

Trunk and Gluteus-Medius Muscles' Fatigability during Occupational Standing in Clinical Instructors with Low Back Pain

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Abstract—Background: Occupational standing is associated with low back pain (LBP) development. Yet, trunk and gluteus-medius muscles' fatigability has not been extensively studied during occupational standing. This study examined and correlated the rectus abdominus (RA), erector-spinae (ES), external oblique (EO), and gluteus-medius (GM) muscles' fatigability on both sides while standing in a confined area for 30min **Methods:** Median frequency EMG data were collected from 15 female clinical instructors with chronic LBP (group A) and 15 asymptomatic controls (group B) (mean age 29.53 ± 2.4 vs 29.07 ± 2.4 years, weight 63.6 ± 7 vs 60 ± 7.8 kg, and height 162.73 ± 4 vs 162.8 ± 6 cm respectively) using a spectrum analysis program. Data were collected in the first and last 5min of the standing task. **Results:** Using Mixed three-way ANOVA, group A showed significantly ($p < 0.05$) lower frequencies for the right and left ES, and right GM in the last 5min and significantly higher frequencies for the left RA in the first and last 5min than group B. In addition, the left ES and right EO, ES and GM in group B showed significantly higher frequencies and the left ES in group A showed significantly lower frequencies in the last 5min compared with the first. Moreover, the right RA showed significantly higher frequencies than the left in the last 5min in group B. Finally, there were significant ($p < 0.05$) correlations among the median frequencies of the tested four muscles on the same side and between both sides in both groups. **Discussion/Conclusions:** Clinical instructors with LBP are more liable to have higher trunk and gluteus-medius muscle fatigue than asymptomatic individuals. Thus, endurance training for these muscles should be included in the rehabilitation of such patients.

Keywords—EMG, Fatigability, Gluteus-medius, LBP, Standing, Trunk.

I. INTRODUCTION

LOW back pain (LBP) is a health problem that is prevalent worldwide. About 70-80% of all adults experience at least one significant episode of LBP at some time in their lives [1]-[5]. LBP is a major cause of work-related disability, accounting for about 40% of absenteeism from work in the United States of America [6]-[8]. Thus, it imposes a great burden on both patients and society [9]-[10].

It is suggested that LBP injuries do not result from a single exposure to loads of high magnitudes. However, it results from cumulative repetitive traumas and/or sustained low load postures [11]. Of these sustained postures is prolonged

standing. Despite the minimal cumulative load imposed on the low back while standing [12]-[14], prolonged standing has long been associated with LBP [15]-[17] and more deteriorated postural control strategies in patients with chronic LBP [18]. In addition, it contributes to both psychological and muscle fatigue [19].

From a biomechanical perspective, hip function affects and contributes to both trunk and spine function, and accordingly, plays a role in the development of LBP [20]-[21]. The hip extensors and abductors are involved in all ambulatory activities. They work synergistically to stabilize the pelvis and transfer forces from the lower extremities to the spine [22]. Special attention was suggested to be paid for the gluteus-medius muscle, being an important pelvic stabilizer during different functional activities. [23].

The gluteus-medius muscle was found to be involved in the development of lower limb problems such as iliotibial band friction syndrome [24], patellofemoral pain syndrome [25]-[27] and functional ankle instability [28]. Reduced gluteus-medius muscle strength was also reported for patients with chronic LBP [29]. Finally, altered gluteus-medius activation pattern was associated with LBP development during prolonged standing. It was found that there is co-activation of the gluteus-medius muscles of both sides in individuals who develop LBP during prolonged standing as opposed to synergistic reciprocal activation in healthy individuals [30].

Muscle fatigue can be technically recognized by recording the changes in the amplitude and frequency of the EMG signals over time [31]. The tested muscle is said to be fatigued if the amplitude of the EMG signal increases and the power spectrum has a lower frequency [32]-[33]. Many studies identified surface EMG to be one of the reliable techniques used for assessing muscle fatigue [34]-[37], [31].

Reviewing the literature revealed that many studies dealt extensively with prolonged standing and the occurrence of LBP in industrial workers [38]-[42]. Moreover, various studies demonstrated that patients with LBP show high fatigability of the back extensors, determined by decreased low back endurance time [43]-[47]. To the best of our knowledge, no studies examined fatigability of both trunk and gluteus-medius muscles in clinical instructors who are known to spend most of their work time standing.

So, the primary purpose of this study was to examine the fatigability of the trunk and gluteus-medius muscles on both sides during prolonged standing in clinical instructors with mechanical LBP. The secondary purpose was to correlate

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within and between both sides for the tested muscles' fatigability.

II. METHODS

A. Participants

This study was conducted on thirty female clinical instructors from the Faculty of Physical Therapy, Cairo University, whose job requires standing for at least 2-3 hours/day, 3-4 days/week. They constituted two groups; 15 with clinically diagnosed mechanical LBP (group A) and 15 asymptomatic healthy controls (group B). Their age ranged from 24 to 32 years, weight from 52 to 72 Kg and height from 157 to 170 cm. All participants of group A should have been experiencing periodic episodes of mild or moderate LBP for more than six months [48] such that the experienced pain shouldn't have been of a neurological origin. At time of conducting the study, all participants of group A should have had some sort of pain and disability to be included in the study. This was assured by asking the participants to rate their initial pain level on the 11-point numeric rating scale (NRS) and to complete the Oswestry Disability Index (ODI). The recorded minimum NRS and ODI scores were "1" and "12%" respectively for the studied patients before starting the standing task. To confirm that the patients' symptoms were consistent with the definition of mechanical LBP; pain that is aggravated by physical activity and upright posture and relieved by rest; the study involved only those whose pain was further aggravated by the end of the standing task. The participants of group B shouldn't have had any LBP episode in at least the previous 12 months [49]. The exclusion criteria involved having any structural deformity such as scoliosis or flat foot, spinal fracture, or spinal surgery or any cardiovascular, neuromuscular or musculoskeletal disorder.

B. Procedures

Prior to data collection, routine clinical examination of all participants was conducted based on history taking and physical examination. The flexibility of the back was assessed using Schober's test. The distance between a point between the sacroiliac dimples and another 10 cm above was initially measured. Then, the participants were asked to flex their trunks and the distance was measured again. An increase of < 4cm indicated range of motion limitation [50]. The flexibility of both hamstrings was additionally assessed using straight leg raising test [51]. The participants were also assessed for any leg length discrepancy [52]. Finally, the strengths of the trunk flexors and extensors and hip abductors were assessed manually such that individuals with grade 3-4 were included in the study. Once participants were verified to meet the specified inclusion criteria, written informed consents were obtained.

Real-time surface electromyography (sEMG) data were collected using Myomonitor[®] Wireless EMG System (DE 2.3 sEMG Sensor, Delsys, Inc., Boston, USA) that had an inter-electrode distance of 1 cm. After rubbing and cleaning the skin with alcohol, the electrodes were placed, bilaterally, over the

rectus abdominus (RA), external oblique (EO), lumbar erector spinae (ES), and GM muscles. The electrodes were placed 3 cm lateral to the umbilicus, 15 cm lateral to the umbilicus, and 3 cm lateral to L3 spinous process respectively for the trunk muscles [53] and 15 cm inferior and 5 cm posterior to the iliac crest for the GM [30]. The reference electrode was placed over the right anterior superior iliac spine (ASIS). All electrode placements were ascertained through palpation and manual resistance.

The participants stood in a confined area (80x80cm) that was marked on the ground, for 30min while discussing with the audience a topic about the hazards of awkward postures and trigger point formation. This topic was printed out and given to all participants. They were asked to act freely as what is habitualized while delivering their lectures. This represented their usual occupational standing task. All participants were asked to wear their own comfortable shoes [12].

C. Data Analysis

Initially, the raw EMG signals were band-pass filtered between 20–450 Hz, differentially amplified (Common mode rejection ratio (CMRR) >80 db at 60 Hz, input impedance = 10 GΩ) and analogue/digital (A/D) converted at a sampling frequency of 1000 Hz using a 16-bit A/D card with a ± 2.5 V range. Data from the 30-min task were saved into two individual data files, each of 5-min (first and last 5min.). The raw EMG data were converted to the frequency domain using Fast Fourier Transform to determine muscle fatigue. From the spectral information, the median frequency (MDF) was generated for each 5-min file. The MDF was calculated using a moving window, with a window length of 1s and a window overlap of 0.5s. The Fast Fourier Transform was applied to the data within the window to determine a power spectrum density (PSD). The MDF was calculated by determining the frequency that divides the PSD into two areas having the same amount of power.

D. Statistical Analysis

All statistical measures were performed using SPSS version 17 for Windows. Initially and as a pre-requisite for parametric analysis, data were screened for normality assumption through using Kolmogorov-Smirnov and Shapiro-Wilks normality tests, and testing for the presence of extreme scores and significant skewness and kurtosis. In addition, data were screened for the homogeneity of variance assumption. Once data were found not to violate the normality and homogeneity of variance assumptions, parametric analysis was conducted.

Mixed three-way ANOVA was used to compare the MDFs of the investigated four muscles between the right and left sides in each group, between the first and last 5min. of the standing task in each group, and between both groups in each of the right and left sides and each of the first and last 5min. of the standing task. Thus, three independent variables were tested; between-subject (healthy and patient groups), within-subject (right and left sides) and within-subject (first and last 5min.). Their effect was tested on one dependent variable which is the MDF.

On another regard, Pearson correlation analysis was conducted to examine the association among the MDFs of the investigated muscles on each of the right and left sides in each tested group. Moreover, the association was tested between the MDFs of the tested muscles on one side and their respective on the other. The level of significance was set at $p < 0.05$ for each of the Mixed three-way ANOVA and the correlation analysis.

III. RESULTS

Descriptive statistics revealed that the mean age, weight and height were 29.53 ± 2.4 vs 29.07 ± 2.4 years, 63.6 ± 7 vs 60 ± 7.8 kg, 162.73 ± 4 vs 162.8 ± 6 cm for group A vs group B. The unpaired t-tests revealed that there were no significant differences ($p > 0.05$) between both groups for the age, weight and height.

The Mixed three-way ANOVA showed that group A had significantly ($p < 0.05$) lower frequencies for the right and left ES, and right GM in the last 5min. and significantly higher frequencies for the left RA in the first and last 5min. than group B. In addition, the left ES and right EO, ES and GM in group B showed significantly higher frequencies in the last 5min. compared with the first. However, the left ES in group A showed significantly lower frequencies in the last 5min. compared with the first. Finally, the right RA showed significantly higher frequencies than the left in the last 5min. in group B. Table (1) presents the mean \pm SD of the median frequency scores of the right and left RA, EO, ES, and GM muscles during the first and last 5min. of the standing task in the patients and healthy controls.

Considering the correlation analysis, there were significant positive correlations between the LRA and each of the RRA ($r = 0.52$, $p = 0.001$), and LGM ($r = 0.33$, $p = 0.036$), between the RES and each of the LES ($r = 0.46$, $p = 0.007$), and REO ($r = 0.38$, $p = 0.02$), and between the RGM and each of the LGM ($r = 0.53$, $p = 0.001$) and REO ($r = 0.39$, $p = 0.017$) in group A.

Meanwhile, there were significant positive correlations between the RRA and each of the LRA ($r = 0.48$, $p = 0.004$), RES ($r = 0.49$, $p = 0.003$), REO ($r = 0.5$, $p = 0.003$), and RGM ($r = 0.34$, $p = 0.032$), between the LRA and each of the LES ($r = 0.51$, $p = 0.002$), and LEO ($r = 0.37$, $p = 0.02$), between RES and REO ($r = 0.58$, $p = 0.000$), between LES and LEO ($r = 0.31$, $p = 0.045$) and between the RGM and each of the LGM ($r = 0.55$, $p = 0.001$) and RES ($r = 0.33$, $p = 0.036$) in group B.

IV. DISCUSSION

The findings revealed significant reduction in the MDF values of the right and left ES and right GM in group A compared with group B during the last 5min. of the standing task. The reduced MDF reflects fatigability of the mentioned muscles. This might have resulted from reduced motor unit action potential firing rate during muscle contraction [54]. In addition, sustained static muscle contraction with limited trunk motion that occurs with prolonged standing might have induced metabolite accumulation in the trunk muscles [55], [56], [9]. Since patients with LBP have reduced physiological oxidative capacity to remove these metabolites, the metabolites might have been maintained within the muscles for a longer duration resulting in fatigue [57], [58].

TABLE I

DESCRIPTIVE STATISTICS OF THE MEDIAN FREQUENCIES OF THE RIGHT AND LEFT TRUNK AND HIP MUSCLES IN THE FIRST AND LAST 5MIN. OF THE STANDING TASK IN THE EXPERIMENTAL AND CONTROL GROUPS

Tested trunk and hip muscles	Side of affection	Experimental group		Control group	
Rectus Abdominus	Right	First 5min.	201.75 \pm 36.66	First 5min.	193.25 \pm 36.29
		Last 5min.	208.26 \pm 30.9	Last 5min.	202.48 \pm 34.4
	Left	First 5min.	205.61 \pm 32.96	First 5min.	176.91 \pm 40.59
		Last 5min.	212.07 \pm 35.18	Last 5min.	173.4 \pm 39.59
External Oblique	Right	First 5min.	167.57 \pm 26.5	First 5min.	172.65 \pm 28.13
		Last 5min.	169.97 \pm 36.47	Last 5min.	191.19 \pm 23.99
	Left	First 5min.	170.67 \pm 34.83	First 5min.	186.32 \pm 33.2
		Last 5min.	165.52 \pm 39.67	Last 5min.	173.39 \pm 40.22
Erector-spinae	Right	First 5min.	168.63 \pm 42.85	First 5min.	170.61 \pm 46.93
		Last 5min.	157.04 \pm 37.09	Last 5min.	210.9 \pm 50.13
	Left	First 5min.	175.72 \pm 37.78	First 5min.	170.53 \pm 46.25
		Last 5min.	150.67 \pm 39.74	Last 5min.	194.86 \pm 46.73
Gluteus-medius	Right	First 5min.	172.4 \pm 48.96	First 5min.	171.41 \pm 38.87
		Last 5min.	158.93 \pm 49.03	Last 5min.	195.19 \pm 34.74
	Left	First 5min.	159.29 \pm 48.81	First 5min.	173.12 \pm 41.36
		Last 5min.	177.18 \pm 53.95	Last 5min.	185.04 \pm 48.04

The perceived fatigability might also have been caused by muscle deconditioning [59], [60]. Chronic LBP was previously found to be accompanied by higher proportions of fast twitch and lower proportions of slow-twitch muscle fibers in the paraspinal muscles compared with healthy individuals [61], [62]. Thus, the endurance capacity is reduced.

Another explanation for the significant differences in the MDF of the fatigued muscles between the investigated groups may be related to the stiffened posture with which patients with chronic LBP present during stance [18]. Such patients have reduced postural changes that are suggested to be caused by the diminished proprioceptive information from the low

back or altered sensory-motor integration. Localized muscle fatigue has been linked to losses of proprioception acuity [63].

The fatigability reported for the ES muscles in group A is supported by the findings reported by [54], [64]. However, it should be noted that they assessed fatigability through analyzing EMG spectral variables while performing back endurance tests not while performing the occupational standing task.

The findings of the present study are contradicted by those reported by [65]. They compared the fatigability of the para-vertebral muscles in patients with chronic LBP and healthy controls during an endurance test. They found a greater decrease in the MDF in the control group compared with the patients. Also, our findings are contradicted by those reported by [66]. They found a less decline, though insignificant, in the MDF of the para-vertebral muscles in the patients compared with the healthy controls. They suggested that their patients may be classified as confronters who remain active despite their pain. The difference between our findings and those reported by [65], [66] may be related to the fact that they assessed fatigability during the endurance test while we assessed it during the standing task itself.

On another regard, the fatigability of the GM muscle reflects the load sharing property between the back and hip abductor muscles during prolonged standing. The GM is designed to stabilize the femur and pelvis during weight bearing activities [67], [68]. This is due to the fact that the GM is one of the tonically active muscles during standing [69]. It has large physiological cross-sectional area and short fibers [67], [68].

The fatigability of the GM muscle was previously associated with LBP development [70]. The latter researchers examined healthy individuals for the liability to develop LBP at the end of a 2-hour standing task. They compared the GM fatigability between those who developed LBP and those who didn't. They found that the individuals who developed LBP had reduced side-bridge endurance time before and after the standing task, as well as greater rate of fatigue for the contralateral GM during the post-standing side-bridge test.

The suboptimal activation of the back and hip musculatures in the patient group, as indicated by lower MDF values, is proposed to contribute to the accumulation of low-magnitude stresses on the lumbo-pelvic region. This might have been responsible for aggravating their pain at the end of the standing task.

On the other hand, group A showed significantly higher MDF values in the left RA during the last 5min. compared with group B. This is attributed to the significant difference in the MDF values of this muscle between both groups at the beginning of the task.

The within-subject effect revealed significant increases in the MDF of the right EO and GM and the right and left ES in group B in the last 5min. compared with the first. Based on the size principle that states that small motor units are recruited first, and with increasing force demands, larger motor units are progressively recruited [71], it could be concluded that additional motor units were recruited to maintain upright

postures during low-level sustained muscular contractions as standing in order to resist the fatigue process that may result. These additionally recruited motor units are high-threshold units, with higher muscle fiber conduction velocity (CV) and larger diameter [72]-[74].

Another explanation for the significant increases in the MDF of the right EO and GM and the right and left ES in group B in the last 5min. compared with the first is provided by the speculations suggested by [75], [76]. They speculated that during prolonged sustained contractions, motor unit substitution protects postural muscles from excessive fatigue. This concept describes a mechanism where higher-threshold motor units are recruited to replace lower-threshold fatigued units that have stopped firing to offset the effects of fatigue [77].

Furthermore, as the participants were allowed to stand in their habitualized comfortable posture throughout the 30-min standing task, they might have made alternative weight shifting. Accordingly, these strategies of minimizing or resisting fatigue might have allowed the working muscles to rest and recover from any perceived pain.

On the other hand, group A revealed insignificant differences in the MDF of the investigated muscles, except for that of the left ES that decreased significantly in the last 5min. compared with the first. The insignificant differences reported for almost all the muscles may indicate that the duration of the examined task (30 min.) was not long enough to induce significant changes in the spectral measure of the EMG signals.

Considering our aim of examining the effect of side of affection on fatigability of the trunk and GM muscles, the findings showed that there is side asymmetry in the fatigability of the investigated muscles in both groups. However, the patients showed higher manifestations of fatigue of the muscle groups on the dominant side of the back and hip. Side asymmetry may be attributed to unilateral pain distribution [78] or hand dominance [79].

Regarding the association analysis, the results revealed that there were positive correlations between the trunk and GM muscles and between the right and left GM muscles during the last 5min. of the standing task in both groups. The positive association between the trunk and GM muscles may reflect their co-operation to maintain lumbar stability during prolonged standing despite the perceived pain.

This study is limited by the inability to generalize the findings on both genders as it was conducted on females only. Females were studied due to the higher prevalence of back pain in them compared with the males [80], [81].

V. CONCLUSION

It is concluded that LBP should not be considered in isolation of hip abductors' fatigability. Thus, trunk and GM muscles should be targeted during endurance training programs for LBP.

ACKNOWLEDGMENT

The authors would like to thank all the participants who kindly volunteered to participate in the study.

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