Underestimation of object mass in lifting does not increase the load on the low back
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Introduction
Mechanical loading is suggested to be an important factor in the development of low back pain (Pope & Novotny, 1993, van Dieën et al., 1999). From epidemiological data it can be concluded that especially sudden, unexpected loading on the low back is related to a high incidence of low back pain (Magora, 1973, Manning et al., 1984). Experiments in which sudden loading was applied during standing revealed increased compression forces on the spine and increased trunk flexion angles (i.e. Cholewicki & McGill, 1996; Cresswell et al., 1994; Thomas et al., 1998; Mannion et al., 2000), which may cause injury to the spine and hence explain this association. A presumably more common source of unexpected loading is an incorrect estimation of the mass of an object to be lifted. Such loading may occur for example when nursing staff handles patients (Ljungberg et al., 1989) or when drivers unload trucks. During this more dynamic daily activity, i.e. lifting, a higher loading could not be demonstrated (van der Burg et al., 2000), which may be due to experimental constraints.

This study was designed to investigate in more depth whether the underestimation of a mass in a whole body, bimanual lifting task increases low back loading. High pre-load levels of the trunk reduced trunk rotations and co-activation in response to a perturbation during stance (Krajcarski et al., 1999). This will attenuate the increase in spinal compression force. Therefore, expected load mass was assumed to mediate the effects of underestimation. We studied the effect of an unexpected addition of 10 kg to two expected masses of 1.6 kg and 6.6 kg. All lifts were performed at a self-selected lifting velocity. Low back load was studied by analysing the torque at the L5-S1 joint, the maximum lumbar angle and the compression force at the L5-S1 joint.

Materials and methods
Ten male subjects (age 21.9 years (SD 2.4), height 1.82 m (SD 0.07), body mass 72.2 kg (SD 10.2)), none of whom had a history of back pain, participated in the experiment. All subjects provided written consent prior to the experiment. The subjects were asked to lift a box, weighting between 1.6 and 16.6 kg, from floor level to acromion height in a self-selected, symmetrical lifting movement. The protocol had been approved by the local ethics committee.

The experiment consisted of 4 series of lifting movements, of which the sequence was varied between the subjects. In all series the same box was used, in which different weights were placed to vary the box mass. To study the unperturbed lifting movements, the subjects performed at least 10 lifting movements with constant box masses of 1.6 kg, 6.6 kg, 11.6 kg or 16.6 kg. At the end of the two expected low mass series (1.6 kg and 6.6 kg), a mass of 10 kg was unexpectedly placed in the box (unexpected loading conditions; respectively 11.6 (1.6) kg condition and 16.6 (6.6) kg condition). The last two lifting movements of each of the four constant box mass conditions were recorded as well the lifting movements in which the mass of the box was unexpectedly increased.

The lifting movement was recorded at 100 Hz using an automated video based recording system (Optotrak™, Nothern Digital Inc., Canada). Ten LED’s were placed on the skin on the right side of the body to indicate the location of the joints and three markers were attached to the box. Ground reaction forces were recorded simultaneously with the movement registration at 100 Hz by means of a force platform (Kristler, 9218B). The torque at the lumbo-sacral (L5-S1) joint was calculated with the use of a dynamic two-dimensional linked segment model (Looze et al., 1992).

To estimate spinal compression, an EMG driven model as described in van Dieën et al.(2000) and van Dieën & Kingma (1999) was used, comprising 90 muscles crossing the L5-S1 joint. Muscle forces were
estimated as the product of the maximum muscle stress, normalised and time shifted (120 ms) EMG amplitude and correction factors for the instantaneous muscle length and contraction velocity. Maximum muscle stress was iteratively adjusted to obtain maximum agreement (least squares) between the time series of the muscle moments and net external moments. EMG data were obtained by surface-EMG recordings of the prime back and abdominal muscles. For normalisation of the signals, the subjects performed maximum voluntary isometric contractions as described by McGill (1991). The maximum value of the three attempts was used for normalisation.

For both mass conditions (11.6 kg and 16.6 kg) an analysis of variance with repeated measures (ANOVA) was used to test the effects of condition (expected low mass, expected heavy mass, and unexpected loading) on the maximum values of the torque at the L5-S1 joint, the lumbar angle and the spinal compression. Significant effects were examined with paired t-tests (two-sided) to test, which conditions significantly differed from each other. In view of the intra-individual variance this was not done for the muscle activity data. Effects were considered to be significant at \( p<0.05 \).

**Results & Discussion**

The subjects did not expect the mass of the box to be heavier in the unexpected load conditions. Before the start of the lifting movement, most parameters of the unexpected load conditions were similar to the low mass condition. Furthermore, the muscle activity after the start of the lifting movement was different from the heavy mass condition. In addition, a more global parameter, the net torque, showed no difference between the low mass conditions and the unexpected conditions before the onset of the lifting movement.

Underestimation of the mass to be lifted did not cause an increase in low back loading. Although the abdominal muscle activity showed a small peak just after the start of the lifting movement, the maximum compression forces in both unexpected loading conditions were similar to the heavy mass conditions (Figure 1, 11.6 (1.6) kg: 5826 - 6023 N, \( p=0.40 \); 16.6 (6.6) kg: 6300 N – 6496 N, \( p=1.00 \)). The maximum net torque at the L5-S1 joint in 11.6 (1.6) kg and the 16.6 (6.6) kg conditions were not significantly different from the corresponding expected heavy mass conditions (Figure 1; 220 Nm - 232 Nm, \( p=0.925 \); 243 Nm – 246 Nm, \( p=1.00 \) respectively). With similar mean back loads, an increased injury risk may be present due to increased variation in back loads and thus an increased probability of peak forces that exceed the injury threshold. However, in this experiment the variations in back load parameters were similar in expected and unexpected loading conditions (Figure 1).

When subjects underestimate the mass, the trunk flexion did not increase, which indicates that no sudden stretch on the posterior structures of the back occurred. The maximum lumbar angle in the 16.6 (6.6) kg condition was not significantly different from the 6.6 and 16.6 kg conditions (\( p=0.31 \), Figure 1). In the 11.6 (1.6) kg condition the maximum lumbar angle was significantly smaller than in the 11.6 kg condition (75.0° compared to 71.8°, \( p=0.005 \)). However, the differences in lumbar angle between these conditions appeared to be very small (Figure 1).
As an indication of the quality of the compression model predictions, the correlation between the net torques and the estimated muscle torques was calculated. All muscle torque estimates were strongly correlated to the net torque (78% above r=0.80). The compression forces found in this study are comparable to the compression forces that are usually described in literature (van Dieën et al., 1999). Although there may be some experimental errors due to the model used, the error will be systematic, in other words the comparison between the different conditions will be valid. Furthermore, we used additional indicators of low back load (i.e. net torque, muscle activity), of which the results converge to the same conclusion.

Expected load mass did not mediate the increase in spinal compression in the unexpected conditions. In both unexpected conditions the compression forces and net torque were similar to the expected heavy mass conditions (Figure 1). However, according to our expectations, the movement pattern was more disturbed in the low mass condition than in the heavy mass condition (Figure 2).

![Figure 2: Time series of the lumbar angle for the 11.6 (1.6 kg) condition (left) and the 16.6 (6.6) kg condition (right). Each trial was synchronised in time to the onset of upward lift force.](image)

So, these data indicate that subjects are able to adequately correct the lifting movement to the heavy mass when they lift an underestimated mass at a self-selected, low velocity. Consequently, no excessive loading will occur. However, it cannot be excluded that unexpected loading will occasionally be the cause of injury due to corrective responses, which did not occur in the limited number of perturbed trials recorded in the present experiment. Also larger discrepancies between the expected mass and the actual mass than studied here might lead to other effects.

**References**


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