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Biomechanical analysis of manual material handling movement in healthy weight and obese workers

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ABSTRACT

The risk of back injury during work remains high today for manual materials handler. The purpose of this study is to identify the potential presence of compensatory strategies in obese and non-obese handlers and evaluate the impact these strategies have on trunk kinematics and kinetics. The biomechanical and ergonomic impacts in 17 obese and 20 healthy-weight handlers were evaluated. The task studied consisted in moving boxes from a conveyor to a hand trolley and back. The results show that the anthropometric characteristics of obese handlers are linked to a significant increase in peak lumbar loading during lifting and lowering of boxes. Few postural differences between the two groups were observed. These results suggest that the excess weight of an obese worker has a significant added effect on the musculoskeletal structures of the back, which exposes obese handlers to a higher risk of developing a musculoskeletal disorder during load handling.

1. Introduction

Manual materials handlers play a critical role in the world economy, but many of them suffer from injuries or disorders related to the physical nature of their work. Studies reported a moderate to high correlation between manual handling and back injuries (Bernard, 1997; Burdorf and Sorock, 1997; Gardner et al., 1999; Hoogendoorn et al., 2000; Kuiper et al., 1999; Liira et al., 1996; Magnusson et al., 1996; Vingard and Nachemson, 2000). A significant amount of research has identified population-wide risk factors for injuries during manual materials handling (Bernard, 1997); work-related risk factors include lifting heavy objects, along with frequent bending and twisting of the trunk, as well as personal risk factors including age and obesity. Considering the increased prevalence of obesity in the workforce (Caban et al., 2005) and the possible influence of obesity on trunk motion and loading during lifting (Ghesmaty Sangachin and Cavuoto, 2016; Singh et al., 2015), further work is needed to better understand the interaction between these factors.

Epidemiological evidence suggests an increase in musculoskeletal injuries and higher treatment costs in obese compared to healthy-weight individuals. In a study of 7690 workers at a U.S. aluminum manufacturing company, of the 2221 employees who had sustained at least one injury, 85% were classified as overweight or obese. Overweight and obese workers are 26% and 45% more likely to experience injuries than healthy-weight workers (Gu et al., 2016). In addition to this higher frequency of injury, obese workers have a rate of absenteeism due to illness, injury or disability that is higher than that of non-obese workers (Trogdon et al., 2008). After monitoring over 10,000 workers for nearly seven years, Ostbye et al. (2007) showed that the number of work days lost because of temporary disability was five times higher for obese workers. Such disabilities are due to injuries at work, especially musculoskeletal disorders (MSDs) of the back. As stated in a systematic literature review published in 2007, there are few studies that have looked at the mechanisms explaining the link between obesity and the high incidence of occupational injuries (Pollack and Cheskin, 2007). These authors proposed several possible mechanisms that may explain this link: work environment ill-suited to larger body circumferences, ill-suited personal protective equipment, alteration of functional capacities due to excess weight, decreased alertness (sleep apnea, sleepiness and fatigue), as well as increased biomechanical stress, impaired motor coordination and fatigue, all potentially induced by extended task duration.

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Obesity is shown to reduce range of motion for the shoulder (extension and adduction), in the lower back (extension and lateral flexion), and knee flexion (Park et al., 2010). In addition, functional limitations have been reported in obese women, revealing increased time needed to complete tasks and difficulties and/or pain and exertion in flexibility tasks, balancing, activities at floor level (bending and kneeling) (Evers Larsson and Mattsson, 2001). Consequently, these factors may impede obese workers abilities to perform physical job demands (Gates et al., 2008) or increase their risk of injury.

One study by Singh et al. (2015) provided estimates of lifting low back biomechanical stresses of severely obese workers based on static biomechanical analyses. They showed that the mean disc compression force at L5/S1 during manual lifts of moderate load weights was significantly larger than the normal body weight group and many exceeded the 3400N NIOSH action limit. Body weight markedly affects spinal loads, whereas it has been reported that body height has less effects on spinal loads during various static symmetric activities (Ghezelbash et al., 2016; Hajihosseinali et al., 2015; Han et al., 2013). By using a personalized kinematic driven musculoskeletal trunk finite element model, it was found that body weight contributed for 98.9% of compression forces and 96.1% of shear forces of spinal loads (Ghezelbash et al., 2016). Uneven distribution of weight in obese subjects, with more body weight positioned on the lower trunk, further increased spinal loads. Our preliminary results revealed that peak moments of force at L5/S1 were 13.3–59.0% higher during both box lifting and lowering (Corbeil et al., 2013).

High spinal load due to excess body weight may lead manual material handlers who are obese to adopt a more biomechanically advantageous lifting strategy. Xu et al. (2008) noted that, during a series of free dynamic lifting tasks performed at two levels of load and lift symmetry, the obese handlers showed higher trunk sagittal plane and transverse plane (twisting) velocity and acceleration, but failed to find any difference between obese subjects and healthy-weight subjects in terms of peak trunk angle during load lifting. Recently, it has been demonstrated that obese subjects bent to a 10° lower peak trunk sagittal flexion angle, took 0.8 s longer per lift and had 17% lower root mean square jerk when performing a prolonged repetitive lifting task of boxes with handles from the ground to knuckle height (Ghesmaty Sangachin and Cavuoto, 2016). In addition to the contradictory results reported regarding distinct trunk kinematics during lifting, limited data exist on how obesity affects spinal loads during dynamic handling activities and the ways in which handling tasks are carried out in situations where the feet are free to move (as opposed to being restricted by small force platforms). It is also necessary to test participants in situations close to those of real work situations to better appreciate the full range of movement strategies and adaptability of workers. Differences in lifting techniques might provide additional insight into this potential occupational and safety and health concern and support the design of handling tasks as well as specific training programs for manual handlers.

The objective of this study was to compare the strategies of obese and healthy-weight handlers. Based on Newtonian mechanics, we would expect that with greater trunk weight there will be greater external (and internal) loads. If true, it is possible that handlers may have developed compensatory strategies to compensate for these loads and preserve the integrity of the back.

2. Methods

2.1. Participants

The study group consisted of 17 obese male handlers aged 22 to 52 and 20 healthy-weight handlers aged 18 to 50 (Table 1).

The participants selected were familiar with the handling tasks in this study (boxes of reasonable size, unconstrained area, etc.). Subjects were recruited through posters and placement agencies. The criteria for selection were as follows: manual materials handler (as principal task), low occurrence of injuries and no injuries in the past year, and more than one month of experience. No participants reported musculoskeletal disorders at the time of the study. This study was approved by the local institution's research ethics committee. Each participant signed an informed consent form prior to participating in the study.

Table 1

Characteristics of participants; means (± standard deviation).

	Healthy-weight handlers	Obese handlers
Age (years)	25.3 (± 6.9)	34.0 (± 7.2)*
Experience (years)	3.7 (± 7.8)	6.5 (± 6.6)
Height (m)	1.75 (± 0.06)	1.74 (± 0.06)
Weight (kg)	67.5 (± 6.9)	95.4 (± 9.6)*
Trunk weight (kg)	30.9 (± 3.5)	48.6 (± 5.9)*
Trunk moment at L5/S1 (Nm)	86.9 (± 7.4)	113.6 (± 14.8)*
BMI (kg/m^2)	21.9 (± 1.1)	31.4 (± 1.5)*
Width of iliac crest (m)	0.27 (± 0.03)	0.32 (± 0.03)*
A-P distance to C7 (m) [a]	0.11 (± 0.01)	0.14 (± 0.01)*
A-P distance to T12 (m) [a]	0.21 (± 0.01)	0.28 (± 0.02)*
A-P distance to S1 (m) [a]	0.20 (± 0.01)	0.27 (± 0.02)*

*Indicates p-value associated with independent samples *t*-test is less than .05; A-P: anterior-posterior; BMI: body mass index.

[a] Average from three tests conducted with a GPM Caliper.

2.2. Equipment

The ground reaction forces exerted during the handling tasks were recorded through an extended force platform (1.90 × 1.40 m) mounted on an AMTI 6-axis load cell (model MC3A-6–1000, Watertown, Massachusetts). The signals were collected at a frequency of 1024 Hz and then low-pass filtered at 10 Hz (2nd order Butterworth filter zero-phase forward and reverse filter). An Optotrak system (Northern Digital Inc., Waterloo, Ontario, Canada) was used, at a sampling rate of 30 Hz, to record the 3-D coordinates of markers attached to the primary body segments and the boxes.

Twelve rigid clusters of markers were attached to each of the following segments: head (1); back at C7 (1); T12 (1) and S1 (1); both arms (2); both forearms (2); both thighs (2); both feet (2). A cluster of markers consisted of four LED diodes (except for seven for the feet) fixed either to an aluminium plate or to a Styrofoam block, which in turn was attached to the subjects' skin. The rigid clusters scanned by the five Optotrak columns were used to locate 48 anatomical landmarks in relation to their respective marker cluster, to be able to estimate the segmental joint centres and subsequently body segment kinematics.

2.3. Experimental procedures

Four boxes were transferred one by one to be stacked in a pile on the hand trolley, with the first box (position 1) taken from the conveyor at the bottom of the pile (2-cm from the ground) and the last box (position 4) at the top (98-cm from the ground) (Fig. 1). Once all four boxes were placed on the hand trolley, the subject returned the boxes from the hand trolley to the conveyor (the return phase), beginning with the box at the top of the pile. The boxes had the following characteristics: one 15-kg box, one 23-kg box, one weakened 15-kg box (contained 12 bottles of sand and water and had no cover, so as to be deformable), and one off-center 15-kg box (center of gravity 27 cm laterally from one side and 8 cm from the other), all with the same dimensions (26 cm deep × 35 cm wide × 32 cm high). The weight of the box (three 15-kg boxes and one 23-kg box), the handling height (and deposit height) and the working configuration (one facing the hand trolley at 180° and the other at 90°) were the independent variables. The balanced order resulted in each type of box being at each position (4 positions) on the conveyor and at each height (4 heights) on the hand trolley twice during the experiment (two trials per condition). The total number of