Towards ambulatory assessment of spinal loading in the field

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Chapter 3

Effects of horizontal transport and familiarisation with different working methods on low back loading in manual lifting

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ABSTRACT

To study the effects of horizontal transport and familiarisation with different working methods, nine subjects lifted low-lying boxes from far and close initial horizontal positions with and without horizontally transporting them to a location at a few meters distance. Subsequently, subjects were familiarised with different working methods (e.g. shifting and tilting) and they repeated the lifting task with horizontal transport. Including horizontal transport in the lifting task caused a 6% increase in back loading for the close-positioned box and familiarisation caused a 10% reduction in back loading for the far-positioned box. As a result, the effect of initial horizontal box position on back loading was smaller for the lifting task with (10%) than without (16%) horizontal transport and vanished after familiarisation. In conclusion, both horizontal transport and familiarisation with different working methods were found to affect low back loading.

INTRODUCTION

Frequent manual lifting has been identified as an important risk factor for the development of low back pain (Hoogendoorn et al., 2000a; Lötters et al., 2003; Kuiper et al., 2005), probably because of the high spinal forces involved, which can exceed the in vitro strength of the spine (Brinckmann et al., 1988; Waters et al., 1993; Norman et al., 1998). Previous studies have shown that decreasing the height of the object to be lifted strongly increases peak low back loading (Jäger et al., 1991; Marras et al., 1999b; Hoozemans et al., 2008; Faber et al., 2009b). Furthermore, some studies have shown that increasing the horizontal distance of low-lying objects relative to the body, further increases peak low back loading during lifting (Dolan et al., 1994; Schipplein et al., 1995; Lavender et al., 1999; Ferguson et al., 2002). However, some other studies did not find an effect of the initial horizontal object position when lifting low-lying objects (Marras et al., 1999b; Faber et al., 2007). In these studies, the object to be lifted was probably shifted towards the body before it was actually lifted, thereby effectively reducing the horizontal moment arm of the object at the instant of peak low back loading (Faber et al., 2007).

A cause of the discrepancy found between these studies might be differences between the lifting tasks studied. In the studies revealing a significant effect of initial horizontal object position, typical laboratory tasks were performed in which the objects were only lifted until an upright body posture was attained (objects were not transported to another location). In contrast, in the studies revealing no effect of initial horizontal object position, more realistic lifting tasks were performed, in which subjects horizontally transported the object lifted from one location to another at a few meters distance. Possibly, compared to a lifting task without horizontal transport, subjects tend to shift an object more towards the body prior to lifting it in a lifting task with horizontal transport because the task itself involves a more pronounced horizontal displacement.

Another factor that might have affected the lifting strategy could be the familiarity of the subjects with the performed working task. In the studies that did not find a significant effect of initial horizontal object position, working tasks were performed by experienced subjects in a mock-up of their actual work environment (warehouse or construction site). It might be that these subjects tended to use working strategies, e.g. involving shifting or tilting of the object, that may reduce effects of initial horizontal position (Gagnon, 2005).

The aim of the present study was to investigate to what extent horizontal transport and familiarity with different working methods affect low back loading when lifting low-lying objects from close and far initial horizontal positions. It was hypothesised that 1) lifting with horizontal transport compared to of lifting without horizontal transport and 2) familiarisation of the subjects with different working methods, would cause a reduction in peak low back loading due to changes in working strategy, especially for the most strenuous condition, i.e. when subjects need to reach far for the box.

METHODS

Subjects

After signing an informed consent, 9 healthy male subjects participated in the experiment which was approved by the local ethics committee. Their average (SD) age, height and body mass were 24 (4) years, 184 (5) cm and 72 (9) kg, respectively.

Experimental procedure

First, marker clusters for motion recording were attached to the relevant body segments and anthropometrical measurements were done. Subsequently, subjects started with the experimental trials in which they lifted a 16.8 kg box (dimensions: width x height x depth = 50 x 30 x 35 cm) that was positioned in front of a force plate (Figure 3-1). The initial handle height of the box was 27 cm. The box was lifted from a close and a far initial horizontal position. The initial horizontal distance between the edge of the force plate and the handles of the box was 17.5 cm for lifting from the close position and 57.5 cm for lifting from the far position. Lifts from both horizontal positions were performed first in a typical laboratory lifting task in which subjects lifted a box without horizontally transporting it to another location and thereafter in a more realistic lifting task in which a box was lifted and transported to a location at a few meters distance (see description below).

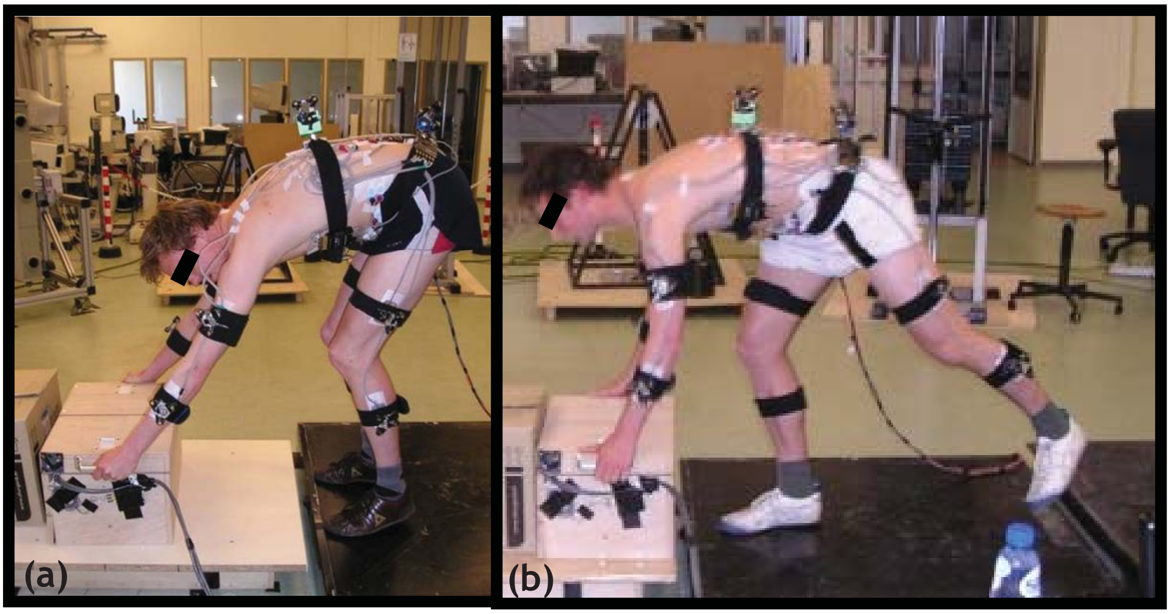

Figure 3-1. *Photographs showing a) a subject performing the typical laboratory lifting task without horizontal transport from a far initial horizontal box position and b) a subject performing the more natural lifting task with horizontal transport to a table behind him from a close initial horizontal box position.*

The order in which the lifts from the close and far horizontal position were performed was counterbalanced over subjects. No instructions were provided with respect to working pace, foot placement or lifting posture (e.g. stoop or squat).

Lifting task without horizontal transport

Subjects started in an upright body posture, standing on the force plate with the box positioned in front of them (free foot placement). Subsequently, subjects lifted the box until an upright body posture was attained. After the lift, the subjects repositioned the box at the horizontal position appropriate for the next lift, as indicated by an empty reference box (see Figure 3-1). Finally, subjects returned to the upright body posture from which they started the next lifting task.

Lifting task with horizontal transport

Subjects started standing behind the force plate, walked over the force plate towards the box, lifted it, turned around, walked back and placed the box on a table. Subsequently, subjects lifted the box from the table and repositioned it at the horizontal position appropriate for the next lift, indicated by the reference box. Finally, they walked back to their starting position behind the force plate from which they started the next lifting task.

Familiarisation with different working methods

After having performed both lifting tasks, subjects underwent a short training in which they were familiarised with different working methods they could use in the more realistic lifting task with horizontal transport. During the training, subjects were introduced to three different lifting strategies. These three strategies were shown on a video in random order, after which the subjects practiced each strategy for several minutes in the order in which the strategies were shown. The three working methods shown in the video were: 1) lifting the box without shifting of tilting it, 2) sliding the box towards the body before lifting it and 3) tilting the box towards the body before lifting it. To prevent fatigue during the training, the three working methods were shown and practiced with a light box (9.5 kg), lifted from a 63 cm high table. An additional aim of showing and practicing the working methods from a high rather than from a low initial position was that this emphasised the load handling method rather than the lifting posture. After practicing, the subjects were told that they should imagine that they worked full-time in a warehouse, where they had to lift and replace objects all day long. The subjects were encouraged to make the work as easy as possible for themselves. Then they practiced, again lifting from the table, with the emphasis on finding their personal optimal strategy for lifting the box using one of the demonstrated working methods, a combination of the demonstrated working methods or another working method not shown in the instruction video. The subjects practiced until they indicated that they had developed a working strategy that was as comfortable as possible. The entire familiarisation training usually took about 5-10 minutes.

After this familiarisation training, the lifting task with horizontal transport was repeated as part of larger experiment, consisting of 36 experimental conditions (five initial vertical box positions x two load weights x three initial horizontal box positions x three surface conditions). In this experimental protocol all 36 lifting tasks were performed twice and the order of the lifting conditions was counterbalanced over subjects. For each lifting task, the second trial was used for analysis.

Data collection and pre-processing

Ground reaction forces were measured using a custom-made 1 x 1 m force plate at a sample rate of 200 samples/s. Kinematics of the trunk, pelvis, upper legs, lower legs (+ feet) and the box were measured at a sample frequency of 50 samples/s by marker clusters containing three Optotrak markers (Northern Digital Inc., Canada). To prevent shifting of the marker clusters over the skin, they were taped and strapped to the body segments using neoprene straps (see Figure 3-1). Before kinematic and force plate data were used as input for an inverse dynamics model (see section 2.4), they were low-pass filtered with a cut-off frequency of 10 Hz. Before the experimental trials started, anatomical landmarks were related to the marker clusters using a probe with six markers (Cappozzo et al., 1995).

Data analysis

To quantify low back loading, a bottom-up dynamic 3D inverse dynamics model was applied to calculate the total net moment at the L5/S1 joint (L5/S1 total moment). This model has previously been described in detail by Kingma et al. (1996), and validated for L5/S1 moments by comparing a top-down and a bottom-up analysis. In short, this model calculates moments about a specified joint based on external forces and segment kinematics and anthropometrics. In the current study, 3D inputs of the model were ground reaction forces and kinematics and anthropometrics of body segments below the L5/S1 joint. A global equation of motion (rather than a segment by segment calculation) was used, as described by Hof (1992):

$$\mathbf{M}_{\mathbf{L5-S1}} = -\mathbf{M}_{\mathbf{g}} - \left(\mathbf{r}_{\mathbf{g}} - \mathbf{r}_{\mathbf{L5-S1}}\right)\times \mathbf{F}_{\mathbf{g}} - \sum_{i=1}^{q}\left[\left(\mathbf{r}_i - \mathbf{r}_{\mathbf{L5-S1}}\right)\times m_i\mathbf{g}\right] + \sum_{i=1}^{q}\left[\left(\mathbf{r}_i - \mathbf{r}_{\mathbf{L5-S1}}\right)\times m_i\mathbf{a}_i\right] + \sum_{i=1}^{q}\mathrm{d}(\mathrm{I}_i\boldsymbol{\omega}_i)/\mathrm{dt},$$

where $\mathbf{M}_{\mathbf{L5\text{-}S1}}$ is the net moment at the L5-S1 joint, $\mathbf{M}_{\mathbf{g}}$ is the ground reaction moment, $\mathbf{r}_{\mathbf{L5\text{-}S1}}$ is the position vector of the L5-S1 joint, $\mathbf{F}_{\mathbf{g}}$ is the ground reaction force, $\mathbf{r}_{\mathbf{g}}$ is the position vector of the point of application of the ground reaction force, $\mathbf{g}$ is the gravitational vector and q is the number of segments; $\mathbf{r}_i$, m_i, $\mathbf{a}_i$, I_i and $\boldsymbol{\omega}_i$ are, for segment i, the vector to the centre of mass, the mass, the acceleration vector, the inertia tensor and the angular velocity vector, respectively; $\mathrm{d}(\ldots)/\mathrm{dt}$ is the time derivative of the expression within parentheses.

For the present study, the model was modified with respect to the anthropometrics. Originally, linear regression equations reported by McConville & Churchill (1980) were used to calculate the inertial parameters of body segments (mass and moments of inertia) based on anthropometric measures (segment length, width and circumference). Because the parameters of 3D objects do not scale linearly with 1-D anthropometrical measures, these linear equations were replaced by non-linear regression equations reported by Zatsiorsky (2002). The positions of the centre of mass of body segments were estimated based on the same anatomical anthropometrical data from the literature (deLeva, 1996; Zatsiorsky, 2002). Furthermore, the anterior-posterior position of the centre of mass of the pelvis was estimated based on anatomical data reported by Plagenhoef et al. (1983) and the L5/S1 joint position was estimated based on anatomical data reported by Reynolds et al. (1982).

Data reduction

For all lifts analysed, the peak L5/S1 total moment was determined. Furthermore, at the instant of peak L5/S1 total moment (PTM) the following variables were determined: the amount of horizontal box shift from it's initial position towards the body (horizontal box shift prior to PTM), the 2D distance in the horizontal plane between the L5/S1 joint and the centre of mass of the box (relative horizontal L5/S1-box distance at PTM), the forward distance from the edge of the force plate to the centre of mass of the box (absolute horizontal box position at PTM), the inclination angle of the trunk segment with respect to an upright reference body posture (trunk inclination angle at PTM), the flexion angle of the lumbar spine (lumbar flexion at PTM), the tilt angle of the box towards the body (box tilt angle at PTM) and the flexion angle of the left and right knees (left knee flexion angle at PTM and right knee flexion angle at PTM, respectively). Note that subjects were instructed to stand on the force plate when lifting, thus the distance of the box from the edge of the force plate defined the minimum reach distance.

Statistical analysis

Repeated-measures ANOVAs were applied to test the effects of initial horizontal box position (close; far), task type (lifting task without horizontal transport; lifting task with horizontal transport; lifting task with horizontal transport after familiarisation) and their interaction on the following dependent variables: the peak L5/S1 total moment (PTM), the horizontal box shift prior to PTM, the relative horizontal L5/S1-box distance at PTM, the absolute horizontal box position at PTM, the trunk inclination angle at PTM, the lumbar flexion angle at PTM, the box tilt angle at PTM, and the left and right knee flexion angles at PTM. In case of a significant interaction, post-hoc dependent student t-tests were applied to test the effect of initial horizontal box position for each of the three lifting tasks and the effect of task type for both initial horizontal box positions. For all statistical tests a significance level of $p < 0.05$ was used.

RESULTS

The averaged time series for the total L5/S1 moment and for the absolute horizontal box position (Figure 3-2) suggest that horizontal transportation as well as familiarisation with different working methods affected the lifting strategy. For all dependent variables, effects of task type and initial horizontal box position are shown in Figure 3-3 and repeated-measures ANOVA results are presented in Table 3-1.

Including horizontal transportation in the lifting task before the familiarisation training did not affect the amount of horizontal box shift prior to PTM. As a result, the expected reduction in peak L5/S1 total moment for the far-positioned box, when performing a lifting task with instead of without horizontal transport, was not found. Moreover, for the close-positioned box, even an increase in peak L5/S1 total moment (14 Nm or 6%) was found when performing a lifting task with instead of without horizontal transport. This seemed to be related to the positioning of the subject with respect to the box rather than to shift of the box since a comparable tendency ($p = 0.106$) was found for the relative horizontal L5/S1-box distance while no such tendency was found for the absolute horizontal box position ($p = 0.942$). Due to the above mentioned effects, the effect of initial horizontal box distance on low back loading was smaller (but still significant) for the lifting task with horizontal transport (30 Nm or 10% higher peak moment for lifting the far-positioned compared to the close-positioned box) than for the lifting task without horizontal transport (45 Nm or 16% higher peak moment for lifting the far-positioned compared to the close-positioned box).

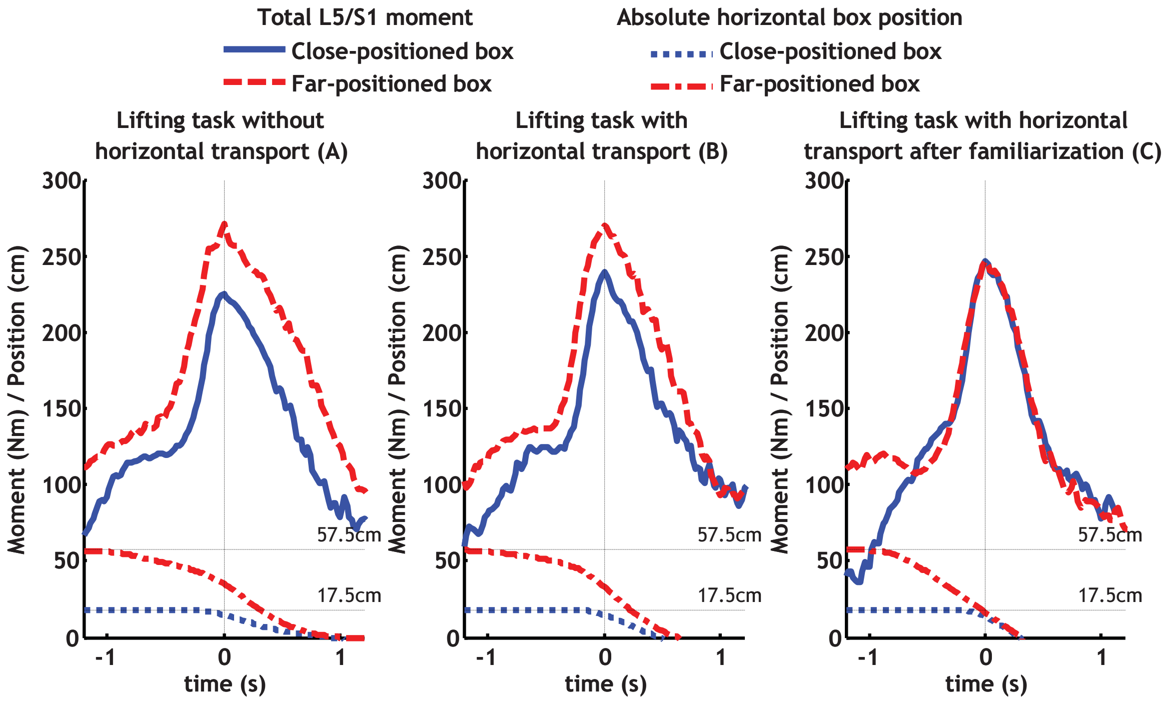

Figure 3-2. *Time series, averaged over subjects, of the total L5/S1 moment and the absolute horizontal box position. Before averaging the moment and position data over subjects these were synchronised at the instant of peak total L5/S1 moment as indicated by the vertical line in each plot.*

Table 3-1. *Results (p-values) of repeated-measures ANOVAs testing the effects of initial horizontal box position, task type and their interaction on all dependent variables.*

	Initial horizontal box position (H)	Task type (T)	H x T
Horizontal box shift prior to PTM	**0.000**	**0.001**	**0.009**
Peak L5/S1 total moment (PTM)	**0.003**	0.388	**0.000**
Relative horizontal L5/S1-box distance at PTM	**0.002**	**0.013**	**0.001**
Absolute horizontal box position at PTM	**0.000**	**0.001**	**0.009**
Trunk inclination angle at PTM	0.272	0.096	0.487
Lumbar flexion angle at PTM	0.094	0.202	**0.017**
Box tilt angle at PTM	0.199	0.639	0.419
Right knee flexion angle at PTM	0.192	0.427	0.070
Left knee flexion angle at PTM	0.122	0.226	0.051

Significant effects (p < 0.05) are indicated by bold values.

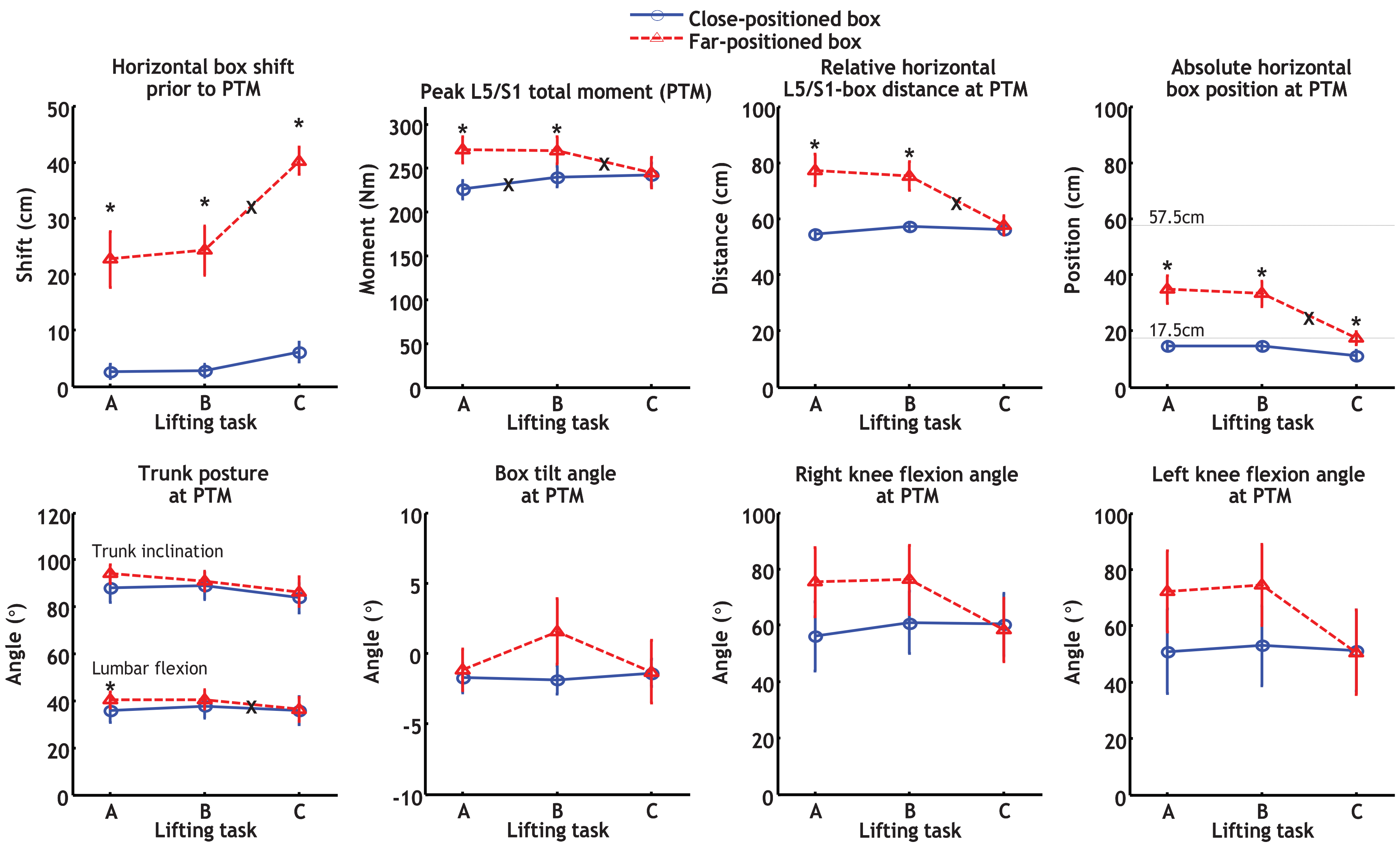

*Figure 3-3. Effect of task type and initial horizontal box position, averaged over subjects, for all dependent variables. A = lifting task without horizontal transport , B = lifting task with horizontal transport and C = lifting task with horizontal transport after familiarisation. In case of a significant interaction between the effect of task type and initial horizontal box position post-hoc test were performed. * = significant post-hoc effect of initial horizontal box position. x = significant post-hoc effect of task type. Error bars indicate 1 standard error of the mean.*

After familiarisation training, subjects shifted the box much more prior to PTM. Consequently, after familiarisation, the absolute horizontal box position at PTM was only slightly smaller for the close-positioned than for the far-positioned box. Relative to L5/S1, the box position difference at PTM between the far-positioned and close-positioned boxes completely vanished after familiarisation. As a result, in accordance with our second hypothesis, for the far-positioned box, familiarisation training reduced the peak L5/S1 total moment (by 26 Nm or 10%). In fact, the L5/S1 moment pattern was, from 0.5 seconds before the occurrence of the peak moment onwards, almost identical to the pattern found for lifting the close-positioned box (Figure 3-2).
The trunk inclination angle at PTM was about 90° in all lifting conditions and was not significantly affected by initial horizontal box position or task type. For the lumbar flexion angle a few significant effects were found but these effects were relatively small. The box tilt angle at PTM was marginal in all conditions (average tilt angles remained between -2° and 2°) and no significant effects were found. For the left and right knee flexion the pattern of results was comparable with the pattern of results found for the peak L5/S1 total moment. However, no significant effects were found.

DISCUSSION

In line with previous research (Dolan et al., 1994; Schipplein et al., 1995; Lavender et al., 1999; Ferguson et al., 2002), in the current study a significant effect of initial horizontal box position was found for the typical laboratory lifting task in which boxes were lifted without horizontally transporting them to another location. It was hypothesised that 1) instructing the subjects to transport the box to another location at a few meters distance (which is the case in most work situations) and 2) familiarising the subjects with different working methods, would cause a reduction in low back load due to changes in lifting strategy, especially for the most strenuous condition, i.e. when subjects need to reach far for the box.

Effects of horizontal box transport

In contrast with the first hypothesis, when the lifting task included box transportation, the box was not shifted closer to the body prior to the instant of peak low back loading. As a result we did not find the expected decrease in the peak total L5/S1 moment for the far-positioned box. Moreover, for the close-positioned box, the peak L5/S1 total moment even increased with 6% when including horizontal transportation in the lifting task, which seemed to be caused by a non-significant tendency of the subjects to stand further from the box during this task. The above mentioned results caused the effect of initial horizontal box distance on low back loading to be somewhat smaller for the lifting task with horizontal transport (10%) than for the lifting task without horizontal transport (16%).

Effects of familiarisation of subjects with different working methods

In accordance with the second hypothesis and previous research (Gagnon, 2003; Faber et al., 2007), we found that, after familiarising subjects with different working methods, the box at the larger initial horizontal distance was lifted closer to the body at the instant of peak low back loading. This appeared to be purely a result of an increased shift of the box towards the body and not a result of box tilt which was barely used by the subjects in the present study. Because of this increased load shift, the horizontal distance from L5/S1 to the box at the instant of peak total moment, was similar between the far- and close-positioned boxes after familiarisation training. Because trunk inclination was barely affected by initial horizontal box position, also peak low back loading was found to be similar for the far- and close-positioned boxes. This is in line with previous studies that investigated the effect of initial horizontal object position on back loading in a lifting task the subjects were familiar with (Marras et al., 1999b; Faber et al., 2007). It should be mentioned that, although no effect of initial horizontal box position on the relative horizontal L5/S1-box distance at PTM was found after familiarisation training, the far-positioned box resulted in a somewhat larger absolute horizontal box position at PTM than the close-positioned box. This disparity indicates that subjects moved less far over the force plate towards the box, when it was positioned at the smaller horizontal distance than at the larger horizontal distance.

Practical implications

The results show that the effect of initial horizontal box position on working strategy and peak low back loading was dependent on whether or not the box, after lifting it, was transported to another location and on the familiarity of the subjects with different working methods. In line with the studies that investigated subjects in a lifting task familiar to them (Marras et al., 1999b; Faber et al., 2007), the results of the current study suggest that, at the workplace, the initial horizontal load position of low-lying objects does not affect peak low back loading. However, one should be careful with generalising this result to all work situations. It is not unlikely that initial horizontal box position actually does affect peak low back loading in situations were the possibility to shift the load towards the body is limited, e.g. when lifting over another box or when lifting from a rough or uneven surface. Furthermore, it should be kept in mind that the current study focused only on lifts of low-lying objects. For lifts from higher initial vertical positions, initial horizontal box position has been shown to have a substantial effect on peak low back loading, even though the task was familiar to the subjects (Marras et al., 1999b; Faber et al., 2007). An explanation for this is that trunk inclination, which has a strong effect on peak low back loading, is affected much more by initial horizontal load position at higher initial vertical box positions (Faber et al., 2007).

Limitations

The most important limitation of the present study is that subjects attained their optimal working strategy after a short familiarisation training by practicing different instructed working methods, whereas in occupational lifting people usually acquire their optimal lifting strategy over a longer period of time by repeatedly performing the lifting tasks during work. It could be argued that familiarisation by instruction might cause different changes in working strategy, than familiarisation caused by experience with the lifting task only. However, the similarity between the present findings and findings reported in studies with experienced workers performing a familiar task (Marras et al., 1999b; Faber et al., 2007) does suggest that the present familiarisation method adequately simulates familiarisation by experience.

A second limitation of the study design is that the order in which the 3 lifting tasks were performed was fixed, which might have biased the results. Firstly, all subjects performed the lifting task without horizontal transport prior to the lifting task with horizontal transport. We chose to do this to avoid that the typical laboratory lifting task without horizontal transport would be affected by lifting experience. It could be argued that the difference in lifting experience (amount of lifts performed) rather than the difference in lifting tasks could have caused the differences found in the present study. To check whether only the amount of lifts performed could have affected the results, the lifting task with and without horizontal transport were both performed 4 times for the last 6 subjects. It was found that, in all three lifting tasks, neither task repetition nor the interaction between task repetition and initial horizontal load position significantly affected the peak L5/S1 total moment (see Figure 3-4).

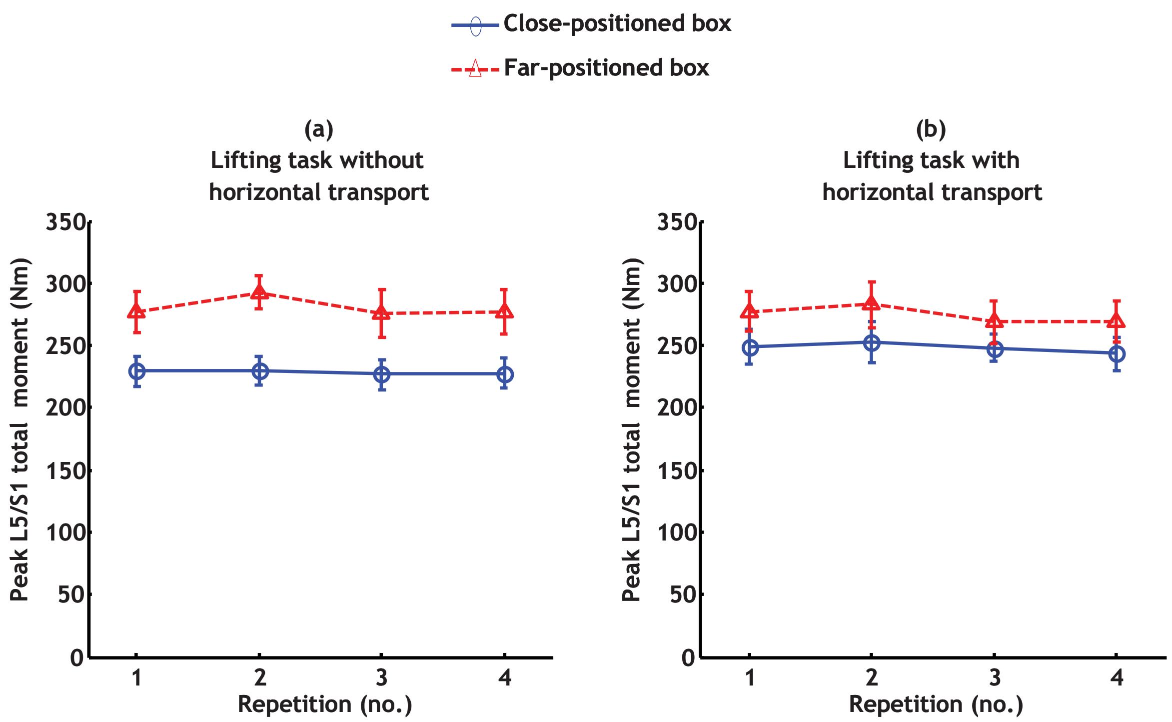

Figure 3-4. *Effect of task repetition and initial horizontal load position on peak L5/S1 total moments, averaged over subjects, for a) the lifting task without horizontal transport and b) the lifting task with horizontal transport. Error bars indicate 1 standard error of the mean.*

This result is in accordance with a previous study reporting no effect of free practice on L5/S1 moments (Gagnon et al., 2002). Therefore, it seems unlikely that the small difference in lifting experience between conditions biased the results of the present study. Secondly, the familiarised lifting task with box horizontal transport was always the last task, and because it was part of a larger set of lifting conditions, some influence of fatigue during the lifting task after familiarisation cannot be excluded. However, subjects could rest between conditions, and fatigue beyond levels seen at a normal working day therefore seems unlikely.

Another limitation of the current study is that only a relatively small group of healthy male subjects participated in the present research because we wanted to be able to make a direct comparison with previous literature in which also only healthy male subjects participated. Although there are no strong reasons to believe that the results of present study do not apply to women or to other age groups, it could be that people with low back pain might shift the far-positioned box close to the body even without familiarisation training because they might try to prevent high spinal loading which could cause pain.

It should also be mentioned that a relatively large initial horizontal distance was used for the far-positioned box and that effects of familiarisation training would probably have been less pronounced when smaller initial horizontal distances would have been used.

Furthermore, the current study only analysed the moments at the level of the L5/S1 joint while loading at higher levels in the lumbar spine could also be of interest. However, the effects for the other lumbar joints are probably comparable to the effects found for the L5/S1 joint since the changes in horizontal distance of the load with respect to the low back also apply to these joints.

Finally, a limitation of the measurement methods is that no spinal compression and shear forces, which are the most direct indicators of low back loading, were calculated in the present study. Since previous studies have shown that net moments at the L5/S1 joint are good indicators of spinal compression forces (McGill et al., 1996; van Dieën & Kingma, 2005) because effects of abdominal co-contraction are generally limited and do not vary much between tasks (van Dieën & Kingma, 2005), spinal compression forces are expected to show the same pattern as the total L5/S1 moments. Shear forces generally co-vary with compression forces, but are more dependent on lumbar posture (Kingma et al., 2004). As postural variations between conditions were small in the present study, shear forces are also expected to show the same pattern as the total L5/S1 moments.

CONCLUSIONS

In conclusion, the current study showed that working strategy and the resulting peak low back loading during lifting depended on whether or not the box was horizontally transported to another location and on how familiar the subjects were with working methods that could be used in the lifting task. Therefore, it should be recommended to measure in the actual work environment or simulate the work task as realistically as possible when studying the effect of task variables on spinal loading. In addition, subjects should be familiar with the task studied or be familiarised with the task by practicing different working methods.

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