Effectiveness of interventions to reduce workload in refuse collectors
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Chapter 4.1

Effect of design of two-wheeled containers on mechanical loading

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Abstract
To prevent low back disorders due to lifting activities, occupational lifting tasks are being replaced by pushing/pulling tasks, for instance in refuse collection. Design factors of two-wheeled carts, such as centre of mass (COM) and handle location, might have large effects on joint loading. The aim of the current study was to find out how the COM and handle location of a two-wheeled container affects handle forces and joint loading. Forces at the handles and joint loading were quantified in four participants during steady, two-handed pushing and pulling of two-wheeled containers with nine different COM locations and eleven different handle locations.

The COM location turned out to have a major influence on handle forces and joint loading, whereas the influence of the handle location was moderate. Participants adapted the tilt angle of the container in response to variations in handle location but hardly did so in response to variations in COM location. For two-handed pushing and pulling it is expected that the current design of Dutch two-wheeled containers can be improved by moving the centre of mass of the loaded container in the direction of the axis of the wheels and by slightly increasing the height of the handles.
4.1.1 Introduction

With growing awareness of the risk of lifting activities for developing musculoskeletal disorders, tasks that used to involve frequent lifting are being replaced by pushing and pulling tasks. For instance, in refuse collecting, two-wheeled containers have been recommended to replace polythene bags, resulting in a marked reduction of compressive forces at the low back. However, pushing and pulling are also known to be risk factors for work-related musculoskeletal disorders. Low back injuries are reported to be caused by pushing and pulling in 9 to 20% of the cases. In addition, pushing and pulling tasks seem to increase the risk of developing pain or stiffness in the neck/shoulder region.

In pushing or pulling a fixed bar or a stable (four-wheeled) cart, the direction of the pushing or pulling force can affect the mechanical loading of the shoulder and lumbosacral joint. In comparison to purely horizontal force application, joint loading can be lower and the maximum horizontal component of the exerted force can be higher if the resulting force is not horizontal.

In contrast to four-wheeled containers, two-wheeled containers are unstable during pushing and pulling (see figure 1). Therefore, they do not offer the possibility to apply force in a direction that minimises joint loading. The angle at which the two-wheeled container is tilted and the horizontally exerted force define the required vertical force. Any change of the magnitude of the vertical force component results in a change of the tilt angle. Considering this constraint, it might be anticipated that changes of the design of a two-wheeled container affect the mechanical loading of different joints during pushing and pulling. For two-wheeled trolleys, used to transport gas cylinders, Okunribid and Haslegrave reported that the height and the angle of the handle did affect the tilt angle of the trolley. In turn, this tilt angle affected the position of the handles and of the centre of mass (COM) with respect to the axis of the wheels, thereby influencing the required forces at the handle and the resulting joint loading.

The location of the COM of a loaded two-wheeled container is another important aspect of the design that might affect mechanical loading of the joints during pushing and pulling. Given a specific tilt angle, a forward or backward shift of the COM immediately affects the required vertical force due to a change of the moment arm of the COM with respect to the axis of the wheels. It should be noted here, that due to the tilting of two-wheeled containers, not only the forward-backward location but also the height of the COM affects joint loading (figure 1). For instance, Van der Beek et al. reported a three-fold increase of lumbar compressive forces when the COM height was drastically increased by inserting a tray in a two-wheeled container.
To our knowledge, the effect of both the handle location and COM location of the two-wheeled container on handle forces and on joint loading during steady pushing and pulling have hardly been studied. Therefore, the main aim of the current study was to find out how the design of a two-wheeled container, in terms of its COM and handle location, affects handle forces and joint loading during steady, two-handed pushing and pulling. Horizontal as well as vertical position changes were taken into account. Handle forces and joint loading were quantified in four participants performing a pushing and pulling task using two-wheeled containers with 9 COM locations and 11 handle locations.
4.1.2 Methods

4.1.2.1 Participants and materials.
Two standard Dutch refuse containers (Otto, 0.240 m³; height 1.00 m; bottom width x depth 0.49 x 0.56 m; wheel diameter 0.2 m) were used for the experiment. The cap was removed from both containers and the handles were replaced by handles attached to 3-D force transducers (AMTI). One container was used to create 9 conditions with different COM locations (figure 2a), using foam and concrete blocks. The other container was used to create 11 conditions with different handle locations (figure 2b) with the aid of aluminium bars, attached to the container.

The location of handles plus force transducers caused some displacement of the container COM (figure 2b). COM locations were measured using a force platform (Kistler). Since heavy containers are more likely to cause high joint loading, a container mass was selected that represented a rather (but not extremely) heavy refuse container. The container plus load was intended to be 59.4 kg for the COM as well as the handle conditions. In all conditions,
foam and straps were used to prevent slipping of the concrete blocks during the experiment. This caused a slight variation of the actual container mass (SD = 0.9 kg) for the COM conditions. Although the main interest of this study was the container design rather than participant anthropometry, it was realised that participant’s body height might have large effects on posture and thus on joint loading. Therefore, the four experienced refuse collectors who participated in this study, were selected in such a way that systematic bias through body height was avoided. Body height, body weight and age were 1.64 m, 67 kg, 28 years; 1.72 m, 65 kg, 34 years; 1.85 m, 86 kg, 43 years; 1.93 m, 80 kg, 32 years for participants 1 to 4, respectively.

### 4.1.2.2 Experimental procedure

For each of the 20 conditions, participants were allowed to practice pushing and pulling a few times before the measurements started, in order to accommodate to the container. First, the 9 COM conditions and then the 11 handle conditions were presented in random order. For each condition, participants were instructed to grab the handles of the container and to tilt the container (they were allowed to use a foot if they wanted to), followed by walking backward while pulling the container at a normal constant speed and with the upper body as symmetrical as possible over a distance of about 5 m on a hard rubber surface. About 1 minute later, the participants were asked to tilt the container, and walk the trajectory in the forward direction while symmetrically pushing the container at a constant speed. LED markers were attached to the left and right side of the body at the L5S1 joint according to de Looze et al.\(^2\), at the acromion, and at the wrist. In addition, markers were attached to the left and right side of the container at the centre of the handles and at 0.4 m and 0.6 m above the axis of the wheels. Marker positions were recorded using an opto-electronic system (Optotrak) with an array of three cameras on both sides of the body. Forces and marker positions were sampled in 3 dimensions at 50 Hz. From the 5 m walking trajectory, about the middle 3 m was selected for averaging marker positions and forces over time. In addition, markers on the left and right side of the body and container as well as the left and right handle forces were averaged.

### 4.1.2.3 Biomechanical model

Elbow positions in the sagittal plane were calculated from wrist and shoulder markers and known upper arm and forearm length. The markers on the container were used to calculate the average tilt angle during pushing and pulling for each trial. Using this angle, the forces at the handles were transformed from local to global co-ordinates. Time-averaged sagittal plane marker co-ordinates and forces were used as input for an upper body static 2-D linked
segment model. The model consisted of four segments: hands, forearms, upper arms, and trunk plus head. Relative segment masses and segment centre of mass locations were obtained from Plagenhoef et al.\textsuperscript{107}. Using standard linked segment mechanics\textsuperscript{36}, reactive forces and torques were calculated at the elbow, shoulder and lumbosacral joints.

### 4.1.2.3 Statistics

Since interactions between COM location and handle location were not taken into account in the experimental setup, statistical analyses were performed separately for the COM and handle conditions. To test the effects of COM and handle location, ANOVAs were applied with participant, pushing/pulling activity, and either COM condition or handle condition as independent variables. Due to limitations in degrees of freedom, interactions with the participant could not be taken into account. The dependent variables were the container tilt angle, horizontal and vertical forces applied at the handles, the torques at the elbow, shoulder and lumbosacral joint, and upper body segment angles. In addition, ANOVAs with the same independent variables were applied to the peak values of the horizontal and vertical force at the initiation of the tilting of the container. A $p$-value smaller than 0.05 was considered statistically significant.
4.1.3 Results

4.1.3.1 Effect of COM and handle location on horizontal forces at the handle

Averaged over participants, the peak initial horizontal force used to tilt the container ranged from $60 \pm 17$ N in the pushing task with the COM located high and close to the axis to $195 \pm 43$ N in the pushing task with the COM located low and far from the axis (figure 3d). This force was highly dependent on the horizontal position of the COM (figures 3a and 3d) and to a lesser extent on the height and forward-backward position of the handle (figures 4a and 4d). As might be expected due to the almost constant container mass, steady horizontal pulling and pushing forces were not significantly influenced by the location of the COM or the handle (tables 1 and 2).

Table 1. Main effects of COM condition, participant, pulling / pushing activity and condition with pull / push interaction on container tilting angle, forces, joint torques and posture, during two-handed pushing and pulling of 9 two-wheeled containers with variable COM location. The peak force were measured during the tilting phase. Significant effects ($p < 0.05$) are indicated by bold numbers.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>condition</th>
<th>participant</th>
<th>pull/push</th>
<th>condition *pull/push</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$p$</td>
<td>$p$</td>
<td>$p$</td>
<td>$p$</td>
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<tr>
<td>Peak tilting force (hor)</td>
<td>0.000</td>
<td>0.000</td>
<td>0.056</td>
<td>0.751</td>
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<tr>
<td>Peak tilting force (vert)</td>
<td>0.289</td>
<td>0.000</td>
<td>0.000</td>
<td>0.951</td>
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<tr>
<td>Horizontal force</td>
<td>0.515</td>
<td>0.875</td>
<td>0.000</td>
<td>0.549</td>
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<tr>
<td>Vertical force</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.914</td>
</tr>
<tr>
<td>Tilt angle</td>
<td>0.417</td>
<td>0.000</td>
<td>0.115</td>
<td>0.696</td>
</tr>
<tr>
<td>Tilted handle height</td>
<td>0.273</td>
<td>0.000</td>
<td>0.094</td>
<td>0.671</td>
</tr>
<tr>
<td>Elbow torque</td>
<td>0.000</td>
<td>0.000</td>
<td>0.605</td>
<td>0.048</td>
</tr>
<tr>
<td>Shoulder torque</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.001</td>
</tr>
<tr>
<td>Lumbosacral torque</td>
<td>0.000</td>
<td>0.000</td>
<td>0.008</td>
<td>0.275</td>
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<tr>
<td>Forearm angle</td>
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<td>0.000</td>
<td>0.022</td>
<td>0.218</td>
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<tr>
<td>Upper arm angle</td>
<td>0.545</td>
<td>0.000</td>
<td>0.000</td>
<td>0.975</td>
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<tr>
<td>Trunk angle</td>
<td>0.000</td>
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<td>0.000</td>
<td>1.000</td>
</tr>
</tbody>
</table>
4.1.3.2 Effect of COM location on tilt angle, forces and joint loading

It was expected that, given a certain COM location, participants would manipulate the tilt angle of the container in order to reduce the required vertical force and / or to reduce the loading of one or more joints. However, it appeared that the container tilt angle was highly dependent on the participant but not on the COM location (table 1; figures 3b and 3e). Because the COM location had no significant effect on the tilt angle, the vertical forces during pushing and pulling were highly dependent on the COM location of the container (table 1). More forward (i.e., at a larger distance from the axis and the participant) and lower locations of the COM resulted in negative (downward) changes of the vertical force (figures 3c and 3f). This effect can be understood by comparing the different COM locations for their resulting horizontal position with respect to the axis of the wheels when the container in figure 2a is tilted.

Table 2. Main effects of handle condition, participant, pulling / pushing activity and condition with pulling / pushing interaction on container tilting angle, forces, joint torques and posture, during two-handed pushing and pulling of 11 two-wheeled containers with variable handle location. The peak force were measured during the tilting phase. Significant effects \( p < 0.05 \) are indicated by bold numbers.

<table>
<thead>
<tr>
<th>condition</th>
<th>participant</th>
<th>pull/push</th>
<th>condition *pull/push</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak tilting force (hor)</td>
<td>0.000</td>
<td>0.000</td>
<td>0.004</td>
</tr>
<tr>
<td>Peak tilting force (vert)</td>
<td>0.082</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Horizontal force</td>
<td>0.073</td>
<td>0.016</td>
<td>0.000</td>
</tr>
<tr>
<td>Vertical force</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Tilt angle</td>
<td>0.000</td>
<td>0.000</td>
<td>0.193</td>
</tr>
<tr>
<td>Tilted handle height</td>
<td>0.000</td>
<td>0.000</td>
<td>0.323</td>
</tr>
<tr>
<td>Elbow torque</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Shoulder torque</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Lumbosacral torque</td>
<td>0.235</td>
<td>0.000</td>
<td>0.010</td>
</tr>
<tr>
<td>Forearm angle</td>
<td>0.000</td>
<td>0.000</td>
<td>0.767</td>
</tr>
<tr>
<td>Upper arm angle</td>
<td>0.613</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Trunk angle</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>
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The COM location had a large effect on the joint torques (table 1) and this effect appeared to be systematically related to the horizontal as well as the vertical location of the COM (figure 5). Interestingly, the effect of COM changes in horizontal as well as vertical direction on L5S1 joint loading appeared to be opposite to the effect on shoulder and elbow joint loading (figure 5).

Roughly, these changes can be explained by the changes in vertical force, since, assuming that the shoulders are not in front of the handles, adding a downward force component at the hands must result in a more extending torque in the elbow and shoulder joint and a less extending torque at the lumbosacral joint. However, with pushing this effect was not consistent at the shoulder joint (figure 6e). This might be related to a postural change, since a significant effect of COM condition on the trunk angle was found (table 1). While pushing, participants were “leaning on the handles” when large downward forces were required. In this way, the reactive forces at the hand nearly pointed at the shoulder joint, so that only small joint torques occurred. In other words, body mass instead of muscle force was used to produce the downward force by leaning on the handles.

4.1.3.3 Effect of handle location on tilt angle, forces and joint loading

Contrary to the COM, the handle location significantly affected the tilt angle of the container (table 2; figures 4b and 4e). Higher and more forward (at a larger distance from the participant but closer to the axis) locations of the handles were associated with a larger tilt angle. However, this increase in tilt angle only partially compensated for the increased handle height, since there was still a significant effect of handle location on the height of the handle during pushing and pulling (table 2). On average, the highest handle locations resulted in a pushing and pulling height of about 18 cm higher in comparison with the lowest handle locations. As a result of the increased tilt angle, the COM of the tilted container was more backward (towards the participant) with respect to the axis of the wheels, resulting in a change of the vertical force in less downward or more upward direction (figures 4c and 4f). Consequently, the extending torque at the elbow joint (figures 6c and 6f) decreased (in pushing and pulling) and shifted to a flexion torque for the highest handle locations (mainly in pulling). In addition, the extending torque at the shoulder joint decreased with forward and upward displacement of the handle during pulling, whereas changes during pushing were marginal (figures 6b and 6c). Furthermore, the extending torque at the lumbosacral joint slightly increased from low to high handle locations (figures 6a and 6d). Despite some postural changes (in terms of trunk and forearm angle) due to the changes of handle location, the trend in changes of joint loading (figure 6) was in line with the change of the vertical force (figures 4c and 4f), i.e. a more upward directed force applied to the handle resulted in a
decrease of extension torques in the elbow and shoulder and in an increase of the extension torque at the lumbosacral joint.

4.2.3.4 Effects of participant and pushing versus pulling

As anticipated, there was a significant effect of participant (most likely due to body height variations) on most of the dependent variables for the COM conditions (table 1) and handle conditions (table 2). Roughly, shorter participants tilted the container more (with consequently more downward directed handle forces and more extending torques in the arms) and longer participants flexed their trunk more (with consequently higher low back loading). Container tilt angles did not differ between pushing and pulling in the COM conditions (table 1) as well as in the handle conditions (table 2). As a consequence of the necessary mechanical equilibrium during steady pushing and pulling, the reversal of sign of the horizontal forces resulted in more downward directed forces at the handle in pushing compared to pulling (figures 3c, 3f, 4c and 4f). For the COM as well as the handle conditions, the upper body posture showed some more trunk and shoulder flexion in pushing as compared to pulling, presumably to facilitate downward pushing.

In absolute sense, vertical forces (and thus the total forces at the handle) were higher in pushing as compared to pulling in the majority of COM and handle conditions. Interestingly, the reverse was the case for all joint torques in almost all conditions, underscoring the importance of force direction for joint loading.
Figure 3. The effect of horizontal and vertical position of the COM on the peak initial horizontal force used to tilt the container (a, d) and on the tilting angle (b, e) and vertical force (c, f) during steady pulling (a-c) and pushing (d-f) of a two-wheeled container in a symmetrical way. Error bars indicate one standard deviation. COM heights were 0.12 (low), 0.23 (medium) and 0.36 m (high) above the axis of the wheels (with 0.1 m radius).
Effect of design of two-wheeled containers on mechanical loading

Figure 4. The effect of horizontal and vertical position of the handle on the peak initial horizontal force used to tilt the container (a, d) and on the tilting angle (b, e) and vertical force (c, f) during steady pulling (a-c) and pushing (d-f) of a two-wheeled container in a symmetrical way. Error bars indicate one standard deviation. Handle heights were 0.84 (low), 0.90 (normal), 1.00 (high), 1.10 (higher) and 1.20 (highest) above the axis of the wheels (with 0.1 m radius).
The effect of horizontal and vertical position of the COM on net torque of the L5S1 (a, d), shoulder (b, e) and elbow (c, f) joint during steady pulling (a-c) and pushing (d-f) of a two-wheeled container in a symmetrical way. Error bars indicate one standard deviation. COM heights were 0.12 (low), 0.23 (medium) and 0.36 m (high) above the axis of the wheels (with 0.1 m radius).
Effect of design of two-wheeled containers on mechanical loading

Figure 6  The effect of horizontal and vertical position of the handle on net torque of the L5S1 (a, d), shoulder (b, e) and elbow (c, f) joint during steady pulling (a-c) and pushing (d-f) of a two-wheeled container in a symmetrical way. Error bars indicate one standard deviation. Handle heights were 0.84 (low), 0.90 (normal), 1.00 (high), 1.10 (higher) and 1.20 (highest) above the axis of the wheels (with 0.1 m radius).
4.1.4 Discussion

4.1.4.1 COM location and mechanical loading

Surprisingly, we found little influence of the COM location of the container on the tilt angle. Contrary to expectations, participants hardly adapted the angle of pulling or pushing when the angle of mechanical equilibrium of the container changed. Consequently, the vertical forces, applied to the handle, and the loading of the joints were highly dependent on the COM location. In contrast to pushing or pulling tasks with a four-wheeled cart or a fixed bar\textsuperscript{30}, the vertical force in the current study was imposed by the container tilt angle and therefore it was largely unrelated to the arm orientation. Consequently, some combinations of horizontal and vertical forces resulted in large moment arms with respect to the shoulder joint, so that forces of moderate magnitude could result in high loading of the shoulder joint. Especially the combination of a downward force and a pulling force can result in a total force vector that is nearly perpendicular to the orientation of the arm, causing a large moment arm with respect to the shoulder and elbow joint. This may cause large shoulder and elbow joint torques even when the downward force only has a moderate magnitude. Such a situation occurred when the COM was located low and forward (see figures 3c, 5b and 5c). In pushing, a comparable effect was found when the COM was located high and backward. In this situation, a combination of pushing and a quite small upward force (figure 3f) resulted in large moment arms with respect to the elbow and shoulder joint, with consequently relatively high elbow and shoulder loads (figures 5e and 5f). These examples show that the COM location, which can easily be influenced through the design of the container, is a major determinant of joint loading in pushing and pulling of two-wheeled containers. In addition, it can be concluded that the magnitude of the force, applied at the handles, is not a good indicator of the mechanical loading of the joints, when the direction of this force as well as the position of the joints are not taken into account.

4.1.4.2 Handle location and mechanical loading

The finding of a reduction of shoulder joint loading with pulling at increasing handle height, as found in the current study, is in agreement with findings using four-wheeled carts\textsuperscript{30}, but the magnitude of the effect is larger. Okunribido and Haslegrave\textsuperscript{104} reported for two-wheeled trolleys, that handle height did affect the tilt angle of the trolley but that participants always tilted the trolley at such an angle that one specific grip height was obtained, regardless of other conditions. In the current study a change of handle height also affected the tilt angle, but not to such an extent that equal handle heights were obtained after tilting. Okunribido and Haslegrave\textsuperscript{104} suggested that the high COM of the trolleys that were studied, may have caused their finding of a constant grip height and this may explain the difference with the current study. Comparable to the COM location, handle location affected the external forces.
and the joint loading not in the same way in the current study. Low handle locations resulted in unfavourable combinations of horizontal and vertical forces: pulling with a low handle resulted in a relatively small downward force (figure 4c) but due to a large moment arm of the force in relatively high shoulder loading (figure 6b).

4.1.4.3 Limitations of the study
First, only four participants of different height participated in the experiments. Clearly, this limits generalisation of the current results, since differences in participant body height can not be separated from other differences between the participants. However, the statistical analysis showed that the number of participants was sufficient to result in many significant effects that were consistent over variables and understandable from a mechanical perspective. Interaction effects between handle location and COM location were not investigated in the present study. These effects might occur since handle height was found to affect the tilt angle of the container. Also, participants had some time to adapt to every condition but it can not be excluded that more experience with each condition would affect the body posture during pushing and pulling. Furthermore, refuse collectors often pull two-wheeled refuse containers with one hand, walking forward instead of backward. This might influence the effect of handle location on joint loading. For instance, short participants may then be forced to either tilt the container too far or to keep their arm in an extremely extended position. Finally, it should be realised, that other parameters than average joint loading (on which we mainly focussed thus far) are important. Especially container stability may affect the risk of musculoskeletal injuries, through peak forces necessary to counteract balance disturbances due to an irregular walking surface. In the next section, some inferences on this issue are made, partially using information obtained from the current experiment.

4.1.4.4 Can the current design of refuse containers be improved?
With homogeneous loading, the COM of the container is normally situated about the midline of the container. Thus, locations 8 and 5 (figure 2a) represent COM’s for the current container design. In comparison with condition 8, a forward displacement of the COM (to condition 9) decreases the low back loading at the expense of increased elbow and shoulder loading. Conversely, backward displacement (condition 7) increased low back loading without reducing elbow and shoulder loading in an absolute sense. In addition, forward displacement results in high upward forces during pulling and backward displacement results in high downward forces during pushing. The only displacement of the COM that does not have adverse effects on either the vertical force or on the loading of one of the joints, is a displacement in the direction of the axis of the wheels (location 4). Although such a displacement of the COM provides only marginal changes in terms of joint loading, any
downward displacement of the COM improves the stability of the container, which is an argument in favour of location 4. The reason for this improvement is a reduction of the moment arm of the COM with respect to the axis. Consequently, disturbances of mechanical equilibrium, which constantly occur during pushing and pulling a container on an irregular surface, require less force adaptation to restore the tilt angle. Furthermore, any handling of a two-wheeled container starts with tilting it. Starting at any COM location, displacing this location in the direction of the axis of the wheels results in a proportional decline of the required initial tilting force. For instance, a displacement of the COM from location 8 to location 4 (figure 2a) roughly halves the required horizontal tilting force (figures 3a and 3d).

It can be concluded that a displacement of the COM of the loaded container in the direction of the axis improves the stability and reduces the required tilting forces without negatively affecting vertical forces or joint loading during steady pushing or pulling. One way to achieve this is to make the container wider and, at the same time, place the axis more forward.

It was already mentioned that interaction effects between COM and handle changes were not investigated in the current study. However, as long as the COM changes are along a line towards the axis of the wheels, such interaction effects are not likely to be large. Compared to the current handle location (condition 4), some increase of the height of the handle (condition 6 and 7) did reduce the average vertical forces and the loading of the elbow and shoulder joint, without adverse effects on low back loading. A more than 10 cm increase of the handle height causes short participants to tilt the container quite far, resulting in an increasing joint loading.

Before we can conclude that design changes as proposed above, are really an improvement, a new design, using the proposed changes, should be tested against the traditional design with more participants, with various container loading conditions and with more realistic working conditions (including one-handed pulling, rotating a container and pulling it up and down the walkway). This study, using 3-D analysis of shoulder and low back loading, and including an EMG-assisted translation of net moments to compression and shear forces, is being undertaken and will be published in a separate paper.

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