Towards ambulatory assessment of spinal loading in the field

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Chapter 2

The effects of ergonomic interventions on low back moments are attenuated by changes in lifting behaviour

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ABSTRACT

This study investigated the effects of ergonomic interventions involving a reduction of the mass (from 16 to 11 and 6 kg) and an increase in the initial lifting height (from pallet height to 90 cm above the ground) of building blocks in a mock-up of an industrial depalletising task, investigating lifting behaviour as well as low back moments (calculated using a 3D linked segment model). Nine experienced construction workers participated in the experiment, in which they removed building blocks from a pallet in the way they normally do during their work. Most of the changes in lifting behaviour that were found would attenuate the effect of the investigated interventions on low back moments. When block mass was reduced from 16 to 6 kg, subjects chose to lift the building block from a 10 (SD 10) cm larger distance from the front edge of the pallet and with a 100 (SD 66) °/s^2 greater trunk angular acceleration. When initial lifting height was increased, subjects chose to shift the building blocks less before actually lifting them, resulting in a 10.7 (SD 10) cm increase in horizontal distance of the building blocks relative to the body at the instant of peak net total moment. Despite these changes in lifting behaviour, the investigated ergonomic interventions still reduced the net total low back moment (by 4.9 (SD 2.0) Nm/kg when block mass was reduced and 53.6 (SD 41.0) Nm when initial lifting height was increased).

INTRODUCTION

Manual materials handling has been shown to be an important risk factor for the development of occupational low back pain (Norman et al., 1998; Granata & Marras, 1999; Lötters et al., 2003). Because lifting objects requires generation of large muscular moments, causing compressive forces at the spine that could exceed the tolerance level of the intervertebral joints (Waters et al., 1993), most studies quantify low back loading either in terms of net moments or in terms of compression forces.

Ergonomic interventions could help to reduce low back loading during lifting. Many studies have investigated the effect on low back loading of ergonomic interventions such as reducing the load mass (Schipplein et al., 1990; Potvin et al., 1992; Schipplein et al., 1995; Davis & Marras, 2000), increasing the initial lifting height and decreasing the initial horizontal position of the load relative to the body (Marras et al., 1999b; Ferguson et al., 2002; Kingma et al., 2004). The majority of these studies have been performed using standardised lifting tasks: the effects of ergonomic interventions were determined, while other task-variables were held constant. For example, the effect of load mass on low back loading is generally investigated with a constant initial horizontal distance of the load. The question is, however, whether the initial horizontal position also remains constant, when the load mass is reduced in a more realistic lifting task. One could for example expect that, when load mass is reduced, the voluntary chosen initial horizontal distance from which the load is lifted increases. This hypothesis is supported by a study of Choi et al. (2004) who found that, when the mass of an object to be lifted was reduced, subjects did tend to increase the voluntarily chosen horizontal distance between the body and the object.

Some studies have investigated the effect of ergonomic interventions in more realistic lifting tasks, but changes in lifting behaviour as a function of these interventions were not reported (de Looze et al., 1996; Marras et al., 1999b). Therefore, we studied the effects on lifting behaviour as well as on low back loading of a reduction of load mass and of an increase in lifting height of building blocks in a mock-up of a depalletising task often performed in construction work. Low back loading was quantified as the net moment at the L5/S1 joint. Lifting behaviour was characterised using kinematic variables that have been shown to be determinants of low back moments (Plamondon et al., 1996; Kingma et al., 2006). Those variables are the horizontal distance of the load, the trunk angular acceleration and the trunk posture. It was hypothesised that ergonomic interventions lead to changes in lifting behaviour that attenuate the effects of the interventions on the net moments at the L5/S1 joint.

METHODS

Subjects

After signing an informed consent form, nine healthy male construction workers, mean (SD) age 36 (13) years, body mass 89 (14) kg, height 1.84 (0.08) m participated in the experiment. The subjects had at least 6 months of experience working with calcareous sandstone building blocks such as the ones used in the experiment.

Procedure

A repeated-measures experimental design was used, in which the subjects performed a depalletising task with three types of calcareous sandstone building blocks of different mass and dimensions (Figure 2-1).

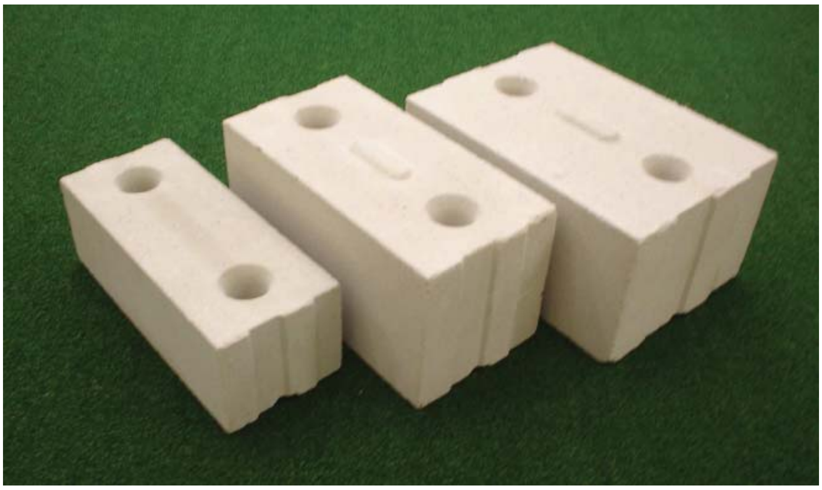

Figure 2-1. *From left to right, the 6 kg, 11 kg, and 16 kg building blocks used in the present study.*

To limit the amount of lifting during the experiment, not all the layers with building blocks had to be removed from the pallet, but building blocks were only lifted from two lifting heights (presented in separate experimental conditions) representing the top and bottom layer of a standard pallet loaded with calcareous sandstone building blocks (Figure 2-2). Lifts of the building blocks from the layers in between the bottom and top layer of the pallet are expected to result in low back moments that lie within the range of low back moments that occur during the lifts of the building blocks from the top and the bottom layer of the pallet.

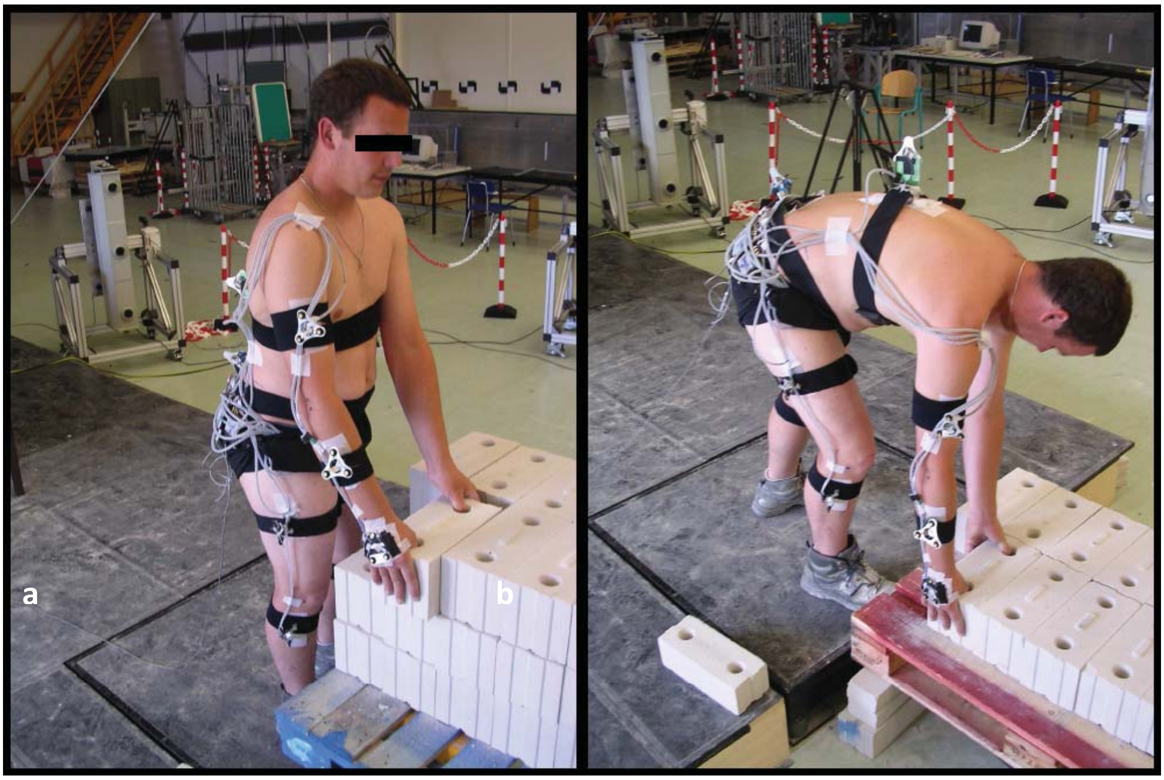

Figure 2-2. *Depalletising task: lifting from the top (a) and bottom layer (b).*

For lifting from the high initial lifting height (top layer, Figure 2-2a), three layers of building blocks were stacked on a pallet which was elevated such that the top of the third layer was at a height of 90 cm. To give the subjects the opportunity to use the depalletising method that they normally use in their daily work (i.e. the layer by layer or pyramid/stepping method), they were allowed to also lift the building blocks from the layer beneath the top layer of the pallet, but these lifts were not analysed because otherwise a fair comparison between lifting conditions would not be possible. For lifting from the low initial lifting height (bottom layer, Figure 2-2b), only one layer of building blocks was placed on the pallet, which had a height of 10 cm.

The masses of the three building blocks that were used for the experiment (as shown in Figure 2-1) were 6, 11 and 16 kg. Their dimensions, respectively, were 30 x 12 x 10 cm, 30 x 15 x 14.5 cm and 30 x 21.5 x 14.5 cm (width x depth x height). The 16 and 11 kg building blocks were both reported to be used frequently in the construction industry in the Netherlands. Based on the National Institute for Occupational Safety and Health 1991 equation (Waters et al., 1993), the 6 kg building block was previously recommended as an upper limit for the mass of blocks handled by brick layers (Arbouw, 2002). The building blocks were stacked on a pallet in the way they are normally stacked in the construction industry (Figure 2-2). As the height of the pallet was 10 cm, the height above the ground of the top of the building blocks, when lifting from the bottom layer, was 20 cm for the 6 kg building blocks and 24.5 cm for the 11 and 16 kg building blocks.

For both initial lifting heights, subjects were instructed to lift the building blocks from the right side of the pallet only (to reduce the number of lifts performed in the experiment) and to keep on removing building blocks from the pallet until they felt they would normally walk around to the other side of the pallet or step on the pallet. In this way, subjects were free to choose how many blocks they would lift in each condition (three building block conditions x two initial lifting heights). After lifting each building block, subjects placed it on a table at a distance of about 1.5 m behind them to obtain the natural pace of lifting they would normally use when moving building blocks from the pallet to the wall that is being constructed. No specific instruction was given with respect to the position of the hands on the block, but the blocks were generally grasped in the standard way, with the thumbs in the holes on top of the building block (as seen in Figure 2-2). The order in which the lifting tasks were performed was systematically varied over subjects to correct for possible order effects. The lifts of the first and the last building block in each condition were analysed.

Data analysis

A dynamic 3D linked segment model, described in detail by Kingma et al. (1996) together with its validation (by comparing a top–down to a bottom–up calculation of net moments), was used to estimate net moments at the level of the L5/S1 intervertebral joint. This model calculates the net moment around the L5/S1 joint on the basis of external forces, kinematics of body segments and anthropometrical data. In the present study, a bottom-up analysis was used. Mass, position of the centre of mass and the inertia tensor of each segment were calculated using regression equations published by McConville & Churchill (1980). Kinematics were measured using a cluster marker construction of two metal plates connected with a double hinge joint. One of the metal plates was taped and strapped to the relevant body segment with an elastic neoprene band. On the other plate, three LED markers were placed (as shown in Figure 2-2). These marker clusters were placed on the pelvis, lower legs (+ feet) and upper legs. Clusters of markers were also placed on the trunk and the right hand, but the data from these were not used in the linked segment analysis. The positions of the markers were measured in three dimensions at a sample rate of 50 Hz using an Optotrak system (Northern Digital Inc., Canada). Markers on each segment were related to anatomical landmarks by making a short recording while pointing at each landmark (Cappozzo et al., 1995) with a pointer containing six markers. The ground reaction force (the external force at the feet) was measured by a custom-made 1 x 1 m force plate at 200 Hz. Force plate data were synchronised to the Optotrak system and stored. Kinematic and force plate data were low-pass filtered at 10 Hz before they were used as inputs to the linked segment model. A global equation of motion (rather than a segment by segment calculation) was used, as described by Hof (1992) with, as a small modification, the addition of the reaction moment about the vertical measured by the force-plate. The use of this global equation of motion allows the use of one instead of two force plates. Anatomical axes of the trunk and pelvis were defined as follows: positive X-axis (lateral flexion) forward; positive Y-axis (flexion-extension) to the left; positive Z-axis (twist) upward. The trunk movement relative to the pelvis (3D lumbar angles) was decomposed in the order Y - X - Z (Euler-decomposition). The 3D components of the net moment (net extension, net lateral flexion and net twist moment) were obtained by projecting the net moment on the local axes of the pelvis.

Statistical analyses

For all conditions, the peak values of the net total moment around the L5/S1 joint, as well as of the absolute 3D components of the net moment at the instant of the peak net total moment were calculated as indicators of low back load. To characterise lifting behaviour, peak value of the initial forward horizontal distance between the edge of the pallet and the centre of the building block lifted (the initial horizontal block position on the pallet) and the peak value of the forward horizontal distance between the L5/S1 joint and the right hand (the initial horizontal L5/S1-hand distance) were determined in each lift. In addition, at the instant of peak net total moment, the following variables were determined: forward horizontal L5/S1-hand distance; trunk inclination (with regard to the vertical); trunk angular acceleration, and absolute 3D lumbar angles (lumbar flexion, lumbar lateral flexion and lumbar twist angle).

A repeated-measures ANOVA was used to test for the effect of first/last block (2 levels), initial lifting height (2 levels) and block mass (3 levels) on the above-mentioned dependent variables. Note that with block mass block dimensions varied as well. Significant three- and two- way interactions were further scrutinised by analysing the appropriate one- and two- way ANOVAs, respectively (simple effect analysis (Keppel, 1991)).

For the initial horizontal block position on the pallet, only the lifts of the last block were included in the statistical analysis. The reason for this was that, for the first block, this distance was invariant over subjects and only depended on block dimensions. The initial horizontal block position of the last block was not invariant over subjects since subjects were free to choose the number of blocks lifted in each lifting condition.

RESULTS

The results of the repeated-measures ANOVA for each dependent variable are given in Table 2-1 and are explained in more detail in the following sections.

For the initial horizontal block position on the pallet only, the lifts of the last blocks were included in the statistical analysis (see section 2.4 for an explanation). Therefore, the main effect of first/last block and the interaction of first/last block with the other independent variables could not be determined. Only a main effect of block mass was found to be significant for the last block: participants chose to grasp building blocks from a greater horizontal distance from the edge of the pallet when block mass was reduced (1.0 (SD 1.0) cm per kg).

Table 2-1. *Results of repeated-measures ANOVAs (p-values) applied to all dependent variables.*

	Initial		**At the instant of peak net total moment**									
	Horizontal block position on the pallet	**Horizontal L5/S1-hand distance**	**Horizontal L5/S1-hand distance**	**Trunk inclination**	**Trunk angular acceleration**	**Net total moment**	**3-D lumbar angles**			**3-D net moments**		
							Flexion	**Lat flex**	**Twist**	**Extension**	**Lat flex**	**Twist**
First/last block (FL)	**-**	**<0.001**	**0.001**	**0.001**	0.518	**0.002**	**0.033**	**0.017**	0.068	**0.004**	**0.005**	0.535
Initial lifting height (H)	0.296	0.585	0.336	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**0.029**	0.691	**<0.001**	**0.014**	0.315
Block mass (M)	**0.009**	**0.020**	**0.011**	**0.029**	**0.001**	**<0.001**	0.161	0.143	0.255	**<0.001**	0.215	0.507
FL * H	-	0.052	**0.004**	**0.001**	0.131	**<0.001**	0.269	0.313	0.468	**<0.001**	**0.028**	**0.019**
FL * M	**-**	**0.015**	0.108	0.130	0.745	0.322	0.297	0.100	0.852	0.207	0.416	0.537
H *M	0.382	0.659	0.127	0.954	0.701	0.427	0.105	0.152	0.920	0.296	0.758	0.791
FL * H * M	-	0.109	0.686	**0.002**	0.788	0.473	**0.019**	0.900	0.323	0.262	0.230	0.339

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

For the initial horizontal L5/S1-hand distance (Figure 2-3, middle panel), the last block resulted in a larger horizontal distance than the first block. However, this difference in horizontal distance was about 10 cm smaller than the difference found for the initial horizontal block position on the pallet (compare the left and the middle panels in Figure 2-3). This indicates that people chose to stand further away from the pallet, when they grasped the first instead of the last block. An interaction was also found between block mass and first/last block. The initial horizontal L5/S1-hand distance was not significantly affected by block mass for the first block ($p = 0.273$), whereas, for the last block, subjects chose to lift from a larger initial horizontal distance from the body when block mass was reduced (0.8 (SD 0.5) cm per kg, $p < 0.001$).

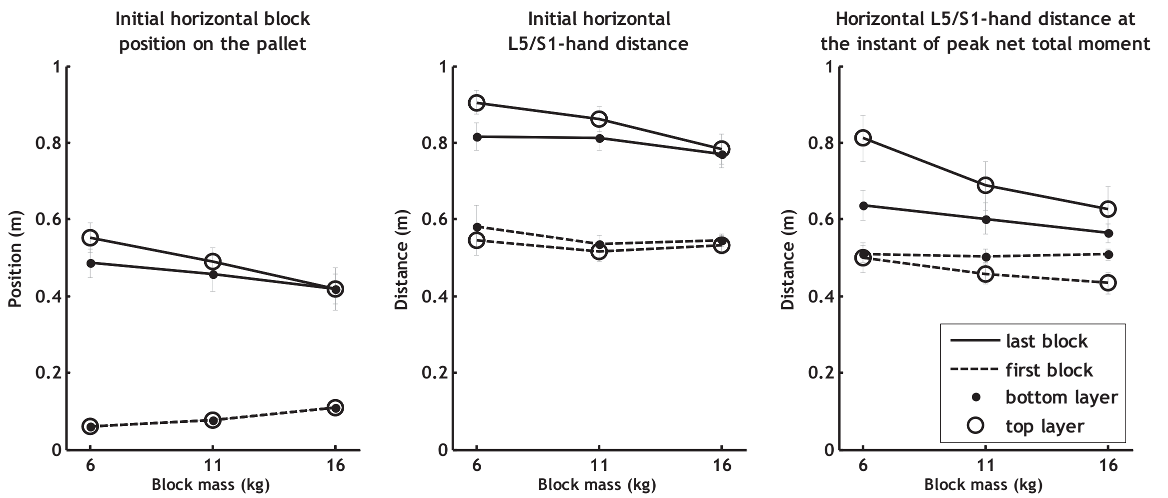

Figure 2-3. *Initial horizontal block position on the pallet (left), Initial horizontal L5/S1-hand distance (middle) and the horizontal L5/S1-hand distance at the instant of peak net total moment (right) for all experimental conditions. Error bars indicate 1 standard error of the mean.*

Prior to actually lifting the building block (peak net total moment) subjects shifted the building block towards the body. This shift was larger for the last blocks than for the first blocks, especially when lifting from the bottom layer (compare Figure 2-3, middle and right panels). As a result, the difference in horizontal L5/S1-hand distance between the first and the last block was significantly smaller at the instant of the peak net total moment than at the initiation of the lift (11.4 (SD 10.0) cm smaller, $p = 0.009$). Additionally, a significant interaction between first/last block and initial lifting height was found. For the first block, the horizontal L5/S1-hand distance at the instant of peak net total moment did not differ significantly between the two initial lifting heights ($p = 0.075$). For the last block, there was a borderline significant tendency ($p = 0.051$) for subjects to adapt their lifting behaviour in such a way that the horizontal L5/S1-hand distance at the instant of peak net total moment increased (10.7 cm (SD 14.0) cm) when initial lifting height was increased. A main effect of block mass was found on the horizontal L5/S1-hand distance at the instant of peak net total moment. Subjects chose to lift the building blocks from a larger horizontal L5/S1-hand distance when the block mass was reduced (0.8 (SD 0.8) cm per kg).

Also trunk motion was affected by initial lifting height, first/last block and block mass. Not surprisingly, lifting from the bottom layer resulted in a 59.6 (SD 6.7)° larger trunk inclination than lifting from the top layer (Figure 2-4, left panel). More interestingly, a three-way interaction between all independent variables was found, indicating a complicated interdependency of first/last block, initial lifting height and block mass in their effects on trunk inclination. When block mass was reduced, trunk inclination increased significantly for lifting the first block from the bottom layer (0.6 (SD 0.6)° per kg, $p = 0.039$) and for lifting the last block from the top layer (0.9 (SD 1.1)° per kg, $p = 0.029$). For lifting the first block from the top layer and lifting the last block from the bottom layer, the effects of block mass were not significant ($p = 0.593$ and $p = 0.283$, respectively).

For the trunk angular acceleration (Figure 2-4, middle panel) only significant main effects of initial lifting height and block mass were found. When the block mass was reduced, subjects increased trunk angular acceleration (10.0 (SD 6.6)°/s ^{2} per kg), whereas, when the initial lifting height was increased, trunk angular acceleration decreased (by 126.5 (SD 50.8)°/s ^{2}).

Despite the changes in lifting behaviour, main effects of first/last block, initial lifting height and block mass on the net total moments were all significant (Figure 2-4, right panel). Block mass did not interact with the other independent variables (first/last block and initial lifting height). Overall, the effect of block mass on the net total moment was 4.9 (SD 2.0) Nm/kg. A strong interaction was found between first/last block and initial lifting height. The effect of initial lifting height on the net total moment was significantly larger for the first block than for the last block ($p < 0.001$). When the initial lifting height was increased, the net total moment increased with 99.6 (SD 25.4) Nm for the first block ($p = 0.004$) and with 53.6 (SD 41.0) Nm for the last block ($p < 0.001$). Furthermore, the effect of first/last block was significant for lifting from the top layer (the last block resulted in a 46.3 (SD

24.9) Nm higher net total moment than the first block, p = 0.001) but, surprisingly, not for lifting from the bottom layer (p = 0.943). The absence of a significant difference in net total moment between the first and the last blocks when lifting from the bottom layer is at odds with the small but significant difference found for the horizontal L5/S1-hand distance at the instant of peak net total moment between these two conditions. An explanation for this could be found in the total net reaction force at the L5/S1 joint at the instant of peak net total moment which represents forces due to the upper body (and block) mass plus acceleration. This reaction force was significantly higher (p = 0.008) for the first block than for the last block when lifting from the bottom layer. This indicates that the first block was lifted with higher upper body (+ block) acceleration than the last block. This would increase the net total moment for the first block, apparently causing the difference in the net total moment between the first and the last block to become non-significant when lifting from the bottom layer.

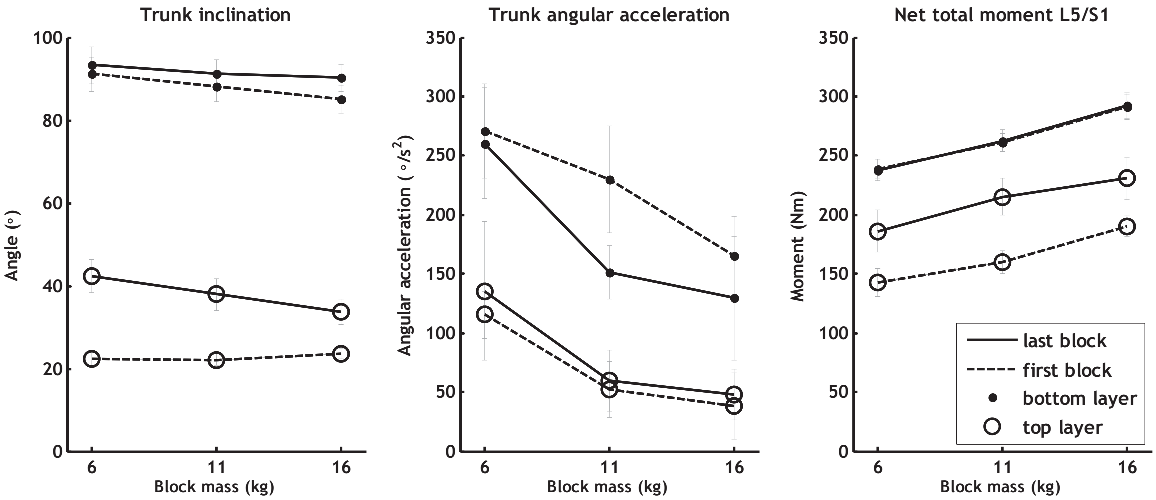

Figure 2-4. *Trunk inclination (left), trunk angular acceleration (middle) net total moment (right) for all experimental conditions. Error bars indicate 1 standard error of the mean.*

In Figure 2-5, 3D components of the lumbar angle (angle between trunk and pelvis) and the net moment at the L5/S1 joint are plotted. The lumbar flexion angle and the net extension moment showed similar tendencies as the trunk inclination and the net total moment, respectively. Although building blocks were symmetrically stacked in front of the subjects, substantial asymmetric lumbar angles and asymmetric net moments were found. When the initial lifting height was increased, the lumbar lateral flexion angle decreased and lifting the first block resulted in a smaller lumbar lateral flexion angle than lifting the last block. For the net lateral flexion moment an interaction between first/last block and initial lifting height was found. Only for the last block (and not for the first block, p = 0.200) a significant increase in net lateral flexion moment was found when initial lifting height was increased (p = 0.005). Lifting the first block resulted only in a significantly (p = 0.008) lower net lateral flexion moment than lifting the last block when lifting from the top layer (and not when lifting from the bottom layer, p = 0.134). The net twist moment was relatively small. A significant interaction was found between first/last block and initial lifting height, but the simple effect analyses did not reveal any significant effects (p = 0.565 and p = 0.117 for the effect of initial lifting height when lifting the first and the last building block, respectively). Reducing the block mass did not have significant effects on asymmetric lumbar angles or asymmetric net moments.

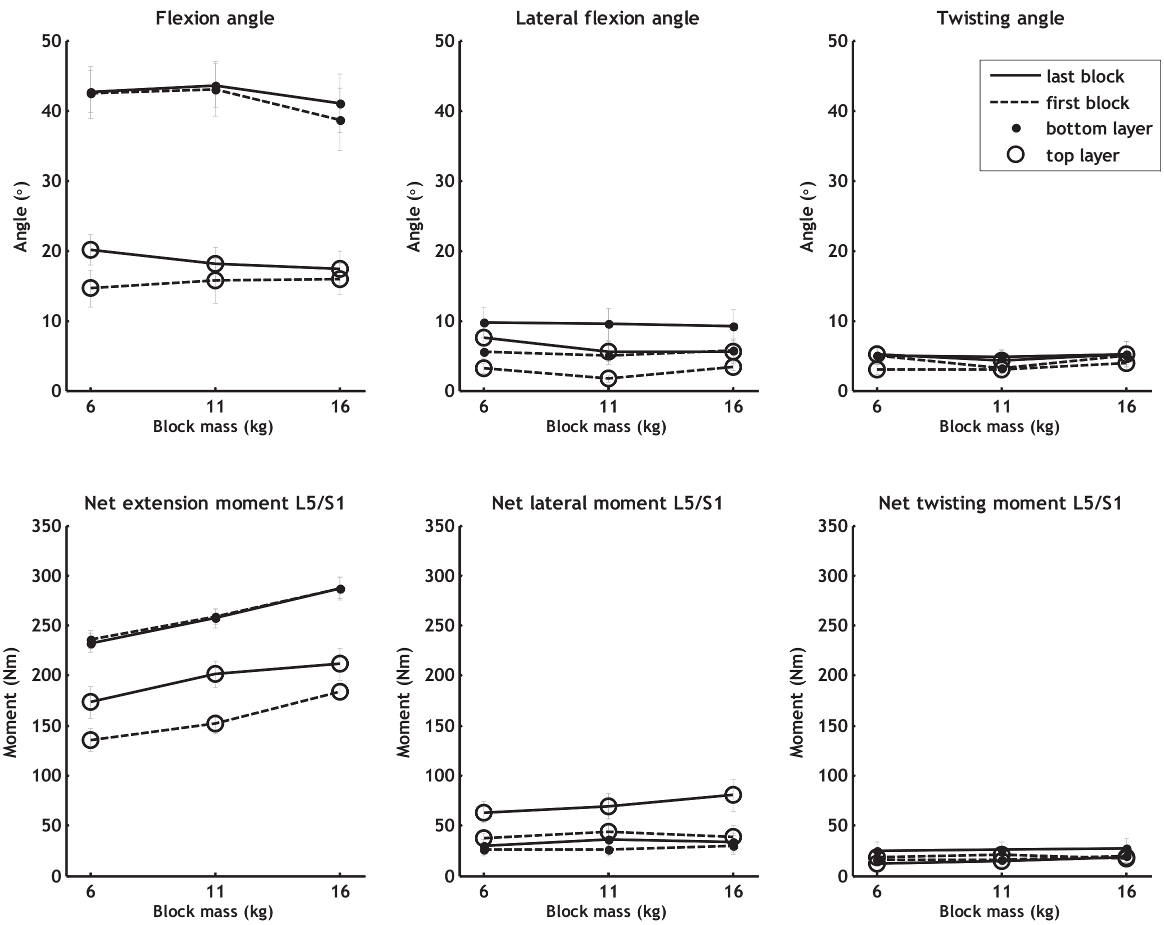

Figure 2-5. *3D components of the lumbar angle (upper panel) and net moment around the L5/S1 joint (lower panel) for all experimental conditions. Error bars indicate 1 standard error of the mean.*

DISCUSSION

The net total moments found in the present study are within the range of net moments found in studies that have investigated the effect of lifting on the net moment with comparable task variables (Schipplein et al., 1990; Potvin et al., 1992; Tsuang et al., 1992; Schipplein et al., 1995; Granata & Marras, 1999; Lavender et al., 1999; Kingma et al., 2004; Kingma & van Dieën, 2004).

In line with the hypothesis, subjects did indeed change their lifting behaviour in such a way that the intended effects of ergonomic interventions (decreasing block mass and increasing initial lifting height) on low back moments would be attenuated.

Effect of block mass

When block mass was reduced, subjects increased their trunk angular acceleration and the horizontal L5/S1-hand distance at the instant of peak net total moment for both the first and the last block that was lifted. For the first block, the reduction of block mass had no effect on the initial horizontal L5/S1-hand distance. These results are in line with the findings of Davis & Marras (2000) who studied the effect of load mass (in the range 9.1 – 41.8 kg) in a lifting task that was comparable to the first block that was lifted in the present study: subjects had to grasp the load from a shelf at knee height, walk 1.5 m and place the load on a shelf at elbow height. As in the present study, they found an increase in maximum trunk angular acceleration (relative to the pelvis) and no change initial horizontal L5/S1-hand distance when load mass was reduced. Other studies that used more standardised lifting tasks found either no (Allread et al., 1996) or a very small (Ferguson et al., 1992) effect of load mass on trunk angular acceleration. The three above-mentioned studies did not report horizontal L5/S1-hand distance at the instant of peak low back loading. For lifting the first block from the bottom layer, a small increase in trunk inclination was also found when block mass was reduced, but the effect of this increase in trunk inclination on low back moments was probably small in this condition because the trunk inclination angle was around 90° and the shift of the centre of mass of the trunk (a main determinant of low back moments) is dependent on the sine of this angle. For the last block, reduction of block mass also resulted in a larger initial horizontal L5/S1-hand distance. In addition, for lifting from the top layer, an increase was also found in the trunk inclination angle. The effect of this increase in trunk inclination on low back moments was probably substantial in this condition since the trunk inclination angle was around 40°.

Effect of initial lifting height

When the initial lifting height was increased, no effect was found on chosen initial horizontal block position on the pallet, but the horizontal distance of the last building block at the instant of peak net total moment did increase substantially with increasing lifting height. This indicated that subjects shifted the last block less before actually lifting it, when they lifted from the top instead of the bottom layer. This effect could have been caused by the friction between the building block and the support surface, which was possibly larger when lifting from the top layer than when lifting from the bottom layer: when lifting from the top layer, the support surface consisted of building blocks, whereas, when lifting from the bottom layer, the wooden pallet served as support surface.

Effect of initial horizontal block position

Although the initial horizontal block position on the pallet was not systematically varied, the effect of this task-variable on lifting behaviour could be investigated by comparing the first and the last blocks that were lifted. When the initial horizontal block position on the pallet was decreased (comparing first and last block) subjects chose to stand further away from the pallet and shifted the building blocks less towards the body before the instant of peak net total moment. As a result, the difference between the first and the last block in horizontal distance of the building block at the instant of peak net total moment was much smaller than the difference between the first and the last block in initial horizontal block position on the pallet. This would attenuate the effect of an intervention aimed at reducing the horizontal position of a load. This is illustrated by the surprising result that no significant difference in net total moment between the first and last block was found when lifting from the bottom layer, although the difference in initial horizontal block position on the pallet was on average about 40 cm. Comparable results were found in a previous study by Marras et al. (1999b) in which the effect of box location on a pallet in a realistic mock-up depalletising task was investigated. They also found practically no effect of initial horizontal box position on low back loading when lifting from a low initial lifting height (about 2% increase in compression force, no significance reported), whereas the effect when lifting from a high initial lifting height was substantial. However, this finding is in contrast to the results of Schipplein et al. (1995) who actually found a relatively large significant increase in net extension moment (23%) as a result of a 40 cm increase in the initial horizontal position of a box when lifted from the ground. Lavender et al. (1999) found similar results. A possible explanation for this is that in these studies (Schipplein et al., 1995; Lavender et al., 1999), a standard lifting tasks was used in which subjects were less free to adapt their lifting behaviour to changing horizontal distance. Subjects were not allowed to change foot placement during these experiments and maybe did not to shift the load as much as found in the present study before the instant peak net total moment. Another explanation could be that the subjects in these studies were not experienced in lifting, whereas in the study of Marras et al. (1999b) and in the present study only experienced lifters participated in the experiments. Experience in lifting could have an effect on the lifting behaviour as reported by Gagnon (2005).

In contrast to the above mentioned changes in lifting behaviour (which would all attenuate the effect of ergonomic interventions on low back moments), trunk angular acceleration decreased when the initial lifting height was increased and would thereby strengthen the effect of the initial lifting height on low back moments. However, this phenomenon will probably also be found in a standard lifting task because it is most likely related to the difference in the required vertical motion trajectory of the upper body between lifting from the bottom and top layers, rather than to the difference in chosen lifting behaviour.

It is noteworthy that, although the building blocks were symmetrically stacked in front of the subjects, asymmetric lumbar angles and asymmetric net moments were substantial, especially for the last block lifted. It appeared that the subjects did not choose to lift in a symmetric way in the industrial depalletising task investigated. This is probably because the subjects, as in their occupational practice, had to place the building blocks behind them and therefore chose to stand more sideward in front of the pallet so that the building block could be moved more easily to the table behind them as would be done when placing the blocks in a wall (see Figure 2-2).

Reducing the block mass had no effect on asymmetric lumbar angles and asymmetric net moments. When comparing the first and the last block lifted (effect of horizontal distance), it was found that the net lateral flexion moment (only significant for lifting from the top layer) and the lumbar lateral flexion angle were smaller for the first block lifted. This could lead to lower spinal loading (Marras & Davis, 1998). This reduction may therefore strengthen the effect of reducing the horizontal distance. When the initial lifting height was increased, the asymmetric net lateral moment increased (only significant for the last block lifted) whereas the asymmetric lumbar lateral flexion angle decreased. The resulting effect on the injury risk is not known.

Limitations

A limitation of the present study was that the effects of the interventions were investigated for a specific population (male construction workers), in a specific lifting task (an industrial depalletising task) and with a small number of subjects. Consequently, the results of the present study can probably not be directly generalised to other work situations. However, this was not the goal of the present study, and the results even emphasise that, in most cases, it is not a good idea to generalise results from laboratory studies to the work field because it is hard to predict how interventions affect lifting behaviour. Another limitation of the present study is that muscle activity was not measured during the experiment. As a result, spinal forces could not be calculated for the experimental trials. However, previous studies have shown that net moments at the L5/S1 joint are good indicators of spinal loading (McGill et al., 1996; van Dieën & Kingma, 2005) since abdominal co-contraction is generally small and does not vary much between tasks (van Dieën & Kingma, 2005). Finally, the location of the right hand was used as measure for the horizontal distance of the block. This was done because, otherwise, markers would have been needed on all the blocks that could have possibly been lifted from the top and bottom layers of the pallet. The horizontal hand position does not exactly represent the horizontal position of the centre of mass of the block. However, it is unlikely that this has affected our findings with regard to lifting behaviour because subjects grabbed the bricks in a consistent way over conditions. Importantly, this inexact representation of the centre of mass of the block cannot have affected the net moments calculated at the L5/S1 joint, as we used a bottom-up inverse dynamics calculation, involving only force plate data and leg and pelvis kinematics.

CONCLUSION

In conclusion, it was found that subjects did change their lifting behaviour in response to ergonomic interventions. The behavioural changes were mostly such that the effect of ergonomic interventions on low back moments would be attenuated. The results show that individuals interact with the workplace and that simple changes (interventions) in the work situation may not always result in the desired effects on low back moments since the individuals may adapt their lifting behaviour. Moreover, individual adaptations in lifting behaviour are likely to interact with the experience of the worker with the task. Therefore, to obtain accurate estimates of the effect of ergonomic interventions on low back moments, it is important to closely simulate the work situation of interest in a mock-up experiment (performed by subjects that have experience with the particular lifting task), or even better, to investigate the effect of ergonomic interventions at the workplace.

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