The Effect of Load Holding Height on Trunk Biomechanics during Sudden Loading

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Sudden loading during manual material handling poses a significant risk of back injury. The present study investigated the effect of load holding height on trunk biomechanics (trunk flexion angle and L5/S1 joint compression force) during sudden loading. Eleven subjects were recruited to perform sudden loading tasks with a 6.8 kg load, while maintaining upright standing posture and holding load at three different height levels in the sagittal plane. It has been found that load holding height significantly affected L5/S1 joint compression force and trunk flexion angle. With a lower load holding height, peak L5/S1 joint compression force decreased by 17.5%. According to these findings, it is suggested that holding load at a lower level could help reduce the risk of low back injury.

INTRODUCTION

In the United States, over one hundred million working days are lost (Guo, 1999) and billions of dollars are spent annually due to work-related back injury (Maetzel & Li, 2002; Stewart, 2003; Yelin & Callahan, 1995). And it has been reported that back injury accounts for 42% of all the reported musculoskeletal disorders. Furthermore, occupations in which manual material handling is involved (warehouse workers, patients handling nurses etc.) reported even higher injury rate (BLS, 2012).

When performing manual material handling tasks, sudden loading caused by external load or loss of postural balance control is a significant risk of back injuries (Manning, 1984; McCoy, 1997; Omino & Hayashi, 1992). When experiencing sudden loading, trunk muscles are instantaneously activated to help maintaining stability (Cholewicki, 1997). However, this muscle natural reaction increases spinal compression force (Granata & Marras, 2000) which, in thus, may lead to back injuries (Bakker, 2007; Norman, 1998). As a result, it is important to develop strategies that could mitigate this potential risk.

Previous studies have already investigated several strategies, such as warning signal and training. It has been shown that the average muscle activation level and spinal compression force decreased by 49.8% and16%, respectively if warning signals were provided before sudden loading event (Lavender & Marras, 1995). Additionally, spinal compression force and peak L5/S1 joint moment were reduced by 29% and 25%, respectively with appropriate training protocol and increased experience (Lavender, 1993; Lawrence, 2005). A more recent study revealed that foot stance also significantly affected trunk biomechanics during sudden loading, and staggered stance could significantly reduce L5/S1 joint moment by 6.6 Nm compare with wide stance (Zhou, 2013[a]). Despite the strategies explored by previous studies, the influence of load holding height on trunk biomechanical responses has not been investigated.

Previous study discovered that during static load holding task, the increase of load height resulted in higher level of trunk muscle co-activation (Granata & Orishimo, 2001), which increased spinal loading and the risk of back injury (Lavender, 1993). And it is believed that load holding height also affects people's biomechanical responses during sudden loading tasks. Consequently, the purpose of the present study is to investigate the effect of load holding height on trunk biomechanics during sudden loading and to understand whether load holding height can work as a strategy to protect against low back injury. Based on previous findings, it is hypothesized that spinal compression force would increase when experiencing sudden loading at a higher position.

METHOD

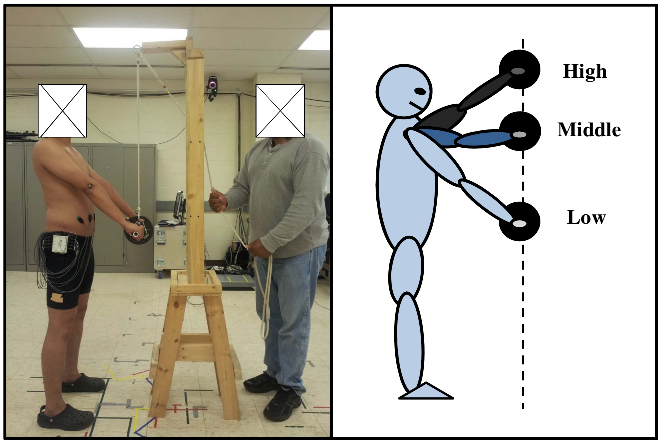
Subjects

Eleven male subjects from student community of West Virginia University volunteered to participate this study. Their mean (SD) height, weight, and age are 176.6 (3.4) cm, 71.2 (6.5) kg, and 26.7 (2.0) years, respectively, and none had a previous history of back or upper extremity injury. This experiment was approved by the Research Integrity and Compliance Committee of the university.

Experimental design

The independent variable was load holding height (HEIGHT), which included three levels: 'High' (eyebrow level: the load was held with its center aligned with the height of eyebrows), 'Middle' (shoulder level: the load center aligned with the clavicle bone height level), and 'Low' (umbilicus level: the center of the load aligned with the height of umbilicus) (Figure 1). In all conditions, the distances between the projected mass center of the load and the midpoint of the participants' ankles are kept constant at 45 cm. The total 12 trials (3 conditions with each repeated for 4 times) were performed with a completely randomized sequence.

Two dependent variables were tested: 1. Peak L5/S1 joint compression force: the maximum compression force at L5/S1 joint during the sudden loading event. 2. Increase in trunk flexion angle: the angle difference between initial trunk posture and the maximum trunk flexion angle during sudden loading event.



Firgure 1. The three height levels and a side view of an experimental trial.

Apparatus and Equipment

A wood structure was built to provide the three different height levels. Standard disc weights were used to make a 6.8 kg load, the center holes of the disc weights were secured by a polyvinyl chloride (PVC) pipe, which also served as a handle to hold (Figure 2).

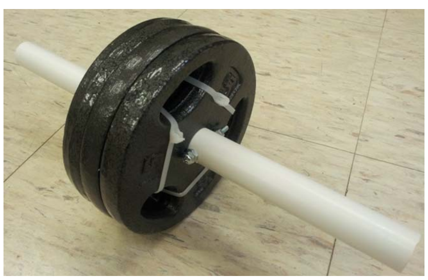


Figure 2. The 6.8 kg load used in the experiment.

An eight camera (MX-13 series) 3D optical tracking system (Vicon, Nexus, Oxford, UK) was used to capture trunk and upper extremity kinematics. As described in a previous study (Ning, 2014), eleven reflective markers were attached on the following locations: left and right shoulder: the most dorsal point of the acromioclavicular joint of shoulders; left and right elbow: the most caudal point of the lateral epicondyle elbows; left and right wrists: the ulnar side of both wrists; left and right hands: the middle of the third metacarpal bone of both hands; C7, T12, and L5 vertebrae. A surface electromyography (EMG) system (Bagnoli, Delsys Inc, Boston, MA, USA) was used to record the activities of four pairs of trunk muscles: left and right erector spinae (4 cm distance to the midline of L3 vertebra); left and right multifidus (2 cm distance to the midline of L4 vertebra); left and right rectus abdominis (2 cm above the umbilicus and 3 cm to the midline of abdomen); left and right external obliques (4 cm above the ilium, and 10 cm distance and 45° angle to the midline of abdomen). The placements of Vicon reflective markers and EMG electrodes are demonstrated in Figure 3. A lumbar dynamometer (Humac Norm, CSMi, MA, USA) was used to secure subjects' pelvis and provide stationary resistance during maximum voluntary contraction (MVC) trials.

Figure 3. The placements of the Vicon reflective markers and EMG electrodes.

Procedure

Upon arrival, experimental procedure was first explained to the subjects and the informed consent forms were signed. Subjects' basic anthropometric data (body stature, mass, trunk length, width and depth) was then measured prior to a warm-up session, which aimed to let subjects warm up muscles and get familiar with the experimental trials. Eight EMG surface electrodes were then attached to the above described trunk muscles after the skin was cleaned by alcohol. In the data collection session, subjects' EMG data of maximum voluntary contraction (MVC) trials in isometric trunk extension/flexion exertions was recorded. The MVC trials were performed using the aforementioned lumbar dynamometer, with a 20 degree trunk forward flexion posture. At least 1 minute of rest was provided between each MVC trial to prevent muscle fatigue. The recorded EMG data was used later to normalize the EMG signals of experimental trials.

After the MVC trials, eleven Vicon reflective markers were fitted to the above mentioned places, and subjects then performed the 12 experimental trials with the sequence completely randomized. In each trial, subjects were asked to stand with an upright posture and hold the load at the corresponding height level in such a manner that a constant distance (45 cm) between the projected center of mass of the load and the midpoint of subjects' ankles was maintained across all trials. Additionally, elbow flexion was not controlled, so that subjects could adjust their elbow joint angles to achieve the designated postures. In the experimental trials, subjects first stood with feet shoulder width apart and held the load stably while without supporting the weight of the load; they were then asked to close their eyes, and the load was suddenly released by an experimenter without prior warning (Figure 1). Subjects were required to stop the falling load instantaneously, and carry it back to approximately its original height level and hold it stably for three seconds.

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Between each trial, at least 2 minutes of rest was provided to prevent muscle fatigue.

Data processing and analysis

EMG signals were filtered, rectified, and smoothed with a 200 sample (0.2 second) sliding window. They were then normalized with respect to EMG data of MVC trials. The normalized EMG signals were finally used to calculate L5/S1 joint compression force using an established EMG-assisted biomechanical model (Marras & Granata, 1997). Vicon reflective markers coordinates were used to estimate trunk and upper extremity kinematics. Trunk flexion angle was defined as the angle formed by the transverse plane and the line connecting C7 and L5 reflective markers.

Statistical analysis

The prerequisite assumptions of ANOVA were tested, and dependent variables that violated one or more assumptions were transformed using deterministic mathematical function (Montgomery, 2005). ANOVA was then conducted with 'subject' served as a blocking factor. Finally, Tukey-Kramer post-hoc test was performed to further explore the differences between each two HEIGHT levels. In all the statistical tests, the criteria p-value was set as 0.05.

RESULT

Results of ANOVA revealed significant effects of HEIGHT on both dependent variables (Table 1).

Independent Variable	ANOVA	
	L5/S1 joint compression force	Trunk flexion angle
HEIGHT	$P<0.001$	$P<0.001$

Table 1: The results of ANOVA test.

The effects of HEIGHT on both dependent variables are demonstrated in Figure 4 and Figure 5. With a higher load holding height, a significantly increased peak L5/S1 joint compression force (on average from 2176N to 2557N) was generated (Figure 4), while smaller increase in trunk flexion angle was also observed (Figure 5).
Besides, the average of peak normalized EMG activity data during the sudden loading event (NEMG average of left and right sides with respect to MVC data) was also examined. And it has been found that, except rectus abdominis, HEIGHT significantly affected peak NEMG of the other three pairs of trunk muscles. With the increase of HEIGHT, larger NEMG values were generally observed (Figure 6).

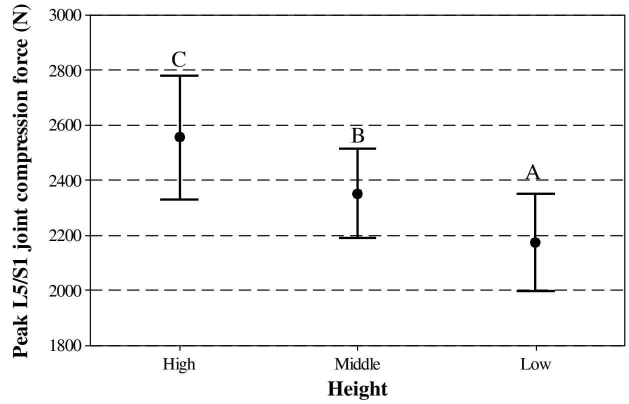

Figure 4: Peak L5/S1 joint compression force caused by sudden external loading under the three different height conditions. Different letters denote forces that are statistically different from one another. Bars indicate the corresponding 95% confidence interval.

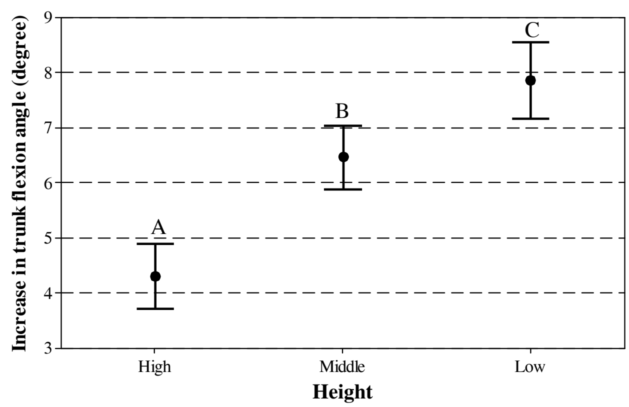

Figure 5: Increase in trunk flexion angle caused by sudden external loading under the three different height conditions. Different letters denote angles that are statistically different from one another. Bars indicate the corresponding 95% confidence interval.

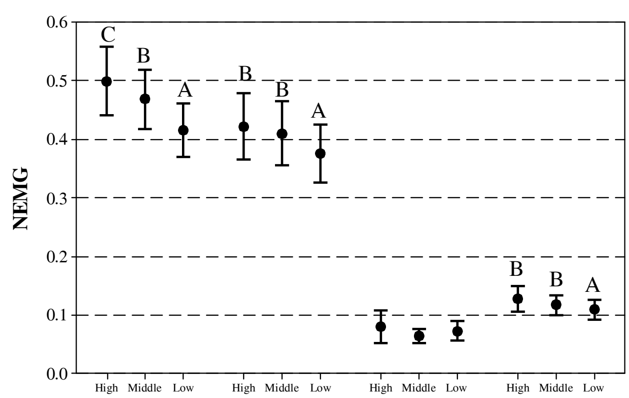

Figure 6. Averaged normalized EMG value (average of left and right sides with respect to MVC) of trunk muscles, ES, MU, RA and EO refer to erector spinae, multifidus, rectus abdominis and external obliques, respectively. Different letters denote values that are statistically different from one another. RA shows no significant difference between different levels. Bars indicate the corresponding 95% confidence interval.

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DISCUSSION

The results of the present study confirmed our initial hypothesis, and showed that spinal compression force would increase with a higher load holding height (Figure 4). This result was caused by trunk muscle co-contraction and postural stability levels, which are closely associated with the nature of vertical height difference. A previous study discovered that when holding load at a higher position, trunk stability would decreased, which in turn required higher level of trunk muscles co-contraction to help keeping balance (Granata & Orishimo, 2001). And spinal compression force, in thus, increased as a result of the higher muscles activities. (Granata & Marras, 2000). The EMG data of the current study verified these previous findings (Figure 6). Since it has already been revealed that the magnitude of spinal compression force was directly associated with the risk of low back injury (Kerr, 2001), our results suggested that when experiencing sudden loading, holding load at a lower height level (umbilicus etc.) could serve as a strategy to protect against this potential risk. Our results also demonstrated that with a higher load holding height, smaller trunk flexion angle was generated (Figure 5). This can also be explained by the above described previous study, which revealed that the increase of load holding height would increase the trunk muscle co-contraction level, and consequently resulted in greater trunk stiffness (Granata & Orishimo, 2001). As a result, with higher level of stiffness, trunk flexion was less likely to happen; therefore smaller trunk flexion angle was observed (Granata & Marras, 2000). Several limitations need to be noted in the present study. First, all the subjects were recruited from university student population. The biomechanical responses of experienced workers in real occupational settings need future investigation. Second, only three height levels were tested in the current study, other conditions (e.g. overhead lifting) should be tested in the future. Third, only one independent variable (HEIGHT) was included in the current experimental design, other factors such as magnitude of load (Zhou, 2013[b]) may be included to explore interaction effect.

CONCLUSION

The current study investigated the influence of load holding height on trunk biomechanics during sudden loading. Our results provided important information on how load holding height can serve as a protective strategy. According to the findings, it is suggested that holding load at a lower (e.g. umbilicus) level can help reduce the risk of low back injury, especially for the occupations in which manual material handling is involved such as nurses and construction workers.

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