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Orchard Evaluation of Ergonomically Modified Apple Bucket

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ABSTRACT. *Background:* While preliminary laboratory tests indicate that a hip belt reduces the load on the back, neck and shoulders associated with musculoskeletal strain, an orchard trial is needed to more realistically assess both effectiveness and acceptability.

Objective: to evaluate the hip belt's effectiveness in three areas: worker acceptance, worker productivity, and one-day muscle fatigue of the back and shoulder.

Methods: Ninety-six New York apple harvest workers were randomly assigned to use the intervention hip belt or placebo belt for one week. In a second week all workers switched conditions. Subjects were interviewed at the end of each week to ascertain intervention acceptance. Employer records were reviewed to determine bushels picked per day. Subjects also underwent muscle fatigue testing at the beginning and again at the end of one workday during each week.

Results: Ninety-one percent of the subjects favored the intervention hip belt. Use of the intervention did not appreciably slow picking speed (bushels per hour) as compared to placebo (8.8 bu/hr vs. 8.89 bu/hr). Both were significantly faster than the regular equipment condition (8.13 bu/hr). No significant differences in one-day muscle fatigue were found with intervention use.

Conclusions: The belt was acceptable to the workers and did not hinder productivity. However, the anticipated ergonomic benefits were not demonstrable using one-day strength testing. doi:10.1300/J096v11n03_10

KEYWORDS. Ergonomics, migrant farmworkers, musculoskeletal strain, muscle fatigue

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INTRODUCTION

Migrant and seasonal farmworkers provide much of the manual labor used in agriculture for planting, pruning and harvesting of fruits and vegetables in the United States. One common result of this activity is musculoskeletal strain due to stooping, reaching, and carrying of heavy loads. A number of published studies indicate that musculoskeletal strains are among the most common injuries for migrant and seasonal farmworkers.[1-5] Very high rates of muscle pain, a common symptom of strain, have also been documented in orchard work.[6,7] In addition to strain and pain outcomes, high levels of exposure to the ergonomic hazards of awkward posture and weight bearing among orchard workers (Figure 1) have been identified.[7,8]

The authors have developed a simple intervention to reduce the load borne by the back, neck and shoulders by apple harvest workers. This intervention consists of a hip belt with a hooking mechanism for attachment to the apple bucket (Figure 2 and Figure 3). Details of the intervention are published elsewhere.[8,9]

Two laboratory studies have demonstrated that the intervention belt reduces load on the mid- and low-back, two site commonly associated with muscle strain.[10,11] The goal of the current research is to evaluate the ergonomic hip belt in a more realistic orchard setting to assess worker acceptance, as well as productivity effects of the hip belt. In addition, field methods developed previously[10] will be employed to determine whether the beneficial effects seen in the laboratory are also seen in the orchard.

FIGURE 1. Orchard harvest workers typically combine flexed postures and weightbearing.

FIGURE 2. Ergonomic intervention belt.

FIGURE 3. Apple worker using belt.

Worker acceptance–Pilot research (n = 14)[9] indicated that a majority of workers rated the hip belt intervention favorably (79%), after 2-3 one-hour trials. This was promising, but was too short an interval and too small a sample to be definitive. The published literature provides instances where an intervention determined to be ergonomically beneficial failed because workers refused to use it. Clearly, this is a critical component for intervention success.

Economic impacts–Depending on the apple variety, weather conditions and market conditions, profitability for the farm and the worker may require fast or slow picking, selective versus indiscriminate picking. The orchard manager must orchestrate these activities very carefully to maximize the return on the apples. To maximize productivity (both in terms of quantity AND quality), the orchards have developed incentive systems for fast picking times (piece rate pay), and for slower picking times (hourly rate plus incentives) For these reasons, it is critical to both the worker and management that the ergonomic intervention not substantially change the daily quantity picked.

Indicators of muscle strain–While arguably the most important of the three endpoints, the presence of muscle strain is also the most difficult to measure, since there is no definitive diagnostic test for the condition. Studies using diagnosis of muscle strain through the use of magnetic resonance imaging or sonography have been published, although the link between radiographic findings and clinically observed muscle strain has not been firmly established.[12-15] In a clinical setting it is most often diagnosed on the basis of patient self-reported pain after ruling out other possible sources. Self-reported pain has been used in a number of studies as well.[3,16-19]

Because of the lack of an objective diagnostic test for muscle strain, and a number of concerns regarding the accuracy of self-reported pain among migrant and seasonal farmworkers, researchers developed and tested a simple mechanical measure of back, arm and shoulder muscle fatigue that could be used in the orchard. The methods and rationale for this development are presented elsewhere.[11]

In the context of this study, fatigue is defined as the pre- to post-exposure decline in maximum performance occurring after a period of exertion.[20] Published fatigue studies of this type measure either time holding a posture, one-time attainment of a maximum reading on a dynamometer or a dichotomous pass/fail metric for performance of weighted or non-weighted tasks.[21-25]

In each study, the performance measures used are selected to simulate the postures involved in the work under study. Perhaps the most commonly used measures are the Sorensen Prone Test for back strength and the Beiring-Sorensen Test for lateral trunk strength.[22,26-29] Both measures are isometric tests where time to failure of holding a posture is measured. A review of published sources located no agricultural studies using these kinds of performance measures. The recent development of one endurance measure by the authors[11] appears to be the first.

In the laboratory portion of this study, the timed arm hold test (35.7% time reduction, 95% CI: 21.81-49.61), and the timed spinal extension test (31.8% time reduction, 95% CI: 23.54-39.96) showed significant fatigue. In the orchard (n = 102), only the timed arm hold showed significant (11.4%, $p < .0001$) fatigue. On the basis of these data, the timed arm hold test was used as the muscle fatigue measure for the current study.

The research presented here focuses on three key components to an effective ergonomic intervention for migrant and seasonal apple harvest workers: (a) worker intervention acceptance; (b) no negative productivity impacts; and (c) a detectable reduction in muscle fatigue using one recently developed orchard muscle fatigue measure.

METHODS

Recruitment

Study Orchards and Workers

Data were collected at two large orchards in northern New York over a three-week period. These two were selected from a pool of 15 volunteer orchards from around the state because they offered the easiest access to a large number of workers over the short harvest season. Because these first two farms did not employ any Mexican workers, who make up a substantial proportion of the apple harvesting work force, a third farm (the largest available that employed Mexicans) was enrolled.

The day before the trial was to begin, researchers visited worker housing on the farm with the owner and manager to give a short introduction to the project and obtain informed consent. It was emphasized to the workers that participation was optional. At this time, subjects were enrolled in the two-week trial, which included weekly interviews and muscle fatigue testing.

Intervention Implementation

Once enrolled, subjects were randomly assigned to use either the intervention or the placebo equipment for the first trial week. The subjects were then switched to the alternative equipment for the second week.

The placebo belt consisted of a belt with the same basic appearance as the intervention belt, but with no hooking mechanism. Since it is the hooking mechanism that allows the weight on the upper back, neck and shoulders to be transferred to the hips, this placebo belt was not expected to provide any of the intervention benefit. The subjects were individually fitted and instructed in the use of this intervention (Figure 4). The use of this placebo belt was considered important because the typical equipment set up for apple hand-harvest workers in New York State ("usual equipment") includes the same bucket and straps as shown in Figure 4, with no hip belt at all.

The following day, subjects began harvest work with their assigned equipment. Over the course of this first morning, researchers observed each worker who was using the intervention equipment to assure that they were using it properly. Equipment was considered to be worn properly when the belt fit snugly above the hips and the bucket straps were adjusted such that the hook on the back of the bucket fit into the metal eye on the belt. This allowed the transfer of the bucket's weight from the shoulder and back area to the hip area. Any necessary adjustments to the equipment were also made at this time.

Intervention Compliance

Within the context of the study, compliance with the intervention was operationally defined as having the belt hooked at all times except when unloading apples or when the bucket was empty. On the day of muscle fatigue testing, two separate observations of compliance were made: one before the morning test and another before the afternoon test. During the morning assessment, any subjects seen using the equipment improperly were corrected.

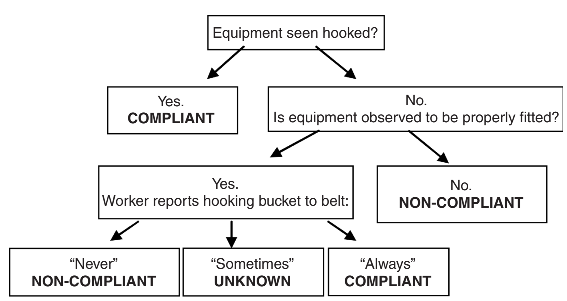
At the time of the afternoon compliance assessment, if the subject was observed with the belt hooked, he was classified as compliant. If the belt was not hooked, but the subject's bucket was empty or he was unloading apples, compliance was assessed using subject self-report. In this case, if the subject's equipment was not being worn properly, he was classified as non-compliant. If the equipment was being worn properly, the subject was then asked to report how often he was hooking the belt. The subject's responses were then categorized as "always," "sometimes," or "never." An "always" response resulted in a compliant classification, while "never" resulted in a non-compliant one. The "sometimes" response group was put into a third category, "unknown compliance." These three classifications were then used in analyzing the data. Figure 5 shows the decision tree for determining intervention compliance.

FIGURE 4. Worker is fitted with a placebo belt.

Definition of Study Endpoints

Worker acceptance of the intervention– Worker acceptance was defined as answering "yes" to the following question: "If this belt were provided by your employer, would you be willing to use it as part of your regular work?" The definition does not distinguish between those who prefer the intervention to those who are equivocal; the reason is that the authors believe that both groups would be receptive to a promotion campaign that emphasized the bene-

FIGURE 5. Subject intervention compliance decision tree.



fits to the worker. Researchers believe that a 50% or higher positive response would be sufficient for successful translation into regular use since it could occur gradually over a number of years.

Productivity effects of intervention use–This endpoint is defined as the total daily productivity (bushels per hour) picked by workers on each of their placebo days versus the same on their intervention days.

One-Day Muscle Fatigue Differences Between Intervention and Placebo

One-day muscle fatigue–In the context of this study, fatigue is defined as the morning (pre-work) to afternoon (post-work) difference time-to-failure (in seconds). A workday is defined as one 5-8 hour period of apple harvest work.

One-day muscle fatigue differences between intervention and placebo–One-day muscle fatigue differences are defined as the placebo one-day muscle fatigue minus the intervention day muscle fatigue.

Data Collection

Measurement of Worker Acceptance of the Intervention

Subjects were interviewed on the last day of using each condition provided they had used it for at least three days. The interview instrument was a structured questionnaire, based on a survey instrument used in previous studies,[9] with the questions further tested with 10 additional orchard workers for clarity and content. Pilot testing of interview questions was conducted in Spanish and English. The instrument was designed such that all questions for the intervention week and the placebo week were exactly the same.

After five days of use of either the intervention or control belt, trained interviewers staff came to the farm and interviewed participating workers just as the workday ended. Interviews were conducted in the workers' native language, and workers were reminded that they could refuse any question that they wished. Equipment was exchanged after the first week, and collected after the second week. The interview consisted of a series of stations, separated by 6-10 feet of space. First, subjects were weighed and measured, and had other anthropometric data collected (first interview only). Then they were asked about their use of the belt that week; how much of the time they wore it, whether there were any problems with it, and what there observations were about it.

The interview collected demographic and anthropometric data (e.g., height, weight, waist and hip circumference, and arm length), and subjective evaluations of the intervention belt. Specifically, subjects were asked if they would be willing to use the intervention belt as part of their regular work if provided by their employer. It was hypothesized that at least 50 percent of workers trying the ergonomic belt would state that they would be willing to use it for their regular work in the future. A 95 percent confidence interval was created for this proportion.

In addition, subjects were asked, "In the past week, have you had trouble (ache, pain or discomfort) in your neck, back or shoulders that lasted a day or more?" If the subject responded positively, they were asked further about the location and duration of the pain. Although self-reported pain was not considered a valid endpoint for the evaluation, this data was still collected, simply to determine whether expectations that data would be sparse were correct.

Worker Productivity Effects

Worker productivity was measured by collecting daily hours worked and bushels picked for each subject from employer records. It is standard practice for orchards to carefully note the daily hours worked and bushels picked by each worker, since piece rate pay or productivity bonuses during hourly work are calculated with these data. Data were collected for both experimental and placebo weeks, and for one "usual equipment" week (the week prior to the beginning of data collection).

Muscle Fatigue

For the intervention and placebo conditions, data collection took place after workers had used the equipment for a minimum of three days so that they would be physically accustomed to it. After completion of two-weeks of testing in both of these conditions, 20 subjects were further tested, following the same protocol, using their customary equipment. These muscle-testing sessions required an average of 15 minutes to complete for each worker, plus an additional ten minutes for walking to and from the test site. At times, the workers were so widely dispersed that it was necessary to move the two to three testing stations several times. This led to some variability in the muscle warm-up time and the working time for each subject.

The rule for beginning muscle testing was that the subject needed to have been working a minimum of 30 minutes. Because of the time involved in testing multiple subjects, subjects could have warmed up for as much as two hours before testing. The sequence of subjects in the morning testing was replicated in the afternoon to make the warm-up and working intervals as close as possible between subjects and weeks.

The rule for beginning afternoon testing was more complex. On a clear day, the crew chief could reliably predict quitting time, and measurement would begin two to three hours prior. However, if rain was possible, it was sometimes necessary to start earlier, in order to prevent the loss of subjects, or the cool-down of muscles. On those days, the working interval (time between tests) was reduced.

Workers completed three repetitions of the timed arm hold test, a test in which the subject held up a ten pound weight in the dominant hand for as long as possible (Figure 6). A timer began when the subject raised the weight until his hand made contact with a bar that activated a light. This bar was set at a height that resulted in the subjects arm being at an angle of 120 degrees measured upward from the trunk. Timing continued until the arm dropped away from the bar and the light was no longer lit. This time was manually recorded after each of the three repetitions. Further details of the muscle testing equipment and data collection protocol are presented elsewhere.[10]

STATISTICAL ANALYSES

Worker acceptance of the intevention–It was hypothesized that at least 50 percent of workers trying the ergonomic belt would state that they would be willing to use it for their regular work in the future. A 95 percent confidence interval was created for this proportion.

FIGURE 6. Subject performing the timed arm hold muscle fatigue test.

Intervention impacts on worker productivity–Bushels per hour were compared for three conditions: intervention, placebo, and usual equipment conditions using a one by three ANOVA. In order to control for any effects of in workday length that may have impacted picking speed, this model adjusted for workday length with a covariance correction.

Muscle fatigue differences between intervention and placebo day–As explained above, there could be considerable variability in both warm-up time and elapsed picking time for a given subject's placebo versus intervention condition. Therefore, Pearson correlations were calculated to measure the extent to which this variability was related to placebo-intervention differences in fatigue scores.

As detailed below, both of these correlations were found to be non-significant. Therefore, as covariance correction was not necessary, the null hypothesis that the mean of the difference (placebo-intervention) in fatigue scores was equal to zero was tested using a paired t-test.

In addition to this main analysis, the subjects were classified into one of two groups according to their observed level of compliance with the intervention ("compliant," versus "non-compliant + unknown"). The mean difference in fatigue scores was compared between these two groups using an independent samples t-test.

RESULTS

One hundred and twenty workers were invited to participate in the study; 102 participated, for a participation rate of 85 percent. Interview data were obtained from 99 workers, with physical measure data collected from 95. These subjects were located on two large and one medium sized farm.

Table 1 shows selected demographic and physical characteristics of the study subjects. The subjects were Jamaicans and Mexicans with varying preferences for bucket carrying position (right, left, front). Additionally, there was a wide range of heights, weights, and body mass indices. However, analyses did not show any associations between these variables. Therefore, these demographics were not considered in any further analyses.

Of the 99 subjects interviewed, 90 reported that they would use the intervention equipment if offered by their employer. All 99 subjects reported that they would use the placebo equipment.

Back, neck, or shoulder pain was reported by three workers during the intervention week, and four workers during the placebo week. These data were too sparse to make any formal statistical comparisons. Workers' comments about the intervention equipment are summarized in Table 2.

With respect to physiological measures, elapsed picking time between tests averaged 5.6 hours (SD = .95) in the intervention condition and 5.7 (SD = 1.0) in the placebo condition. Warm-up times averaged 1.8 (SD = .73) in intervention and 1.7 (SD = .68) in placebo. Neither of these differences was statistically significant.

Within-subject values for differences in elapsed picking time on the intervention day versus elapsed picking time on the placebo day had a mean of 0.09 (SD = 1.4). Similarly, warm-up time differences within subjects had a mean of −0.15 (SD = 0.7).

The correlation between elapsed picking time differential and fatigue score difference was not significant ($r = .14$, $p = .18$). The correlation between warm up time differential and fatigue score difference was also not significant ($r = .13$, $p = .19$). Since there was no meaningful correlation, subsequent analyses did not apply covariance correction for either of these variables.

As shown in Table 3, employer record review indicated that workers' mean picking speed per hour during their intervention did not differ significantly between intervention and placebo weeks. Picking speed for both of these weeks was significantly higher than picking speed during the regular equipment week.

Intervention compliance assessment revealed that of the 96 subjects evaluated, 69 (72%) were found to be compliant, 10 (10%) were found to be clearly non-compliant, and 17

TABLE 1. Demographic characteristics of orchard trial subjects, N = 96

	n	
Mean age	92	42.1
% Male	93	98.0%
Jamaican	82	80%
Mexican	20	20%
Mean height	93	1.72 m (67.8 in)
Mean weight	93	75.9 kg (169.1 lb)
Mean BMI	93	25.7
% Bucket left side	7	7.5
% Bucket right side	12	12.9
% Bucket center	59	63.5

TABLE 2. Subject comments regarding the intervention belt, N = 59

Back and body felt more firm and supported	28
Hooks get caught	14
Eases stress and pain in the waist	14
Makes me feel less tired	14
More comfortable	13
Reduces pressure and pain in the shoulders	10
Reduces pressure and pain in the back	10
Felt less pain	7
Felt better	7
Felt more protected	3
Hard to move bucket in tree	3
Needs shoulder pads	1

(18%) were classified as partially compliant or unknown.

As shown in Table 4, muscle fatigue differences between intervention and placebo days were evaluated three ways: first, without regard to observed compliance, next, excluding known or possibly non-compliant subjects, and finally by comparing fatigue score differences between compliant and non-compliant subjects. None of these analyses resulted in statistically significant outcomes.

DISCUSSION

A number of factors were examined in this study: intervention acceptance, productivity effects, and one-day muscle fatigue effects. While worker acceptance was extremely high, and no negative impacts on productivity were found, it was not possible to detect meaningful reductions in back and shoulder muscle fatigue over one day of work.

The 90 percent acceptance of the intervention equipment was higher than anticipated. The hypothesis for this study, based on the authors' previous research, was that at least 50 percent of workers would accept it.[9] Other agricultural studies introducing new equipment to migrant and seasonal farm workers have found varying degrees of acceptance, from none to a majority accepting.[10,30,31] Even though the workers on these three study farms do not constitute a random sample, the overwhelming support among them suggests that this intervention equipment would be popular among apple harvest workers generally.

One unexpected observation was the 100 percent acceptance for the placebo equipment, the intervention belt without the attaching hook. This raises the question of whether the back belt itself may confer some benefit apart from that conferred by engaging the hook. This is suggested in Table 2 by comments such as: "*[My] back and body felt more firm and supported,*" "*[The belt] eases stress and pain in the waist.*" It should be noted, however, that previous research has not demonstrated that back belts alone prevent back injuries.[32-34] Given the possibility that the belt alone may confer some previously unidentified benefit, it may be advisable to change the placebo condition to one with no belt at all.

Another key element of employee and employer acceptance of the intervention is its effect on picking speed. The fact that picking speed was significantly increased with both intervention and placebo conditions as compared with regular equipment suggests either a rather strong Hawthorne effect or some benefit from the belt itself. Further research is needed to determine which is the case. For the current study, it is sufficient to determine that use of the intervention does not reduce picking speed.

In contrast to the favorable outcomes seen for intervention acceptance and picking speed, the intervention did not demonstrate reductions in muscle fatigue: a difference of 5.35% ($p = .45$) is neither statistically significant nor biologically meaningful.[12,35,36]

TABLE 3. Subject picking speed (bushels per hour), N = 82

	Bushels/hr	P comparison with placebo	P comparison with original equipment
Intervention	8.80	0.43	< 0.0001
Placebo	8.89	---	< 0.001
Original equipment	8.13	< 0.0001	---

TABLE 4. Fatigue score differences between intervention and placebo day, analyzed three ways: without regard to confirmed compliance, confirmed compliance only, and grouped by compliance level

	n	Mean fatigue difference between intervention & placebo day	p
Timed arm hold, all subjects	95	0.13	.97*
Timed arm hold, only compliance-confirmed subjects	65	1.5	.72*
Timed arm hold, comparing compliant to non-compliant	91**		
Compliance-confirmed	(65)	1.5	.45**
Compliance unconfirmed	(26)	−4.1	

* Paired t-test
** 2-sample t-test

In order to consider the question of timed arm hold sensitivity further, fatigue scores were obtained on a sub-sample of 14 of the test subjects during a non-working day. These scores were then compared to the same subjects' work day fatigue scores, obtained in the placebo condition, to see whether the timed arm hold could detect fatigue attributable to work, that is, that only occurred on a working day. The resulting lack of difference observed between these fatigue scores ($p = .73$) indicate that fatigue effects resulting from a day of harvest work are too subtle to be detected with the timed arm hold test. In light of this finding, it appears that electromyographic methods should be reconsidered. Electromyography has been used in a number of studies to detect changes in muscle activity associated with work activities.[11,37-41]

One limiting factor in the muscle fatigue component of the study is that there was only one measure used, the timed arm hold, which had been validated in previous research.[10] This seriously limits the current study's ability to detect beneficial effects of the belt, if, for example, these beneficial effects are limited to the lower back muscles.

The development of just one fatigue measurement instrument occurred as a result of the difficulty of using muscle strength measurements with the farmworker population and the additional difficulty of taking measurements in the orchard. Previous instrument validation research[10] found substantial strength reductions after a day of work for both the timed arm hold and the timed spinal extension (35.7% and 31.8% time reductions, respectively).

However, in order for the second test to be used in the orchard, the timed spinal extension had to be converted to a standing, dynamic test. The resulting test (the "standing spinal extension") did not show significant fatigue associated with picking work. This test appeared to be more affected by the lack of completely level ground and by small individual variations in how the contraction was performed. In addition, all of the voluntary testing was subject to the limitation that workers might not exert fully in the morning before the beginning of a long workday. Again, these limitations suggest that electromyography may be a more appropriate measurement instrument for this component. Another difficulty of muscle strength testing for detection of muscle fatigue is that it is impossible to isolate one single muscle in the test. Muscles operate in groups; therefore any strength deficit found will reflect a net deficit in a muscle group. If a strong muscle compensates for a fatigued one, it will not be detected with this methodology.

CONCLUSION

This field research establishes that an intervention that was initially found to be effective in the laboratory[11] is acceptable to workers and does not negatively impact productivity in the orchard. Current methods were not sufficiently sensitive to determine if subtle muscle fatigue differences between the intervention and placebo were present, however. Future research should employ more sensitive methods to identify fatigue effects and determine muscles most at risk for strain.

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