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Original Article

Effect of pelvic forward tilt on low back compressive and shear forces during a manual lifting task

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Abstract. [Purpose] To examine the effect of an instruction to increase pelvic forward tilt on low back load during a manual lifting task in the squat and stoop postures. [Subjects] Ten healthy males who provided informed consent were the subjects. [Methods] Kinetic and kinematic data were captured using a 3-dimensional motion analysis system and force plates. Low back compressive and shear forces were chosen as indicators of low back load. The subjects lifted an object that weighed 11.3 kg, under the following 4 conditions: squat posture, stoop posture, and these lifting postures along with an instruction to increase pelvic forward tilt. [Results] In the squat posture, the instruction to increase pelvic forward tilt reduced the low back compression and shear forces. [Conclusion] The present results suggest that a manual lifting task in the squat posture in combination with an instruction to increase pelvic forward tilt can decrease low back compression and shear forces, and therefore, might be an effective preventive method for low back pain in work settings.

Key words: Manual lifting task, Low back load, Motion analysis

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INTRODUCTION

A large number of people in developed countries have low back pain. The prevalence rate of lifetime low back pain in Japan was reported to be 83.5%[1)], and low back pain accompanies most occupational diseases. Manual lifting tasks are reported to confer the highest risk of low back pain in occupational work[2, 3)]. Lifting tasks are often conducted with 2 types of posture, namely the squat posture, with the knees and hips flexed and the back extended, and the stoop posture, with the hips and back flexed and the knees extended. Previous studies have compared low back load between these 2 conditions. The squat technique is widely recommended to prevent low back pain while conducting lifting tasks. However, Van Dieën et al.[4)] reported in a systematic review that no difference in low back load was observed between manual lifting tasks with the squat posture and those with the stoop posture. A large trunk forward bending angle is needed in combination with increase of pelvic forward tilt in the stoop posture. Less trunk forward bending angle in the squat posture than in the stoop posture, but the pelvic forward tilt angle decreases. Therefore, the appropriate posture for minimizing low back load in lifting tasks is still unclear. Low back load during a lifting task is biomechanically and directly affected by the lever arm, which is the distance from the center of the rotation of the low back joint to the center of gravity of the object. Accordingly, increasing pelvic forward tilt while executing the lifting task would decrease the lever arm, and thus, it might decrease low back load

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during the lifting task. However, no previous study has compared low back load between with and without increase of pelvic forward tilt during the lifting task. Hence, the purpose of this study was to examine the effect of an instruction to increase pelvic forward while lifting an object with the squat and stoop postures on low back load.

SUBJECTS AND METHODS

The participants were 10 healthy male university students (mean ± SD: age, 20.9 ± 0.5 years; height, 174.9 ± 4.3 cm; weight, 64.1 ± 4.8 kg). The ethics committee of International University of Health and Welfare approved all study procedures (No. 12-210), which were consistent with the Declaration of Helsinki. The authors obtained informed consent from all the subjects prior to their participation in the study.

The experimental tasks were 3 trials of lifting an object from force plates under the following 4 conditions: 1) squat, hips and knees flexed and the back extended; 2) stoop, hips and back flexed and the knees extended; 3) squat and 4) stoop, respectively with an instruction to increase pelvic forward tilt. To increase pelvic forward tilt, participants were instructed to move their navel closer. After practicing each lifting posture with the instruction to increase pelvic forward tilt several times, subjects conducted the lifting tasks. In a pilot study, the subjects who performed squat and stoop lifting without an instruction to increase pelvic forward tilt changed their lifting maneuvers after conducting the lifting with the instruction. Therefore, the subjects first lifted the object with squat and stoop without any instruction in a random order, and then they lifted the object with squat and stoop with the instruction to increase pelvic forward tilt in a random order. Subjects lifted a box (37.5 × 50 × 21 cm; 11.3 kg) to waist height. A 10-kg weight was placed in the middle on the bottom of the box that weighed 1.3 kg. Previous studies have reported that the distance from the feet of subjects to an object affects the lifting posture and low back load[5, 6]. Hence, in this study, the object was placed on the centerline of 2 force plates, at one half the length of the foot from the toe, as in a previous study[7]. In addition, experiments were conducted after repeatedly practicing each task, and the subjects had enough time to rest, at least 5 minutes, between tasks (Fig. 1).

A 3-dimensional motion analysis system consisting of 10 infrared cameras (Vicon MX, Vicon, Oxford, UK) and 4 force plates (AMTI, Watertown, MA, USA) was used to record 3-dimensional marker displacements and ground reaction force data at a sampling frequency of 100 Hz. Forty-five reflective markers were attached to each subject according to the procedure described in the study of Katsuhira et al[7]. In addition, 4 markers were also attached to the upper frame of the box.

Several studies have used electromyography (EMG) to evaluate low back load during lifting tasks[8, 9]. Several studies have also used 3D motion analysis systems to measure low back compression force and low back shear force as parameters of low back load. The analysis of low back compression force has the advantage, that it can be compared with the safe limit proposed by National Institute of Occupational Safety and Health (NIOSH)[10]. Low back compressive and shear forces were chosen as indicators of low back load in the present study. The computation methods reported by Yamazaki et al.[11] and Katsuhira et al.[7] were used to obtain these forces in our study. Katsuhira et al. reported that low back compressive and shear forces almost simultaneously show peak values[7]. Therefore, they extracted the shear force at the time of the peak of the low back compressive force. As the same tendency was confirmed in our pilot study, the shear force was calculated at the time of the peak of the low back compressive force, and the pelvic angle and lever arm from the L4/5 joint to the center of the gravity of were calculated at the same time. Low back compressive and shear forces were normalized using the subjects'

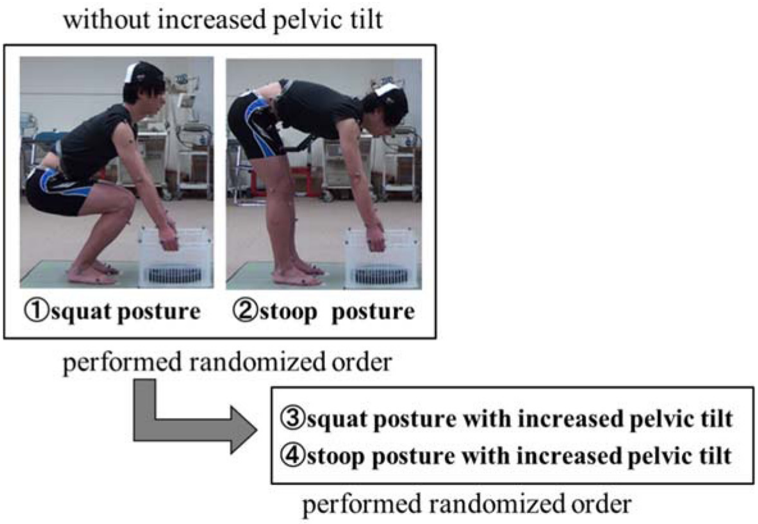

Fig. 1. Experimental condition

body masses to offset the difference in physical attributes between the subjects, in accordance with the method described in a previous study[7]. Moreover, the actual values of the low back compressive and shear forces before the normalization using body mass were compared with the safe limits of the compressive force reported by the NIOSH[10], and the shear force reported by Gallagher et al[12].

The paired t-test was used to assess individual differences between with and without the instruction to increase pelvic forward tilt in each posture. In addition, repeated-measures analysis of variance (ANOVA) was used to compare the differences among the 4 experimental conditions, and the Bonferroni post hoc test was conducted to identify which lifting condition showed the minimum value of low back load. P values < 0.05 were considered statistically significant. Statistical analysis was conducted by using the software package SPSS version 20 (IBM Inc., Armonk, NY, USA).

RESULTS

The mean values of the low back compression and shear forces are shown in Table 1. In the comparison between conditions with and without the instruction to increase pelvic forward tilt, the paired t-test showed there was a significant decrease in low back compression force in the squat posture with the instruction to increase pelvic forward tilt, but not in the stoop posture. In addition, one-way repeated-measures ANOVA and the post hoc test showed there was a significant increase in the low back compressive force in the squat posture without the instruction to pelvic forward tilt, compared the other 3 conditions. The mean increase peak values of the low back compression force in the present study were compared with the safety limit recommended by NIOSH, which is 3400 N. Low back compression force exceeded the safe limit under all 4 conditions.

The paired t-test showed there were no significant differences in standardized low back shear force in both the squat and stoop postures between with and without the instruction to pelvic forward tilt. Moreover, the one-way repeated-measures ANOVA and post hoc test showed there was a significantly smaller value of the low back shear force in the squat posture with the instruction to increase pelvic forward tilt than in the other 3 conditions.

In the comparison of the present results of low back shear force to the safe limit of the shear force reported by Gallagher et al., low back shear forces under all 4 conditions were lower than the safe limit.

The mean pelvic forward tilt angle and distance from the low back joint to the center of gravity of the object are shown in Table 2. The paired t-test showed there was a significant increase in pelvic forward tilt in the squat posture when subjects were instructed to increase pelvic forward tilt, but not in the stoop posture. Also, there was a significant decrease in the lever arm from the low back joint to the center of gravity of the object in the squat posture with the instruction to increase pelvic forward tilt but not in the stoop posture.

Table 1. Mean values of low back compression and shear forces

	Squat posture		Stoop posture		
	without increased pelvic tilt	with increased pelvic tilt	without increased pelvic tilt	with increased pelvic tilt	ANOVA
Normalized low back compression force (N/kg)	66.0±4.5*	59.5±5.5	59.60±5.1	58.2±4.9	a*, b*,c*
Low back compression force (N)	4,219.3±4.5	3,819.2±485.6	3,820.2±441.1	3,725.5±363.9	a*, b*,c*
Normalized low back shear force (N/kg)	1.5±0.5	1.15±0.6	1.8±0.3	1.8±0.4	a*,c*,d*,e*
Low back shear force (N)	92.7±31.1	75.4±38.7	113.4±20.4	117.1±25.1	a*,b*,c*,d*,e*

Mean ± SD, *p<0.05
a: Squat posture without increased pelvic tilt vs. squat posture with increased pelvic tilt
b: Squat posture without increased pelvic tilt vs. stoop posture without increased pelvic tilt
c: Squat posture without increased pelvic tilt vs. stoop posture with increased pelvic tilt
d: Squat posture with increased pelvic tilt vs. stoop posture without increased pelvic tilt
e: Squat posture with increased pelvic tilt vs. stoop posture with increased pelvic tilt
f: Stoop posture without increased pelvic tilt vs. stoop posture with increased pelvic tilt

Table 2. Mean values of pelvic forward tilt angle and distance from the low back joint to the center of gravity of the object

	Squat posture		Stoop posture	
	without increased pelvic tilt	with increased pelvic tilt	without increased pelvic tilt	with increased pelvic tilt
Pelvis forward tilt angle (°)	17.8±17.2	31.1±23.6*	41.3±12.5	44.2±12.7
Distance from low back joint to Center of gravity of an object (mm)	611.4±50.2*	569.2±45.4	505.3±38.9	487.6±35.7

Mean ± SD, *p<0.05

DISCUSSION

Giving an instruction to increase pelvic forward tilt significantly decreased the low back compression force only during lifting in the squat posture. Accordingly, an instruction to increase pelvic forward tilt might be more beneficial to decrease low back load during lifting in the squat posture than in the stoop posture. Low back compression force is an indicator of low back load which is related to low back joint moment. Low back extension moment especially relates to low back compression force in lifting tasks[7]. The distance from the L4/5 joint to the center of gravity of the object or the center of gravity of the head, trunk and arms is defined as the lever arm of the low back extension moment.

When the instruction to increase pelvic forward tilt was given in the squat position, pelvic forward tilt significantly increased with a significant decrease in the lever arm from the low back joint to the center of gravity of the object. The increase in pelvic forward tilt moved the L4/5 joint forward resulting in a decrease in the lever arm, and thus decreased the low back compressive force during lifting in the squat posture. However, no significant differences in the pelvic forward tilt or lever arm were found between with and without the instruction to increase pelvic forward tilt in the stoop posture. Lifting in the stoop posture is requires increase of pelvic forward tilt. Therefore, further increase in pelvic forward tilt might be difficult to perform.

Normalized low back shear force was the smallest in the squat posture with pelvic tilt. The trunk bending angle in the squat posture was smaller than that in the stoop posture. Low back shear force was calculated as the anteroposterior direction force applied to the L4/5 joint. Thus, a small trunk bending angle could decrease the low back shear force. Moreover, increasing pelvic forward tilt increases lumbar lordosis, which would have contributed to the decrease in the low back shear force.

Normalized low back compressive force during lifting in the squat posture without pelvic tilt was the greatest. No significant differences were observed among the other 3 conditions. Normalized low back shear force was significantly smaller during lifting in the squat posture with pelvic tilt. The low back compressive force exceeded the safe limit of 3400 N proposed by NIOSH[10]. Thus, smaller low back shear force would be advantageous the prevention of the risk of low back pain. The values of the low back shear force under all 4 conditions were lower than the safe limit of 700 N proposed by Gallagher et al[12]. However, a previous study suggested that even a small low back shear force might cause damage, resulting in spondylolysis[13]. Hence, the squat posture with an instruction to increase pelvic forward tilt, which can decrease both low back compressive and shear forces, be the recommended lifting posture.

The present study had several limitations. First, low back load was calculated using inverse kinematics. Hence, smaller low back load values were obtained than the actual values of low back load during co-contraction of both the abdominal and back muscles. The authors intend to construct a hybrid model using electromyography and inverse kinematics to obtain the low back load, taking into account co-contraction, in a future study. Second, the subjects of our study were healthy university students. Accordingly, the authors intend to study workers who engage in lifting tasks to confirm the effects of increasing pelvic forward tilt. The authors also intend to investigate the effects of work environment and mental conditions to clarify factors influencing low back load in lifting tasks.

In this study, the effects of an instruction to promote pelvic tilt on low back load during lifting an object from the ground were examined. Making workers aware of pelvic forward tilt during lifting in the squat posture could decrease both low back compressive and shear forces and might lower the incidence of low back pain. Low back pain caused by lifting in work settings has been a problem in both developing and developed countries. The authors recommend the lifting posture identified in this study and suggest that providing education on lifting posture would benefit workers who engage in lifting.

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