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Effects of restrictive clothing on lumbar range of motion and trunk muscle activity in young adult worker manual material handling

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ABSTRACT

The objective of this study was to examine the effect of wearing restrictive trousers on lumbar spine movement, trunk muscle activity and low back discomfort (LBD) in simulations of manual material handling (MMH) tasks. Twenty-eight young adults participated in the study performing box lifting, liquid container handling while squatting, and forward reaching while sitting on a task chair when wearing tight pants (sizes too small for the wearer) vs. fit pants (correct size according to anthropometry). Each task was repeated three times and video recordings were used as a basis for measuring lumbar range of motion (LRoM). The response was normalized in terms on baseline hip mobility. Trunk muscle activity of rectus abdominis (RA) and erector spinae (ES) muscles were also measured in each trial and normalized. At the close of each trial, participants rated LBD using a visual analog scale. Results revealed significant effects of both pants and task types on the normalized LRoM, trunk muscle activity and subjective ratings of LBD. The LRoM was higher and trunk muscle (ES) activity was lower for participants when wearing tight pants, as compared to fit pants. Discomfort ratings were significantly higher for tight pants than fit. These results provide guidance for recommendations on work clothing fit in specific types of MMH activities in order to reduce the potential of low-back pain among younger workers in industrial companies.

1. Introduction

Physical activities involving trunk flexion are common among occupational and daily living tasks, particularly lifting, forward reaching and squatting. Epidemiologic studies have reported that tasks involving lifting with repetitive trunk bending and heavy loads pose risk factors for low back pain (LBP) (Hoogendoorn et al., 2000; Widanargo et al., 2011). Recent research has found LBP in adolescents to be more frequent than previously suspected (Burton et al., 2006). In Thailand, the prevalence of LBP among adolescent workers attributed to bending and reaching tasks was approximately 77% (Keawduangdee et al., 2012). These findings are in accordance with high LBP prevalence rates for workers in the USA and Switzerland (36 and 51%, respectively; Burton et al., 1996; Demoulin et al., 2007).

Trunk bending requires multi-joint coordination for lumbo-pelvic and hip movements as well as trunk muscle activation (Lee and Wong, 2002; Wong and Lee, 2004). However, if there is restriction of one of the multiple joints in the lumbo-pelvic and hip regions, this can result in altered movement and biomechanics of the remaining unrestricted joints (Yoo and Yoo, 2012). Tight pants, specifically sizes smaller than fit to a wearer's anthropometry, may restrict hip movement and alter trunk muscle activity during work tasks and leisure (Anders et al., 2005). Such clothing has become a popular clothing choice for Thai adolescents.

Previous research observed reduced hip mobility in association with increased spinal flexion and extension. This mobility limitation and spinal motion may be factors contributing to development of LBP (e.g., Dolan and Adams, 1993; Lee and Wong, 2002; Wong and Lee, 2004). In addition, based on the flexion–relaxation phenomenon (FRP), compensatory responses to hip mobility

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restriction are likely to decrease the supporting role of trunk musculature during full trunk flexion tasks (Anders et al., 2005). With respect to the FRP, McGill and Kippers (1994) reported apparent electromyographic silencing of lower back muscles during a standing to full trunk flexion maneuver. On this basis, it is hypothesized that lower back muscles decrease their supporting role (activation level) during full trunk flexion resulting from reflexogenic stimulation of stretch receptors in passive structures, specifically the posterior spinal ligaments (Solomonow et al., 1999; 2003a,b). Beyond this, with reference to the length–tension relationship theory, Aratow et al. (1993) reported that elongation of a muscle (with a focus on the lower back) can decrease the number of actin and myosin cross-bridges and subsequently decrease active force output. Therefore, EMG measured muscle activity decreases with elongation.

Changes in spine and hip mobility, and trunk muscle activations can lead to stresses at the lumbar motion segment, including altered loads and forces on spinal joints and the posterior spinal ligaments (Dolan and Adams, 1993; McGill and Kippers, 1994). Restricted and altered movement patterns of the hip and lumbar spine, respectively, may lead to low-back discomfort, which can ultimately be a cause of low-back pain and disability (Anders et al., 2005).

Historical workplace safety guidelines and regulations have addressed workers wearing loose clothing while operating machines and the potential for garments to become entangled in moving machinery parts (OSHA, 1992). Conversely, little, if any research, has focused on the impact of wearing excessively tight clothing at work, such as tight pants, on occupational illnesses for workers, such as LBP.

The objective of this research was to investigate the effect of wearing tight pants (smaller than fit sizes) on hip and lumbar spine movement, trunk muscle activity and perceived low-back discomfort in young adults. The study examined wearing tight garments as a cause of hip movement restriction in simulations of realistic work tasks in a lab environment. Specifically, we compared young adult lumbar range of motion, associated trunk muscle activity and low back discomfort (LBD) during box lifting, manual material handling (MMH) while squatting, and forward reaching while sitting on a chair. All tasks were performed by participants when wearing tight vs. fit (i.e., the correct size according to anthropometry) pants. The study was expected to complement prior research in the safety area by focusing on risks associated with wearing restrictive garments in work tasks vs. loose fitting clothing hazards.

We previously reported on a preliminary study (Eungpinichpong et al., 2012) of a similar nature involving a smaller sample size and no assessment of trunk muscle activity. The results of that study revealed an effect of restrictive garments on hip mobility and increased spinal flexion/extension. Preliminary discomfort ratings also revealed increases for the tight pants condition over fit pants. The research motivated the present investigation with a larger sample and assessment of muscle activity in conjunction with spinal motion and perceived discomfort.

2. Methods

2.1. Participants

A sample of twenty-eight young adults was recruited from the Khon Kaen University community in Thailand. All twenty-eight persons (14 males, 14 females), with a mean age of 22 ± 1.99, participated in the study. This mean age was selected to ensure participants represented the target population of the research ("teenagers") but could still provide informed consent for participation (i.e., no minors under the age of 18 years). All participants were also required to have a body mass index (BMI) between 18.7 and 25 kg/m^2. This range represents persons who are not considered to be "overweight" or "obese" (WHO expert consultation, 2004). The BMI range was also limited to promote a homogenous sample and to ensure representation of the majority of the Thai adolescent population.

Participants were excluded from the sample for the experiment if they met any of the following exclusion criteria: (1) they had experienced LBP, which required medication or consultation with a health professional, and/or had days away from work within the last 6 months caused by LBP; (2) they were diagnosed with a medical condition that affected the musculoskeletal system, such as lumbar spondylosis, spondylolisthesis, lumbar herniated nucleus pulposus, ankylosing spondylitis or rheumatoid arthritis; (3) they had recent lumbo-pelvic and/or abdominal surgery; (4) they had symptoms, such as recent back pain, leg pain, or numbness in their back or legs prior to the experimental period; or (5) they were pregnant (O'Sullivan et al., 2006a).

2.2. Tasks

The tasks and equipment used in the test trials were representative of tasks performed by workers in grocery stores and factories, and are described as follows:

(1) A box lifting task required participants to stand erect with their toes touching a tape line on the floor. They were then directed to bend at the knees and spine in order to pick-up a box on the floor and lift it to knuckle height. Participants were permitted to bend at the knees with flexion of up to 90°. (If maximum flexion exceeded 90°, trials were repeated.) Participants returned the box to the floor to complete the task (see Fig. 1a).
(2) A forward reaching task required participants to sit in a task chair with their feet flat on the floor with 90 degrees of flexion at the knee. They were then required to pick-up a box on a worktable directly in front of them and place it at their maximum reach distance on the same table. Participants were instructed to flex their spine and to extend their arms as much as possible (see Fig. 1b).
(3) A squatting task required participants to bend the knees with maximum flexion at the spine in order to pick up a package of drink containers on the floor and to place it in a box (see Fig. 1c).

Each of the three test tasks was repeated three times by each participant.

2.3. Independent variables

The independent variables were: (1) type of pants with two levels, including tight (sizes too small for the wearer) and fit (the correct size according to anthropometry) long pants; and (2) type of leisure or work task, including the maximal forward reaching while sitting, box lifting, and MMH while squatting.

Tight pants were objectively defined as pants with a waist size one size too small for the wearer. Beyond this, the pants were subjectively defined as causing participants to feel "tightness" at the hip, buttock and thigh. In addition, the pants were subjectively confirmed participant's feeling tightness by a simple discomfort question in which participants responded "Yes" they felt tightness at the hip, buttock or thigh, or "No" they did not feel tightness in these locations (Fig. 2).

Fit pants were objectively defined as pants for which the waist size was correct according to a participant's anthropometry. They

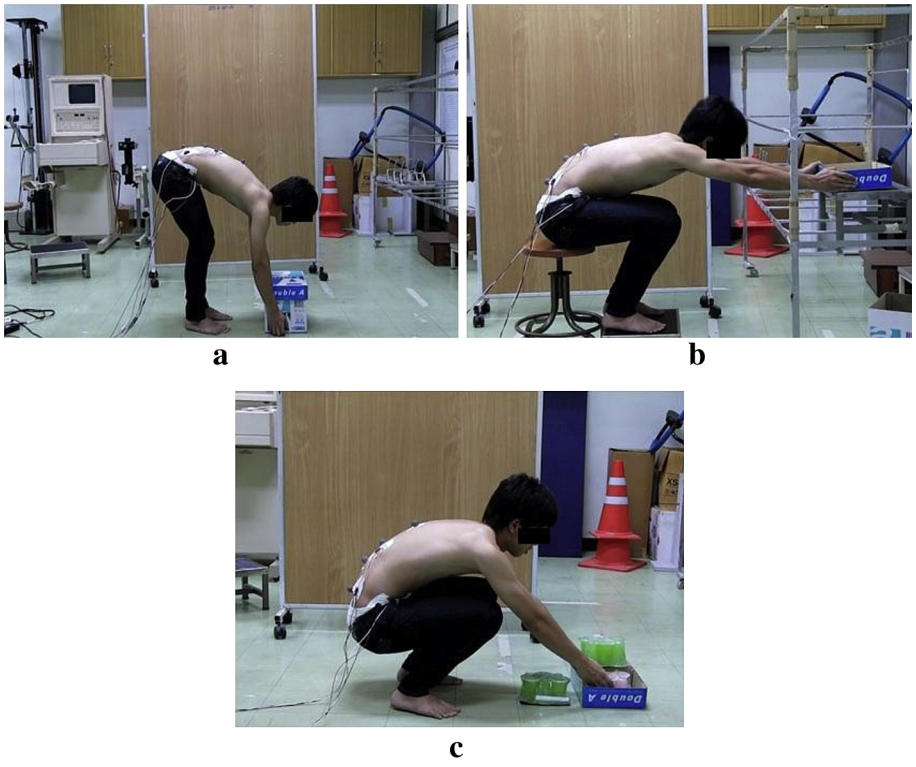

Fig. 1. Tasks examined in the study: a) forward reaching; b) box lifting and c) squatting (figures show participant wearing tight pants).

were also subjectively defined as pants that did not cause participants to feel tightness or restriction around the hip, buttock and thigh. The same subjective questionnaire used to assess the tight pants was used to assess the fit pants (Fig. 3).

2.4. Procedure

The study followed a completely within-subjects design with all participants being exposed to all combinations of garment fit and leisure or work task type. The procedure for the experiment involved randomly assigning a participant to one of two groups, including those wearing tight pants first, followed by fit pants, and those wearing fit pants first followed by tight pants. Subsequent to donning a pair of pants, the participant's hip range of motion was assessed in a supine posture position on a standard medical examination table. Directly following, participants began performing the test trials in the various tasks. The order of task presentation was randomized within-subject (i.e., participants served as a

Fig. 2. Lateral and anterior views of participant wearing tight pants.

Fig. 3. Lateral and anterior views of participant wearing fit pants.

blocking factor). As previously mentioned, each task was repeated three times by each participant with a single trial lasting approximately 5 s (for reaching, lifting or squatting). Once a participant completed all trials in the first task, they moved on to the second task type and then the third. After completing each task trial, subjects were asked to stand in an erect posture and rate their low-back discomfort. After having completed all nine test trials, participants were permitted a 10 min rest period while wearing a pair of fit shorts. At the close of the rest, they donned the alternate type of pants and began the work task trials. At the completion of the second batch of test trials, participants were debriefed and dismissed from the experiment. The entire experiment procedure took about 2 h per participant.

2.5. Dependent variables

Trunk muscle activity was recorded using surface electromyography (EMG), specifically a BIOPAC MP 36 system (Goleta, California, USA). Lumbar movement was recorded with a digital video camera. The lumbar range of motion was analyzed using video frame extraction software, a computer drawing application, and graphical measurement package. Low-back discomfort was captured using a unidimensional subjective rating scale. Responses were determined by measuring the distance along the scale between the level of discomfort rated by participants and a scale anchor (Areeudomwong et al., 2012; Callaghan et al., 2010).

2.5.1. Electromyography (EMG)

Regarding the EMG measurement, standard 4 mm Ag/AgCl electrodes were used for capturing muscle activity levels at the right Rectus abdominis (RA) and Erector spinae (ES) muscles. Normally, trunk muscles generate active force equally among both sides when performing symmetrical tasks. We measured the right side muscle EMG levels based on other previous studies that also chose to observe the right side of trunk muscles (Bressel et al., 2009; Cholewicki et al., 2009; Olson, 2010). The skin of a participant was properly cleaned and prepared for electrode placement to reduce external noise in the signal. Electrode pairs were placed at skin locations over the belly of each muscle, as described in other research (Imai et al., 2010; Danneels et al., 2001). For the RA muscle, active electrodes were placed on the anterior abdomen at the level of the umbilical and medial to sagittal plane. A ground was placed over the anterior portion of the iliac crest on the same side as the muscle being measured. Regarding the ES, active electrodes were placed on the low back at the level of L1 and medially to the lumbar spine. A ground electrode was placed over the posterior portion of the iliac crest.

For both muscles, EMG signals were recorded at 1024 Hz. A pre-amplifier was used to achieve signal amplitudes in the expected range for EMG (up to −5 to 5 mV, depending on the signal frequency). The signals were post-processed using low-and high-pass band filters and a 50 Hz notch filter (for electrical system interference (in Thailand)). The root mean square of the EMG response for each test trial was calculated for 50 ms time windows in the signal in order to reduce spurious variation in the responses. The maximum RMS value for the EMG for each muscle in each trial was then amplitude normalized to the maximal voluntary isometric contraction (MVIC) for the same muscle captured in advance of the test trials. To generate MVICs for the right RA muscle, participants laid in a supine position with both legs straight and strapped to a standard medical table with a belt. Participants performed a resisted sit-up with maximal manual isometric resistance applied in a symmetrical manner through the shoulders of the participant by an experimenter, who stood at the head end of the medical table (O'Sullivan et al., 2006a). To generate MVICs for the right ES muscle, participants laid on the medical table in a prone position with the upper edge of the iliac crests aligned with the edges of the table. The lower body was flexed to the table by three straps at the pelvis, knees and ankles. With arms across the chest, participants were asked to isometrically maintain the upper body in a horizontal position. Symmetrical manual resistance was applied to the scapular region by an experimenter, who stood at the head of the participant (O'Sullivan et al., 2006a). There were three MVIC trials of 5 s each, with a 3-minute rest period between trials in order to avoid the cumulative effect of muscle fatigue (McLean et al., 2003).

The normalized response EMG was expressed as a percentage of MVIC. The average of the three normalized EMG observations for

each pant type × task type condition was subsequently determined for each participant for statistical analysis purposes.

2.5.2. Lumbar range of motion (LRoM)

Regarding the lumbar range of motion measurement, reflective markers were placed at vertebral joints along the spine T10, L2, L4 and S2. These joint locations have been previously observed to determine lumbar spine angle (O'Sullivan et al., 2006b). Videos of all test trials were recorded with a digital video camera with a frame rate of 30 Hz. All video files were imported into the VirtualDub video processing software (version 1.9.11 by Avery Lee, GNU General Public License) and individual frames were exported as image files. Image files were subsequently inspected using the software for identification of the most extreme posture position for a specific task (i.e., a single frame for each test trial was used for analysis purposes). One researcher inspected all image files and the video frames used for analysis were selected based on when a participant achieved maximal trunk bending during each task. The spinal angle for a selected video frame was measured using the ImageJ analysis software version 1.46 (National Institute of Mental Health (NIMH), USA). A line segment was constructed overlaying the marker images at T10 and L2 and another segment was constructed passing over the marker images for L4 and S2. The two line segments were extended to a point of intersection occurring approximately over the L3 joint. The angle between the two segments was automatically computed by the software (see Fig. 4). Related to this, all participants were measured lumbar motion during task performance occurring in the sagittal plane, perpendicular to the line of view of the video camera.

For data analysis purposes, the LRoM was normalized based on the hip RoM (HRoM) collected at the outset of each block of test trials for each participant. Related to this, we observed significant restriction of the tight pants on participant HRoM. These values were used as denominators in normalizing the various LROM responses.

2.5.3. Visual analog scale (VAS): low back discomfort scale

After each trial, participants rated their low-back discomfort using a 100 mm visual analog scale with anchors including "none" to "intolerable" (Areeudomwong et al., 2012; Callaghan et al., 2010). Discomfort ratings were specifically focused on the low-back. The participants used pen and paper to complete ratings by marking locations along the scale that best represented their feeling of discomfort after a trial. An analyst used a metric ruler to measure the distance from the "none" anchor to the location of a marking and data was manually entered into a computer for analysis purposes.

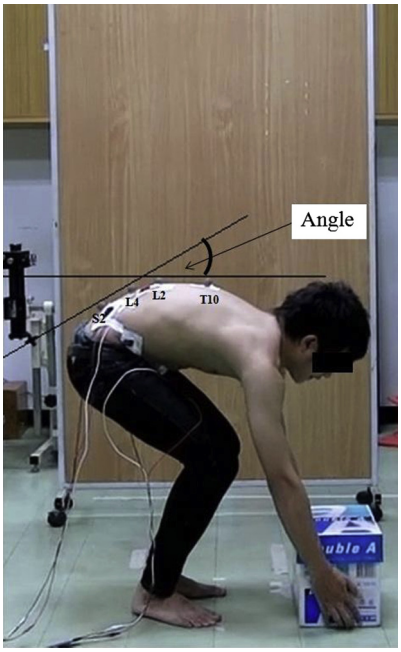

Fig. 4. Method of lumbar angle measurement.

2.6. Hypotheses

We expected that tight pants, typical of the style currently worn by Thai adolescents, would decrease hip mobility (flexion and extension) when compared to fit pants. Related to this, tight pants were hypothesized to increase LRoM as a result of the restricted hip motion (Hypothesis (H)1). It is important to note that the lumbar LRoM was not expected to decrease as a result of tight pants, as the waist line of test garments fell below the L5/S1 joint for all male and female participants. Related to this, trunk muscle activation levels (for the RA and ES) were also expected to decrease with hip restriction caused by wearing tight pants (H2). The feeling of low-back discomfort, as measured with the VAS, was expected to increase as a result of tight pant use (H3). Beyond this, the task types were expected to differ in normalized LRoM, trunk muscle activation levels, as well as perceived discomfort due to whole-body posture variations among the tasks (H4). Specifically, box lifting was expected to the generate greatest RoM, muscle activity and discomfort ratings due to extreme spinal flexion compared to MMH while squatting and extreme forward reaching.

2.7. Data analysis

Diagnostics of the normalized LRoM and the VAS ratings revealed the data to be normally distributed and to have equal variances across the types of pants and tasks. However, the trunk muscle activation responses did not have these characteristics. Therefore, logarithmic transformations were applied to EMG data and the transformed muscle activity levels satisfied the normality assumption of the ANOVA. The three-way (participant, pants and task types) ANOVA models with two-way interaction of pant and task types were applied to each response measure. The p-value was set at <0.05.

3. Results

The mean HRoM in flexion for tight pants was 87°, which was significantly less than for the fits pants with a mean HRoM of 103° ($t = 4.2893$, $p = 0.0002$). With respect to the HRoM in extension, the mean HRoM for tight pants was 21°, which was significantly less than for fits pants with a mean HRoM of 27° ($t = 6.8474$, $p = 0.0001$). A series of univariate ANOVA models were conducted on transformed muscle activity of RA, transformed muscle activity of ES, normalized LRoM and perceived low-back discomfort responses. A statistical model was initially constructed with five independent variables, including: 1) participant; 2) pants type; 3) order of pants; 4) task type; and 5) order of task, as well as an interaction term of pant and task types. Both order of pants and tasks did not have significant effects on any response measure so the order of participant exposure to conditions was dropped from the statistical models.

With respect to normalized LRoM, results revealed significant effects for both pant ($p = 0.0004$) and task type ($p < 0.0001$) (see Table 1 for statistical test information). In line with the hypothesis, the LRoM was higher when wearing tight pants than when wearing fit pants (Fig. 5a). Post-hoc analysis using Tukey's Honestly

Table 1
ANOVA results on response measures.

Effect	ROM	EMG ES	EMG RA	VAS
Participants	$F(27,135) = 28.9517$, $p < 0.0001^*$	$F(27,135) = 4.7401$, $p < 0.0001^*$	$F(27,135) = 14.3483$, $p < 0.0001^*$	$F(27,135) = 9.9906$, $p < 0.0001^*$
Type of pants	$F(1,135) = 13.4334$, $p = 0.0004^*$	$F(1,135) = 5.1680$, $p = 0.0246^*$	$F(1,135) = 1.9567$, $p = 0.1642$	$F(1,135) = 472.7159$, $p = 0.0246^*$
Task	$F(2,135) = 27.0640$, $p < 0.0001^*$	$F(2,135) = 63.1713$, $p < 0.0001^*$	$F(2,135) = 25.6518$, $p < 0.0001^*$	$F(2,135) = 11.4464$, $p < 0.0001^*$
Type of pant * task	$F(2,135) = 0.7175$, $p = 0.4898$	$F(2,135) = 0.8557$, $p = 0.4273$	$F(2,135) = 0.0428$, $p = 0.9581$	$F(2,135) = 0.5336$, $p = 0.5877$

Note: * – significant at alpha = 0.05 level.

Significant Difference tests revealed box lifting and squatting to produce significantly greater ($p < 0.05$) spinal flexion than reaching tasks (Fig. 5b). Statistical analysis also revealed no significant effect on interaction terms for normalized LRoM.

With respect to the normalized EMG responses, results revealed significant effects for both pant ($p = 0.0246$) and task type ($p < 0.0001$) on EMG ES. The EMG RA response only revealed a significant effect of task type ($p < 0.0001$; see Table 1 for test information). In line with hypothesis, ES muscle activity was significantly higher for participants when wearing fit pants (i.e., with less spinal flexion), as compared to tight pants (see Fig. Fig. 6a). Post-hoc analyses revealed activation levels for both trunk muscles were significantly higher ($p < 0.05$) for participants when performing box lifting task followed by squatting and forward reaching, which were not different from each other (see Fig. 6b for EMG ES; Fig. 6c for EMG RA). There was no significant effect of the pants × task type interaction term on EMG ES or RA.

Significant effects for both pants ($p < 0.0001$) and task type ($p < 0.0001$) were also found for the subjective ratings of low-back discomfort (see Table 1). Results also revealed no significant effect of the interaction term on low-back discomfort. Conforming with expectation, VAS ratings were significantly higher for tight pants than fit (Fig. 7a). However, contrary to the hypothesis, post-hoc analysis revealed participants to perceive squatting to cause significantly greater ($p < 0.05$) discomfort followed by lifting and reaching, which were not different from each other (Fig. 7b).

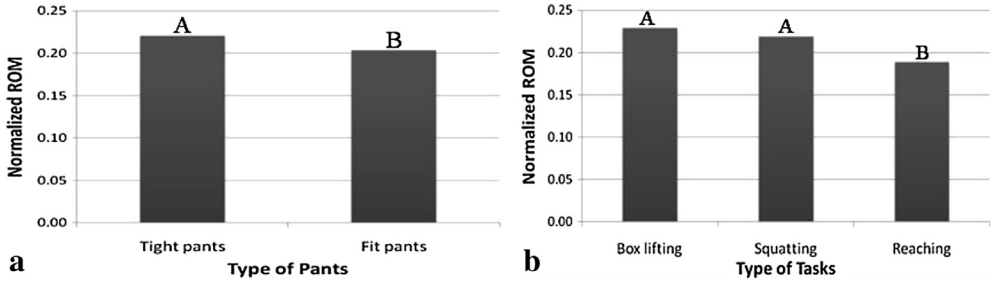

Fig. 5. Results on comparison of normalized lumbar range of motion: a) between tight pants and fit pants; b) among box lifting, squatting and reaching (means with different letter labels are significantly different from the each other).

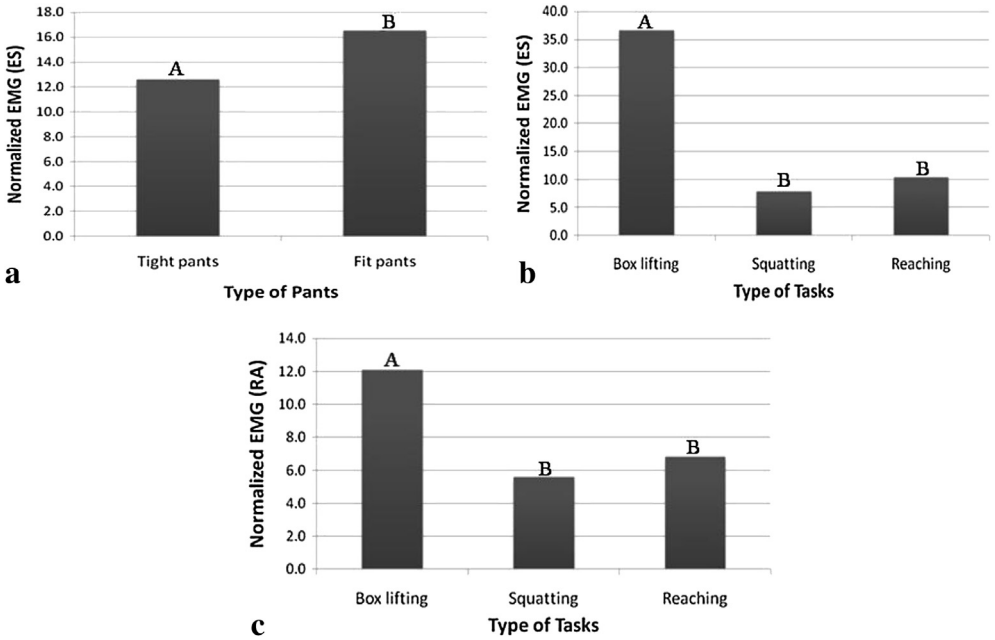

Fig. 6. Results on normalized EMG comparisons for: a) ES between tight pants and fit pants; b) ES muscle among box lifting, squatting and reaching; c) RA muscle among box lifting, squatting and reaching (means with different letter labels are significantly different from the each other).

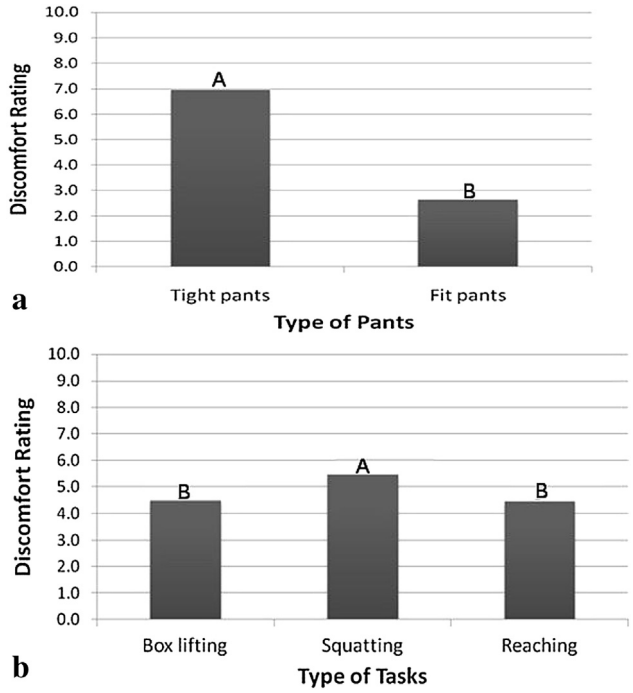

Fig. 7. Results on comparison of discomfort ratings: a) between tight pants and fit pants; b) among box lifting, squatting and reaching (means with different letter labels are significantly different from the each other).

4. Discussion

In the present study, we compared young adult LRoM and associated trunk muscle activity during box lifting, manual material handling (MMH) while squatting, and forward reaching while sitting on a chair, when wearing tight vs. fit pants. We also analyzed perceived low-back discomfort in performing the various tasks wearing the different pants.

In general, results revealed no significant effect of the interaction of pants × task type for any response. It is possible that the effect of pant type overshadowed the effect of task type or that tight and fit pants may have consistent effects on LRoM, EMG and discomfort ratings across task types.

Findings revealed an increase in normalized LRoM for participants when wearing tight pants during box lifting, MMH while squatting and maximal forward reaching while sitting. In baseline HRoM measurement, we observed significant restriction in mobility when participants wore tight pants. This restriction may have contributed to compensatory movement in the lumbopelvic region. Spine movements appeared to occur more frequently and with greater range during the experimental tasks requiring hip flexion. These observations were in line with expectation (H1) and prior research. Yoo and Yoo (2012) reported a significant increase in lumbar flexion angle and decrease in hip flexion angle when wearing tight jeans compared to general jeans. Other previous research (Esola et al., 1996; Lee and Wong, 2002) has found lumbar spine movement to have a relationship with hip movement, including forward, backward and lateral bending of the trunk. Therefore, alteration of either lumbar or hip movement, in general, appears to contribute to compensatory responses in the other movement.

Our results also showed that box lifting and squatting produced greater spinal flexion than reaching tasks. This finding was also in line with expectation (H4) and may have been due to each task requiring a different LRoM for completion. For example, the forward reaching task produced less lumbar flexion than the box lifting and squatting. We observed that the arms and upper-back are key body segments to achieving this task as compared to the others. For this reason, the forward reaching task produced less LRoM when compared with the box lifting and squatting.

Results also indicated that normalized EMG of the ES muscle was lower for participants when wearing tight pants, as compared to fit pants. This finding was also in line with our expectation (H2). During full lumbar flexion in each task, the ES muscle may decrease its active force, passively stretch and, consequently, increase in length. According to the FRP, ES muscle EMG decreases during full trunk flexion tasks (McGill and Kippers, 1994). Our findings were generally in line with the hypothesis that ES muscles would decrease their supporting role during full trunk flexion resulting from reflexogenic stimulation of stretch receptors in passive structures, specifically the posterior spinal ligaments (Solomonow et al., 1999; 2003a,b). Regarding to length–tension relationship theory (Aratow et al., 1993), lengthening of a muscle can lead to decreased active force output. When the muscle is lengthened, the number of actin and myosin cross bridges decreases, resulting in a reduction of active force and, consequently, decreased EMG measured muscle activity. While the RA muscle co-contracts with the ES muscle during forward bending tasks (Granata et al., 2005), we found no significant difference in the normalized EMG for the RA muscle between the two types of pants. It is possible that the RA muscle was not stretched and not affected by the FRP when wearing either tight or fit pants. Further, EMG data was collected on this muscle when the trunk was fully flexed during the course of each task. Related to this, the muscle was not elongated with an increase in LRoM; therefore, the RA muscle freely generated force under both pants conditions.

We also found that both trunk muscle activities were higher for participants when performing box lifting as compared with squatting and forward reaching. This may be explained by differences in task demands. For example, the required range of motion and ability to control postural balance, as well as muscle forces, differed among the tasks. In general, participants required more muscle force to complete the box lifting and less force during MMH while squatting and forward reaching.

With respect to the occurrence of low-back discomfort, alteration of movement patterns of the lumbar spine and hip may have been a contributing factor. Dolan and Adams (1993) reported that changes in spine and hip mobility alter bending stresses on the spinal motion segment and, consequently, alter loads on facets of the posterior spinal ligaments (see Adams and Hutton, 1983). These outcomes could translate into pain experiences for workers. Our results on VAS discomfort ratings revealed tight pants to increase the feeling of discomfort, as compared to fit pants. This finding was also in line with expectation (H3). The experience of discomfort might also be due to the hip mobility restriction with the tight pants reducing low-back muscle (ES) activity during task performance and leading to overloading of vertebral structures, such as the intervertebral discs and posterior spinal ligaments (Hansen et al., 1998; Pope et al., 2002). Furthermore, previous research has reported occurrence of meralgia paresthetica when wearing tight pants for a prolonged time (Moucharafieh et al., 2008). This condition results from an entrapment of the lateral femoral cutaneous nerve (in the upper thigh) and involves a persistence burning sensation and tingling (Moucharafieh et al., 2008). Therefore, wearing tight pants may affect both the musculoskeletal and neurological systems.

Regarding task type, result showed higher muscle activity during box lifting when compared to squatting and reaching. This was support to H4. Although we attempted to ensure a relatively consistent spinal loading across the tasks, given the various posture

positions, it is important to note that object weight during each task was unequal (5% of BW for the heavy lifting task and 0.5 kg for the reaching tasks); thus, muscle activity responses might have been influenced not only by the task type but also the object weight. According to low back discomfort in each task, results also showed VAS ratings during squatting to be higher than box lifting and reaching. This was opposite to H4. This finding may be explained by the body position in each task. In a post-experiment interview, participants commented that the squatting posture required the greatest hip flexion, more so than box lifting and forward reaching. They also said they perceived the tight pants to restrict the hip movement most in the squatting posture (although the LRoM response showed box lifting to be more restrictive) leading to a greater sense of discomfort than in the other tasks.

5. Conclusion

This study observed that restriction of hip mobility due to tight pants may lead to a compensatory response of increased lumbar motion in manual handling tasks as well as reduced lower trunk muscle activation levels (ES). Such alterations in hip and spinal movements are a possible contributing factor to increasing stress on lumbar structures and could be a potential cause of low-back discomfort.

The findings of this study may provide an applicable guide for recommendations on work clothing fit in specific types of MMH activities among younger workers in industrial companies. For small to medium size companies (e.g., 10–100 workers) that may not provide workers with uniforms, companies should provide information on the potential for low-back discomfort associated with wearing tight pants and recommend fit or comfortable personal protective work clothing be worn during MMH tasks.

Regarding limitations of the present study, we did not examine LRoM, trunk muscle activity and back discomfort in more complex physical tasks, such as asymmetrical lifting. This type of lifting is common in industrial settings and reduces the generalizability of our findings. Second, we only investigated the effect of tight pants on young adult performance of MMH tasks. There is a need to look at the influence of restrictive garments on LRoM and pain experiences in other working age groups, such as the elderly. Third, this study recruited only normal BMI participants. Therefore, the findings of this study cannot be extrapolated to overweight or obese persons. Fourth, although the RA and ES muscles act as prime movers during trunk bending tasks, other anterolateral abdominal and low back muscles across the waist, including the internal oblique, transversus abdominis (muscular brace), quadratus lumborum and lumbar multifidus muscles, are important to stabilization of the lumbar spine during bending and lifting tasks (Bergmark, 1989; Panjabi, 1992). Further study should measure the activity levels of these muscles during task performance with tight pants. Fifth, we did not measure compressive load at the lumbar spine for tight and fit pants in the various MMH tasks. A link between the findings of this study and LBP may be limited due to the analysis approach. Future study should use biomechanical methods, such as a motion tracking system and 3DSSPP to estimate compressive loads and shear forces at the lumbar spine for this purpose. Finally, this study did not measure HRoM during task performance and only measured subjective low back discomfort rather than “low back pain”. Therefore, advance testing in these aspects should be considered in future study.

Conflict of interest statement

The authors have no personal or financial conflicts of interest associated with this work.

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