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상자들기동안 스쿼트동작과 스투프동작에 따른 허리주변 근육의 근피로도 분석

Electromyography Analysis of Fatigue of the Paraspinal Muscles during a Squat and Stoop Lifting Task in Healthy Participants

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[Purpose] The purpose of this study was to examine changes in muscle fatigue of the erector spinae, rectus abdominis, quadratus lumborum, and gluteus maximus muscles during repetitive lifting using the squat-to-lift and stoop-to-lift techniques. [Method] Participants were 17 healthy young students in their 20 s. The change in the median frequency of the surface electromyography signal was calculated between baseline and the fatigue trial, where fatigue was self-reported. [Results] A significant decrease in median frequency was identified for the quadratus lumborum and gluteus maximus muscles using the squat-to-lift technique ($p < 0.05$). [Conclusion] The squat-to-lift technique is associated with fatigue of the quadratus lumborum and gluteus maximus muscles and may not be preferable to the stoop-to-lift technique in all cases.

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1. Introduction

Repetitive movements are a common cause of musculoskeletal pain due to the increase in physical burden born by the tissues.[1] A common example is the association between repetitive lifting tasks and low back pain.[2-6] Lifting through bending of the lower limbs (squat-to-lift), rather than flexion of the low back while keeping knees straight (stoop-to-lift), has been promoted as the proper technique to reduce the risk of low back pain.[7,8] However, van Dieën et al.[9] did not find sufficient evidence of a protective effect of the squat-to-lift technique in lessening the burden on the low back compared to the stoop-to-lift technique. Moreover, they reported that the stoop-to-lift technique might be safer than the squat-to-lift technique for maintaining balance during lifting.[10] Biomechanically, the pressure exerted on the lumbar vertebrae is determined by multiple factors, including the weight of the box and the speed and acceleration of the movement, and, to a lesser extent, by the amount of bending at the waist.[11] Similarly, Hwang et al.[12] found no significant difference in the peak moment at the lumbar spine between the squat-to-lift and stoop-to-lift techniques for lifting of 5 kg and 10 kg boxes. Moreover, the peak moment was greater for the squat-to-lift than stoop-to-lift technique for 15 kg boxes. However, Kim[13] reported more rapid fatiguing of the multifidus and iliocostalis lumborum muscles for the stoop-to-lift than squat-to-lift technique. Of note, however, Kim evaluated fatigue of the paraspinal muscles during an isometric holding task rather than a repetitive lifting task that is common in the workplace and everyday life. Moreover, analysis of only the multifidus and iliocostalis lumborum muscles may not be representative of all paraspinal muscles.

Muscle fatigue reduces strength and proprioception, decreasing the capacity of muscles to provide stability to the lumbar spine and increasing the risk of injury during lifting.[14,15] Therefore, preventing muscle fatigue during lifting would improve the stability the lumbar spine.[10]

The quadratus lumborum muscle attaches directly to the lumbar spine and plays a major role in the final phase of straightening the lumbar spine during lifting, as well as enhancing the stability of the lumbosacral spine, in conjunction with the lumbodorsal fascia.[16,17] The lumbodorsal fascia consists of three layers; the anterior layer lies on the anterior surface of the quadratus lumborum muscle, the middle layer between the quadratus lumborum and erector spinae muscles, with the posterior layer lying on the posterior surface of the erector spinae. The stabilizing effect of the lumbodorsal fascia is enhanced by the tension generated by the gluteus maximus muscle.[18] As such, both the coordination and fatigue status of the paraspinal muscles, including the quadratus lumborum and gluteus maximus, will influence the stability of the lumbosacral spine during lifting. However, although various studies have evaluated muscle activation and fatigue of the erector spinae, multifidus and iliocostalis lumborum muscles, the activation and fatigue of the quadratus lumborum muscle and gluteus maximus muscles remain to be clarified. Therefore, the purpose of this study was to compare the profile of muscle fatigue of the erector spinae, rectus abdominis, quadratus lumborum, and gluteus maximus muscles for the squat- and stoop-to-lift techniques.

2. Participants and Methods

2.1 Participants

Our study was approved by the Institutional Review Board of the U1 University. Participants were recruited from the student body of the University. Prospective participants were screened to exclude a history of musculoskeletal or neurological disorders or surgery of the upper or lower extremities and spine. Seventeen healthy participants were enrolled into the study, and provided informed consent.

2.2 Measurement Method

The squat-to-lift and stoop-to-lift techniques were performed using a 10 kg plastic box, with handles on either side, and of the following dimensions: height, 40 cm; width, 50 cm; and length, 30 cm.[13,19,20] Surface electromyography (EMG) of the paraspinal muscles was acquired using a MP150 surface EMG system (BIOPAC System Inc. Santa Barbara, CA, United States), with Ag-Ag/Cl surface electrodes. Surface EMG signals were collected at a sampling rate of 1000 Hz and processed offline using the AcqKnowledge 4.1 (Biopac Systems, 2012) software. Signal processing included band-pass and notch filtering (30-500, 60 Hz, respectively), followed by full wave rectification.

Prior to recording, both lifting techniques were demonstrated to participants. For the squat-to-lift task, participants were asked to bend their knees to pick-up the box and to subsequently lift the box by straightening their knees, keeping their lumbar spine straight. For the stoop-to-lift task, participants flexed the lumbar spine, keeping their knees extended, to pick-up the box and to subsequently lift the box by straightening the lumbar spine. Each participant completed a few repetitions of each technique to determine the appropriate distance between the box and the feet. For the test maneuvers, participants stood in front of the box placed on the floor, grabbed the box using the side handles, lifted the box to a standing position and then re-placed the box on the ground. Participants repeated the lifting task until self-reported fatigue was attained. The order of lifting technique was randomly determined across participants, with sufficient rest provided between techniques until participants reported having recovered from the fatigue of the previous set of trials.[10]

For analysis, the EMG signals obtained from the second trial of each set was used as the baseline. The fatigue trial was defined as the trial preceding the last trial performed on either task. As an example, if a participant performed 13 repetitions of the squat-to-lift task and 15 of the stoop-to-lift task, then the EMG signals for the 12th repetition was used as the fatigue trial for both tasks. The median frequency of the EMG signal, calculated from the Fast Fourier Transform, and compared between the baseline and fatigue trials.

2.3 Statistical Analysis

The sample size was calculated a priori using the software G Power, version 3.1.5. We considered a statistical power of 95% and a significance level (α-value) of 5%. Using the data from Kim for our calculation,[13] a minimum of 16 participants were required. To evaluate the effects of lifting technique on muscle fatigue, we compared the total number of lifting trials performed for each technique as well as the change in median frequency of the EMG signals for the fatigue trial compared to baseline using the Wilcoxon Signed-Rank test. Analyzes were performed using SPSS (version 12.0), with a p-value $<$ 5% considered statistically significant.

3. Results

3.1 General Characteristics of the Participants

The general characteristics of our participants are presented in Table 1.

3.2 Number of Repetitions

The total number of repetitions was equivalent for the two lifting techniques ($p > 0.05$; Table 2).

3.3 Change in the Median Frequency for Each Muscle

There was no difference in the median frequency of EMG signals between the two lifting techniques for all muscles ($p > 0.05$). With fatigue, the median frequency decreased, from baseline, in the quadratus lumborum and gluteus maximus muscles only with the squat-to-lift technique ($p < 0.05$; Table 3).

Table 1 General characteristics of the participants

	Mean ± SD
Sex (M/F)	9 / 8
Age (years)	22.53 ± 2.24
Height (cm)	168.8 ± 7.11
Weight (kg)	63 ± 12.95

Table 2 Total number of repetitions completed for each lifting technique

Repetitions, mean ± SD		z	p
Squat-to-Lift	Stoop-to-Lft		
10.25 ± 5.495	9.75 ± 3.235	-0.032	0.975

4. Discussion

The purpose of this study was to compare fatigue of the erector spinae, rectus abdominis, quadratus lumborum, and gluteus maximus muscles for two lifting techniques, the squat-to-lift and stoop-to-lift techniques. There was no significant difference in the number of repetitions between the two techniques. Moreover, there was no change in the median frequency of the EMG of the erector spinae and rectus abdominis muscles for either technique, with the sensation of fatigue likely being contributed specifically by the quadratus lumborum and gluteus maximum muscles.

As in our study, Park and Kim[21] confirmed activation of the erector spinae muscles during lifting. As the erector spinae muscles are comprised of Type I fibers, they would be resistant to the effects of fatigue with repeated lifting maneuvers.[22] By comparison, the absence of fatigue in the rectus abdominis muscle is explained by its functional role in supporting the weight of the object and body during the lifting task, rather than providing stability to the lumbar spine,[23] compared to the extensor muscles

Table 3 Change in the median frequency of paraspinal muscles in the fatigue trial, from baseline

		Squat	Stoop	z	p
Erector spinae	Initial	49.683 ± 13.05	47.295 ± 11.288	-0.543	0.587
	Latter	45.616 ± 10.243	45.235 ± 13.969	-0.483	0.629
	Diff	4.066 ± 8.469	2.060 ± 11.282	-1.293	0.196
	z	-1.758	-0.052		
	p	0.079	0.959		
Rectus abdominis	Initial	37.155 ± 24.879	29.427 ± 19.163	-1.165	0.244
	Latter	27.069 ± 14.812	25.864 ± 11.648	-0.129	0.897
	Diff	10.086 ± 24.88	3.563 ± 14.68	-0.982	0.326
	z	-1.396	-0.517		
	p	0.163	0.605		
Quadratus lumborum	Initial	42.716±8.048	44.71±9.037	-0.982	0.326
	Latter	39.725±8.824	44.518±7.676	-2.715	0.007**
	Diff	2.991 ± 4.363	0.193 ± 7.807	-0.982	0.326
	z	-2.689	-1.034		
	p	0.007**	0.301		
Gluteus maximus	Initial	35.118 ± 9.323	39.963 ± 14.865	-1.939	0.052
	Second	32.837 ± 8.329	38.567 ± 10.946	-2.982	0.003**
	Diff	2.281 ± 3.509	1.396 ± 7.035	-0.672	0.501
	z	-2.146	-0.672		
	p	0.032*	0.501		

(Median frequencies are reported as the median ± standard deviation; units, Hz; $^{*}p < 0.05$, $^{**}p < 0.01$)

which maintain the erect posture of the spine, particularly in the final phase of the lift.

The quadratus lumborum and gluteus maximus muscles had a significantly lower median frequency, and hence fatigued to a greater extent,[24] during the squat-to-lift than the stoop-to-lift technique. This difference might be explained by differences in the amount of flexion at the hip between the two techniques, being greater for the stoop-to-lift than squat-to-lift technique.[12] Greater flexion of the hip joint would increase the passive tension in the lumbodorsal fascia during initial flexion phase of the lift to grab the box.[17] The elastic force developed by the passive tension applied to the fascia would be available to assist with extension of the lumbar spine to return to a standing position. In contrast, for the squat-to-lift technique, this extension to return to a standing position is actively performed by the gluteus maximus muscle, with the decrease in median frequency of the EMG signal indicating that fatigue that develops over repeated cycles of the squat-to-lift technique.

The limitations of our study need to be acknowledged. First, we only included only healthy participants in their 20 s from the same geographic area. Therefore, future studies should be conducted with a wider variety of participants with regard to age, stature and physical fitness. As well, we did not evaluate the effect of past history of back injury and other health conditions on profiles of muscle fatigue. Lastly, we only considered fatigue, without evaluation of the underlying coordination between muscles. This aspect should be evaluated in future studies, including a larger set of muscles and lifting techniques.

5. Conclusions

Using an EMG-based analysis of muscle fatigue, we identified the quadratus lumborum and gluteus maximus to contribute to fatigue during repetitive squat-to-lift maneuvers. In contrast, fatigue did not develop when using the stoop-to-lift technique, indicating that the squat-to-lift technique should not always be considered as the preferred technique for lifting.

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