Biomechanical Evaluation of Case Hook Designs for Selector Use in Distribution Centers

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Abstract

Case hooks are tools used in distribution centers by selectors to help them reach and pull products located on the back half of a pallet. This study investigated the postural, electromyographic, and usability responses as 4 handle and 3 tip types were used to pull cases forward on a pallet. The data suggest the pistol grip may be most biomechanically advantageous. With the pistol grip, the rake and conventional tips worked well and had good usability scores.

Keywords

Warehouse, Distribution Center, Case Hook, Pick Hook, Ergonomics, Shoulder Injury

Introduction

"Grocery and Related Product Wholesalers" have strain/sprain injury rates that are over three times the overall industry average (BLS, 2019). The majority of the reported back and shoulder injuries in distribution centers (DC's) are experienced by the "selectors" or "pickers" and that grocery selector jobs are some of the highest risk jobs across the distribution industry (Lavender et al., 2012).

Most grocery DCs store their products in racks. Product selection usually occurs from the first two racking levels (Figure 1). The second racking level, where pallets are often 1.2m (48 inches) above the floor, may have product stacked as high as 2.1 m (84 inches) above the floor. In most facilities the racking is designed such that 102 cm (40-inch) wide side of the 102 x 122 cm (40" x 48") pallet is facing the aisle, thereby making it difficult for selectors to pick the products from the back half of the pallet on both the first and second levels.

DC's address this challenge by providing the selectors with "case hooks" so they can extend their reach to the cases of product located further back on the pallet (figure 2). Figure 3 shows some of the varied designs encountered in our recent study exploring ergonomics practices in Grocery DCs (Lavender and Sommerich, 2022). In that study, we found that while nearly every facility had case hooks available, the designs varied across the facilities as did the reported utilization, which may in part be due to case hook design limitations and case hook accessibility. Therefore, the overall goal of this project was to identify case hook designs that effectively reduce the biomechanical loads during 2-tier picking in grocery DC operations, and are perceived by grocery selectors to be useful, usable, and desirable. Prior work using focus groups with grocery selectors at nearby distribution centers identified different design features that were worthy

Figure 1. An example of 2-tier racking commonly found in grocery distribution centers.

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of biomechanical investigation (figure 4). Based on these design concepts, prototypes were developed and tested in a laboratory environment to determine if particular designs or design components led to lower biomechanical demands during a simulated case pulling process.

Methods

Participants

Twelve participants, 10 males and 2 females volunteered to participate in the study. None of the participants had ever worked in distribution operations. Their stature ranged from 164 to 190 cm.

Experimental Design

A within subject design was used in which three independent variables were tested: (1) the handle design - Inline, T-Handle, Pistol, and Counter-balanced (CB) Pistol; (2) the tip design - Conventional, Hook, and Rake; and (3) Box placement - Back row, One row forward from the back row. The dependent measures were the muscle recruitment levels from the anterior and lateral deltoid muscles and the shoulder postures.

Apparatus

The tested handle and tip designs are shown in figures 5 and 6. The length of the hooks from the center of the grip to tip were 85 cm. The counter-balanced tool had a weight attached to the proximal end the resulted in the center of gravity of the tool being at the pistol grip handle. The tool weights for the different handle and tip designs are shown in Table 1.

The boxes were placed on a pallet which was in turn placed on a rack to simulate second level picks in a distribution center (figure 7). In this simulation, the top of the upper layer boxes that were pulled by the participant were 162 cm above the floor. The box dimensions were 30 cm by 30 cm by 13 cm and each box weighed 5.5 kg. This size and weight were selected as they are representative of case sizes and weights frequently slotted within second level slots in grocery distribution operations.

Procedures

After reviewing and signing the IRB approved consent document, participants were prepared for electromyographic (EMG) recordings. Wireless electrodes (Delsys Trigno) were placed over the anterior and lateral deltoid muscles of the arm that participant planned to use for the pulling tasks, as well as over the extensor carpi radialis. Once signals were verified, participants were asked to perform a set of maximal muscle exertions in postures where maximal signals would likely be experienced during the testing protocol. After these data were obtained, a resting value for each muscle was also obtained. These maximal and resting values were used to normalize the EMG data collected during the box pulling tasks.

Electromagnetic kinematics sensors (The Motion Monitor, Innovative Sports Training Inc.) were then attached to the pelvis (over the sacrum), thorax (at the T4 level), and bilaterally on the upper arms using Velcro straps. These sensors provided data used to measures the three dimensional shoulder and spine postures.

Participants were instructed how to perform the specific box pulling task. Participants started each task by stepping forward one step (as they would if they were walking to a rack location in a DC), turn to the side so that they were facing the rack, position the case hook and pull the case towards the front of the pallet such that it was in a position where it could be easily lifted with minimal reaching. At this point, participants were instructed to place both hands on the box as though they were going to lift it, but to not actually do so. This motion in the arm not holding the case hook was used to signal the end of trial in the data analysis process. When pulling the box in front, as shown in figure 6, the four boxes (two on the bottom and two on the top) were positioned as shown. When pulling the rear box, the front two boxes were removed. The sequence of handle design and tip conditions was randomized for each participant. Within each condition, there were two trials. At the completion of the session, the participants were asked to rate the usability of each handle and tip configuration on a 5 point rating scale that ranged from "very difficult to use" to "very easy to use".

Data Analysis

EMG data from each muscle were normalized relative to maximal and resting values. The 90th percentile values for each muscle were obtained for each trial and then averaged across trials. Maximal postural deviations were obtained from the neutral posture to quantify the shoulder abduction and flexion, and the spine flexion, lateral flexion, and twisting. EMG and postural data were analyzed using a within-subjects analysis of variance procedure within the SAS software. Multiple comparisons between significant effects were evaluated with the REGWQ procedure within SAS to control type I errors.

Results

In the analysis of the kinematic data both the type of handle and the tip design significantly affected the shoulder flexion and abduction ($p<.001$). Figure 8 shows that pistol grip resulted in reduced motions in both planes relative to the other handle designs tested. Figure 9 shows that the hook tip design produced the lowest shoulder flexion values and was equivalent with the conventional tip with regards to the peak shoulder abduction during the task (Figure 9). However, handle by tip design interaction effects were also significant for both measures. The analysis of these interactions showed that increased flexion and abduction with the rake tip design was most pronounced when used with the inline and t-handle tools. The differences were smaller with the pistol grip handles. When the box was further forward on the pallet, the shoulder flexion and abduction decreased for the pistol grip handles, but not for the Inline or T-handle.

The electromyographic results show that there were significant main effects and interactions for each muscle tested ($p<.001$). Figure 10 shows the effect of the different handle designs as a function of the handle. With regards to the handle design, the pistol grip generally led to lower muscle activations across all muscles tested. The main effect for the tip design suggest that the conventional tip worked best across the three muscles tested, however the interaction effects show that these differences were dependent upon the handle design (Figure 11). For example, with the pistol grip, there were no differences due to tip design after the Bon Feronni

Figure 2. A case hook being used to access a 2nd tier case.

Figure 3. Examples of case hooks curreinlyiised ill grocery distribution centers.

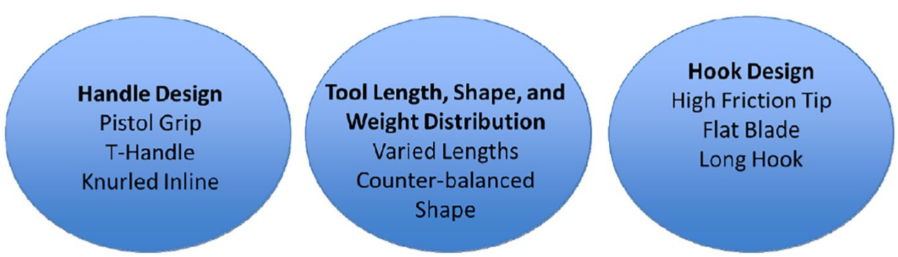

Figure 4. Design attributes from focus group sessions with DC workers.

alpha level correction was applied for the anterior or lateral deltoid muscles.

Usability data showed significant effects ($p<.01$) for both the handle and the tip designs. The interaction effect was not significant. Figure 12 shows the ratings for the handle and tip designs, where higher values indicated a design was easier to use. These data suggest the inline and pistol grip handle were the easiest to use. The rake style tip was also rated easiest to use. Participants were also asked to rank their 3 most preferred handle and tip combinations. The in-line with the rake style tip received 10 top 3 rankings. The in-line with the conventional tip and the pistol with rake received 6 and 5 top three rankings, respectively. In terms of number one rankings, each of these hand and tip combinations had 3 number one rankings.

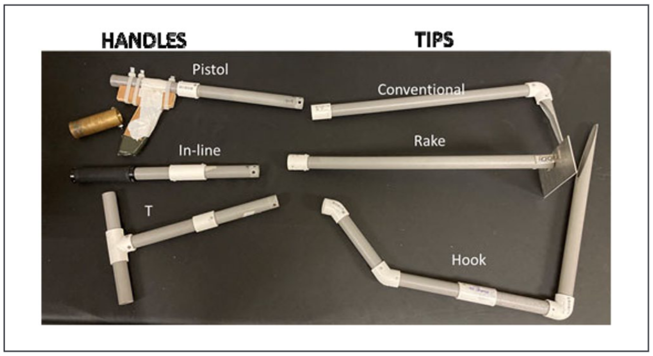

Figure 5. The different handles and tip* tested. The counter-balance weight next to the pistol grip was attached to the proximal end of the tool.

Discussion

The shoulder posture and EMG results suggest the use of pistol grip tools to reduce the biomechanical loading of the shoulders when using case hooks to obtain products. These findings are also supported by the usability data wherein the pistol grip was considered one of the easier tool handles to use. This may be due to pistol grip affording information regarding the tip orientation. While the same could be said for the T-handle, extra effort was required to control the pitch of the tool as the handle could more easily rotate within the hand.

The counter-balanced pistol grip yielded similar biomechanical findings to the pistol grip without the counterbalance weight, however, the usability ratings were not as high. There was a non-significant trend towards reduced flexor

Figure 6. Examples of the box pulling task with the different handle and tip designs.

Table 1. Tool weights (kg) based on handle and tip design.

Handle \ Tip Design	Conventional	Rake	Hook
T-Handle	0.48	0.52	0.66
In-Line Handle	0.50	0.55	0.68
Pistol Grip	0.53	0.57	0.71
CB Pistol Grip	1.39	1.45	1.57

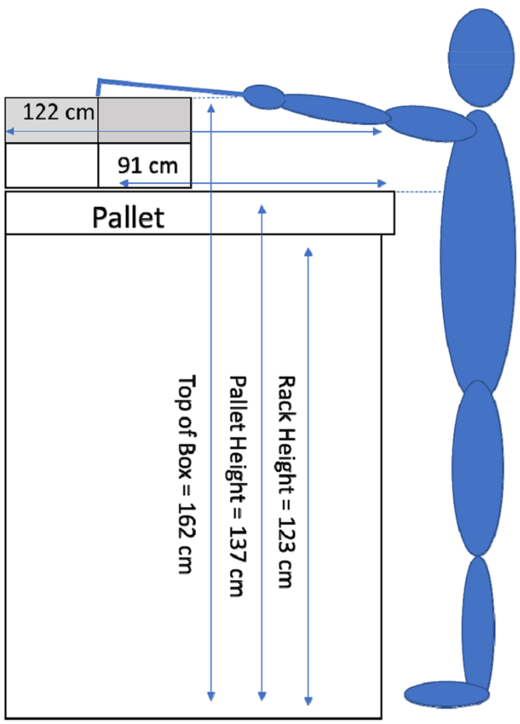

Figure 7. The simulated rack and case positions used during the picking task. The gray boxes show the initial locations of the pulled boxes.

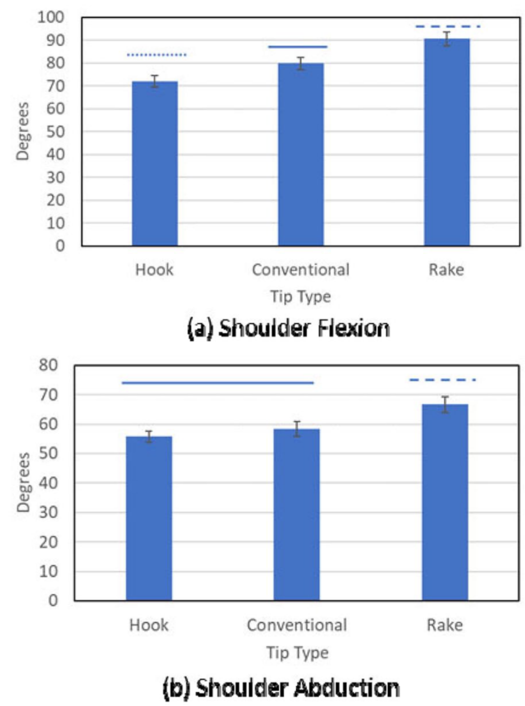

Figure 9. Shoulder motion as a function of the tip design. Bars connected by the same style horizontal line are not statistically different in post-hoc tests.

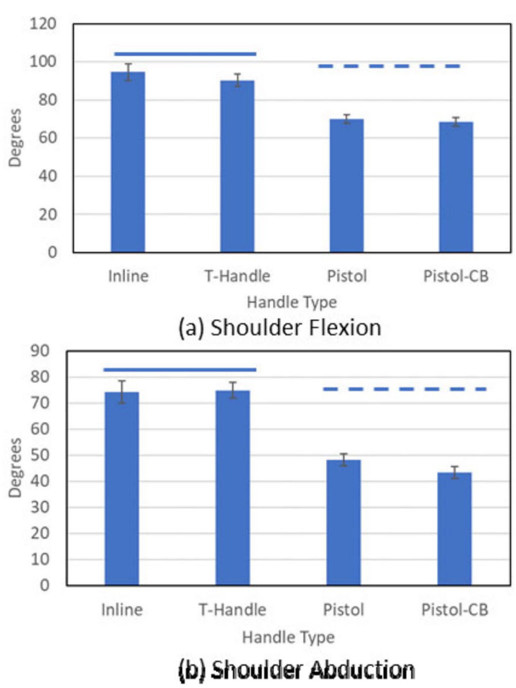

Figure 8. Shoulder motion as a function of the handle design. Bars connected by the same style horizontal line are not statistically different in post-hoc tests.

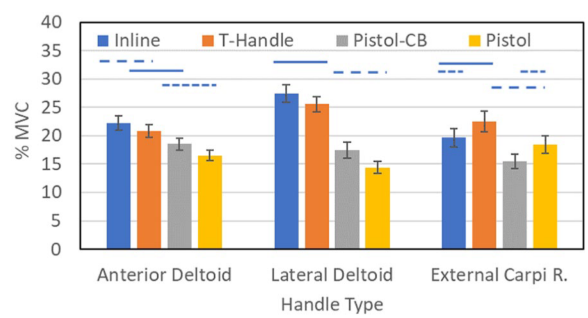

Figure 10. The effect of handle design on the normalized EMG responses of the three muscles tested. Bars connected by the same style horizontal line are not statistically different in post-hoc tests.

carpi radialis activation that supported the hypothesis that a change in the tool's balance point would reduce the moment about the wrist. But this small reduction in flexor carpi radialis came at the expense of the non-significant increase in anterior and lateral deltoid activation levels due to the increased tool weight.

The higher ease of use ratings for the rake tip were likely due to the improved directional control over the box as it was pulled forward. With the conventional tip, there were more

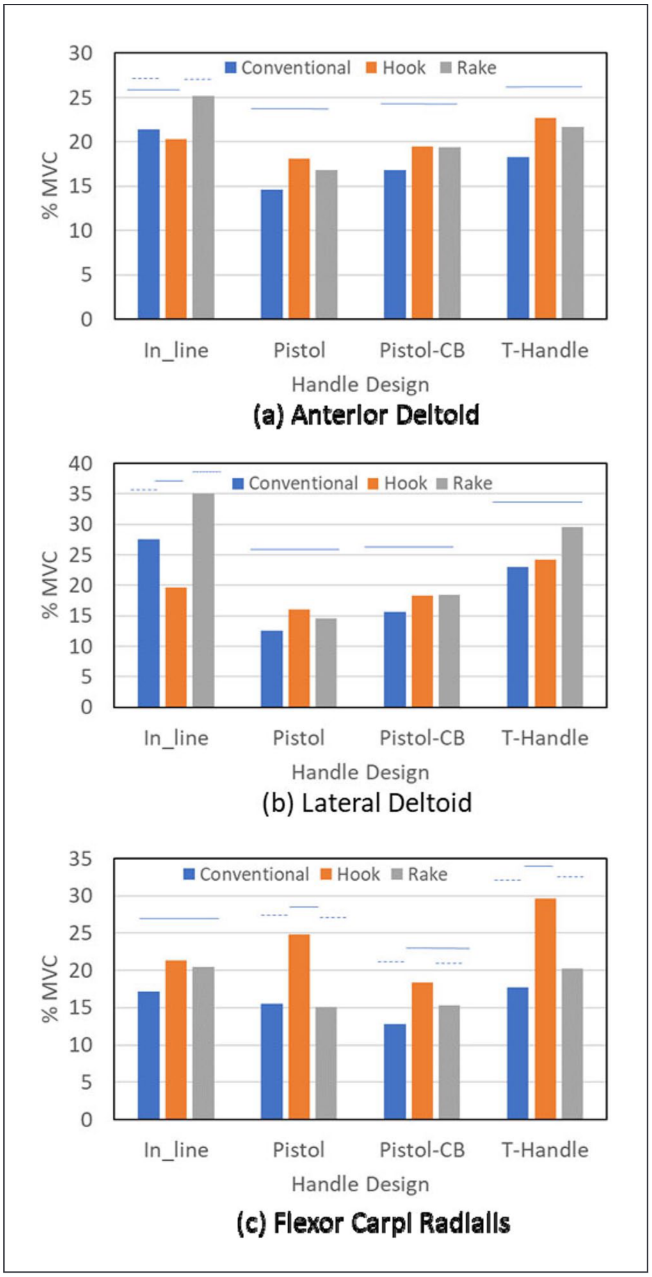

Figure 11. The interaction effects of handle and Tip design on the normalized EMG responses of the three muscles tested. Ban connected by the same style horizontal line are not statistically different in post-hoc testa.

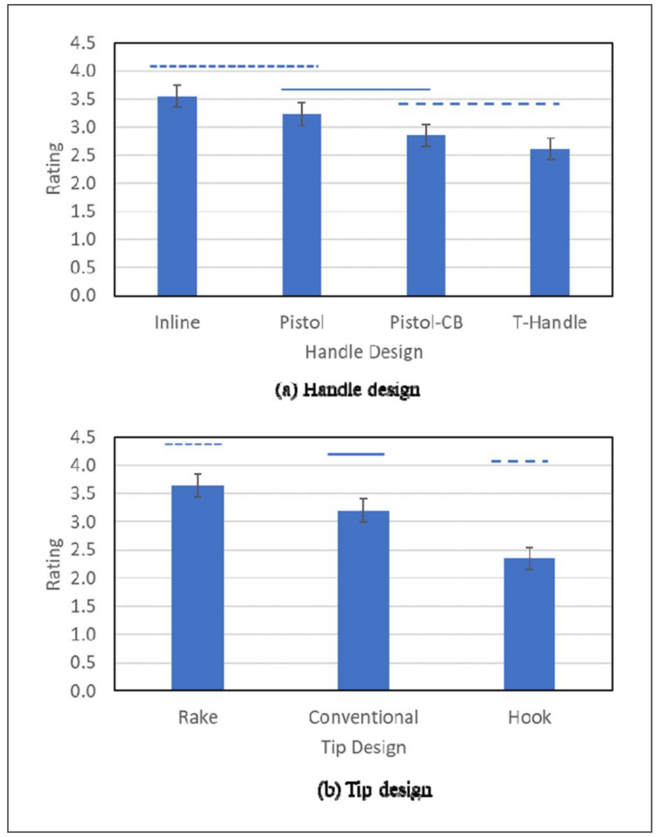

Figure 12. Ease of me rating ax **a** fiinction of handle design (aj and tip deaign fbj. Bars connected with Mime style line are not slaHsHcslly different in post line tests.

occurrences of the box spinning as it was pulled forward. This would occur if the tip was not placed near the center of the rear side of the box. The low ease of use ratings for the hook were largely driven by the extra effort required to work the hook around the back side of the box.

In terms of prior literature to which these results can be compared, there does not seem to be any prior studies published on case hook design. This statement is further supported by Glock et al.'s (2021) recent paper that reviewed the literature for assistive devices that could be implemented to aid selectors in warehousing operations. The authors of this paper did not discuss case hooks.

A limitation of this work is that the participants were inexperienced with the case selection process. Future work will need to focus on the usability of the tools with experienced workers. This may further identify which tip design is most easily used in these fast paced work environments.

In summary, this work shows there are differences in biomechanical loads and ease of use ratings that can be expected with different case hook designs. Hooks with a pistol grip should be considered as these have the potential reduce the biomechanical loads experienced in the shoulders in these repetitive product selection tasks.

Acknowledgments

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References

Bureau of Labor Statics (BLS) (2019). Incidence rates for nonfatal occupational injuries and illnesses involving days away from work per 10,000 full-time workers by industry and selected natures of injury or illness, private industry, 2017. https://www.bls.gov/iif/oshwc/osh/case/cd_r5_2017.htm

Glock, C.H., Grosse, E.H., Neumann, P., & Feldman, A. (2021) Assistive devices for manual materials handling in warehouses: a systematic literature review, International Journal of Production Research, 59:*11*, 3446-3469, DOI: 10.1080/00207543.2020.1853845

Lavender, S.A., Marras, W.S., Ferguson, S.A., Splittstoesser, R.E., & Yang, G. (2012). Developing physical exposure-based back injury risk models applicable to manual handling jobs in distribution centers. *Journal of Occupational and Environmental Hygiene*, *9*, 450-459.

Lavender, S.A., & Sommerich, C.M. (2022). Identifying ergonomics best practices currently used by grocery distribution centers. https://u.osu.edu/ergonomics4grocerydc/