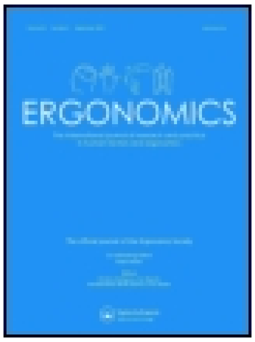

Ergonomics

ISSN: 0014-0139 (Print) 1366-5847 (Online) Journal homepage: http://www.tandfonline.com/loi/terg20

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To cite this article: Giulia Earle-Richardson , Paul L. Jenkins , David Strogatz , Erin M. Bell , Andris Freivalds , Julie A. Sorensen & John J. May (2008) Electromyographic assessment of apple bucket intervention designed to reduce back strain, Ergonomics, 51:6, 902-919, DOI: 10.1080/00140130801939790

To link to this article: https://doi.org/10.1080/00140130801939790

Ergonomics
Vol. 51, No. 6, June 2008, 902–919

Electromyographic assessment of apple bucket intervention designed to reduce back strain

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The authors previously developed an apple bucket that was modified by use of a hip belt to reduce muscle fatigue. The intervention of belt use was accepted by workers and shown not to interfere with productivity. However, use of this intervention did not appear to reduce muscle fatigue when measured by tests of voluntary muscle strength. The purpose of the present study was to evaluate the intervention's effect on muscle fatigue employing surface electromyographic (EMG) amplitude. Amplitude measurements on 15 muscles were taken from 10 laboratory volunteers who were carrying a full bucket of apples, once while wearing the intervention belt and once without the intervention. These measurements were taken for seven different postures (four angles of trunk flexion (0°, 20°, 45°, 90°) and three raised-arm positions (both up, dominant up, non-dominant up)) common to apple harvest work. Participants were measured in these conditions both with the bucket carried in front and with the bucket carried to the side. Significant reductions in amplitude favouring the intervention were seen for 11 of the 15 muscles in models considering the four body flexion angles. Ten of these were of the middle and lower back. These control/intervention differences were seen with both bucket-carrying positions (front vs. side) and tended to increase with increasing flexion angle. In contrast, no significant intervention effects were observed in models considering treatment by arm-raised position. One significant main effect (upper trapezius, side bucket) showed an amplitude reduction in the treatment condition. Another main effect showing increased amplitude in the intervention condition use was observed in the dominant levator scapulae (side bucket). Thus, the use of the intervention belt reduces EMG amplitude among a number of mid- and lower-back muscles. This is suggestive of a protective effect against back strain.

Keywords: agricultural ergonomics; migrant farm workers; musculoskeletal strain; muscle fatigue; EMG; agriculture

1. Introduction

Migrant and seasonal farm workers are commonly employed for relatively short but intense periods to harvest orchard fruits, such as apples, peaches and pears. Such activities as reaching up, bending down and balancing on ladders and tree branches, while carrying a full bucket of fruit, make musculoskeletal strains common occurrences for these workers

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ISSN 0014-0139 print/ISSN 1366-5847 online

DOI: 10.1080/00140130801939790
http://www.informaworld.com

(Ciesielski *et al.* 1991, Husting *et al.* 1997, Osorio *et al.* 1998, Villarejo and Baron 1999, McCurdy *et al.* 2003). Frequent muscle pain, a common symptom of strain, has also been documented in orchard work (Sakakibara *et al.* 1995, Calisto 1999). In addition to strain and pain outcomes, high levels of exposure to the hazards of awkward posture and weight bearing among orchard workers have been identified (Calisto 1999, Earle-Richardson *et al.* 2004).

In an effort to reduce the level of neck, back and shoulder muscle exertion inherent in this work, the authors have developed a simple hip belt that hooks to the apple harvesting bucket (Figures 1– 2). Details of the research employed in developing this intervention are published elsewhere (Earle-Richardson *et al.* 2004, 2005).

In order to evaluate the intervention's effectiveness, researchers compared muscle fatigue effects between the intervention and a placebo (Earle-Richardson *et al.* 2006a). Muscle fatigue was measured using before- and after-work muscle strength testing. In this trial, 96 New York State apple harvest workers were randomly assigned to use the intervention hip belt or the control equipment for 1 week. In a second week, all workers switched conditions. Participants were interviewed and muscle fatigue measurements made (morning vs. afternoon muscle strength) after several days of using the assigned equipment. The results of this trial indicated that the intervention belt was acceptable to workers and did not hinder productivity. However, the anticipated ergonomics benefits were not observed.

Upon further study, it appeared that the muscle fatigue measurement methods used were not adequately sensitive to detect the level of change in muscle fatigue occurring during 1 d of work. This was shown when muscle fatigue results were obtained at the end of the harvest season on a non-working day and found to be very close in value to those obtained for a full day of apple picking work.

For this reason, the current study evaluates the physiological effects of the hip belt intervention using surface electromyography (SEMG) in the laboratory. The rationale for its use is that muscle recruitment (necessary for muscle exertion) generates electrical current, measurable with electromyography. The amplitude of this electrical current has been shown to vary with muscle exertion magnitude. Since muscle exertion magnitude is determined by the size of the handled load, electromyographic (EMG) amplitude can be used as an indicator of the magnitude of the load to which a participant is exposed. SEMG is one of the most widely used measurement instruments for evaluating muscle activity in

Figure 1. Intervention belt.

Figure 2. Apple harvest worker using intervention belt hooked to bucket.

the occupational setting (Krantz *et al.* 2004, Alkjaer *et al.* 2005, Asundi *et al.* 2005, Bloemsaat *et al.* 2005, Dong *et al.* 2005, Mathiassen *et al.* 2005, Rolander *et al.* 2005, Steingrimsdottir *et al.* 2005).

It is important to note that in changing methods, the research now focuses on identifying differences in muscle loading (an exposure) rather than muscle fatigue (an outcome). Using decreased muscle loading as an indicator of success for the hip belt intervention assumes a demonstrated causal relationship between increased muscle loading and musculoskeletal strain. In 1997, the National Institute for Occupational Safety and Health (NIOSH) undertook a comprehensive review of the published literature on this topic and concluded that:

> There is **strong evidence** that low-back disorders are associated with work-related lifting and forceful movements. Of the 18 epidemiologic studies that were reviewed, 13 were consistent in demonstrating positive relationships. ... [Studies] using more objective assessments had odds ratios ranging from 2.2 to 11. ... The review provided **evidence** that work-related awkward postures are associated with low-back disorders. Results were consistent in showing positive associations, with several risk estimates above three.
>
> (Bernard 1997, pp. 6–1 to 6–2)

Other studies since 1997 also support this finding of association (Holmberg *et al.* 2003, Labry *et al.* 2004, Sbriccoli *et al.* 2004, Carrivick *et al.* 2005, Village *et al.* 2005). It is important to note that few of the studies referenced here employed SEMG in exposure assessment. Rather, workplace observation of postures, weighing of loads and worker self-report were more frequently used.

Previous hip belt research by the authors identified reductions in three of four back muscles with intervention use while in 45° of forward flexion (Earle-Richardson *et al.* 2006b). The current study undertakes a much more comprehensive evaluation, assessing 15 muscles of the neck, shoulder, back, buttocks and hamstrings, across one set of four trunk postures and one set of three arm positions, then replicated using a second bucket-carrying method. This results in 60 different belt vs. no belt comparisons.

2. Materials and methods

2.1. Participants

A total of 10 healthy male volunteers were recruited from the Pennsylvania State University, University Park, Pennsylvania. Written informed consent was obtained from each of the participating individuals. The study was approved by the university's Institutional Review Board.

2.2. Apple picking equipment

Participants were measured while carrying a semi-circular plastic apple bucket (Wells & Wade Harvest Bucket^{TM}; Superior Fruit Equipment, Wenatchee, WA, USA) in front, with one strap over each shoulder, (Figure 3) and also when carrying to one side, with both straps over one shoulder (Figure 4). This bucket contained 17 kg of apples for all measurements.

2.3. Target muscles

Target muscles for measurement were identified by a licensed physical therapist while observing a participant with a loaded bucket and visually noting which muscles were flexed. A total of 15 muscles were identified. Because the EMG equipment could only record eight muscles at a time, two muscle groups were assessed (identified as groups A and B in Figure 5). To minimise the chances of electrical interference from one lead to another, the muscle groups were chosen in such a way as to maximise the distance between attached EMG leads on the body. For certain muscles having a greater potential to be

Figure 3. Front carry, two strap.

Figure 4. Side carry, one strap.

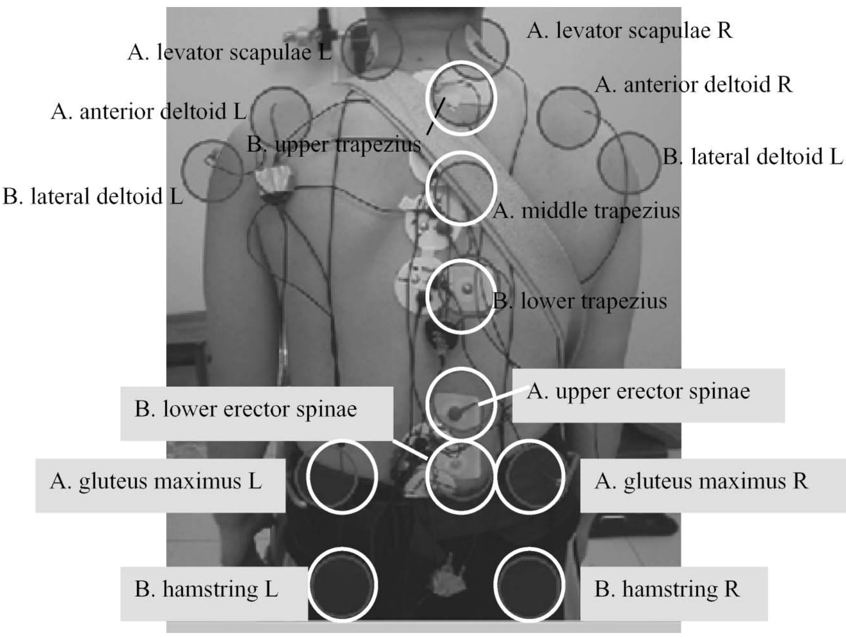

Figure 5. Electromyographic placement for muscles in muscle test sets A and B. Muscles for which significant amplitude reductions were found with intervention use are circled in white.

affected by handedness, both dominant and non-dominant sides were measured (e.g. anterior and lateral deltoids). The trapezius and erector spinae muscles had electrodes placed as near the centreline as possible without reference to handedness.

2.4. Experimental trunk flexion postures and arm positions

In order to mimic postures commonly assumed by orchard workers, the four experimental trunk postures assumed by the participants were standing straight (0° flexion), then at 20°, 45° and 90° angles of flexion from vertical. The three arm positions were dominant arm raised, non-dominant arm raised, both arms raised. 'Raised' was defined as producing an angle of 120° with the participant's vertical trunk.

2.5. Dominant hand side vs. non-dominant hand side

Since EMG amplitude for the arm-raising positions and for carrying the bucket to the side could both potentially be affected by whether the participant was right- or left-handed, all measurements were recorded in terms of 'dominant hand side' and 'non-dominant hand side'. For example, data from a left-handed participant raising his left arm and data from a right-handed participant raising his right arm would both be categorised as 'dominant hand side arm raised'.

This same convention was adhered to with regard to bucket carrying side. Specifically, this was recorded as 'carried on dominant hand side' vs. 'carried on non-dominant hand side'.

2.6. Experimental procedure

Randomisation of testing order was utilised for all four repeated measures variables. These were muscle testing sets A and B (Figure 5), experimental conditions (intervention belt, no belt), testing postures and positions (four trunk angles, three arm positions) and bucket carrying method (bucket front, bucket to one side).

In addition to these four repeated measures effects, the study also included one between-participants effect. This related only to situations where the bucket was carried to the side. In these cases, five participants were randomised to carry the bucket on the non-dominant side, with the remaining five carrying to the dominant side.

For logistical reasons, all testing was completed with one muscle set before proceeding with the second. Thus, once one of the two muscle sets was selected at random, the four possible combinations of intervention/control and bucket front/side were randomly ordered. Then, within each of these four combinations, the four trunk postures and three arm-raised positions were randomly sequenced. So, for any given participant, the following testing protocol was applied (see Appendix 1).

2.7. Attachment of the electromyographic leads and measurement of maximum baseline exertion

Each EMG electrode contained two leads, which were placed on the designated muscle (Cram *et al.* 1998). EMG leads were then connected to the EMG data recorder (FlexComp Infiniti™ data acquisition system; NexGen Ergonomics, Montreal, Canada).

2.8. Establishment of maximum muscle amplitude

For each muscle, a maximal exertion motion was identified (Cram *et al.*1998) to obtain the participant's maximal contraction reading for that muscle. Before data collection began, the participant was instructed to perform this motion with all possible effort. This was done to permit each subsequent contraction reading for each muscle to be expressed as a percent of maximum exertion.

2.9. *Participant measurement for assigned postures*

All seven of the postures and arm positions were demonstrated to the participant and the postures and positions were evaluated for correctness using a goniometer. The participant was asked to hold the posture for 5 s, during which the electromyography was recorded, and then given 2 min to rest. Each posture was assumed three additional times for a total of four repetitions.

2.10. *Data processing*

The raw microvolt data, which constitute the input from a given electrode, was smoothed and averaged over a running window of time to give continuous root mean squared (RMS) data. The resulting 1200 processed data points were then averaged to give one RMS value for each combination of muscle by posture by condition for each 5-s time sample (and three repetitions; de Luca 1997, 2002, pp. 1–10, Cram *et al.* 1998).

2.11. *Statistical analysis*

The mean of the four amplitude values obtained from the four repetitions of a given experimental condition served as the endpoint for data analysis. These were expressed as a percent of the maximum exertion level for each muscle.

The effect of the intervention belt was analysed in two separate models, one for the four trunk postures and one for the three arm-raised positions. For those cases where the bucket was carried to the front, the trunk postures were analysed using two (intervention/control) by four (0°, 20°, 45°, 90°) ANOVA. The arm-raised position data were analysed via a two by three (dominant, non-dominant, both arms) model. All effects in these models were within-participant effects, except for participant effects.

A mixed ANOVA model was required for those analyses where the bucket was carried to the side. These two models contained the same within-participant effects as the two models specified above and, in addition, a between-participants effect for bucket carrying to the side (dominant vs. non-dominant).

3. Results

The 10 male participants had a mean age of 28.7 years. Mean stature and weight were 172.2 cm (67.8 inches) and 70.7 kg (155.5 lbs), respectively. Eight participants were right-handed, two were left-handed.

3.1. *Summary of overall levels of exertion*

Table 1 shows the mean muscle exertion (as a percentage of maximum) by muscle type, bucket position and by condition (no-belt/belt). As this table is intended to give a general summary of overall exertion levels, the data are pooled across trunk flexion angles and arm-raised positions.

Table 1. Mean muscle exertion (% of maximal exertion) by muscle across flexion angle and across arm-raised position.

	Apple bucket carried in front				Apple bucket carried on the side			
	Trunk angle		Arm position		Trunk angle		Arm position	
	No belt	Belt	No belt	Belt	No belt	Belt	No belt	belt
Neck, Shoulder, Upper Back								
Levator scapulae D	05.39	05.35	07.84	06.61	06.80	06.13	09.10	08.15
Levator scapulae ND	05.29	05.73	08.75	09.69	07.27	06.11	09.71	09.64
Lateral deltoid D	01.18	00.86	08.59	08.26	01.48	01.52	08.57	07.22
Lateral deltoid ND	01.91	00.85	09.71	09.99	01.93	01.50	09.85	09.20
Anterior deltoid D	03.77	01.05	34.83	32.64	01.43	01.23	31.27	31.99
Anterior deltoid ND	02.49	01.56	32.57	32.10	02.07	01.73	30.38	30.58
Upper trapezius	09.03	06.25	27.23	24.56	09.23	06.21	26.71	21.38
Middle Back								
Middle trapezius (right only)	06.88	03.98	06.75	06.96	09.16	05.42	05.89	05.51
Upper erector spinae (right)	18.72	16.37	14.42	13.38	17.17	14.59	12.59	11.48
Lower trapezius	13.10	06.39	12.31	11.62	12.86	07.18	10.67	09.64
Lower Back And Trunk								
Lower erector spinae	27.24	19.29	16.79	17.91	22.65	17.81	19.31	19.12
Gluteous maximus D	18.07	16.23	20.63	19.54	16.13	11.05	10.00	09.96
Gluteous maximus ND	14.88	12.82	14.73	14.71	17.10	15.80	14.46	17.56
Hamstring D	11.15	10.77	08.22	09.22	10.62	07.72	06.76	06.72
Hamstring ND	12.94	11.94	09.77	09.26	11.77	08.91	06.93	06.69

D = dominant hand side; ND = non-dominant hand side.

For muscles of the upper body region (the neck, shoulders and upper back) these percentages were typically less than 10%. Noteworthy exceptions were the anterior deltoid and upper trapezius muscles in the arm-raised condition, where exertion ranged from approximately 21% to 35%. In the middle back, the highest exertion (approximately 15%) occurred in the upper erector spinae. This was followed by the lower trapezius (approximately 10%) and, finally, the middle trapezius at approximately 5%. Exertion levels in the lower back and trunk were approximately 15% in the gluteals, 10% in the hamstrings and 20% in the lower erector spinae.

3.2. *Assessment of handedness vs. bucket carrying side*

No significant bucket side (dominant vs. non-dominant) by treatment group (intervention vs. control) interaction effects were seen. This was true both for models including the four trunk flexion angles and for those considering the three arm-raised positions. Because of this, the dominant vs. non-dominant bucket-carrying dimension was eliminated from both of these models and the data re-analysed.

3.3. *Assessment of intervention effects*

3.3.1. *Bucket carried in front*

As shown in Table 2, the ANOVA results for the model that considered the body flexion angles while carrying the bucket in front varied between different muscles. No significant

Table 2. Reductions in muscle-specific muscle recruitment, based on % of maximum electromyographic exertion, when wearing hip belt intervention for two bucket carrying styles (in front and to the side), and two sets of body postures (trunk flexion and hand raising).

	Apple bucket carried in front						Apple bucket carried on the side					
	Belt vs. no belt across four postures: 0°, 20°, 45°, 90° forward flexion			Belt vs. no belt across −Dominant hand raised −Non-dominant hand raised −Both hands raised			Belt vs. no belt across four postures: 0°, 20°,45°, 90° forward flexion			Belt vs. no belt across −Dominant hand raised −Non-dominant hand raised −Both hands raised		
(−reduced exertion with intervention belt; +increased exertion with intervention belt) (shown for p values of 0.2 or less only)	−/+	p	p interaction with posture	−/+	p	p interaction with which arm is raised	−/+	p	p interaction with posture	−/+	p	p interaction with which arm is raised
Neck, Shoulder, Upper Back												
Levator scapulae D		0.94	0.71		0.09	0.47		0.24	0.20	+	0.02	0.34
Levator scapulae ND		0.38	0.47		0.28	0.98		0.08	0.68		0.84	0.42
Lateral deltoid D		0.27	0.47		0.74	0.53		0.92	0.70		0.08	0.33
Lateral deltoid ND		0.13	0.50		0.83	0.58		0.41	0.61		0.57	0.48
Anterior deltoid D		0.14	0.09		0.48	0.89		0.07	0.58		0.69	0.47
Anterior deltoid ND		0.33	0.40		0.88	0.82		0.06	0.77		0.67	0.44
Upper trapezius (D side only)	−	0.04	0.89		0.58	0.87	−	0.05	0.97	−	0.04	0.15
Middle Back												
Middle trapezius (D side only)	−	<0.0001	0.03		0.84	0.85	−	0.03	0.01		0.41	0.93
Upper erector spinae (D only)	−	0.04	0.24		0.19	0.94	−	0.03	0.29		0.19	0.28
Lower Back/Extremities												
Lower trapezius (D only)	−	<0.0001	<0.0001		0.73	0.34	−	0.003	<0.0001		0.18	0.73
Lower erector spinae (D only)	−	<0.0001	0.01		0.37	0.32	−	0.01	0.07		0.86	0.18
Gluteus maximus D	−	0.18	0.04		0.27	0.98	−	0.02	0.004		0.98	0.99
Gluteus maximus ND	−	0.01	0.0003		0.98	0.20		0.84	0.03		0.07	0.24
Hamstring D		0.50	0.26		0.11	0.40	−	0.01	0.11		0.95	0.87
Hamstring ND		0.20	0.16		0.61	0.48	−	0.01	0.23		0.80	0.24

D=dominant hand side; ND=non-dominant hand side.

main or interaction effects were seen for the dominant and non-dominant hamstring, dominant and non-dominant anterior deltoid, dominant and non-dominant lateral deltoid and the dominant and non-dominant levator scapulae.

There were significant main effects favouring the intervention in the upper trapezius and upper erector spinae that were not accompanied by significant treatment by body-angle interaction. These results were characterised by amplitude differences ranging from 1% to 6%.

Significant treatment by body-angle interactions were seen for the dominant and non-dominant gluteals, the lower and middle trapezius and the lower erector spinae. These were accompanied by significant main effects for all but the dominant gluteus. Ordinal interactions were seen for the lower and middle trapezius and erector spinae. Figure 6 shows that these were characterised by little or no difference at 0° flexion, with progressively greater differences favouring the intervention at higher degrees of flexion. The interactions for both gluteals were disordinal, with the control bucket favoured at 0° and 20° and the intervention bucket favoured at 45° and 90° (Figure 7). Treatment vs. control differences were maximised for all five of these muscles at 90° of flexion and ranged from a low of 6% for the middle trapezius to a high of 18% for the lower erector spinae.

No significant main or interaction effects were seen for any of the 15 muscles in the models considering the arm-raised positions with the bucket carried to the front.

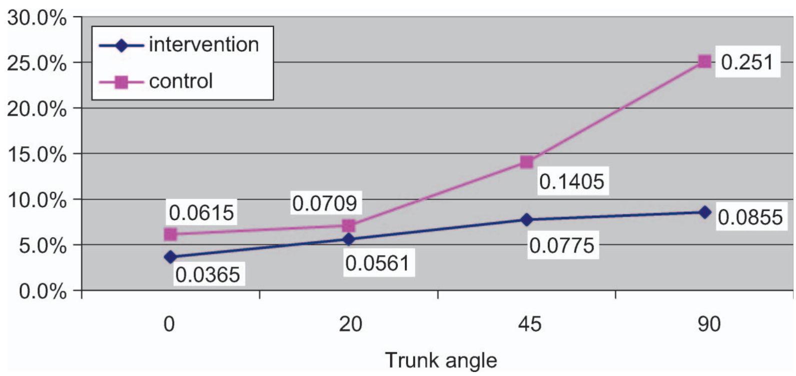

Figure 6. Front bucket, lower trapezius muscle recruitment, % of maximum.

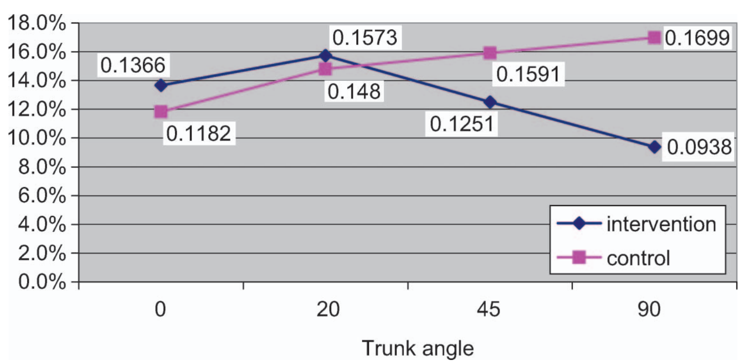

Figure 7. Front bucket, gluteous maximus (non-dominant) muscle recruitment, % of maximum.

3.3.2. Bucket carried on the side

Results seen for the body flexion angles with the bucket carried to the side showed considerable variability across muscles (Table 2). Five muscles (the dominant and non-dominant hamstring, upper and lower erector spinae and upper trapezius) showed significant main effects for treatment without angle-by-treatment interaction. These results were characterised by reduced amplitude for the intervention for all four angles of flexion with the sole exception of 0° of flexion for the lower erector spinae, where no difference was observed. Intervention vs. control differences were generally smaller at lower degrees of flexion and increased to approximately 6% at 90°.

Two general patterns, occurring for both treatment conditions, were observed for these five muscles. The first, which was seen for both hamstrings and the upper erector spinae, was characterised by a monotonic increase in amplitude with increased body angle (Figure 8). The second pattern, seen in the upper trapezius and lower erector spinae, consisted of an increase in amplitude from 0° to 45° of flexion with a marked drop from 45° to 90° (Figure 9).

Three other muscles showed main effects in favour of the intervention (without interaction) that approached, but did not reach, significance. These were the dominant anterior deltoid ($p = 0.07$), non-dominant anterior deltoid ($p = 0.06$) and the non-dominant levator scapulae ($p = 0.08$) (Figure 10).

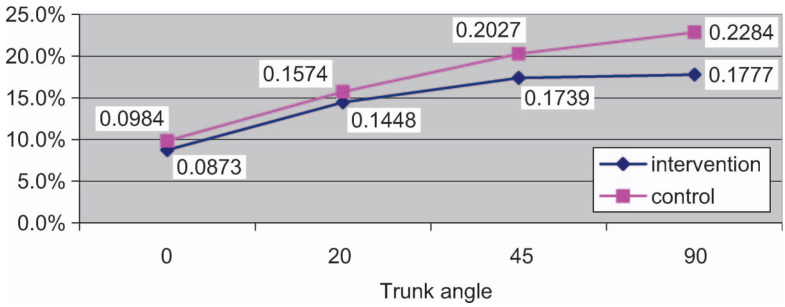

Figure 8. Side bucket, upper erector spinae muscle recruitment, % of maximum.

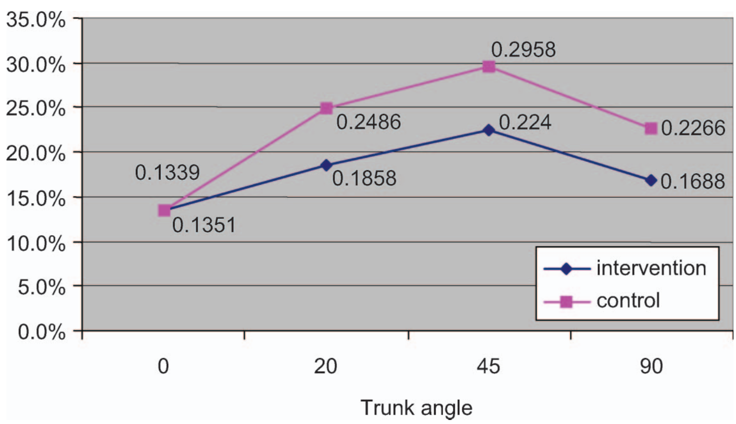

Figure 9. Side bucket, lower erector spinae muscle recruitment, % of maximum.

Four muscles, the dominant and non-dominant gluteals and the lower and middle trapezius, showed significant treatment by body-angle interactions. The interactions for both trapezius muscles were ordinal, with progressively greater differences favouring the intervention at higher angles of flexion (Figure 11) (10% for the middle trapezius and 17% for the lower trapezius).

Both interactions for the two gluteal muscles were disordinal, with the control bucket resulting in lower amplitude at smaller flexion angles (0° for the dominant gluteal and both 0° and 20° for the non-dominant) and the intervention bucket being clearly favoured at the higher angles (Figure 12). The reduced amplitudes in favour of the control condition at the lower angles were less than 3%. In contrast, the reduced amplitudes associated with the intervention condition at higher angles ranged from 4% to 9%.

No significant main or interaction effects were seen for the dominant and non-dominant lateral deltoid and the dominant levator scapulae.

There were no significant treatment by arm position interactions in the models with the bucket carried to the side. However, two of the 15 muscles had significant main effects, as shown in Table 2. One of these, the dominant levator scapulae, had significantly increased mean amplitude for the intervention condition compared with the control when pooled across the three positions; however, the results were equivocal in that amplitude was actually lower in the intervention condition for two of these three (both hands up and non-dominant hand up). The other significant main effect (for the upper trapezius) favoured the intervention for all three arm positions.

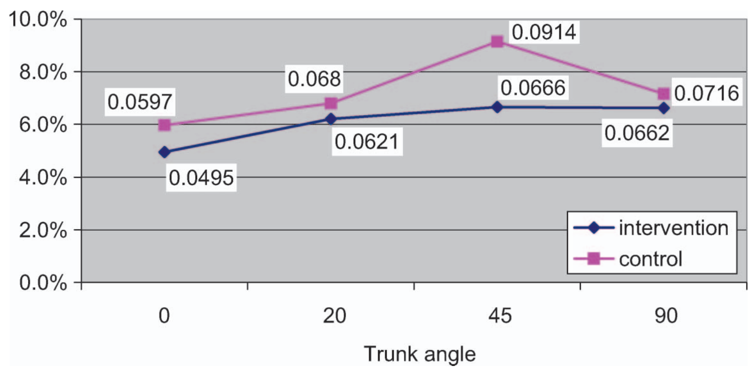

Figure 10. Side bucket, levator scapulae (non-dominant) muscle recruitment, % of maximum.

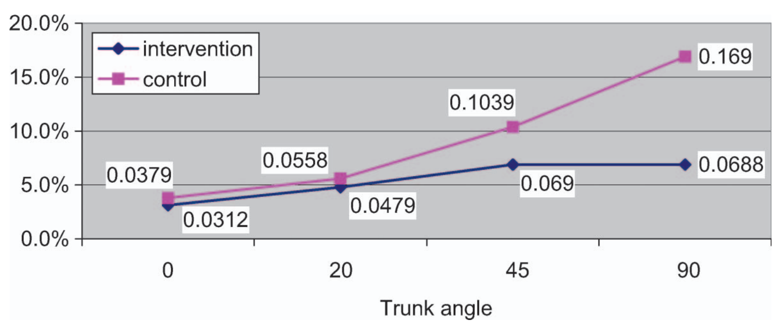

Figure 11. Bucket carried on the side, mid-trapezius muscle recruitment, % of maximum.

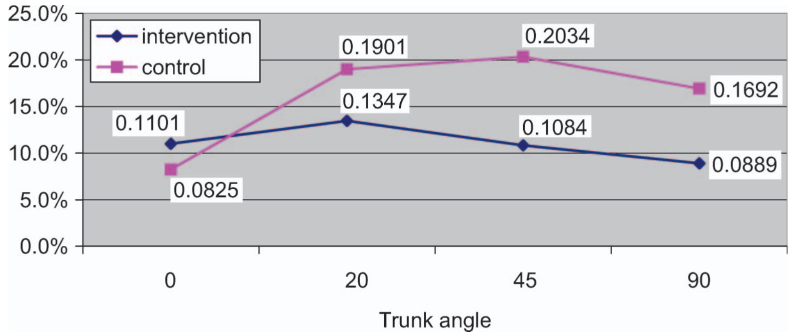

Figure 12. Side bucket, gluteous maximus (dominant) muscle recruitment, % of maximum.

4. Discussion

4.1. Overall levels of muscle recruitment

Maximum EMG amplitudes in response to the four flexion angles did not exceed 27.2%. Amplitudes in response to the arm-raised postures were maximised at 34.8%. This suggests that muscle strain of the back, shoulders and neck in apple harvest work occurs with moderate and low levels of muscle recruitment. Other studies (Magora 1972, Bergenudd and Nilsson 1988, Burdorf *et al.* 1991, Punnett *et al.* 1991, Jensen *et al.* 1993, Toroptsova *et al.* 1995, Skov *et al.* 1996, Madeleine *et al.* 2003) have found associations between moderate loads and musculoskeletal injury. These comparisons must be interpreted with caution, however, since most of this research did not use SEMG to quantify load.

When pooled across trunk flexion angle, the upper and lower erector spinae and the dominant side gluteus maximus have amplitudes in the 25% range. As stated previously, these are among the higher overall muscle amplitudes observed in response to trunk flexion. Therefore, among the muscles studied, they would appear to be the best initial targets for a muscle load reduction intervention. Since the highest levels of muscle recruitment in response to the three arm-raised positions were observed in the anterior deltoids (34.8%, 32.6%) and the upper trapezius (27.2%), an intervention for this region of the body might best focus on these muscles.

4.2. Intervention-control differences

Although the results seen for the body flexion angles with the bucket carried to the side are slightly more complex than those for the cases where the bucket was carried to the front, the themes that emerged are similar enough to be discussed as a single entity. There were many cases in which the intervention belt reduced amplitude more or less uniformly across the four trunk angles. There were also many instances where the benefit of the intervention belt tended to increase with increasing body angle. In some cases, the intervention was seen to reduce amplitude by half. This suggests that hip belt intervention has the potential to reduce load and the corresponding muscle recruitment when workers are in a flexion posture.

Previous research by the authors (Earle-Richardson *et al.* 2004) found that apple harvest workers spend approximately 22% of their picking day carrying loads in moderate or extreme forward flexion. Given the difficulty of reducing the exposure duration, this substantial reduction in muscle recruitment brought about by the hip belt may offer a more feasible method for reduction in back strain.

Out of all 60 models, only one showed a significant main effect that favoured the control condition. The dominant levator scapulae had significantly increased mean amplitude for the intervention condition vs. the control when pooled across the three positions; however, the results were equivocal in that amplitude was actually lower in the intervention condition for two of these three (both hands up and non-dominant hand up).

4.3. Location of muscles most affected by the intervention belt

The significant reductions in recruitment seen with belt use across the four body angles were consistently located in the large central muscles of the middle and lower back, specifically the three trapezius and two erector spinae muscles. This was true for both front and side bucket-carrying positions.

4.4. Resulting reductions in muscle strain

Taken as a whole, the data clearly indicate a statistically significant reduction in EMG amplitude when using the hip belt. This reduction in muscle recruitment is widely viewed as a reliable indicator of a reduction in muscle activity that would lead to muscle strain (Roquelaure *et al.* 2002, Mathiassen *et al.* 2003, Nevala *et al.* 2003, Peper *et al.* 2003, Matern *et al.* 2004, Anders *et al.* 2005, Dainoff *et al.* 2005). However, there currently exists insufficient quantitative data on the EMG amplitude–muscle strain relationship to estimate the magnitude of the reduction in muscle strain offered by the hip belt intervention (Simoneau *et al.* 2003).

A small number of studies have quantified EMG amplitude–injury relationships by estimating safe exertion limits for the trapezius. Jonsson (1982) recommended no more than 2% to 5% of maximum voluntary contraction (MVC) in the trapezius for 8 h, while others assert that this may be too high (Aaras 1987). Then again, other researchers (Westgaard *et al.* 1986, 1993) have found varying results with different working populations. In this context, differences of up to 18% (from 30.9% to 13.2% of MVC) seem quite large.

One study by Village *et al.* (2005) compared median peak neck/shoulder muscle activity (as a percentage of MVC) between health care facilities with high vs. low injury rates. In this study, the four health care facilities with the higher rates had a mean median trapezius amplitude of 18.5% of maximum, whereas the four with the lower rates had a mean of 11.3%. The correlation between injury rate and median trapezius amplitude was 0.40, and markedly higher correlations were seen between injury rate and two other EMG-derived measures, peak spinal compression ($r = 0.86$) and cumulative spinal compression ($r = 0.84$). This provides some evidence that differences found in the current study are large enough to result in injury reduction.

There are additional published data that indicate quantitative relationships between exposure factors (load, duration and body angle) and musculoskeletal strain (Chaffin and Park 1973, Bringham and Garg 1983, Anderson *et al.* 1985, Herrin *et al.* 1986, Village *et al.* 2005); however, the correspondence between these exposures (e.g. compressive forces, load in kg or task) and EMG amplitude used in the current study is unclear.

It is generally believed that EMG amplitude is an indicator of muscle activity that occurs in response to not only load in kg, but also such factors as horizontal distance of the load from the spine, body angle and emotional factors (Chaffin 1969, van den Bogert 1994, Wells *et al.* 1994, Rissen *et al.* 2000, Mientjes *et al.* 2003). In the present study, the fact that data were analysed within participants and collected in the laboratory controlled many of these factors. The data appear to confirm the hypothesis that the actual downward force on the back muscles would decrease as weight is transferred to the hips, and that an additional reduction on muscle stress would be provided by keeping the load attached to the lower trunk. Further research is needed to determine which of these had the greater impact and how it correlates with injury.

5. Conclusion

The intervention resulted in substantial reductions in muscle recruitment of the middle and lower back muscles for participants in forward flexion and the magnitude of these reductions tended to increase with increasing flexion angle. This pattern was present for both front and side bucket-carrying methods. No meaningful reductions were seen with neck and shoulder muscles, nor were reductions obtained with varied arm-raised positions. These data suggest that muscle strain would be reduced for apple pickers (and potentially other fruit pickers) wearing the intervention hip belt. Further research is needed to quantify the extent of this reduction in musculoskeletal strain occurrence.

Acknowledgements

The work described in this paper was supported by NIOSH Grant # R010H008153–02. The authors would like to thank Shihyun Park, of the Pennsylvania State University, University Park, Pennsylvania, USA, for his assistance with this study.

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Appendix 1

Randomly select muscle group order (A then B or B then A)	Muscle group A	Randomly select order of four intervention-bucket side conditions	→	Intervention/front	Randomly select order of 7 postures*	8 simultaneous muscle readings
			→	Control/front carry	Randomly select order of 7 postures*	8 simultaneous muscle readings
			→	Intervention/side carry	Randomly select order of 7 postures*	8 simultaneous muscle readings
			→	Control/side carry	Randomly select order of 7 postures*	8 simultaneous muscle readings
	Muscle group B	Randomly select order of four intervention-bucket side conditions	→	Intervention/front	Randomly select order of 7 postures*	8 simultaneous muscle readings
			→	Control/frontcarry	Randomly select order of 7 postures*	8 simultaneous muscle readings
			→	Intervention/side carry	Randomly select order of 7 postures*	8 simultaneous muscle readings
			→	Control/side carry	Randomly select order of 7 postures*	8 simultaneous muscle readings

*Four trunk postures and three arm-raised positions: no arms up; one arm up; two arms up; 0° trunk flexion; 20° trunk flexion; 45° trunk flexion; 90° trunk flexion.