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Short Communication

Effect of belt/bucket interface in apple harvesting

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Abstract

Migrant and seasonal orchard harvest workers experience musculoskeletal strain caused by carrying heavily loaded buckets and holding awkward postures. An ergonomic hip belt has been shown (both in this and previous studies) to significantly assist in redistributing weight from the shoulders to the hips. Two types of belt/bucket interfaces were tested: A hook belt with hooks on the buckets attaching to prepositioned D rings or a cable belt with hooks sliding a cable attached to the belt. A laboratory study of simulated harvesting postures showed significantly ($p<0.001$) reduced loading on the shoulder strap and greater transfer of the load to the hips using the cable belt. This was confirmed with significantly ($p<0.05$) reduced subjective ratings of shoulder discomfort for the cable belt as compared to the hook belt. Field testing with apple harvesters showed similar but nonsignificant results. This effect is hypothesized to be due to the cable belts more uniform distribution of load and greater flexibility in adjusting the position of the bucket on the belt.

Relevance to industry

Improved belt/bucket interfaces have the potential for significantly reducing back and shoulder strain in apple harvesters.

Keywords: Apple harvesting; Belt; Bucket; Back strain; EMG

1. Introduction

Migrant and seasonal farm workers provide much of the manual labor used in the harvesting of fruits in the United States. Apples are hand-harvested by workers who carry them from the tree to a $0.71\,m^3$ bin in bushel buckets weighing as much as 19 kg (42 lbs), when full. Harvest workers carry this bucket on one side or in front, held by canvass or nylon straps fastened around either one or both shoulders. Harvest work activities include climbing ladders, leaning to one side, reaching for apples, and bending forward to release the apples out of the bottom of the bucket (as far away from the edge of the collection bin as possible). Many of the awkward postures are held with full or partially full apple buckets, increasing the potential for muscle strain. Data collected at the Northeast Center for Agricultural and Occupational Health indicate that back, neck, and shoulder strains constitute 37% of all occupational problems for which workers sought care at migrant health centers between 2000 and 2003. This is the leading injury type, three times greater than the next most common problem, ‘‘falls’’. Similarly, a recent published study of farmworker injury risk reported an overall strain/sprain rate of 31% per season (McCurdy et al., 2003). A number of other studies also place musculoskeletal strains among the most frequent injuries for migrant and seasonal farmworkers (Ciesielski et al, 1991; Husting et al., 1997; Osorio et al., 1998; Villarejo and Baron, 1999). Exploratory research has identified a number of high-risk activities and postures for back, neck, and shoulder strain (Fulmer et al., 2002) and has determined that the NIOSH safe lifting load is commonly exceeded (Earle-Richardson et al., (2004).

During 2001–2002 researchers held seven intervention development meetings with orchard owners and managers, farm workers, and other apple industry representatives and

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individual interviews with various community members. One intervention selected for further testing was based on earlier mail bag research done by Page (1985), demonstrat that wearing one strap over the shoulder and one strap around the waist while carrying the load in front is effective at reducing the load on the lower back. Consequently, a hip belt made of soft-padded neoprene was added to the apple harvest bucket. Details on the intervention effects of belts over traditional no-belt buckets are found in Earle-Richardson et al. (2006) and Jenkins et al. (2006).

The original design of the belt/bucket interface utilized hooks on buckets slipping onto D-rings attached to the belt (Fig. 1(a)). Thus, the bucket could be removed and reattached to the belt at will. However, the location of the bucket was fixed with respect to the D-rings on the belt and was inconvenient for the harvesters as they maneuvered around tree branches, on or off ladders. A second design placed the hooks on a polyethylene-covered steel cable on the belt, allowing the bucket to slide freely on the belt, but still transferring much of the weight to the belt (Fig. 1(b)). This was thought to be a more flexible approach and was tested in both a controlled laboratory setting and with harvesters in the field.

Fig. 1. (a) Hook belt with hooks attached to D-rings and (b) cable belt with hooks attached to cable.

2. Laboratory study

2.1. Methods

Ten healthy male volunteers recruited from Penn State University were included in the study. None had any apple harvesting experience. Subjects' mean age was 30.6 years (25–35), mean height was 67.68 in (65.4–70.1), and 154.6 (137–172) pounds. Informed consent was obtained from each individual, and the study was approved by the University Institutional Review Board. They were tested with three different belt conditions for a standard apple bucket with one shoulder strap (Wells and Wade, Wenatchee, WA): no belt (NB), a cable belt (CB), and a hook belt (HB). The bucket was loaded with approximately 17 kg (37 lbs) of apples to approximate a full bucket as collected in orchards. Each subject assumed two different postures, for an approximately 5-s period: standing erect with 0° back angle, and standing in a semi-bent posture with 45° back angle (Fig. 2). These are similar to postures assumed by apple harvesters in the orchard (Fig. 3). A fully randomized design with two trials and 2-min rest between trials was utilized.

Dependent variables collected included electromyograms, pressure distributions, and subjective ratings of discomfort. Electromyograms (EMG) were recorded of the trapezius muscle in the upper shoulder (EMG_1), latissimus dorsi muscle in the lower shoulder (EMG_2), and erector spinae muscles in the lower back, approximately L3 level (EMG_3), and also in the low back, approximately L5 level (EMG_4), as shown in Fig. 4. Pressure distributions were measured using FlexiForce force sensitive resistor (FSR) sensors (Tekscan, Boston, MA) under the shoulder strap (FSR_1) and under the hip belt (if worn) on the left side (FSR_2) and the right side (FSR_3). Subjective ratings of discomfort were obtained using the Borg CR-10 scale (Borg, 1982) for shoulder discomfort (Borg_sh), for back

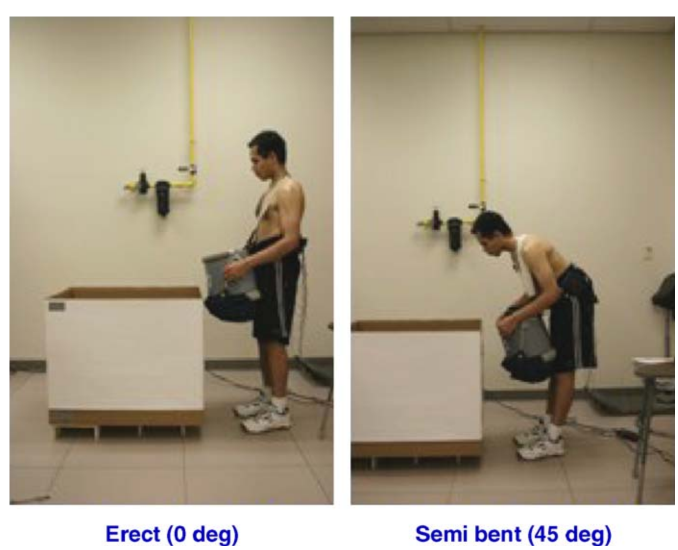

Fig. 2. Laboratory postures.

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Fig. 3. Postures used in the field.

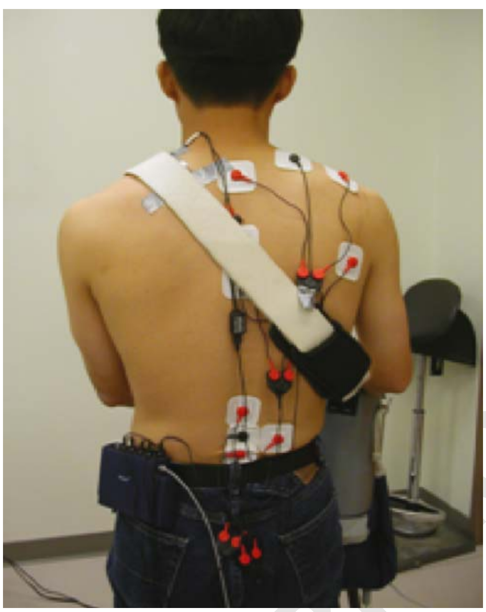

Fig. 4. Electrode placements.

discomfort (Borg_ba), and overall discomfort (Borg_all). The physiological measurements were collected on-line using the FlexComp Infiniti™ data acquisition system (NexGen Ergonomics, Montreal, Canada).

2.2. Results

The dependent variables were normalized on a scale of 0–1 for better comparison purposes:

$$\mathrm{EMG_{norm}} = (\mathrm{EMG_{value}} - \mathrm{EMG_{min}})/(\mathrm{EMG_{max}} - \mathrm{EMG_{min}}),$$
$$\mathrm{FSR_{norm}} = \mathrm{FSR_{value}}/\mathrm{FSR_{max}},$$
$$\mathrm{Borg_{norm}} = \mathrm{Borg_{value/}}\mathrm{Borg_{max}}.$$

They were then plotted by posture: Standing erect (Fig. 5) and semi-bent posture (Fig. 6) and analyzed using analysis of variance. For both postures, the shoulder loading (FSR_1) was significantly higher ($F(2,161) = 53.46$, $p < 0.001$) in the no-belt condition. (Note that there are no FSR_2 or FSR_3 readings in the no-belt condition, because there is no pressure on these sensors, if there is no belt present.) This effect was further confirmed with both shoulder muscle EMG (trapezius—EMG_1 and latissimus dorsi—EMG_2) and upper back erector spinae muscle (EMG_3) being significantly more active in the no-belt conditions ($F(2,161) = 2.36$, $p < 0.1$; $F(2,161) = 7.07$, $p < 0.001$; $F(2,161) = 5.47$, $p < 0.01$, respectively).

In terms of subjective ratings of discomfort, all ratings (shoulder—Borg_sh, back—Borg_ba, and overall—Borg_all) were significantly higher for the no-belt condition as compared to the belt conditions ($F(2,161) = 36.24$, $p < 0.001$; $F(2,161) = 4.09$, $p < 0.05$; $F(2,161) = 7.84$, $p < 0.001$, respectively) for the erect and semi-bent postures. Therefore, apparently, the subjects could sense the reduction in shoulder loading afforded by the use of the belts.

In terms of the difference between the types of belts used, the loading on the cable belt, for both left and right sides (FSR_2 and FSR_3) was significantly higher ($F(1,104) = 53.92$, $p < 0.001$; $F(1,104) = 50.01$, $p < 0.001$, respectively) than on the hook belt. This was thought due to the stiffer nature of the cable belt which tended to distribute the load better to the hips. This was confirmed with reduced loading on the shoulder (FSR_1) using the cable belt. None of the EMG measures showed any significant differences between the two types of belts, though. On the other hand, the subjective rating of shoulder discomfort was significantly higher for the hook belt ($F(1,104) = 4.64$, $p < 0.05$), but subjective ratings for the back and the overall measure did not show significant differences between the two types of belts.

In terms of posture, for all three belt conditions, all dependent measures (EMG, pressure loading, and subjective ratings) increased significantly ($p < 0.001$) as the back went from an erect posture to the bent posture.

3. Field study

3.1. Methods

Two healthy migrant apple harvesters in an upstate New York orchard volunteered to participate in the field study. Informed consent was obtained from each individual and the study was approved by the University Institutional Review Board. They were tested with the same Wells and Wade apple bucket, using one shoulder strap under the same three belt conditions as in the laboratory: NB, a CB, and a HB. The order of belt presentation was randomized for each subject. For each trial, the subject picked apples until the bucket was full and then emptied the bucket into the collection bin. This took approximately 2–2.5 min. After, approximately a 10 min rest (the time it took to remove the bucket, switch belts, check for electrode integrity, and replace the bucket), the subject repeated

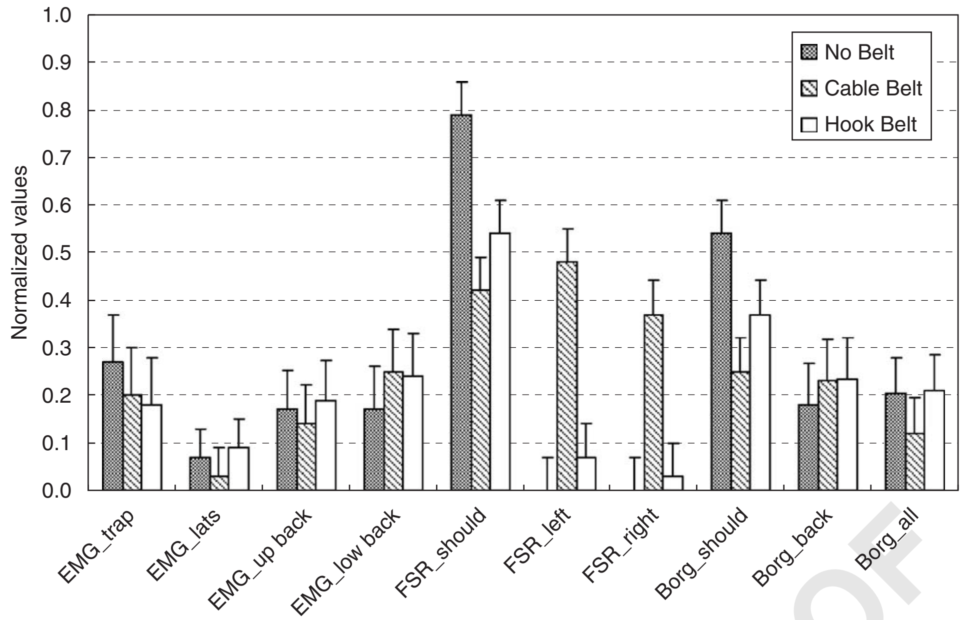

Fig. 5. Dependent variables for standing erect (0° back angle).

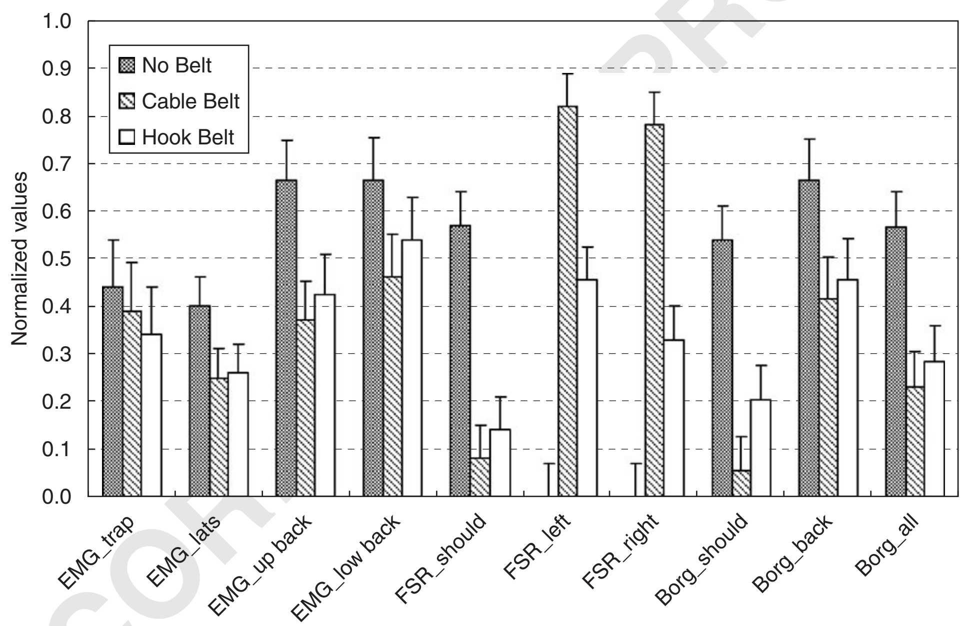

Fig. 6. Dependent variables for standing in semi-bent posture (45° back angle).

the cycle with a different belt/bucket combination. Due to cold temperatures (close to freezing, which limited battery life) and damp conditions (which required some reattachment of electrodes), only one trial of each condition for each subject could be obtained. This also limited the power of subsequent statistical analyses.

A reduced set of dependent variables was collected due the four-channel limitation on the ProComp telemetry data acquisition system (NexGen Ergonomics, Montreal, Canada).

Electromyograms (EMG) were recorded from the trapezius muscle in the upper shoulder and erector spinae muscles in the low back. Pressure distributions were measured under the shoulder strap and under the posterior part of the hip belt (if worn). Subjective ratings of discomfort were obtained using the Borg CR-10 scale for shoulder discomfort, back discomfort, and overall discomfort.

3.2. Results

EMG readings were again normalized (nEMG). Fig. 7 shows the raw data for one subject for all four measurements (shoulder FSR, back FSR, shoulder nEMG, and

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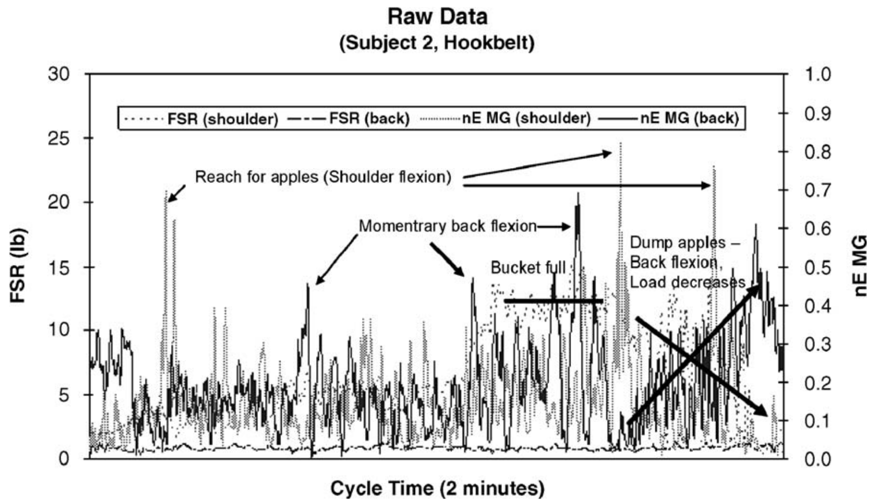

Fig. 7. Raw data for apple harvesting while using the hook belt.

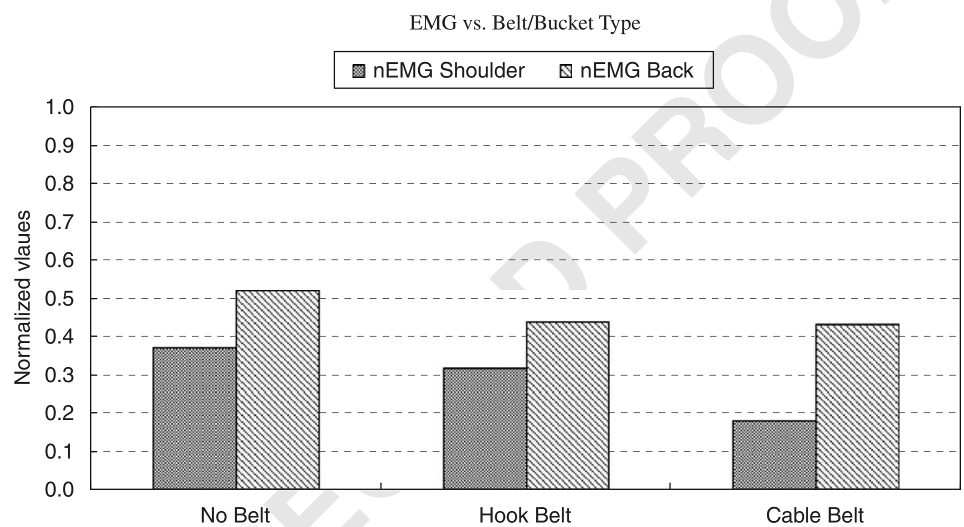

Fig. 8. Peak EMG as a function of belt/bucket interface.

back nEMG) over one full cycle (approximately 2 min): Starting with an empty bucket, picking apples, filling the bucket, and then finally emptying it in the bin. In general, shoulder FSR values increase monotonically during the cycle, indicating increasing weight on the shoulder as the bucket is filled. Back FSR values increase primarily when the worker leans forward to reach for apples or when emptying the bucket in the bin. Shoulder nEMG does not show a consistent trend; it varies according to specific motions made by the worker, e.g. shoulder flexion while reaching for distant apples. Back nEMG increases for forward flexion and at the very end of the cycle (last 10 s) as the apples are being unloaded into the bin.

Peak back nEMG values (indicating greatest muscle activity and potential strain) occurred in the no-belt condition (see Fig. 8). Peak values for the cable and hook belts are relatively similar. Peak shoulder nEMG was again highest in the no-belt condition. However, in this case, the cable belt had somewhat lower EMG values than the hook belt. In terms of subjective ratings, the no-belt condition produced considerably greater discomfort as compared to either belted condition for both the shoulder and an overall rating. The ratings for the back were relatively similar across all three conditions (see Fig. 9). In comparing the two belt/bucket interfaces, the hook belt was lower on two of the three ratings. None of the trends for EMG or Borg ratings were significant due to the limited number of data points.

4. Discussion and conclusions

Adding a hip belt to a traditional apple harvesting bucket (with one shoulder strap) significantly reduced shoulder loading by transferring some of the load to the hips. This was evidenced, in a controlled laboratory study, by lower shoulder pressure levels, smaller EMG values for shoulder and upper trunk muscle, and decreased subjective ratings of discomfort. This finding is important in light of

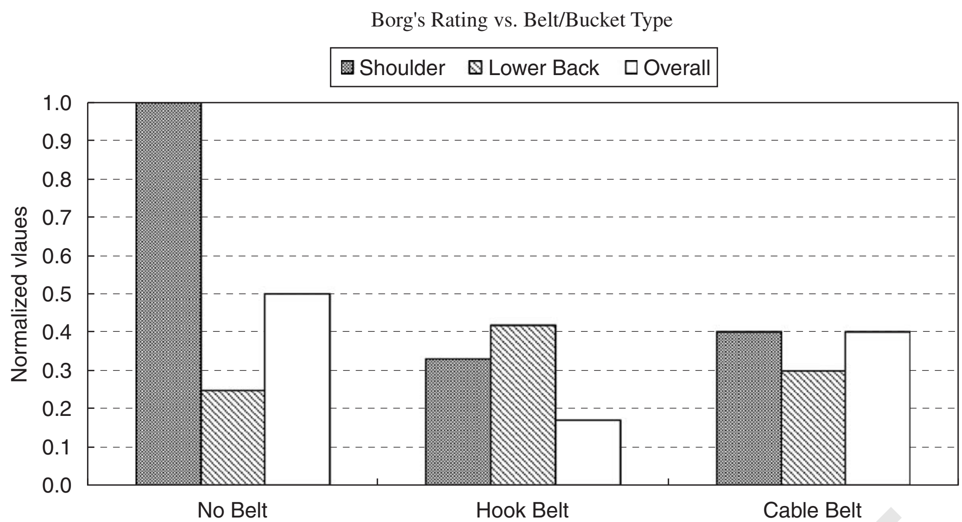

Fig. 9. Borg's subjective ratings as a function of belt/bucket interface.

previous research that found that apple harvest workers spend over 20% of observed work periods in the moderate flexion (45°) posture, and close to 80% of observed work periods with a full or partially full apple bucket (Earle-Richardson et al., 2005). Therefore, the reductions in load brought about by the belt intervention have the potential to reduce back and shoulder exertion for roughly 20% of the workday.

Of the two types of belt/bucket interfaces tested, the cable belt showed a significantly greater transfer effect, perhaps due to its stiffer nature and more uniform distribution of load and, perhaps, also due to the flexibility in adjusting the position of the bucket on the belt. This difference between belts was also reflected in reduced shoulder EMG and lower ratings of discomfort for the cable belt.

Although these same effects were found with professional apple harvesters in the field, the differences were not statistically significant due to the limited sample size. However, both workers consistently evidenced greater satisfaction with either type of belt and were quite reluctant to return the belts at the end of the work day. Further testing in the field with a larger sample size is warranted to conclusively establish the superiority of the cable belt.

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