



Original Article

Comparison of trunk muscle activities in lifting and lowering tasks at various heights

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Abstract. [Purpose] Biomechanical data for manual material handling are important for appropriate engineering design. The goal of this study was to investigate differences in trunk muscle activity in lifting and lowering tasks at various heights. [Subjects and Methods] Thirty healthy, young adult subjects performed 6 asymmetrical lifting and lowering tasks at various heights. Trunk muscle activity of the abdominal external oblique muscle (EO), rectus abdominis muscle (RA), and lumbar erector spinae muscles (ES) were recorded using surface electromyography (EMG). [Results] The EMG activities of the bilateral ES differed significantly among heights. The left EO activity in the ankle to knee lifting task was significantly increased compared with that of the knee to ankle lowering task. However, there were no significant differences in the right EO, bilateral ES, or RA between lifting and lowering tasks. [Conclusion] The results show that the optimal range for manual material handling was at trunk height, not only for lifting but also for lowering tasks.

Key words: Manual material handling, Lifting and lowering task, Electromyography

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INTRODUCTION

Manual material handling (MMH) is present in many industrial jobs. Many workers who perform MMH face a high risk of work-related low back pain and impairment¹⁾. Ergonomic approaches for reducing the incidence of MMH-related injuries have involved engineering design/redesign to fit the task to worker capabilities²⁾. Acceptable demands for a task can be determined by examining a biomechanical database³⁾. Many investigators have studied lifting tasks at various heights and asymmetric conditions⁴⁻¹²⁾. The workplace environment might affect postures during lifting. Lower lifting origin heights increase trunk flexion, and asymmetric starting and ending points increase twist and lateral flexion motions⁸⁻¹⁰⁾.

To address trunk function, biomechanical studies generally measure trunk muscle activity using surface electromyography (EMG). MMH studies typically focus on measurements of the lumbar erector spinae extensor muscle, because trunk extensor tasks are a serious risk for low back pain¹³⁾. Several previous studies reported that trunk extensor muscle activity correlated linearly with trunk extension strength^{4, 14, 15)}. These studies suggested that increased trunk bending posture required increasing extensor activity of the trunk muscles. Others found that nonsagittal trunk moments can influence spine loading^{8, 16-18)}; the activity of trunk muscles increased compared to a sagittal symmetric origin. Therefore, trunk function research has reported on the impact of the load destination position and asymmetric posture when a worker lifts a load. For a lowering task, one study investigated trunk muscle EMG activation in subjects with and without chronic low back pain¹⁹⁾. However, there is insufficient information on lowering tasks. The objectives of this study were to investigate the differences in trunk muscle activity in lifting and lowering tasks at various heights.

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Table 1. Comparison of muscle activities (mean \pm SD, mV) according to the heights and tasks

		Lt. EO	Rt. EO	Lt. ES	Rt. ES	Both RA
Lifting Task	AK	12.9 \pm 4.9*	10.9 \pm 3.9	34.8 \pm 16.2	33.1 \pm 12.6	6.7 \pm 2.9
	AS	14.9 \pm 5.9	12.0 \pm 3.7	37.4 \pm 17.9	35.0 \pm 15.4	8.0 \pm 4.1
	KS	12.3 \pm 6.0	12.0 \pm 5.9	26.9 \pm 10.7	23.1 \pm 9.1	6.4 \pm 2.7
Lowering Task	KA	9.7 \pm 3.2*	11.0 \pm 4.7	32.1 \pm 15.3	29.4 \pm 12.4	6.3 \pm 3.6
	SA	12.9 \pm 5.6	12.7 \pm 4.7	33.7 \pm 14.9	30.4 \pm 12.0	7.2 \pm 2.9
	SK	12.0 \pm 4.4	10.7 \pm 4.1	25.3 \pm 10.6	21.1 \pm 7.9	6.0 \pm 2.6

Values indicate means \pm SD. AK: ankle to knee height, AS: ankle to shoulder height, KS: knee to shoulder height, KA: knee to ankle height, SA: shoulder to ankle height, SK: shoulder to knee height. *Comparison between lifting and lowering task ($p < 0.05$).

SUBJECTS AND METHODS

The experiment was conducted on 30 current students (13 males, 17 females; mean age 20.40 ± 0.65) at S University (Republic of Korea), who had no medical history of injury, musculoskeletal disorders, cardiovascular, or neurological conditions. Their average heights and weights were 168.40 ± 6.93 cm and 59.70 ± 7.07 kg, respectively. All subjects were fully informed about the procedures and aims of the current experiment, and the study protocol was approved by our Institutional Review Board.

To measure muscle activity resulting from repetitive lifting and lowering tasks, this study used an wireless zerowire system (Aurion, Milan, Italy). Analog signals collected from 6 wireless channels of a surface EMG were converted into digital signals, and data were analyzed using MyoResearch XP Master 1.06 (Noraxon System Inc., Scottsdale, AZ, USA) with a personal computer. The raw EMG signals were amplified with a gain of 1,000 and frequency bandwidth of 20–450 Hz. Muscle activity was assessed by attaching electrodes (type SX230 Data Log II, Biometrics Ltd., Gwent, UK) to both sides of the abdominal external oblique muscle (EO), rectus abdominis muscle (RA), and lumbar erector spinae muscles (ES). The electrode placement for ES was 30 mm lateral to the L3 spinous process. The electrodes for the EO were placed on the mid-axial line between the 10th rib and the anterior superior iliac spine, and for the RA, over the muscle belly, about 30 mm lateral to the abdominal midline and above the umbilicus.

The design of this experiment was cross-sectional and a one-group repeated test. The weight of the load ($60 \times 40 \times 20$ cm) was fixed at 10 kg and 6 kg for males and females, respectively. Six asymmetrical (90° counter-clockwise, sagittal plane) lifting and lowering tasks were performed 3 times at 3 heights. The ranges of lifting tasks were from ankle to knee height (AK), from ankle to shoulder height (AS), and from knee to shoulder height (KS). The lowering tasks were from knee to ankle height (KA), from shoulder to ankle height (SA), and from shoulder to knee height (SK). The performance order was randomized. The subjects performed both lifting and lowering tasks at their self-selected speeds. Before execution of the tasks, the subject was introduced to the general technique for squat lifting (straight back, bent knees).

For statistical comparisons, muscle activities were averaged over the 3 trials. One-way analysis of variance (ANOVA) was used to determine the main effects of the heights on each muscle and task. Least Significant Difference (LSD) was used for post hoc comparisons of muscle activity at various heights. An independent *t*-test was used for determining differences in muscle activity in lifting and lowering tasks. Statistical analyses were performed using SPSS software (ver. 12.0 for Windows; SPSS Inc., Chicago, IL, USA), and statistical significance was set at $p < 0.05$.

RESULTS

The mean and standard deviations of muscle activities for heights and tasks are presented in Table 1. For bilateral ES, there was a significant main effect of height on lifting task ($p < 0.05$). According to the post hoc analysis, the muscle activity of the bilateral ES was significantly lower in KS (left: 26.86 ± 10.70 ; right: 23.06 ± 9.10), versus AK (left: 34.82 ± 16.15 ; right: 33.07 ± 12.61) and AS (left: 37.44 ± 17.91 ; right: 35.03 ± 15.37) in the lifting task ($p < 0.05$). However, there was no significant difference in EO or RA ($p > 0.05$) in the lifting task. For the lowering task, the muscle activity was statistically significantly different in the left ES (KA: 32.14 ± 15.26 ; SA: 33.69 ± 14.89 ; SK: 25.28 ± 10.59), right ES (KA: 29.35 ± 12.40 ; SA: 30.36 ± 12.04 ; SK: 21.07 ± 7.89), and left EO (KA: 9.72 ± 3.22 ; SA: 12.86 ± 5.57 ; SK: 11.95 ± 4.39) ($p < 0.05$). The post hoc analysis showed that the EMG activity of bilateral ES was significantly lower with SK than with KA or SA ($p < 0.05$).

There was no significant difference in the right EO, bilateral ES, or RA between the tasks ($p > 0.05$). However, the left EO activity in the AK (lifting task) was significantly higher compared with that of the KA (lowering task) ($p < 0.05$).

DISCUSSION

This study showed that the muscle activity of ES in the trunk range (KS and SK) was lower than that of the other ranges for lifting and lowering tasks. On the other hand, EO activity was higher in the lifting task compared with that in the lowering task in the lower range (AK vs. KA). Several biomechanical studies have reported that large moments were created in the trunk area during lifting tasks. In particular, the lumbar area between L5 and S1 had the potential to incur the greatest moment in lifting^{20, 21}). The muscle fibers sampled by the EMG electrode are assumed to be a reasonable approximation for the activity of the entire muscle body. EMG and muscle force are considered to be related linearly²²). In this study, the task height increased the muscle activity of ES not only in the lower range but also in the higher range, as compared with the trunk area. Roy et al. reported that trunk extensor muscle activity increased ~25% for a maximal extension task performed at more flexed postures (40°) in comparison with upright postures¹⁴). Thus, the decreased muscle activity of the ES indicates that the trunk area is the most effective territory for lifting and lowering, with similar trends for lifting tasks reported previously⁴). In the current study, there was no significant difference in muscle activities of the EO or RA for the various heights. The ES is assisted by additional musculoskeletal mechanisms to provide sufficient extensor moment when lifting heavy weights²³). Intra-abdominal pressure and partitioned muscles are included in the mechanisms for additional moments from other structures. We used a relatively light weight for safety. Thus, differential recruitment of the EO and RA muscles might have been unnecessary for the various heights with the weight used.

MMH includes not only lifting but also lowering. However, there have been few studies examining the psychophysical data and movement velocity of differences between lifting and lowering^{3, 24, 25}). Lee investigated the minimal acceptable handling time interval in which subjects could perform lifting and lowering task at various weights (10, 15, 20 kg) without becoming strained, uncomfortable, tired, weakened, overheated, or out-of-breath, during 4-hour endurance handling period using a psychophysical methodology²⁴). The minimum handling time interval for each lifting task was significantly higher than that of its corresponding lowering task. On the other hand, heavier loads produced larger minimum acceptable handling time intervals. Potvin demonstrated that decreased maximum loads were acceptable during lifting tasks compared with lowering tasks³). In contrast, the present study demonstrated that the muscle activities of the ES, RA, and right EO were not significantly different in lifting and lowering. In physics, power is the rate of doing work, equivalent to an amount of energy consumed per unit time. In this study, the subjects performed both lifting and lowering tasks at their self-selected speeds. The movement velocity of the lowering task was higher than the lifting task²⁵). Thus, it is assumed that the workers thought the lifting task was harder for the lighter weight because of movement velocity. In this study, the left EO activity was lower in the lowering task compared with that in the lifting task at the lower range (AK vs. KA). The left EO decelerated trunk rotation as an antagonist muscle during the counter-clockwise task. The function of the antagonist muscle was assumed to be relatively unnecessary during the KA lowering task because this position appeared to show soft tissue pressure. This is apparently the first report to demonstrate differences in trunk muscle activity in lifting and lowering tasks at various heights.

In conclusion, trunk muscle activity was investigated for lifting and lowering tasks using EMG. The results show that the optimal range for the task was at trunk height, not only for lifting but also for lowering tasks. Additionally, there was no significant difference in ES between the lifting and lowering tasks, which could be applied to job design in actual workplaces. However, this study was limited by the use of a relatively light weight for safety reasons and by failure to measure the velocities of the tasks.

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