Applied Ergonomics 45 (2014) 1558–1569

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

Sex differences in lifting strategies during a repetitive palletizing task

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ARTICLE INFO

Article history:
Received 29 October 2013
Accepted 16 May 2014
Available online 13 June 2014

Keywords:
Manual material handling
Lifting
Sex

ABSTRACT

Forty-five manual material handlers (15 females, 15 expert males and 15 novice males) performed series of box transfers under conditions similar to those of large distribution centers. The objective of the study was to verify whether sex differences in joint motions and in back loading variables (L5/S1 moments) exist during multiple box transfers. The task consisted in transferring 24 15-kg boxes from one pallet to another (4 layers of boxes; 6 boxes/layer: 3 in the front row, 3 in the back) at a self-determined pace and then at an imposed pace of 9 lifts/min. Full-body 3D kinematic data were collected as well as external foot forces. A dynamic 3D linked segment model was used to estimate the net moments at L5/S1. The results show that the peak L5/S1 moment during lifting for females was significantly lower than for males, but once normalized to body size the difference disappeared. In general, the female workers were very close to the posture adopted by the novice males at the instant of the peak resultant moment. However, females were closer to the box than the male workers. One major sex difference was seen when lifting from the ground, with the use of interjoint coordination analyses. Female workers showed a sequential motion initiated by the knees, followed by the hip and the back, while expert males showed a more synchronized motion. The lifting strategy of females likely stretches lumbar spine passive tissues, which in turn put them at greater risk of back injuries. As observed in our previous studies, these differences between expert males, novice males and females are especially notable when the box is lifted from the ground.

1. Introduction

Manual material handling (MMH) tasks have been associated with low back injuries in a large number of studies (Hoogendoorn et al., 1999; Kuiper et al., 1999; Lötters et al., 2003; National Research Council, 2001; da Costa and Vieira, 2010; Nelson and Hughes, 2009). The National Research Council (2001) indicated that heavy lifting shows the greatest risk for injury when loads are lifted from low heights, when the distance of the load from the body is large, and when the trunk assumes a flexed, asymmetric posture. The risk should decrease as the physical exposure to these factors also decreases. Our previous studies (Plamondon et al., 2010, 2012) demonstrated that expert male workers differed from novice male workers mostly in the posture-related variables, with experts more often adopting a recognized safe back posture. An extension of this work is to determine whether females work differently than males when lifting a given absolute load (in kg), as the load is not scaled to strength capabilities in work settings.

The large majority of studies on MMH are on male participants and it is not known if the findings can be extrapolated to females (Lindbeck and Kjellberg, 2001) considering they are smaller in size and not as strong as males. For instance, on average, a female's lifting strength ranges between 45 and 76% of a male's, depending on the measurements used (Kumar and Garand, 1992; Mital et al., 1997; Stevenson et al., 1990). According to Zhang and Buhr (2002), back and leg muscle strengths are two primary limiting factors of a person's lifting capacity.

Several studies have indicated that sex differences in anthropometry and strength could explain the differences in lifting styles. In the Li and Zhang (2009) study, males were more likely to use the back-preferred strategy, whereas females more often used the leg-preferred strategy. Furthermore, participants with a back-preferred strategy had more back strength than knee strength, whereas participants with the leg-preferred strategy had more knee strength than back strength. Marras et al. (2003) indicated that

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http://dx.doi.org/10.1016/j.apergo.2014.05.005

females adopted a lifting style that made more use of their hips, whereas much of the lifting motion for males was from the lumbar spine. According to these authors, females' greater dependence on the pelvis may be due to their limited strength capacity in the lumbar region. Also, males produced higher spine loads when performing identical heavy physical tasks. However, as males tolerate higher compressive forces than females, women were closer to their tolerance values and therefore at higher risk of injury. Davis et al. (2003) found that the only sex difference was for sagittal trunk flexion, males bending their trunk further (by about 5°) than females. Interestingly, for lifting close to the floor, the hips of females dominated and the lifting style resembled more of a squat lift than a stoop lift. Males also adopted more of a squat lifting style when close to the floor.

Lindbeck and Kjellberg (2001) emphasized the importance of interjoint coordination in the biomechanics of lifting. Several papers investigated the coordination between lower extremity joints and the back and found that as the load weight increased, the lumbar spine motion was lagging further behind the lower extremity joint motion. In other words, the knee extension proceeded sooner than the back extension as the load lifted was increased; or the lumbar spine extension was delayed with heavier loads (Davis and Troup (1965); Scholz, 1993a, 1993b; Scholz and McMillan, 1995; Burgess-Limerick et al., 1995).

Interjoint coordination appears to vary between sexes as well. Lindbeck and Kjellberg (2001) found that the hip-knee coordination was more in phase (synchronized) in females during a squat lift, the hip extension lagging more behind knee extension in males. This is surprising as females are generally weaker than males, but to take into account the differences in physical capacity between sexes, females were given less weight to lift (8.7 kg) than the males (12.8 kg). To control for sex differences in body size and strength, Albert et al. (2008) adjusted the weight of the load relative to the lifting capacity (20% relative load) as well as the height of the lift relative to the subjects' height. Their results revealed that there were no significant sex effects in the posture adopted at the start of the lift and in the lifting interjoint coordination. The common pattern disclosed by the interjoint coordination analyses was the trunk lagging behind the knee early in the lift. In a more recent study, Sadler et al. (2011), using principal component analyses, found no sex differences as regards to the lifting technique. However, the two load conditions in their study involved very light standardized loads (0% and 10% of maximum isometric back strength), which might not be challenging enough to reveal sex differences.

The body size and physical capacity of males and females are no doubt different, which has the potential to influence lifting strategies in the work setting, i.e., when load height and mass are not adjusted to the worker's body size and strength. How this is so is not very clear at this moment. There are very few studies that differentiate males and females in MMH, and the work context generally studied consists of sagittal lifts from the floor to a shelf. Moreover, the majority of the participants have no experience in MMH. Plamondon et al. (2010, 2014) published two studies on the difference between expert and novice male workers. We propose to extend this work with female workers having experience in MMH. This study aimed to investigate whether a challenging task of multiple depalletizing-palletizing would make female workers differ from their male counterparts (expert and novice workers). During this task, the workers had to continuously transfer 24 15-kg boxes from one pallet (depalletizing) to another (palletizing) at two different lifting frequencies: self-paced and imposed pace (9 lifts/min). It was hypothesized that the lifting style of female workers would be significantly different from that of males, as shown by measures of joint motions, back loading (L5/S1 moments) and interjoint coordination.

2. Method

The method used in this study is similar to the one used previously (Plamondon et al., 2014). Initially only males (experts and novices) were studied and subsequently, female workers were invited to do the same type of task. The study for both genders was divided into three experimental sessions, but only the second session, which specifically involved repetitive transfers of boxes from one pallet to another, is the object of the present paper. Most of the sections below present the main steps in the method used, which was already detailed in Plamondon et al. (2014). Only the most important elements are repeated here.

2.1. Subjects

Initially, two groups of male subjects were recruited. The first group consisted of 15 male experts who met the following three criteria: a minimum of 5 years of experience; a low lifetime incidence of injuries (particularly to the back); and no injury in the year preceding the study. The second group consisted of 15 male novices meeting the following criteria: 3–6 months of handling experience and no incidence of injury in the year preceding the study. The third group was 15 females who originally had to meet the same criteria as our expert male workers. Each worker had to fill out the standardized Nordic questionnaire for the analysis of musculoskeletal symptoms (Forcier et al., 2001; Kuorinka et al., 1987) and had to meet the inclusion criteria. However, the recruitment of females was difficult and the criterion of a low lifetime incidence of back injury had to be dropped. Consequently, females having more lifetime injuries to the back were not classified as experts but as workers with experience. None of the subjects had musculoskeletal problems during the tests that could affect the normal performance of their work. Table 1 presents the subjects' main anthropometric characteristics. The female group differs from the males with regard to height and strength. These variables should therefore have some impact on the different biomechanical parameters. It should be noted that the three groups were significantly different with

Table 1
Mean values (*M*) and standard deviation (SD) for several anthropometric characteristics of the subjects ($n = 45$).

Variables	Experts (E)		Novices (N)		Females (F)		*P* value	Post-hoc
	M	SD	*M*	SD	*M*	SD		
Age (yrs)	38.0	9.8	25	5.9	41.1	8.6	**<0.01**	N < E, F
Weight (kg)	75.9	12.2	74.2	11.4	66.8	10.3	0.08	
Height (m)	1.71	0.07	1.75	0.05	1.62	0.07	**<0.01**	F < E, N
Experience	15.4	9.3	0.5	0.4	7.3	2.3	**<0.01**	N < F < E
HAT weight moment (Nm)	96	17	95	15	70	10	**<0.01**	F < E, N
Back extension strength (Nm)	347	68	322	59	186	37	**<0.01**	F < E, N
Leg lifting strength (kg)	138	28	139	25	68	16	**<0.01**	F < E, N

Note: *Post-hoc* test when the main effect is significant; Bold faces = $p < 0.05$.