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Trunk Muscle Activities during Lifting in Upright and Stooped Postures

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Abstract

In most cases, lifting a symmetrical load instead of a single load resulted in reduction of peak compression forces at the lumbar-sacral joint. While this probably reduces low back loading, the magnitude of this effect on low back muscle activity is not known. The effects of symmetrical lifting with hand loads beside the body on the erector spinae and multifidii muscles activities in conjunction with standing-upright and stooped postures were evaluated. A surface electromyography (sEMG) experiment was performed to evaluate the effects of symmetrical lifting. A total of 40 healthy right-handed subjects (20 male and 20 female from 20 to 30 years old) performed 16 lifting tasks with combinations of four stooping angles (0, 10, 20 and 30 degrees), and four hand loads (0, 6.5, 11.5 and 16.5 kg). The results showed that the possibility of fatigue of the back muscles is more pronounced in females than in males and also when lifting heavier loads with a more flexed posture. A future study will focus on muscle activity evaluation during symmetrical and asymmetrical lifting with hand loads in front of the body.

Keywords: Muscle fatigue, manual material handling, upper body flexion

I. INTRODUCTION

The number of instances of low back injury has been increasing steadily in industrial settings, despite advancement in automation and material handling devices [1]. Approximately 70–85% of all people experience low back pain (LBP) at some time in their life and this is becoming a large socioeconomic burden in Korea, as well as in other industrialized countries [2, 3]. The ergonomics risk factors associated with manual lifting tasks include lifting weight, postures, horizontal distance, lifting height, lifting frequency, site of the spine subjected to force, etc [4-9]. The onset of LBP is frequently associated with lifting techniques such as stooped, semi-squat, squat and free-style [7,8, 10,11]. Studies have described the prominent risk factors for LBP as workplace characteristics; mechanical variables; and repetitive postures during load lifting, twisting, bending, and muscle fatigue [12-14].

The high incidence of LBP is probably due to high back loads involved in lifting [15-17]. Thus, reduction of low back loads in lifting might help to prevent low back injury and re-injury. This can be accomplished by lifting loads beside the body rather than in front of the body [15-17]. Faber et al. [17] performed a study to compare low back loads in lifting symmetrical loads and single loads with loads between the feet and loads beside the body, where the lifts were performed from a prescribed initial height with four different techniques (stooped, squat, straddle and kneeling). In most cases, lifting a symmetrical load instead of a single load resulted in reduction of peak compression forces at the lumbar-sacral joint. In theory, while lifting one load in each hand, the horizontal distance of the combined load relative to the low back can be reduced to zero [17]. While this probably reduces low back loading, the magnitude of this effect on low back muscle activity is not known.

Muscle fatigue is defined as a failure to maintain required or expected force [18]. EMG has been used to identify the level of local muscle fatigue [16, 18-21], and both amplitude and frequency parameters have been used to evaluate questions related to fatigue [16, 21-23]. Muscle fatigue is associated with increased amplitude and decreased frequency parameters of EMG signals for a given performance [18, 21, 24-26].

Chen et al. [5] evaluated the ergonomics risk factors associated with 72 manual lifting tasks (combinations of posture, loads, lifting height, lifting speed and different box size) using EMG on erector spinae muscles. The results concluded that the EMG average amplitude for lifting the heavier load was greater than that for lifting the lighter load. However, their study involved on manual lifting tasks performed only with hand loads in front of the body. Watanabe et al. [27] evaluated EMG of trunk muscle activity while lifting objects of unexpected weight, with the subject sitting on a stool in an erect posture with the soles of his feet in contact with the floor. The muscle activity of the rectus abdominis, external oblique and erector spinae muscles and the transversus abdominis and lumbar multifidus muscles were measured. The RMS of muscle activities was compared, with the result that trunk muscles may not be able to function appropriately when individuals lift an object that is much heavier than expected [27].

Andersson et al. [28] studied four different angles of forward flexion during external loading of the spine with asymmetric loading of 0–300 N. The myoelectric activity of the posterior muscles of the back was studied quantitatively using signal amplitude estimation and power spectrum analysis. The result showed that the myoelectric activity increased when the angle of flexion increased and when the external load was increased at a fixed angle of flexion. Also, spectral changes increased when the signal amplitude increased, indicating localized muscle fatigue [28].

Trunk function studies are generally focused on measuring activities of the erector spine muscles, since the highest level of EMG activity during trunk extension tasks is associated with these muscles [5, 7, 11, 21, 29-31]. It is widely accepted that the lumbar multifidii contribute to stabilization and control of the lumbar spine in humans, and are also capable of producing extension, lateral flexion and rotation. EMG studies confirm that multifidii muscles act more as stabilizers than as prime movers of the vertebral column and also play a vital role in controlling intersegmental motion [21, 24, 32]. In order to identify the relationship between back pain and the multifidii, a study [32] compared the level of back muscle activity in healthy controls and patients with LBP during coordination, stabilization and strength exercise; EMG activities of the back muscles, namely the multifidii muscles and the iliocostalis lumborum, were measured when the subjects performed the exercise.

The aim of the current study was to determine the effects of symmetrical lifting with hand loads beside the body on the erector spinae and multifidii muscle activities in conjunction with standing-upright and stooped postures. A sEMG experiment was performed to evaluate the effects of symmetrical lifting beside the body by comparing the EMG frequency and amplitude parameters of the muscles.

II. MATERIALS AND METHODS

II. I. Subjects

A total of 40 healthy right-handed individuals were examined; 20 were male and 20 female (from 20 to 30 years old). The subjects' anthropometric details are: Age, year (SD); Height, cm (SD); Weight, kg (SD): Male [26.2 (2.4); 174.8 (5.4); 75.8 (16.5)] and Female [25.6 (2.0); 162.7 (4.5); 55.9 (5.4)], respectively. In terms of handedness, about 94% of Koreans are right-handed [33, 34], therefore this study considered only right-handed individuals. Only subjects with sound health and who claimed to have no history of back pain were allowed to participate in the experiments. All subjects were aware of the purpose and procedure of the experiment and willingly participated and signed a consent form. The subjects were compensated for their participation.

II. II. Design

The muscles studied from the lumbar region were the erector spinae (ES) and multifidii (MI). For better understanding of the musculoskeletal load distribution during symmetrical lifting, both right (RT) and left (LT) sides were considered for male and female. In this study, a 2 x 4 x 4 mixed-factor design was used with the following independent variables: sex (between-subject factor) and stooping angles and hand loads (within-subject factors). Dependent variables consisted of the normalized EMG parameters: Mean Power Frequency (MPF), Median Frequency (MF), and Root Mean Square (RMS).

II. III. Instrumentation

To measure the electrical activity of the ES and MI muscles, a surface electromyography (sEMG) system (Telemyo 2400T G2 Telemetry EMG system; Noraxon, USA) was used. All surface EMGs were collected from both sides of ES and MI muscles for a 10 s period in each loading condition. To measure EMG signals, pairs of disposable Ag/AgCl surface electrodes (4.31 cm diameter, 2.06 sq. cm sensor area and approximately 4 cm of inter-electrode distance) were affixed to the skin over the four muscles with a sticky gel. The skin was abraded and cleansed with alcohol before the electrodes were placed using standard placement procedures [35, 36]. A spring-type dynamometer was used for isometric maximum voluntary contraction (MVC) trials.

For the ES muscles, the electrodes were placed bilaterally at the level of the spinous process of L3 vertebrae, approximately 5 cm from the midline. The reference electrode was placed over the superior aspect of the left iliac crest. For the MI muscles, the electrodes were placed bilaterally just lateral to the midline of the body, above and below a line connecting both posterior superior iliac spines; this was a location at the level of the L5 vertebrae. Many researchers [21, 32, 35-40] have suggested that for the multifidii muscle, surface EMG measurement at the L5 vertebral level may be satisfactory. Therefore, we performed the measurements with surface-type electrodes. However, Stokes et al. [41] suggested intra-muscular electrodes need to be used to obtain EMG from multifidii muscle. Further investigations need to be performed before a definite conclusion can be derived about the use of surface electrodes for the MI muscles.

II. IV. Experimental procedures

At the start of the experiment, subjects' back muscle strength was measured using a back & leg dynamometer. To measure, subjects were instrumented with electrodes and then secured to the dynamometer arm. The subjects were positioned with body erect and knees bent so that the grasping hand rested at proper height. Then, by straightening the knees and lifting the chain of the dynamometer, pulling force was applied to the handle. For the MVC trials, the subjects were brought to a 30 degree trunk flexion position (0 degrees being an upright standing position) with the trunk dynamometer arm. At the 30 degree trunk flexion position, the subjects were instructed to gradually increase the extension moment over 3 s without any sudden jerks against the locked dynamometer arm to reach his/her maximum level, and then to maintain the level for approximately 5 s, and to gradually decrease the moment in 3 s. Data collection began with the recording of EMG frequency and amplitude of respective muscles during MVC trials. The EMG parameters were measured from each MVC trial during the 5 s hold. The MVC trials were performed three times with a rest period of at least 2 min in an upright standing position between consecutive trials. In order to normalize subsequent EMG data, the peak EMG parameter of each channel from the trials was selected as the MVC EMG for the corresponding channels. Following the MVC trials and a rest period, the real experimental session was carried out.

The subjects were briefed on the study protocol, which involved four types of postures with knee straight and a constrained hand position. The postures were standing neutrally (upright standing posture), considered as 0 degrees, and stooped-standing postures with 10, 20 and 30 degree stooping angles. The subjects were required to hold the symmetrical hand loads with a particular posture for a period of 10 s. The symmetrical hand loads were 0 (without any hand load), 6.5, 11.5 and 16.5 kg. EMG data were captured from the four muscles for a 10 s period in each loading condition. A total of 16 cases (4 hand loads x 4 stooping angles) per subject were considered. After every loading condition/posture, the subjects were allowed to rest in an upright standing posture for 1 min. Two subjects performed the task in an experimental session. When one subject was performing the task, the other was at rest. Combinations of experimental conditions were presented to the subjects in a randomized order.

II. V. Data analysis

All the EMG signals were acquired using a wireless-type Noraxon Telemyo 2400T G2 telemetered EMG system and A/D converted at 1500 samples/second using a 16-bit A/D card with a $\pm$5V range. The recording system included analogue band-pass filtering (10–500 Hz) and differential amplification (common-mode rejection ration >100 dB, input impedance 100 MΩ) of the detected signal. The muscle activities were observed constantly on a monitor and stored digitally in raw form for further analysis using (MyoResearch XP Master Edition; Noraxon Inc., USA) software at 1000 Hz sampling frequency. In the analysis software, the raw data were band-pass (FIR) filtered between 10 to 500 Hz in a hamming window, full wave rectified for frequency parameters and smoothed based on the RMS algorithm with a 50 ms window for amplitude parameters. The percentages of normalized EMG parameters were calculated by dividing the corresponding EMG MVC.

II. VI. Statistical analysis

Analyses of variance (ANOVA) with a repeated measures design (2 x 4 x 4 mixed-factor design) were used to investigate the main and interaction effects of the independent variables (sex, stooping angles and hand loads) on each of the dependent variables (MPF, MF and RMS). Multiple comparisons were performed using post hoc (Tukey's HSD) analysis. Statistical analyses were performed using SPSS (release 18, SPSS Inc., Chicago). The confidence level for statistical significance was set at alpha equal to 0.05. The assumption of normality and homogeneity of variances for MPF, MF and RMS were satisfied for all group combinations of sex, stooping angles and hand loads, as assessed by Kolmogorov-Smirnov test ($p > 0.05$) and Levene's test of homogeneity of variance ($p > 0.05$) respectively, and not satisfied for correlation on each dependent variables ($p > 0.05$).

III. RESULTS

ANOVA for MPF, MF and RMS of the four muscles, when testing the main and interaction effects of sex, stooping angles, and hand loads are presented (Table 1). ANOVA revealed significant difference in the MF of RTES ($p < 0.05$) and RMS of LTES ($p < 0.05$) according to the main effects of sex (Table 1). ANOVA revealed significant difference in the MPF, MF and RMS of the four muscles according to the main effects of stooping angles ($p < 0.01$) (Table 1). ANOVA revealed significant difference in the MPF of RTES ($p < 0.05$) and LTES ($p <0.01$), MF of LTES ($p < 0.01$), and RMS of all muscles ($p < 0.01$) according to the main effects of hand loads (Table 1). There were significant interaction effects between the sex and stooping angles on LTMI ($p < 0.05$) of MPF, and LTES ($p < 0.01$) and LTMI ($p < 0.01$) of MF. There were significant interaction effects between the sex and hand loads on LTES ($p < 0.01$) and RTMI ($p < 0.05$) of MF. Also, there were significant interaction effects between the stooping angles and hand loads on RTES and LTES ($p < 0.01$).

III. I. Mean Power Frequency (MPF)

When the stooping angle increased, the MPF of RTES, LTES and RTMI was significantly greater at 30 degrees ($p < 0.05$, 0.01) than other angles (Table 2, Fig. 1). However, MPF of the LTMI was significantly greater at 20 degrees ($p < 0.05$, 0.01) than other angles (Table 2, Fig.1). When the hand load increased, the MPF of RTES was significantly less at 11.5 kg compared with 6.5 kg ($p < 0.05$). Also the MPF of LTES was significantly less at 16.5 kg compared with 0 kg and 6.5 kg ($p < 0.01$) (Table 3, Fig. 1). The MPF of males' LTMI was significantly greater than the females' only at 0 degrees ($p < 0.05$, Fig. 1). The MPF of males' and females' LTMI was increased from 0 degrees to 10 degrees ($p < 0.01$).

III. II. Median Frequency (MF)

The MF of males' RTES was significantly greater than that of the females' ($p < 0.05$, Fig. 1). When the stooping angle increased, the MF of RTES, LTES and RTMI was significantly greater at 30 degrees ($p < 0.05$, 0.01; Table 2, Fig. 1) than at other angles. However, the MF of the LTMI was significantly greater at 30 degrees ($p < 0.01$) than at 0 degrees and 10 degrees (Table 2). The MF of males' LTES was significantly greater than the females' at 0 degrees ($p < 0.01$), and was significantly less than the females' at 30 degrees ($p < 0.05$). The MF of males' LTMI was significantly greater than the females' at 0 degrees and 10 degrees ($p < 0.05$, 0.01, Fig. 1). The MF of males' and females' LTMI was significantly increased from 0 degrees to 10 degrees ($p < 0.01$). When the hand load increased, the MF of LTES was significantly greater at 16.5 kg (Table 3) than at 0 kg. The MF of males' LTES was significantly less than the females' at 0 kg, and significantly greater at 6.5 kg, 11.5 kg and 16.5 kg ($p < 0.01$). The MF of males' LTES was significantly increased from 0 kg to 6.5 kg ($p < 0.01$). The MF of males' RTMI was significantly greater than females' only at 6.5 kg ($p < 0.01$).

III. III. Root Mean Square (RMS)

When the stooping angle increased, the RMS of muscles was significantly greater at 30 degrees ($p < 0.01$) than at other angles (Table 2, Fig. 1). When the hand load increased, the RMS of RTES, LTES, and RTMI was significantly greater at 16.5 kg ($p < 0.01$) than at other loads, and the RMS of LTMI was significantly greater at 16.5 kg ($p < 0.01$) compared with 0 kg and 6.5 kg. The RMS of RTES was significantly greater at 16.5 kg ($p < 0.05$) than at 0 kg when stooping angle was 20 degrees and 30 degrees (Fig. 1). For all the hand loads, the RMS of RTES was significantly greater at 30 degrees ($p < 0.01$) than at

0 degrees and 10 degrees (Fig. 1). The RMS of females' LTES was significantly greater than the males' ($p < 0.05$) (Table 2). When the hand loads were 0 kg and 11.5 kg, the RMS of LTES was significantly greater at 30 degrees ($p < 0.01$) than 0 degrees and 10 degrees (Fig. 1). However when the hand loads were 6.5 kg and 16.5 kg, the RMS of LTES was significantly greater at 30 degrees ($p < 0.01$) than at other angles.

IV. DISCUSSION

Trunk muscle fatigue in symmetrical lifting with hand loads beside the body in conjunction with standing-upright and stooped postures was evaluated. The results are summarized in Table 4.

IV. I. ES and MI muscle activity and fatigue difference on gender (sex)

Results of the MF of RTES (Male > Female) and RMS of LTES (Male < Female) show gender differences in muscle activity while performing symmetrical lifting (Table 4). These results show that the possibility of fatigue of the back muscles is more pronounced in females than in males. The healthy males and females performing various lifting tasks showed gender differences in muscle activity [12, 37, 42]. In an earlier study [37], significant differences were found in EMG amplitudes (%MVC) during therapeutic exercise with respect to different parts of the paraspinal muscles and gender; the multifidii EMG amplitudes (% MVC) were higher in females than in males in therapeutic exercises.

EMG parameters were analysed to determine the interaction effect of sex, stooping angles and hand loads on the ES and MI muscle activity difference. A decreased trend of MPF was observed for females' LTMI when stooping angles increased, and a decreased trend of MF was observed for females' LTES and LTMI when stooping angles increased (Table 4, Figure 2). These results suggest that when increasing the stooping angles the possibility of fatigue on ES and MI muscles is more pronounced in females than in males [37].

The MF of females' LTES was greater than males' when without any external loading; however, when hand loads increased, MF of females' LTES was less than males'. The MF of females' RTMI was less than males'. The MF of females' LTES and RTMI showed decreased trend when hand loads increased (Table 4, Figure 2). One possible explanation is that males have greater muscle volume and muscle force than females [43]; therefore when hand loads increased, females experienced more fatigue.

IV. II. ES and MI muscle activity and fatigue difference on stooping angle and hand load

The results of MPF, MF and RMS of four muscles have shown stooping angle differences (almost most flexed posture had greater muscle activity than other angles) in muscle activity while performing symmetrical lifting (Table 4). Roy et al. [29] found that trunk extensor muscle activity increased by approximately 25.3% for maximal extension tasks performed in more flexed postures (40 degree) in comparison to upright postures. However, the results of this study observed an increase of approximately 15% in trunk extensor muscle activity for maximal extension (30 degrees) tasks performed in comparison to upright. Tan et al. [44] investigated erector spine muscle activity patterns and reported a significant increase in extensor EMG activity during tasks performed at greater flexion angles (35 degrees). Also, several previous studies [28, 45, 46] showed increasing erector spinae EMG activity during maximum isometric extension tasks performed at increasing flexion angles. Lim et al. [7] analysed discomfort of the whole body and showed that the subjects rated higher discomfort for a back angle of 45 degrees compared to upright posture. Therefore, a worker lifting symmetrical hand loads beside the body at a flexed posture of more than 30 degrees would experience fatigue and discomfort.

EMG parameters were analysed to determine the ES and MI muscle activity difference on hand loads. When lifting heavier loads, less MPF of ES muscles and greater RMS of ES and MI muscles was observed. These results showed that the possibility of fatigue of the back muscles is more pronounced while lifting heavier loads than when lifting lighter loads (Table 4). This is consistent with the results of a previous study, which found the average EMG amplitude of the erector spine muscle while lifting heavier loads was greater than when lifting lighter loads [5]. Studies have described that the muscle activities were significantly correlated with the loads carried [20, 47].

EMG parameters were analysed to determine the interaction effect of stooping angles and hand loads on ES and MI muscle activity difference. The RMS of RTES was greater with a 16.5 kg hand load when stooping angle was 20 degrees and 30 degrees. The RMS of RTES was greater at a 30-degree stooping angle than at 0 degrees and 10 degrees for all hand loads. The RMS of LTES was increased and greater at a 30 degree stooping angle than at other angles for all hand loads (Table 4, Figure 2). These results showed that RMS increased with the combination of heavier hand load and greater stooping angle. Therefore, the possibility of fatigue of the back muscles is more pronounced when lifting heavier loads with a more flexed posture. A previous study showed that myoelectric activity increased when the angle of flexion increased and when the external load was increased at a fixed angle of flexion [28].

Some limitations and suggestions regarding the present study should be mentioned. Cross-talk can be a limitation when using surface electrodes. In the present work, for the MI muscles, the electrodes were placed bilaterally just lateral to the midline of the body, above and below a line connecting both posterior superior iliac spines; this was a location at the level of the L5 vertebrae [21, 32, 35-40]. Nevertheless, the multifidus muscle activities can be accurately recorded using wire electrodes to avoid cross-talk. Further investigation needs to be performed before a definite conclusion can be derived about the use of surface electrodes for the MI muscles. Also this study limited by the fact that hand loads were not correlated to the individual capacity. The female subjects were working at a higher percentage of their individual capacities comparison with male subjects.

V. CONCLUSION

The effects of symmetrical lifting with hand loads beside the body in standing-upright and stooped postures were evaluated by comparing the average frequency and amplitude of EMG signals for the erector spinae and multifidii muscles. The results showed that the possibility of fatigue of the back muscles is more pronounced in females than in males and also when lifting heavier loads with a more flexed posture. A further study will consider symmetrical and asymmetrical lifting with hand loads in front of the body.

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Table 1. ANOVA examine the main and interaction effect of sex, stooping angles and hand loads on EMG parameters of muscles.

Parameters	Muscles	Sex	S.A’s	H.L’s	Sex x S.A’s	Sex x H.L’s	S.A’s x H.L’s	Sex x S.A’s x H.L’s
MPF	RTES	$F_{(1, 38)}=3.89^{a}$	$F_{(3, 114)}=156.66^{**}$	$F_{(3, 114)}=3.03^{*}$	$F_{(3, 114)}=0.24^{a}$	$F_{(3, 114)}=1.25^{a}$	$F_{(9, 342)}=1.20^{a}$	$F_{(9, 342)}=0.61^{a}$
	LTES	$F_{(1, 37)}=1.93^{a}$	$F_{(3, 111)}=91.54^{**}$	$F_{(3, 111)}=4.72^{**}$	$F_{(3, 111)}=0.86^{a}$	$F_{(3, 111)}=0.68^{a}$	$F_{(9, 333)}=0.58^{a}$	$F_{(9, 333)}=0.46^{a}$
	RTMI	$F_{(1, 38)}=1.20^{a}$	$F_{(3, 114)}=115.21^{**}$	$F_{(3, 114)}=1.55^{a}$	$F_{(3, 114)}=1.10^{a}$	$F_{(3, 114)}=1.63^{a}$	$F_{(9, 342)}=0.79^{a}$	$F_{(9, 342)}=0.48^{a}$
	LTMI	$F_{(1, 38)}=0.28^{a}$	$F_{(3, 114)}=60.20^{**}$	$F_{(3, 114)}=0.35^{a}$	$F_{(3, 114)}=2.76^{*}$	$F_{(3, 114)}=1.01^{a}$	$F_{(9, 342)}=1.09^{a}$	$F_{(9, 342)}=0.21^{a}$
MF	RTES	$F_{(1, 38)}=5.75^{*}$	$F_{(3, 114)}=118.18^{**}$	$F_{(3, 114)}=1.07^{a}$	$F_{(3, 114)}=1.26^{a}$	$F_{(3, 114)}=1.88^{a}$	$F_{(9, 342)}=0.86^{a}$	$F_{(9, 342)}=0.97^{a}$
	LTES	$F_{(1, 34)}=0.69^{a}$	$F_{(3, 102)}=22.66^{**}$	$F_{(3, 102)}=32.14^{**}$	$F_{(3, 102)}=34.31^{**}$	$F_{(3, 102)}=49.32^{**}$	$F_{(9, 306)}=1.40^{a}$	$F_{(9, 306)}=0.38^{a}$
	RTMI	$F_{(1, 32)}=0.35^{a}$	$F_{(3, 96)}=104.19^{**}$	$F_{(3, 96)}=0.34^{a}$	$F_{(3, 96)}=0.60^{a}$	$F_{(3, 96)}=3.15^{*}$	$F_{(9, 288)}=0.78^{a}$	$F_{(9, 288)}=0.75^{a}$
	LTMI	$F_{(1, 31)}=0.10^{a}$	$F_{(3, 93)}=159.86^{**}$	$F_{(3, 93)}=0.41^{a}$	$F_{(3, 93)}=5.61^{**}$	$F_{(3, 93)}=1.16^{a}$	$F_{(9, 279)}=1.12^{a}$	$F_{(9, 279)}=0.82^{a}$
RMS	RTES	$F_{(1, 38)}=3.73^{a}$	$F_{(3, 114)}=73.82^{**}$	$F_{(3, 114)}=11.43^{**}$	$F_{(3, 114)}=0.35^{a}$	$F_{(3, 114)}=0.20^{a}$	$F_{(9, 342)}=3.76^{**}$	$F_{(9, 342)}=0.99^{a}$
	LTES	$F_{(1, 38)}=4.09^{*}$	$F_{(3, 114)}=106.40^{**}$	$F_{(3, 114)}=5.43^{**}$	$F_{(3, 114)}=0.97^{a}$	$F_{(3, 114)}=0.27^{a}$	$F_{(9, 342)}=3.04^{**}$	$F_{(9, 342)}=0.42^{a}$
	RTMI	$F_{(1, 35)}=2.26^{a}$	$F_{(3, 105)}=105.48^{**}$	$F_{(3, 105)}=8.32^{**}$	$F_{(3, 105)}=1.06^{a}$	$F_{(3, 105)}=1.54^{a}$	$F_{(9, 315)}=2.86^{a}$	$F_{(9, 315)}=0.49^{a}$
	LTMI	$F_{(1, 38)}=2.87^{a}$	$F_{(3, 114)}=158.48^{**}$	$F_{(3, 114)}=9.96^{**}$	$F_{(3, 114)}=1.69^{a}$	$F_{(3, 114)}=0.42^{a}$	$F_{(9, 342)}=3.86^{a}$	$F_{(9, 342)}=0.23^{a}$

S.A’s – Stooping Angles; H.L’s – Hand Loads; RT – Right side; LT – Left side; ES – Erector Spinae Muscle; MI – Multifidii Muscle.

**$p < 0.01$.

*$p < 0.05$.

[a] NS : Non-significant.

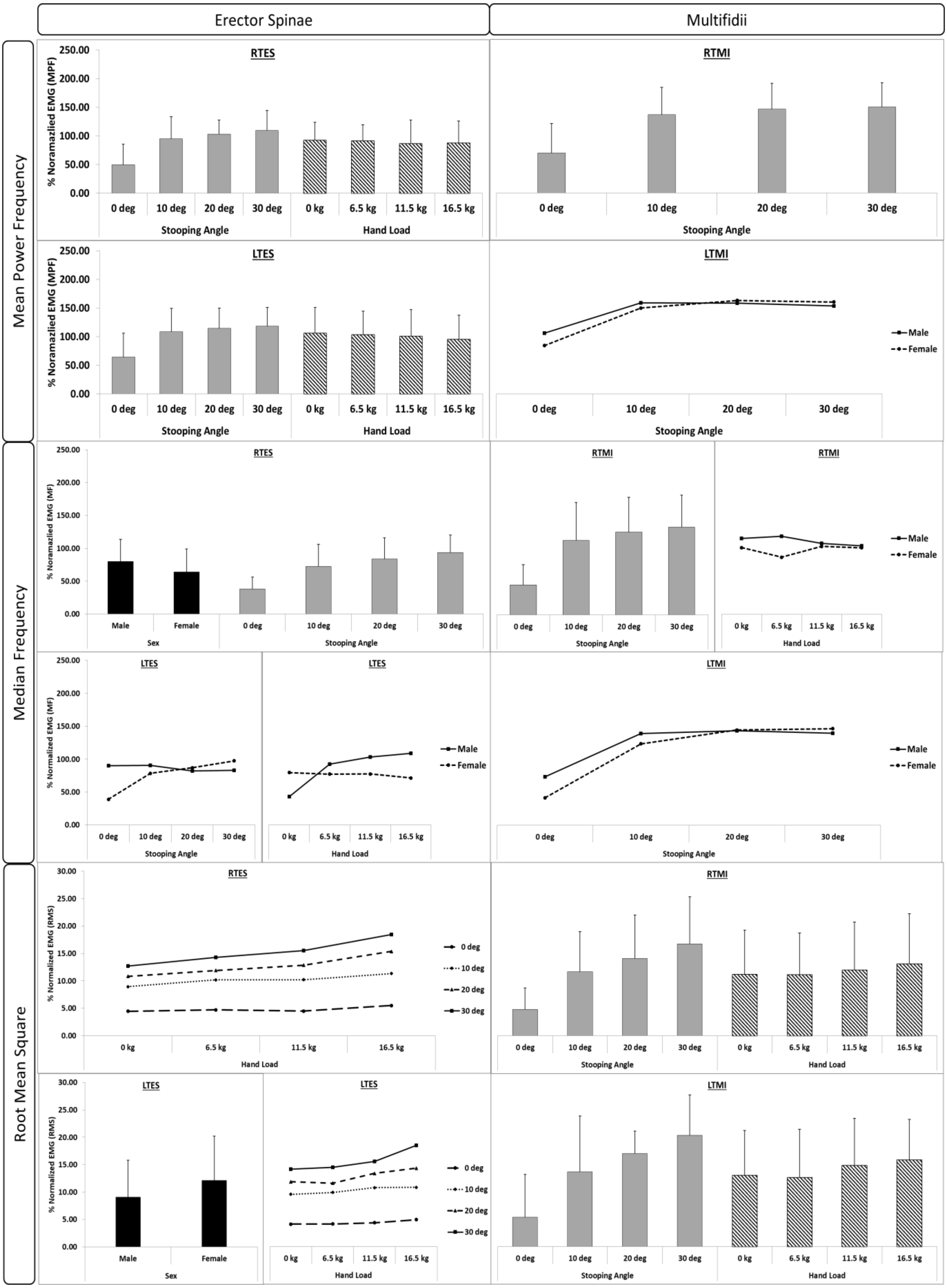

Fig. 2. Main and interaction effects of muscles

Table 2. Multiple comparison (Tukey's HSD post-hoc) for stooping angles

Parameters		RTES				LTES				RTMI				LTMI			
MPF	Stooping Angle	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
	1	-	$1<2^{**}$	$1<3^{**}$	$1<4^{**}$	-	$1<2^{**}$	$1<3^{**}$	$1<4^{**}$	-	$1<2^{**}$	$1<3^{**}$	$1<4^{**}$	-	$1<2^{**}$	$1<3^{**}$	$1<4^{**}$
	2	$2>1^{**}$	-	$2<3^{**}$	$2<4^{**}$	$2>1^{**}$	-	$2<3^{**}$	$2<4^{**}$	$2>1^{**}$	-	$2<3^{***}$	$2<4^{**}$	$2>1^{**}$	-	$2<3^{*}$	$2=4^{a}$
	3	$3>1^{**}$	$3>2^{**}$	-	$3<4^{**}$	$3>1^{**}$	$3>2^{**}$	-	$3<4^{**}$	$3>1^{**}$	$3>2^{**}$	-	$3<4^{*}$	$3>1^{**}$	$3>2^{*}$	-	$3>4^{*}$
	4	$4>1^{**}$	$4>2^{**}$	$4>3^{**}$	-	$4>1^{**}$	$4>2^{**}$	$4>3^{**}$	-	$4>1^{**}$	$4>2^{**}$	$4>3^{*}$	-	$4>1^{**}$	$4=2^{a}$	$4<3^{*}$	
MF	Stooping Angle	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
	1	-	$1<2^{**}$	$1<3^{**}$	$1<4^{**}$	-	$1<2^{**}$	$1<3^{**}$	$1<4^{**}$	-	$1<2^{**}$	$1<3^{**}$	$1<4^{**}$	-	$1<2^{**}$	$1<3^{**}$	$1<4^{**}$
	2	$2>1^{**}$	-	$2<3^{**}$	$2<4^{**}$	$2>1^{**}$	-	$2=3^{a}$	$2<4^{*}$	$2>1^{**}$	-	$2<3^{**}$	$2<4^{**}$	$2>1^{**}$	-	$2<3^{**}$	$2<4^{**}$
	3	$3>1^{**}$	$3>2^{**}$	-	$3<4^{**}$	$3>1^{**}$	$3=2^{a}$	-	$3<4^{**}$	$3>1^{**}$	$3>2^{**}$	-	$3<4^{**}$	$3>1^{**}$	$3>2^{**}$	-	$3=4^{a}$
	4	$4>1^{**}$	$4>2^{**}$	$4>3^{**}$	-	$4>1^{**}$	$4>2^{*}$	$4>3^{**}$	-	$4>1^{**}$	$4>2^{**}$	$4>3^{**}$	-	$4>1^{**}$	$4>2^{**}$	$4=3^{a}$	-
RMS	Stooping Angle	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
	1	-	$1<2^{**}$	$1<3^{**}$	$1<4^{**}$	-	$1<2^{**}$	$1<3^{**}$	$1<4^{**}$	-	$1<2^{**}$	$1<3^{**}$	$1<4^{**}$	-	$1<2^{**}$	$1<3^{**}$	$1<4^{**}$
	2	$2>1^{**}$	-	$2<3^{**}$	$2<4^{**}$	$2>1^{**}$	-	$2<3^{**}$	$2<4^{**}$	$2>1^{**}$	-	$2<3^{**}$	$2<4^{**}$	$2>1^{**}$	-	$2<3^{**}$	$2<4^{**}$
	3	$3>1^{**}$	$3>2^{**}$	-	$3<4^{**}$	$3>1^{**}$	$3>2^{**}$	-	$3<4^{**}$	$3>1^{**}$	$3>2^{**}$	-	$3<4^{**}$	$3>1^{**}$	$3>2^{**}$	-	$3<4^{**}$
	4	$4>1^{**}$	$4>2^{**}$	$4>3^{**}$	-	$4>1^{**}$	$4>2^{**}$	$4>3^{**}$	-	$4>1^{**}$	$4>2^{**}$	$4>3^{**}$	-	$4>1^{**}$	$4>2^{**}$	$4>3^{**}$	-

Where: RT – Right side; LT – Left side; ES – Erector Spinae Muscle; MI – Multifidii Muscle.
Where: 1 – 0 deg; 2 – 10 deg; 3 – 20 deg; 4 – 30 deg.
$^{**}p < 0.01$.
$^{*}p < 0.05$.
^{a} NS : Non-significant.

Table 3. Multiple comparison (Tukey's HSD post-hoc) for hand loads

Parameters		RTES				LTES				RTMI				LTMI			
MPF	Hand Load	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
	1	-	$1=2^{a}$	$1=3^{a}$	$1=4^{a}$	-	$1=2^{a}$	$1=3^{a}$	$1>4^{**}$	-	$1=2^{a}$	$1=3^{a}$	$1=4^{a}$	-	$1=2^{a}$	$1=3^{a}$	$1=4^{a}$
	2	$2=1^{a}$	-	$2>3^{*}$	$2=4^{a}$	$2=1^{a}$	-	$2>3^{a}$	$2>4^{**}$	$2=1^{a}$	-	$2=3^{a}$	$2=4^{a}$	$2=1^{a}$	-	$2=3^{a}$	$2=4^{a}$
	3	$3=1^{a}$	$3<2^{*}$	-	$3=4^{a}$	$3=1^{a}$	$3=2^{a}$	-	$3=4^{a}$	$3=1^{a}$	$3=2^{a}$	-	$3=4^{a}$	$3=1^{a}$	$3=2^{a}$	-	$3=4^{a}$
	4	$4=1^{a}$	$4=2^{a}$	$4=3^{a}$	-	$4<1^{**}$	$4<2^{**}$	$4=3^{a}$	-	$4=1^{a}$	$4=2^{a}$	$4=3^{a}$	-	$4=1^{a}$	$4=2^{a}$	$4=3^{a}$	-
MF	Hand Load	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
	1	-	$1=2^{a}$	$1=3^{a}$	$1=4^{a}$	-	$1<2^{**}$	$1<3^{**}$	$1<4^{**}$	-	$1=2^{a}$	$1=3^{a}$	$1=4^{a}$	-	$1=2^{a}$	$1=3^{a}$	$1=4^{a}$
	2	$2=1^{a}$	-	$2=3^{a}$	$2=4^{a}$	$2>1^{**}$	-	$2<3^{*}$	$2=4^{a}$	$2=1^{a}$	-	$2=3^{a}$	$2=4^{a}$	$2=1^{a}$	-	$2=3^{a}$	$2=4^{a}$
	3	$3=1^{a}$	$3=2^{a}$	-	$3=4^{a}$	$3>1^{**}$	$3>2^{*}$	-	$3=4^{a}$	$3=1^{a}$	$3=2^{a}$	-	$3=4^{a}$	$3=1^{a}$	$3=2^{a}$	-	$3=4^{a}$
	4	$4=1^{a}$	$4=2^{a}$	$4=3^{a}$	-	$4>1^{**}$	$4=2^{a}$	$4=3^{a}$	-	$4=1^{a}$	$4=2^{a}$	$4=3^{a}$	-	$4=1^{a}$	$4=2^{a}$	$4=3^{a}$	-
RMS	Hand Load	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
	1	-	$1<2^{**}$	$1<3^{*}$	$1<4^{**}$	-	$1=2^{a}$	$1=3^{a}$	$1<4^{**}$	-	$1=2^{a}$	$1=3^{a}$	$1<4^{**}$	-	$1=2^{a}$	$1<3^{*}$	$1<4^{**}$
	2	$2>1^{**}$	-	$2=3^{a}$	$2<4^{**}$	$2=1^{a}$	-	$2=3^{a}$	$2<4^{**}$	$2=1^{a}$	-	$2=3^{a}$	$2<4^{**}$	$2=1^{a}$	-	$2<3^{**}$	$2<4^{**}$
	3	$3>1^{*}$	$3=2^{a}$	-	$3<4^{**}$	$3=1^{a}$	$3=2^{a}$	-	$3<4^{**}$	$3=1^{a}$	$3=2^{a}$	-	$3<4^{**}$	$3>1^{*}$	$3>2^{**}$	-	$3=4^{a}$
	4	$4>1^{**}$	$4>2^{**}$	$4>3^{**}$	-	$4>1^{**}$	$4>2^{**}$	$4>3^{**}$	-	$4>1^{**}$	$4>2^{**}$	$4>3^{**}$	-	$4>1^{**}$	$4>2^{**}$	$4=3^{a}$	-

Where: RT – Right side; LT – Left side; ES – Erector Spinae Muscle; MI – Multifidii Muscle.
Where: 1 – 0 kg; 2 – 6.5 kg; 3 – 11.5 kg; 4 – 16.5 kg.
$^{**}p < 0.01$.
$^{*}p < 0.05$.

^{a} NS : Non-significant.

Table 4. Summary of results

Parameters	Muscles	Sex	S.A's	H.L's	Sex x S.A's	Sex x H.L's	S.A's x H.L's
MPF	RTES		$30^{**} > 0, 10, 20$	$6.5^{*} > 11.5$			
	LTES		$30^{**} > 0, 10, 20$	$^{**}0, 6.5 > 16.5$			
	RTMI		$30^{**} > 0, 10; 30^{*} > 20$				
	LTMI		$20^{*} > 10, 30; 20^{**} > 0$		*Female < Male only at 0 deg; *Male and Female (0 < 10 deg)		
MF	RTES	*Female < Male	$30^{**} > 0, 10, 20$				
	LTES		$30^{**} > 0, 20; 30^{*} > 10$	$^{**}16.5, 11.5, 6.5 > 0; 11.5^{*} > 6.5$	*Female < Male only at 0 deg; *Male < Female only at 30 deg	**Female > Male only at 0 kg; **Female < Male at 6.5, 11.5, 16.5 kg; *Male (0 < 6.5 kg)	
	RTMI		$30^{**} > 0, 10, 20$			**Female < Male only at 6.5 kg	
	LTMI		$30^{**} > 0, 10$		*Female < Male at 0 and 10 deg; *Male and Female (0 > 10 deg)		
RMS	RTES		$30^{**} > 0, 10, 20$	$16.5^{**} > 0, 6.5, 11.5$			16.5 kg > 0 kg when stooping angles at 20 and 30 deg; **30 deg > 0 and 10 deg for all hand loads
	LTES	*Female > Male	$30^{**} > 0, 10, 20$	$16.5^{**} > 0, 6.5, 11.5$			**30 > 0 and 10 deg when hand loads 0, 11.5 kg; **30 > 0, 10, and 20 deg when hand loads 6.5, 16.5 kg
	RTMI		$30^{**} > 0, 10, 20$	$16.5^{**} > 0, 6.5, 11.5$			
	LTMI		$30^{**} > 0, 10, 20$	$16.5^{**} > 0, 6.5$			

S.A's – Stooping Angles; H.L's – Hand Loads; RT – Right side; LT – Left side; ES – Erector Spinae Muscle; MI – Multifidii Muscle.
$^{**}p < 0.01$.
$^{*}p < 0.05$.

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