contractions induce more severe fatigue in the small fibres mainly active in postural control whereas the ES contractions induces more severe fatigue in the large fibres which do not have specific role in postural control according to this previous studies reported that VOL fatigue lead to more postural control disturbance. Present study showed that VOL and ES fatigue affect COP displacement in the anterior-posterior direction (Y-axis) more than the medial–lateral direction (X-axis). Impairment of the monopedal postural control after fatigue, ensure the specific stabilising role of quadriceps muscle in the sagittal plane (7).

Displacement of the COP in Y-axis and X-axis direction was minimal and did not change sway area. Hip and ankle fatigue affects postural control in the sagittal plane (Y-axis) while hip muscles lead to postural control to be affected in both fatigued plane (Y-axis) and non-fatigued plane (X-axis) (34). The monopedal postural control maintain by a combination of ankle and hip strategies (35). Because ankle and hip strategies are compensatory strategies after quadriceps fatigue, so that these strategies lead to postural control maintains and decreases disturbance of postural control after fatigue. Therefore, sway area and mean velocity did not change.

Conclusion

Thirty percent of MVC loss in quadriceps muscle does not impair postural control in healthy subjects. Therefore 30% decrease in MVC after training and exercise therapeutic programs will not lead to postural control disturbance.

Acknowledgments:
None

Conflict of interest:
None

Funding support:
This research has been supported by Iran University of Medical Sciences & health Services grant No: 320/682.

Authors' contributions:
All authors made substantial contributions to conception, design, acquisition, analysis and interpretation of data.

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