ERGONOMIC EVALUATION OF AN APPLE PICKING BUCKET INTERVENTION DESIGNED TO REDUCE MUSCULOSKELETAL STRAIN IN ORCHARD HARVEST WORKERS

by

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ABSTRACT

Previous research has shown that back and shoulder musculoskeletal strain is a significant occupational health problem affecting migrant orchard harvest workers. The author has developed a simple intervention to reduce back and shoulder strain while picking apples. In order to evaluate this intervention, three studies were conducted.

In the first study, researchers sought to identify measures of muscle fatigue for use in a subsequent field study. In the laboratory, the timed arm hold test, (35.7% time reduction), and the timed spinal extension, (31.8% time reduction), showed statistically significant fatigue. In the orchard, only the timed arm hold, (11.4% time reduction), showed significant fatigue. The potential effect of field conditions and subject motivation on these results needs further exploration.

The orchard study evaluated the hip belt's effectiveness in three areas: intervention acceptance, effects on worker productivity, and one-day muscle fatigue of the back and shoulder. One hundred two 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. Ninety-one percent of the subjects favored the intervention hip belt. Use of the intervention did not appreciably slow picking speed. However, the anticipated ergonomic benefits of the intervention were not demonstrated using the timed arm hold and the standing spinal extension tests.

The third study employed alternative means to evaluate the effect of intervention. Surface electromyography is a method able to detect subtle changes in muscle activity. Electromyographic measurements on 15 muscles were taken from 10 laboratory

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volunteers who were carrying a full bucket of apples, once while wearing the intervention belt, and once without the intervention.

Significant reductions in amplitude favoring the intervention were seen for 11 of 15 muscles, mostly in the middle and lower back. These intervention versus control differences were seen with both bucket carrying positions (front vs. side) and tended to increase with increasing flexion angle. Thus, the use of the intervention belt reduces electromyographic amplitude (indicative of muscle activity) among a number of mid- and lower-back muscles. This is suggestive of a protective effect against back strain.

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Dissertation committee, David Strogatz, Chair

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Chapter I. INTRODUCTION AND BACKGROUND

The goal of the research presented here is to rigorously evaluate the effectiveness of an intervention belt designed by the author in reducing musculoskeletal strain among apple hand harvest workers. In this introductory chapter, the background and rationale for the selection of: the population of interest, the problem of musculoskeletal strain and the hip belt intervention are presented.

Orchard hand harvest work

Many thousands of individuals work at orchards in the Northeast each year. The New England and Middle Atlantic states account for more than one fifth of the country's apple production and produce substantial amounts of other tree fruit. The 2.2 billion pounds of apples picked in this region in 2004 (USDA, 2005) required the effort of an estimated 15,000 to 20,000 workers — largely seasonal and migrant (Larson, 2002).


Figure I.1. A worker lifts a full bucket of apples over the side of the bin

Typically the harvesting process involves the use of "apple buckets." These are buckets made of plastic, aluminum or canvas stretched over a steel frame. All types have a cylindrical canvas extension at the bottom that can be folded closed to retain the apples or opened to empty them. A filled bucket weighs 14 to 19 kilograms (30 to 42 lbs.), and is suspended from the shoulders by canvas straps so that the bucket hangs in front or to the

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side of the torso, slightly below the waist. To deposit a full bucket of apples, the worker must bend at the waist over a three-foot high bin, which can contain roughly 20 buckets or about one half ton of apples (Figure I.1). The bucket is lowered to within inches of the bottom of the bin, and then the hatch at the bottom of the bucket will be opened to release the apples The average worker fills from 4 to 10 bins per day. Tables I.1 and I.2 depict the apple hand harvesting experience in terms of activities and materials.

Table I.1. Common apple hand-harvest activities, by proportion of observation interval

	Activity	**% time**
Picking task	Picking apples (grasping and pulling only)	62.9
	Placing or moving apples in bucket, adjusting bucket (after picking)	8.7
	Climbing ladder (up or down)	3.3
Emptying bucket	Emptying bucket into bin (opening bucket, lifting/setting, pulling back)	7.8
Handling ladder	Carrying ladder, set down/pick up, reposition, adjust coupling	4.1
Other tasks	Walking	8.1
	(activities of 1% or less are not shown)	

Table I.2. Proportion of observation interval spent bearing weight and materials weights

Bearing weight	**% time**
Either carrying apples in buckets or carrying ladders, irrespective of activity	78.5

Materials weights	**lb/kg**
Full apple buckets (maximum)	42/19
Ladders, aluminum	10/4.5
Ladder, wood	25/11

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Musculoskeletal strain definition

According to the National Institute of Arthritis and Musculoskeletal and Skin Diseases (2005), musculoskeletal strain is defined as a stretch or tear of a muscle or a tendon. Strains can occur suddenly or develop over days or weeks. A sudden strain is caused by: an acute injury event, lifting heavy objects or suddenly overtaxing the muscles. Chronic strains are usually caused by moving the muscles and tendons the same way, over and over. Two common sites for muscle strain are the back and the hamstring muscle in the back of the thigh. Signs and symptoms of strain include: pain, muscle spasms, weakness, swelling, cramping, and movement difficulty.

Muscle strains are graded according to their severity: Grade 1 involves muscle or tendon stretching with some micro-tearing (up to 10% of muscle fibers). No palpable defect in the muscle is present. Recovery can be complete in about two weeks. A Grade 2 strain involves the partial tearing (between 10 and 50%) of muscle fibers. A definite palpable defect in the muscle belly is present. Recovery can take up to 1-2 months. In a Grade 3 strain, there is extensive or complete tearing (rupture) of muscle fibers (From 50 to 100%), with a possible recovery time of more than three months. A very large palpable depression in the muscle is found. The muscle may be torn away completely. In rare cases, surgery may be needed to repair the torn muscle fibers. For a severe strain, the patient may have an Magnetic Resonance Imaging (MRI) scan to see if the tearing requires surgical repair, and to predict the length of the recovery period (Emory Healthcare, 2006; Leone, 1998).

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Sprains are slightly different, although they are often grouped together with strains because of the difficulty of distinguishing them, and because they are generally treated in the same manner. In a sprain, one or more ligaments is stretched or torn. Many things can cause a sprain. Falling, twisting, or getting hit can force a joint out of its normal position. This can cause ligaments around the joint to stretch or tear. Sprains can occur if people fall and land on an arm or wrist, fall on the side of their foot, or twist the knee. Sprains happen most often in the ankle. A sprain to the thumb is common in skiing and other sports. The usual signs and symptoms of a sprain are: pain, swelling, bruising, and inability to move or use the joint. Sometimes people feel a pop or tear when the injury happens. A sprain can be mild, moderate, or severe (National Institute of Arthritis and Musculoskeletal and Skin Diseases, 2005). As with sudden strains, sprains are more commonly results of acute events and do not develop over time due to overuse.

For the purposes of the current research, strains of all three grades will be included, although it is recognized that many of the Grade 1 strains will resolve through the body's own conditioning response. Sprains, which are more acute in nature, are not included in this definition, although it may be necessary to refer to studies using a "sprain and strain" definition, because they are so often treated interchangeably.

This definition of strain must also be distinguished from another common usage of the term, "strain," which refers to exertion. It is possible to strain, (i.e., greatly exert oneself), without causing oneself injury of muscle strain. This distinction is important to

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keep in mind because much of the ergonomic literature examines muscle exertion as an outcome ("straining"), and this should not be confused with strain as an injury state. In the current discussion, "strain" will be used only to refer to musculoskeletal injury.

Epidemiology of musculoskeletal strain

According to the Bureau of Labor Statistics (Waters, 2004), sprains, strains and tears constituted the nation's leading injury and illness category for every major private industry division. Sprains, strains and tears accounted for four out of every 10 nonfatal injuries and illnesses involving days away from work in 2001. Cases included in these data are generally moderate to severe, with a median of six days away from work. Slightly more than one fourth of these cases (27.3%) resulted from overexposure to lifting, and 45.1 percent of the cases were back sprains, strains or tears. As an industry, agriculture had the third highest incidence of sprains, strains and tears (91.6 per 10,000 workers). This is substantially elevated above the all industry rate of 73.7 per 10,000 (Waters, 2004).

National level data also indicate high levels of self-reported musculoskeletal strain symptom (i.e., musculoskeletal pain or discomfort) among hired agricultural workers. Within the orchard category, 15 percent of workers reported one or more musculoskeletal pain or discomfort symptoms in the previous twelve months. Stratified by number of years working in U.S. farm work, 11 percent of those having worked one year or less reported symptoms, while 19 percent of those reporting more than ten years reported symptoms. It is difficult to know to what extent these experience-related differences reflect worsening musculoskeletal health associated with U.S. farm work as

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opposed to an increasing willingness to report symptoms as the worker becomes more established and less fearful of reporting injury (Waters and Wilkins, 2004).

Back, neck and shoulder strain among orchard workers

Orchard workers are at higher than average risk for musculoskeletal problems. A recent published study of farmworker injury risk reported an overall strain/sprain prevalence of 31 percent 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 (Baron, 1996; Booth-Jones, 1998; Ciesielski, 1991; Cole, 2002; Faucett, 2001; Husting, 1997; Ohlsson, 1994; Osorio, 1998; Villarejo, 1999).

For example, a study in Japan examining musculoskeletal symptoms in apple and pear work found self-reported neck pain and stiffness ranging from 25-50 percent of workers in apples, and 40-60 percent of workers in pears. Sixty-five to 70 percent of workers in both commodities reported stiffness in the shoulder, with roughly one third of apple workers and one half of pear workers reporting shoulder muscle pain (Sakakibara et al., 1995). Calisto (1999), found similarly elevated levels of pain among fruit growers in the upper and lower back (19% and 57%, respectively), and of the neck and shoulders (both at 38%). These are higher frequencies than those found in many other industries (Andersen et al., 2003; Lee et al., 2001; Guo et al., 1999). For example, a study of industrial workers found rates of neck/shoulder strain of 14 percent among workers performing repetitive tasks, and 3.8 percent among other workers (Andersen et al., 2003). Shoulder pain among sewing machine operators has been reported as 15.2 percent (9.0 % among controls). A study of low back pain in an industrial setting found a self-reported frequency of 11 percent among workers (Lee et al., 2001).

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Exposure to hazardous postures and loads among apple harvest workers

Self-reported pain has limitations as an outcome for evaluation purposes. Perceptions of pain and report of pain may be quite variable, even within the same individual. While pain may indicate muscle strain, it may also be an indicator of some other disease or injury process. Because of the difficulties associated with documenting strain outcomes beyond self-reported pain, much of the agricultural ergonomics literature has focused on documenting hazardous postures and loads. These are most commonly measured through job cycle observation (Vieira and Kumar, 2004; Fulmer, et al., 2002; Calisto, 1999; Estill and Tanaka, 1998; Pinzke, 1997;Bucholz, 1996; Conlan, et al., 1995; Burdorf, 1992;).

In 2001, the research team had quantified hazardous postures in apple hand harvest work using timed ergonomic job analysis (Earle-Richardson et. al, 2004). Approximately 50,000 individual observations were made pertaining to 14 orchard workers over four observation days. Workers were observed carrying a full or partially full bucket 78.2 percent of the observation time. The worker's apple buckets were reported to be between 17.2 and 19 kg, which are above the safe maximum bucket load range as estimated via the NIOSH Safe Lifting Equation (Waters, 1994). If workers are bearing this weight for 78 percent of workdays that average 8.5 hours and can run as long as 12 hours, they will frequently exceed this standard.

Hazardous postures most frequently observed were: one or both hands over the shoulder (59% of observation time), standing with the one arm up with a full or partially full bucket (23%) and bending with moderate trunk flexion with a full or partially full bucket (18%). When all non-neutral trunk postures were combined, workers were

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observed in non-neutral trunk postures one-third of the time. This represents significant stress to the back and upper body on a nearly daily basis. These postures are cited in a number of other studies as being related to musculoskeletal disorders (Calisto and Kleisinger, 2001; Pan et al., 1999; Meyers et al., 1998; Pinzke, 1997; Sakakibara et al., 1995; Bjelle et al., 1979).

Proportions of time observed for similar stances in the construction industry presented in a PATH analysis by Buchholz and colleagues (1996), provide some basis for comparison with another high-risk industry. In four comparisons, orchard workers had higher proportions of time spent in moderate trunk flexion (a range of 5 - 9% of work interval vs. 22% for orchard workers), time spent carrying a light to moderate load (19 - 80% vs. 78% among orchard workers), lower in time spent in a flexed and twisted posture (19 - 50% of work interval vs. 6% orchard workers), and roughly the same for time spent in severe trunk flexion (0 - 10% vs. 4% orchard workers). Other PATH research on retail workers also serves to emphasize the relatively high level of ergonomic hazard experienced in apple harvest work (Pan et al., 1999).

These orchard postural results are also comparable to workers in nursing homes, another occupation thought to be ergonomically at high-risk. In terms of shoulder posture, nursing home workers were found to have one or both arms up about 38 percent of the time (Rockefeller, 2002), compared to apple workers at 36 percent. Nursing home workers were found to be in a neutral trunk posture about 62 percent of the time (compare to apple workers: 64%). However, one difference is that nursing home workers bear weight less frequently, but when handling patients, some of the weights lifted can be substantially greater than those handled by apple harvest workers.

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Association between exposures to ergonomic hazards and musculoskeletal injury

Two different comprehensive reviews of the existing epidemiologic literature conclude that there is an association between occupational ergonomic hazards and musculoskeletal injury.

In 1997, the National Institute of Occupational Safety and Health published a review that included over 2,000 published papers. They concluded: "there is strong evidence that working groups with high levels of static contraction, prolonged static loads, or extreme working postures involving the neck/shoulder muscles are at increased risk for neck/shoulder musculoskeletal disorders" (Bernard, 1997). The reviewers found evidence of a relationship between musculoskeletal disorders of the shoulder and repeated or sustained shoulder postures with greater than 60 degrees of flexion or abduction. The review also concluded that there is evidence that shoulder tendonitis, nonspecific shoulder pain, and low-back disorders are associated with work-related awkward postures. Similarly, the relationship between raised arms and shoulder musculoskeletal disorders was demonstrated. Finally, the literature also indicates that in combination, non-neutral postures and weight bearing are a particularly great hazard for musculoskeletal disorders (Punnett and Wegman, 2004; Punnett, 2000).

The following year, in 1998, the National Institutes of Health asked the National Academy of Sciences/National Research Council to assemble a group of experts to examine the scientific literature relevant to work-related musculoskeletal disorders of the lower back, neck, and upper extremities. A steering committee was convened to design a workshop, to identify leading researchers on the topic to participate, and to prepare a report based on the workshop discussions and their own expertise. The steering

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committee included experts in orthopedic surgery, occupational medicine, epidemiology, ergonomics, human factors, statistics, and risk analysis. The following is a summary of their conclusions.

> The steering committee has explored the complex problem of musculoskeletal disorders in the workplace. We have supplemented our professional expertise with workshop presentations, commissioned papers and other submissions, and discussions with invited workshop participants. We find very clear signals on some topics and weaker signals on others-but little in the way of contradiction. Thus, while there are many points about which we would like to know more, there is little to shake our confidence in the thrust of our conclusions, which draw on converging results from many disciplines, using many methods:
>
> 1. There is a higher incidence of reported pain, injury, loss of work, and disability among individuals who are employed in occupations where there is a high level of exposure to physical loading than for those employed in occupations with lower levels of exposure.
> 2. There is a strong biological plausibility to the relationship between the incidence of musculoskeletal disorders and the causative exposure factors in high-exposure occupational settings.
> 3. Research clearly demonstrates that specific interventions can reduce the reported rate of musculoskeletal disorders for workers who perform high-risk tasks. No known single intervention is universally effective. Successful interventions require attention to individual, organizational, and job characteristics, tailoring the corrective actions to those characteristics (National Research Council and Institute of Medicine, 2001).

Development of the intervention for apple harvest work

In 1998 Northeast Center researchers began studying hand harvest work activity in orchards in New York and Pennsylvania as described by Fulmer and colleagues (2002). Preliminary observations by study ergonomists produced a list of possible hazardous postures and activities likely to lead to back, neck and shoulder strain. Shoulder hazards observed were: reaching with elbows over shoulder height, downward pressure from the bucket's strap, and carrying the ladder. Important back strain hazards

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identified were: holding strenuous picking postures, bending to empty the picking bucket into the bin, supporting a full load with the lower back, and carrying and setting the ladder.

These hazardous postures were then documented and quantified using timed ergonomic job analysis (Earle-Richardson et. al, 2004). Table I.3 shows the trunk postures and arm positions identified, and the proportion of the harvest workday in which those postures are held, with or without any load from apples in the bucket. Figure I.2 shows an orchard worker in moderate forward flexion (>20°, <45°).

Table I.3. Postures observed: overall and in combination with full/partially full bucket as a proportion of observation interval

Body posture	% time	s.d.	% time combined with bucket load	s.d.
Trunk - neutral (<20°)	63.1	.167	49.4	.148
Trunk - moderate flexion (>20°, <45°)	23.4	.132	18.8	.119
Trunk - severe flexion (>45°)	3.5	.037	2.4	.027
Trunk - lateral bend or twist	6.1	.047	5.7	.044
Trunk -lateral bend or twist and flexion	1.9	.023	1.6	.024
Not observed (body part obscured)	2.0	-	-	-
Arm/Shoulder - 2 elbows down	39.4	.144	29.0	.126
Arm/Shoulder - 1 elbow up (>60°)	30	.111	25.5	.096
Arm/Shoulder - 2 elbows up (>60°)	29.3	.156	23.9	.132
Not observed (body part obscured)	1.2	-	-	-

Figure I.2. Workers bending forward in moderate forward flexion to pick

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The preliminary observational research conducted in 1998-1999 also generated suggestions for preventive interventions. These included a padded shoulder strap, detachable bucket hip belt, adjustable height apple bin, and an ergonomic picking tool. Appendix 1 shows a comprehensive list of intervention ideas suggested by the ergonomist and considered for implementation.

During 2001-2002 researchers held seven group meetings and five individual interviews with orchard workers, owners and managers, and others using an ergonomic team-building process (Baron et al., 2001; Zalk, 2000; Ehlers and Palermo, 1999; Meyers et al., 1997; Miles and Steinke, 1996). The goal was to consider several intervention concepts and collectively select one to test in the orchard.

Ideas discussed at these meetings covered a range of possible intervention targets: the apple bins, harvest ladders, worker harvest equipment and harvest practices. They were evaluated on their potential efficacy, cost, acceptability to the worker, likely impact on harvest speed, and potential for unintended consequences. Facilitation included providing opportunities for each participant to voice his opinion (language translation was provided when needed), and adoption of a consensus statement at the end.

The intervention that emerged from this process was the hip belt that attaches to the apple-picking bucket. The belt is made of soft, padded neoprene and attaches to a hook on the bucket with a metal bar approximately three inches long (Figures I.3-I.6). A worker using the hip belt in the orchard is shown in Figure I.7. The bucket may be attached and removed to the belt at will. This intervention redistributes weight from the upper back, neck and shoulders to the hips.

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The hip belt intervention had some advantages over the other ideas. It is simple to use and requires minimal additional investment by the farm to accommodate its use. The intervention belt went through several stages of development before researchers arrived at the model currently being tested, shown below. Appendix 2 outlines seven different model variations that were developed sequentially in response to feedback from farm workers testing the models.

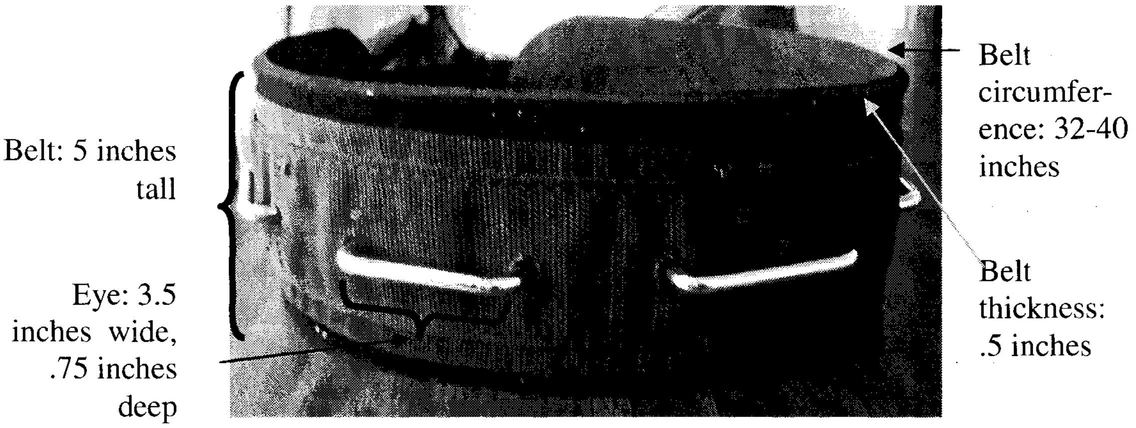

Figure I.3. Intervention belt

Figure I.4. Interior of intervention belt, showing eye anchoring with .5 inch washers between Velcro belt layers

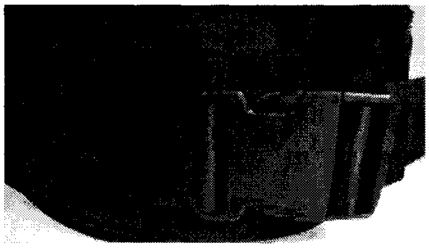

Figure I.5. Back of intervention belt, 2.5-inch attachment mechanism

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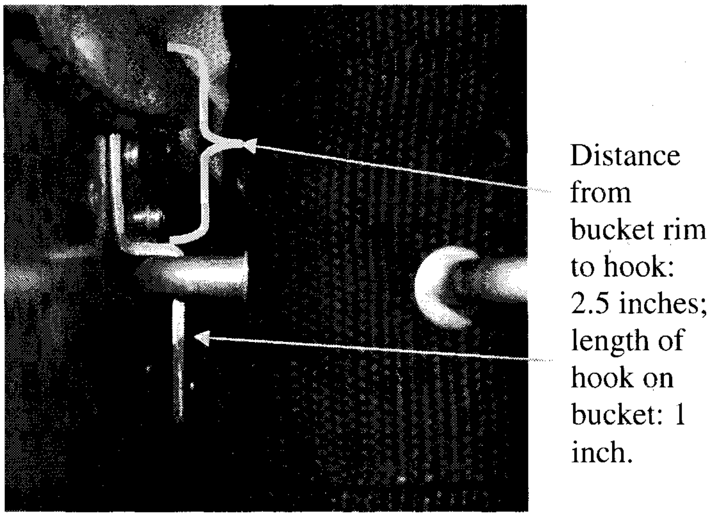

Figure I.6. Intervention belt attached to bucket

Figure. I.7. Apple harvest worker using intervention belt, side carry option

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Chapter II. LITERATURE REVIEW

While available data suggest that apple harvest workers experience increased frequency of back, neck and shoulder strain, and also that they are disproportionately exposed to the ergonomic hazards of weight bearing and awkward posture, there do not appear to be any published studies (other than the author's) pertaining to ergonomic hazard reduction in orchards.

Similar ergonomic research

None of the ergonomic intervention studies identified through Medline, NIOSHTIC AGRICOLA, BIOSIS, First Search Databases (dissertation abstracts and proceedings), or WorldCat pertained to orchard work. However, several studies were found evaluating interventions designed to reduce back strain among letter carriers (Dempsey et al., 1996; Bloswick and Mecham, 1994; Page, 1985; Cook 1984; Imrie and Crosbie, 1982; Weames and Robertson (unpublished). Research by Bloswick and Mecham evaluated one design that is quite similar to the apple bucket belt when worn to the side condition. (Figures II.1 and II.2 below).

Figure II.1. Apple bucket (worn to the side) with intervention hip belt

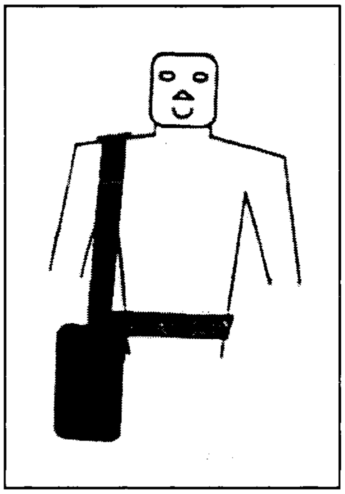

Figure II.2. Mail bag with intervention waist strap (Bloswick et al., 1994)

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Page and colleagues conducted a biomechanical assessment of five mail bag designs (some with the bag hanging to the side and some to the front), and concluded that those with a hip belt or with the bag carried in front were superior. At the highest stepping pace (120 paces/min), and maximum load (35 lbs.), researchers found a 30 percent drop in average peak compressive forces when the waist belt was added to the side bag (1,750N vs. 1,221N). Bloswick and colleagues (1994) further evaluated three of these designs. They found that the mail bag with a belt resulted in significantly less muscle fatigue in the low back than the same design without one. Other studies found that activity of the contralateral trunk muscles is reduced with this type of belt support (Cook 1984; Imrie and Crosbie; 1982). Additional mail bag research found that supporting the load at the waist resulted in less discomfort and was preferred by most subjects (Holewijn and Lotens, 1992; Vernon and Laufer, 1982).

These studies support the hypothesis of the current research, that is that the addition of a hip belt to the apple bucket, which is very similar in design and weight carried to the mail bag, will reduce the load on certain at-risk muscles, and ultimately reduce the frequency and intensity of strain. These studies come to this conclusion using a range of measurement methods for assessing strain potential: biomechanical modeling, mechanical muscle fatigue testing after work intervals, muscle activity measured by electromyography, metabolic changes (as a measure of overall physical exertion), and self-reported discomfort with use.

Ergonomic research in groves, vineyard and field crop agriculture

A review of published evaluation studies of ergonomic interventions in hand-harvest agriculture did not reveal any research on orchard interventions. Twelve

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intervention trials in other commodity groups were identified (9 published), involving a range of hand harvest crops: bush and vine crops such as blueberries and wine grapes, assorted fruit and vegetable ground crops, plant nurseries and several tropical crops, such as cassava, oil palm, and manually harvested wheat. The interventions from the U.S. and several other countries, primarily involved tools or small equipment; only two consisted of modified work practices independent of tools and equipment changes. None focused on the physical redesign of the workplace. While common in other industries, this type of intervention would be more difficult to undertake in the outdoor setting of agriculture.

Studies identified in this review are shown in Table II.1, below. It should be noted that the review was limited to ergonomic interventions for hand-harvest work in ground, tree or bush crops. Agricultural machinery operation and livestock handling were excluded, as were interventions primarily aimed at preventing acute injury, even if an ergonomic component was present. These areas were judged as departing from the goals of the current intervention to be relevant to the current discussion. For example, two studies examining ladder modification, one in an orchard (Salazar et al., 2004), one in a citrus grove (Miles and Steinke, 1996), were excluded because the interventions were primarily targeted at reducing acute injury from falls. Acute injury hazards present a different set of issues in terms of effectiveness measurement and intervention acceptance.

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Table II.1. Ergonomic intervention evaluation studies in crop hand-harvest agriculture

Author(s)	Population, design, sample size	Intervention being evaluated	Main outcomes (dependent measures)	Results and conclusions
1. Adetan and Adekoya (1995)	Nigerian harvest worker crews (N=14 crews); randomly selected crew observed each of 14 days	2 oil palm hand-harvest methods: 1. climbing and hand cutting or 2. pole cutting	Total harvest time, and proportion of time spent in hazardous activities	Method 1 more time-consuming; method 2 also hazardous. New methods needed.
2. Chapman et al. (2003)	Pre- and post-intervention self-reported survey among Wisconsin fresh marker vegetable operations (n=207) with control group (n=35)	Mesh bags and standard size produce containers	Intention to adopt; perceptions of intervention profitability	Non-significant increase in both outcomes for mesh bag intervention
3. Duraj et al. (unpublished, 1999)	Qualitative implementation and observation; number of California workers and farms not specified	Conveyor belt that raises grapes from ground level into transport trailer.	Implementation and observation only	No apparent difficulties; productivity levels same or higher, higher quality product; worker and management interest in system
4. Estill and Tanaka (1998)	Part of a cross sectional study on Maine Blueberry raker strain symptoms, N=134. Association between self-reported slower raking at the beginning of the season	Raking slower at the beginning of the season	Self-reported pain	Raking more slowly did not reduce pain
5. Hermes et al. (1986)	German fruit tree pruners, N=15. measurements with manual, pneumatic and pruning saw	Pruning fruit trees using pneumatic shears	Heart rate and energy transformation	Pneumatic shears require less physical work than with pruning saw
6. McNeill and Westby (1999)	Ghanese farmers, N=6; case study over a working day with one farmer; repeated measures two-condition design	Ergonomically modified cassava chopping machine	Heart rate, body angle, productivity, Self-reported discomfort (and "strain"); work rate and worker acceptance	Preferred by all workers, greater comfort, faster rate.
7. Miles et al. (unpublished, 1998)	California farmworkers, N=12 quasi-experimental design in the nursery , then N=30; 8 months of use	A number of interventions described, only the hand grip tool evaluated quantitatively.	Self-reported pain; use of self-treatment; productivity; worker/supervisor acceptance	Reduction in self-reported pain, self-treatment of symptoms

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Table II.1. Continued

Author(s)	Population, design, sample size	Intervention being evaluated	Main outcomes	Results and conclusions
8. Nag et al. (1988)	Analysis of ergonomic features on 9 sickles on 6 Indian farmers. Field and laboratory measurement	Design features of nine different types of wheat sickle	Body angle, heart rate, work performance	Optimal sickle design specifications identified
9. Parish (1998)	Mechanical laboratory test using wooden dowels of different sizes, and force meter	9 varieties of commercially available manual pruning shears.	Force required to cut dowels of different sizes	Two of the four most efficient were also the least expensive.
10. Roelofs (2004, unpublished)	Dutch harvest workers (unspecified sample size) reported every hour while doing planting or weeding using on one of four methods	Two lying prone workstations (legs straight, legs bent) and one upright sitting workstation.	Self-reported level of discomfort for all relevant parts of the body, as compared with walking.	Prone interventions relived back and upper legs, but caused armpit and head discomfort. While upright sitting caused discomfort in lower back and buttocks, it was preferred in parcels with little weed.
11. Sen and Sahu (1996)	30 Indian farmworkers completed two work tasks, during which physical and productivity measures were taken. An opinion survey was administered.	Multi-purpose shovel-cum-hoe for manual material handling	Perceived exertion, heart rate, productivity, acceptance	High acceptance, purposes of both shovel and hoe fulfilled. No detectable ergonomic advantage in terms of perceived exertion.
12. Tewari et al. (1991)	Laboratory experiment with Indian farmers (N=3); randomized block design; five levels of load Then a field test measuring pulse and productivity (n=3)	Three manually operated weeding devices.	Comfort; energy expenditure (heart rate and oxygen consumption); output	Intervention hoe is more efficient than traditional model A, and produces higher output than traditional model B.

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While none of the reviewed interventions shown in Table II.1 were functionally similar to the ergonomic hip belt, it is still useful to consider some characteristics of these intervention evaluations. Two-thirds involve quasi-experimental field study designs, in which up to 30 subjects are assigned to different intervention conditions (with varying degrees of randomization), and then observed for physiological exertion indicators. Subjects also provided self-reported exertional and comfort data. Physiological measures used were most commonly heart rate, oxygen uptake or force produced. Only three studies involved a laboratory component.

None of the studies evaluated strain, exertion or fatigue of specific muscles or muscle groups. The most commonly used measures, energy output (4 studies) and increased heart rate (5 studies), provide only very general indicators of exertion. While these measures are still properly referred to as "fatigue," experts in this field make a distinction between overall metabolic fatigue, and musculoskeletal fatigue, which typically occurs to specific muscles or muscle groups ("localized muscle fatigue") (Fitts, 1996; Baidya and Stevenson, 1988; Malmqvist et al., 1981)). It is localized muscle fatigue that is most commonly studied in ergonomics in relation to prevention of musculoskeletal strain (Stauber, 2004; Sbriccoli et al., 2004; LaBry et al., 2004; Ferguson et al., 2004; Solomonow, 2003; Lariviere et al., 2002; Dedering et al., 2002; Dedering et al., 2000; Chan et al., 2000).

Self-reported strain symptoms (2 studies), and discomfort with use (3 studies), are perhaps more closely related to musculoskeletal injury, but these measures are highly subjective, and are particularly difficult to use effectively with foreign subjects, due to the varied cultural influences affecting perceived pain and discomfort. Miles and

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colleagues (1998), address this problem in an innovative way: they ask subjects about frequency of self-treatment behaviors in addition to pain and discomfort. While it appears to be somewhat more reliable, the development of such an indicator requires extensive cultural and behavioral research, and it probably would also require separate studies for each cultural group involved. This further underscores the difficulty of the use of the self-reported pain endpoint. The challenges of designing and carrying out a scientifically rigorous evaluation in the field setting may explain why non of the above studies met the initial review criteria of an extensive review of ergonomic intervention effectiveness research conducted in 1997 by Westgaard and Winkel.

In contrast, ergonomic research in livestock handling ergonomics and in the non-agricultural arena has focused more specifically on localized muscle exertion and fatigue (Simmer-Beck et al., 2006; Allread et al, 2004; Stal et al., 2003; Pinzke et al., 2001; Turner-Stokes and Reid, 1999). This is most commonly done with muscle strength testing or electromyography. This more muscle-specific research is needed to develop credible models of back, neck and shoulder strain. This is an area of weakness in the current hand-harvest crop ergonomic literature.

While this is a weakness, there are also some important strengths in this group of studies. In the majority of them, worker acceptance is evaluated as a major endpoint, and feedback from workers is obtained in a number of different ways. Furthermore, the productivity impacts are also considered. Productivity and intervention acceptance are critically important in the agricultural sector, whereas they may be less so in larger, more highly regulated workplace environments. While employee input is always beneficial, in the typical industrial or office workplace, safety enhancements have a greater opportunity

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to be "built-in" to the workstation, or be legally mandated by government regulation, thereby reducing the dependence on worker (or employer) acceptance of the intervention for success. Northeastern agricultural workplaces are generally outdoors, with a less fixed workstation, and many farms (those with 10 or less paid employees) receive little or no oversight from safety agencies such the Occupational Health and Safety Administration (U.S. Department of Labor, Occupational Safety & Health Administration, 2005). Therefore, the acceptance of an intervention by farm owners, managers and workers is essential for their successful implementation.

The range of indicators used in evaluating ergonomic intervention effectiveness

Perhaps the most difficult challenge in the area of ergonomic intervention evaluation is identifying an appropriate outcome measure. The main difficulty lies in the fact that there is no readily available test for the presence of musculoskeletal strain. In the clinical setting it is most often diagnosed on the basis of patient self-reported pain after ruling out other possible sources of pain.

Studies using diagnosis of muscle strain through the use of magnetic resonance imaging or sonography have been published (Jacobsen, 1989; Palmer et al., 1999; Deutsch and Mink, 1989), although the link between radiographic findings and clinically observed muscle strain has not been firmly established. In the absence of such a diagnostic test, researchers have used self-reported pain and other symptoms, and intermediate indicators of strain (or likelihood of strain development) such as muscle fatigue, muscle exertion, and force production as study outcomes.

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Self-reported pain

While pain is the most commonly reported musculoskeletal strain symptom, its use in research is problematic for a number of reasons. Pain may be an indicator of some other injury or disease. The problem of individual variability in pain perception is compounded by the fact that multiple cultures are represented in the target population of the current research. This results in differing understandings of terms like "pain," "discomfort" and "injury." Furthermore, among migrant and seasonal workers there can be a very high level of concern that reporting muscle pain may result in being given less desirable work tasks on the farm, or losing one's job altogether. In the study by Miles and colleagues (1998), referenced above, the fact that there was a discrepancy between levels of self-reported pain and self-reported self-treatment for pain (the latter being more frequent), is a further indication of the underreporting of pain among migrant and seasonal farmworkers.

In preliminary meetings with migrant and seasonal apple harvest workers, researchers found a wide variation in general comments relating to the prevalence musculoskeletal pain and stiffness among workers. Anecdotally, it appeared as though workers with more secure employment arrangements (those with Department of Labor arranged contracts) were more likely to describe musculoskeletal symptoms as common, whereas those not working through the Department of Labor program were less likely to say so. This raised further concerns among researchers about the utility of this measure in the current research.

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Other indicators related to the development of musculoskeletal strain

The first challenge in undertaking a thorough evaluation was to identify an outcome measure that is not beset by the problems associated with self-reported pain. In selecting the most appropriate endpoint, it is helpful to consider the sequence of events leading to musculoskeletal strain. Figure II.3 illustrates a model proposed by Armstrong and colleagues (1993), to describe the musculoskeletal strain development process. It is a sequence of four phases: *exposure*, *internal dose*, *capacity* and *response*. Figure II.3 shows examples of components of each phase compiled from a number of sources (Green, 1997; Armstrong et al., 1993; Warren et al., 1999; Clarkson and Hubal, 2002; Bystrom, 1994; Oberg, 1994; Clarkson and Sayers, 1999; Clarkson and Newham; 1995).

A key additional component to this model is the concept that a given *response* can also create additional *internal doses* (Wells et al., 1997). For example, muscle strain can result in slowing of certain metabolic processes, which in turn further reduces the body's ability to maintain normal muscular function. (Clarkson and Hubal, 2002).

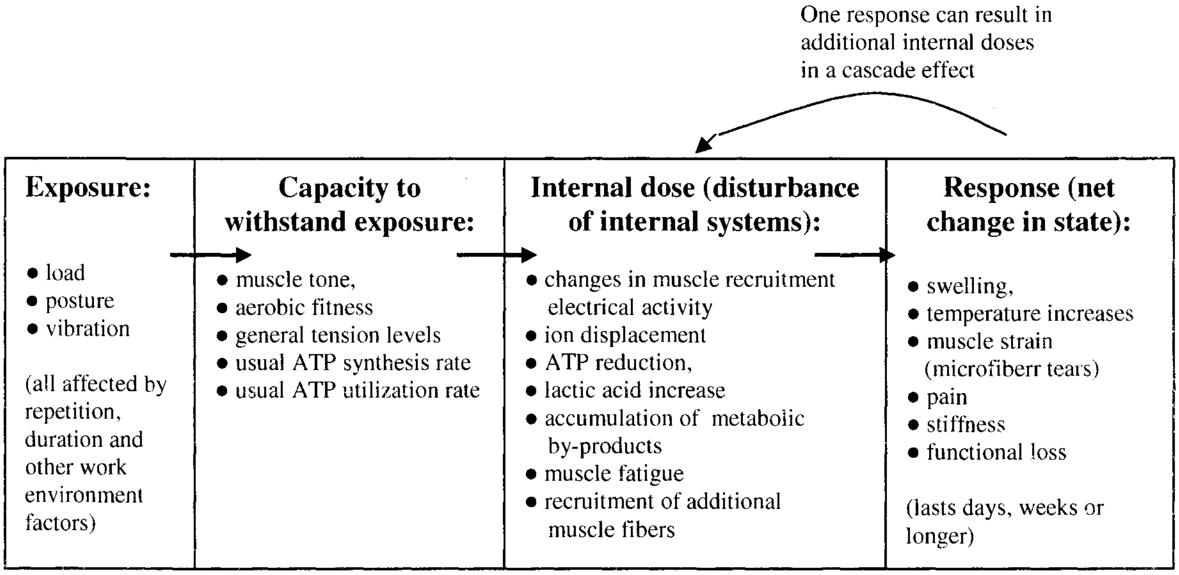

Figure II.3. Proposed model for musculoskeletal strain

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Because it is not currently feasible to objectively measure muscle strain, and there is little known about the relationship of the other *response* variables in relation to muscle strain, the current research will focus on two *internal dose* endpoints that are most commonly seen in the literature as surrogate indicators of musculoskeletal strain potential: changes in electrical muscle recruitment activity and muscle fatigue.

Changes in electrical activity associated with muscle recruitment

In order for a muscle to contract, it must recruit motor-unit potentials, and this activity generates electrical current. The amplitude of this current can be measured non-invasively with surface electromyography (EMG), which involves the placement of two electrical leads per muscle on the skin. The amplitude of this electrical current has been shown to vary with muscle exertion magnitude under controlled experimental conditions. While muscle recruitment generally increases with increasing force demand, there are a number of variables that may affect the amount of force produced by a given level of recruitment, and thus muscle recruitment should not be thought of as a measure of force production. Referring back to the model above, muscle recruitment can be viewed as an internal response to exposure to a given weight or force demand. Surface EMG is one of the most widely used measurement instruments for evaluating muscle activity in the occupational setting (Bloemsaat et al., 2005; Rolander et al., 2005; Asundi et al., 2005; Alkjaer et al., 2005; Mathiassen et al., 2005; Steingrimsdottir et al., 2005; Dong et al., 2005; Krantz et al., 2004).

Association between EMG amplitude changes and musculoskeletal strain A positive relationship between ergonomic exposures (load, duration, and body angle) and

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musculoskeletal strain has been demonstrated. (Village et al., 2005, Punnett and Wegman, 2004; National Research Council and Institute of Medicine, 2001; Punnett, 2000; Bernard, 1997; Herrin et al. 1986, Anderson, 1985; Chaffin, 1973). The association between increasing load and increased EMG amplitude has also been demonstrated (Marras et al., 2001; De Luca, 1997; Kumar and Mital, 1996; Freivalds et al., 1984), although the precise dose-response relationship between these exposures (e.g. compressive forces, load in kilograms, or task) and EMG amplitude is still unclear.

A small number of studies have quantified EMG amplitude-injury relationships (Jonsson, 1982; Aaras, 1987; Westgaard et al., 1986; Westgaard et al., 1993; Village et al., 2005). While the body of literature is relatively small at the current time, a reduction in EMG amplitude is widely viewed as a reliable indicator of a reduction in muscle activity that would lead to muscle strain (Anders et al., 2005, Dainoff et al., 2005, Matern et al., 2004, Nevala et al., 2003, Peper et al, 2003, Mathiassen et al., 2003, Roquelaure, 2002).

Preliminary EMG research on the ergonomic hip belt Early in the development of the intervention belt, pilot EMG amplitude research was conducted in the laboratory (Earle-Richardson et al., 2005). Researchers compared exertion of four key muscles in the back and shoulder when wearing the apple bucket alone and with the hip belt. Ten laboratory volunteers were assessed at three common postures carrying loads of 17 Kg, the maximum customary load for an apple bucket. Significant reductions in EMG amplitude were found for two of the four muscles. In addition, significant reductions were also observed for shoulder surface pressure and self-reported discomfort.

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One of the major drawbacks of using SEMG to evaluate the hip belt intervention is the difficulty of using it in an orchard. There are many possible sources of interference, including heat, cold, moisture, and external sources of electromagnetic radiation (Cram, 2004; De Luca, 2002; Lanza , 1999). In addition, SEMG amplitude measurement requires that measurement be taken with the subject standing still, with the joints surrounding the muscle of interest at the same angle in each measurement. In the orchard setting this is difficult due to ground that is not level, and the natural variability of work postures during harvest work. Finally, the need to move EMG measurement equipment in between measurements to allow subjects to continue working has the potential to affect EMG readings. Lastly, the willingness of working farmworkers to wear the electrode and wire attachments is unknown.

Measurement of muscle fatigue through changes in strength or endurance

A second commonly used method of assessing changes in potential for musculoskeletal strain is muscle fatigue. As with muscle recruitment associated with exertion, muscle fatigue is part of the body's response to a force demand. Initially, the muscle recruitment is adequate to produce the needed force, but after some period of time, the force production becomes insufficient, under normal metabolism. Certain changes then occur: muscle recruitment increases, and a number of metabolic changes take place, such as ion displacement, ATP reduction, and a lactic acid increase. The smaller muscle fibers, generally recruited for this work, and better suited for long periods of work are then assisted by the larger fibers, able to generate greater force, but for a shorter time. When these fibers can no longer continue firing, a downward cycle begins,

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which ultimately results in muscle failure. Whether this translates to external performance failure depends on whether other muscles or muscle groups are able to take over the force generation task. From this scenario, two means used by researchers to identify muscle fatigue can be described.

Decline in muscle performance First, because a given muscle will ultimately fail, a physical test of muscle performance can identify the presence of fatigue (and how quickly it occurs) by testing a muscle's ability to perform after a force demanding exposure. For example, in the current study, we might hypothesize that if the hip belt intervention is effective for a given muscle, that muscle could work longer before it failed. This type of measurement would necessitate isolating a potentially failing muscle from others around it that might activate to assist it.

In the published ergonomic literature, researchers have calculated fatigue by measuring differences in pre-work to post-work muscle performance. This has been done a number of different ways. Some studies measure isotonic strength (the ability to hold a posture), by having the subject assume a posture and hold it as long as possible, and measuring seconds to failure (Lanza, 1999; Bloswick, 1994; Nussbaum et al., 2001). Others measure strength by measuring the one-time attainment of as high a reading on a ergometer or dynamometer (Hughes et al., 1999; Vollestad, 1997), others use a dichotomous pass/fail metric for performance of weighted or non-weighted tasks (Lee et al., 2001). Regardless of the manner in which strength is measured, the endpoint of interest is always the difference between the pre- and post- exposure strength.

In each study, the performance measures used were selected based on the muscle activity involved in the work under study. Perhaps the most commonly used measures

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are the Sorensen Prone Test for back strength and the Bering-Sorensen Test for lateral trunk strength (Biering-Sorenson et al., 1983; Bloswick et al., 1994; Stewart et al., 2003; Latimer et al., 1999; Keller et al., 2001). Both measures are isometric tests where time to failure of holding a posture is measured. While these endurance-based measures are more commonly used, there is no clear consensus as to which is preferable (Vollestad 1997; Mayer et al., 1995).

Loss of muscle strength in relation to musculoskeletal strain As with EMG amplitude as an indicator of muscle exertion, there are little data that explicitly quantify the relationship between strength loss and muscle strain. However, its presence after moderate and heavy exertion has been well documented (Mullaney et al., 2005; Byrne and Eston, 2002; Clarkson and Hubal, 2002; Warren et al., 2002; Rinard et al., 2000; Howell et al., 1993), as has the presence of weakness in cases of musculoskeletal strain (U.S. Department of Health and Human Services, 2005; Stauber, 2004; Byrne et al., 2000; Pool-Goudzwaard et al., 1998). In the clinical setting, a 10 percent strength deficit is commonly used as the threshold value for being indicative of injury (Jackson LaBudde, MD, personal communication, July 13, 2005).

Electromyographic shifts in median signal frequency It has been stated above that part of the process of muscle fatigue involves the recruitment of larger muscle fibers, which then fail before the smaller ones. Because these large fibers have higher electromyographic firing frequencies, it is possible to identify when the larger muscle fibers ultimately fail by detecting an overall lowering of the median frequency of the muscle (Ferguson *et al.*, 2004; De Luca, 1997; Hagg, 1991; Hagberg, 1981). Because this shift is easily detected through electromyography, this moment of large fiber failure

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is used as a sign of the presence of fatigue. In general, when this occurs, the muscle fibers also undergo an increase in amplitude, but there is less of a firm consensus on this indicator (Ebaugh et al., 2005; Kramer et al., 2005; Mathur et al., 2005; Strimpakos et al., 2005; Roman-Liu et al., 2004; Dimitrova and Dimitrov, 2003).

This type of fatigue measurement has the advantage of being muscle-specific, but in current practice is limited to only extremely intense exertions of short duration. In current practice, it is used for muscle contractions at or above 80 percent of an individual's maximum ability, which naturally is short (a matter of seconds or minutes) in duration. An exertion of lesser intensity would take hours or even days to develop (with some fluctuations associated with rest intervals), and could not be feasibly measured in a continuous fashion with the subject in a sustained contraction.

While EMG measurement of muscle median frequency may be a useful tool in the future when some of the obstacles relating to measurement of slower fatigue processes are overcome, it isn't currently a viable option for intervention evaluation.

Implications To summarize, in the current research context, self-reported symptoms of musculoskeletal strain are believed to be a relatively poor indicator of effectiveness of the intervention hip belt in reducing back, neck or shoulder strain among orchard hand-harvest workers. On the basis of the published literature, two other viable alternatives appear to be electromyographic measurement of muscle activity (exertion), and measurement of muscle fatigue through comparisons of before and after-work muscle strength levels.

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Intervention acceptance and impacts on productivity

Earlier in this chapter it was observed that many of the ergonomic intervention evaluation studies in crop hand-harvest agriculture included measures of worker acceptance of the intervention and the intervention's effect on worker productivity. These are important considerations for the ergonomic hip belt intervention.

Intervention acceptance In the orchard work environment, farm owners generally provide apple picking buckets for the workers. They distribute them at the beginning of the season, and collect them at the end. Anecdotally, it appears that orchard owners would purchase and distribute hip belts in the same manner. However, all of the employers from whom researchers have received feedback have indicated that use of the belt would be an individual decision. This is somewhat different than what occurs in many industrial settings, where ergonomic practices are adopted uniformly across a department or unit. Therefore, it will be critically important to systematically assess the level of acceptance of the intervention among workers. There are examples in the literature of ergonomic interventions believed effective in reducing musculoskeletal strain that have been largely ignored by workers (Miles et al, 1996; Mayer, 1995).

In an initial pilot study, 14 workers were asked to try the intervention belt for 90-minute intervals over two days (Earle-Richardson et al., 2005). Seventy-nine percent of interviewed workers preferred the intervention. This is encouraging, but must be tested over a longer time period with a larger sample.

Rogers (1995), *Diffusion of Innovation* theory identifies a number of intervention characteristics believed to affect the likelihood of a new innovation being adopted by any population: relative advantage, "trialability," compatibility, "observability" and

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complexity. A review of these characteristics, and how they might apply to the intervention hip belt will assist in predicting the likelihood of acceptance, and may also identify attributes that should be further developed after the evaluation if acceptance proves to be insufficient.

Table II.2. Attributes of innovations that have been shown to influence their extent and rate of adoption (Greenhalgh et al., 2004)

Attribute	Definition	Extent to which to ergonomic hip belt intervention has attribute
1 Relative advantage	Benefit in economic terms, social prestige, convenience, or satisfaction	**Unknown -** Pilot tests indicate that workers find the intervention comfortable, but think it may reduce productivity (64.3% said regular use of modified bag would slow their work)
2 Compatibility	Consistency with existing practices and values, past experiences, and needs of potential adopters and their social system	**Highly Compatible** - Job cycle analysis has demonstrated that work practices do not change with intervention use. On another level, there may be some degree of cultural incompatibility with taking steps to reduce back, neck and shoulder discomfort during work.
3 Complexity	Degree to which the innovation is perceived as difficult to understand and use	**Low Complexity** - Generally perceived as simple. Obtaining correct tension between hip belt and shoulder straps is the only complexity
4 Trialability	the degree to which an innovation may be experimented with on a limited basis	**High trialability** - This has been made easy by the fact that researchers provide intervention belts on the farm, with adapted buckets, and individually fitted to each worker.
5 Observability	the degree to which the results of an innovation are visible to others	**Unknown -** May be influenced by culture. American farm owners and managers universally agreed that, "you could see how it would help your back just by looking at it." However, this response was not observed among Spanish-speaking or Jamaican workers. Whether there were observable advantages among those using the intervention would have to be determined a larger field study.
6. Re-invention	the extent to which the innovation is changed or modified by the user in the process of adoption and implementation	**Low re-invention potential** Other than adjustments to the belt to fit body type and bucket carrying preferences, there are no known modification opportunities.

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Overall, the hip belt intervention appears to rate highly on compatibility, complexity, and trialability, low on re-invention, and unknown on effectiveness and observability. Research in this area indicates that effectiveness, compatibility and complexity tend to be the most strongly associated with intervention acceptance (Greenhalgh et al., 2004). Therefore, the workers will need to have the field trial opportunity to form their perception of effectiveness, and this is likely to have the greatest influence on acceptance.

Intervention impacts on productivity Little mention has been made during this discussion of the intervention acceptance on the part of farm employers, even though they have the ability to effectively prohibit use of the intervention if they choose. Informal conversations with over 25 orchard owners (not a random sample), revealed that there was a nearly universal agreement that if the workers found the intervention beneficial, and there were no negative impacts on productivity, the intervention would be welcomed.

Therefore, the final component to the evaluation must be an assessment of the productivity impacts on the worker when using the intervention. While the primary goal of the research is the reduction in back, neck and shoulder strain, it is recognized that this can only occur in the context of a productivity neutral or positive intervention. Apple orchards in New York and across the U.S. are under financial stress as a bad crop year in 2002 and increasing competitive pressure from foreign countries has resulted in a steady decline in the number of commercial orchards in New York State over the last 15 years (National Agricultural Statistics Service, 2006). In this environment, it is particularly important to address the farm's need to maintain the highest level of profitability.

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Chapter III. OVERVIEW OF DISSERTATION OBJECTIVES AND METHODS

Dissertation objectives

The main goal of the current research is to assess the potential effectiveness of the intervention hip belt in reducing the frequency and severity of back, neck or shoulder strain among orchard hand-harvest workers. As described above, effectiveness is comprised of efficacy (*Does the hip belt reduce muscle strain when used properly?*), worker acceptance (*Will workers use the hip belt properly?*), and productivity impacts (*Can the hip belt be integrated into regular work practice without negatively affecting worker or farm revenue?*). If the intervention is found to be effective, it will then be introduced into use throughout New York and Pennsylvania.

This goal translates into the following specific objectives:

1. To ascertain whether hip belt use is likely to reduce back, neck or shoulder strain by determining if there is a significant reduction in muscle exertion or muscle fatigue in one or more of these muscles;
2. To determine whether 50 percent of workers would accept regular use of the hip belt intervention; and
3. To examine intervention hip belt impacts on productivity by comparing daily and hourly bushels picked by workers when using the intervention hip belt to when they are using a placebo belt, or no belt at all.

Dissertation methods overview

In fulfilling these objectives, researchers used the following framework:

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Select an outcome measurement method – As described in previous chapters, there were two viable options for a measure of muscle strain: electromyographic measurement of muscle exertion (EMG amplitude), and muscle fatigue measurement using differences in pre and post-work muscle strength. Each method has it strengths and weaknesses. While EMG amplitude for measuring muscle recruitment has the advantage of detecting more subtle differences and better distinguishing between muscles, there are a number of potential problems with electrical interference, a high technical level of knowledge is required for its use, and the willingness of farmworkers to participate in this type of testing is unknown.

Muscle fatigue measurement using strength testing is a somewhat cruder measure, but has several advantages. Muscle fatigue is temporally closer to injury occurrence than muscle exertion. Muscle exertion happens early on in the process, and consequently there is more opportunity for mediating factors to occur that might prevent or reduce the effect of strain. In addition, it appears that muscle strength testing is logistically easier, and presumably less intimidating for workers. For these reasons, muscle strength testing was selected as the first outcome measure to be developed.

Develop and validate the measure During the summer and early fall of 2004, several candidate muscle fatigue measures were developed and evaluated. This is presented in Chapters IV, V, and VI.

Develop a strategy for field measurement Based on the results of this research, an orchard intervention effectiveness trial was developed to assess efficacy, intervention acceptance and intervention effects on productivity. This design incorporated approximately a hundred farmworker subjects, to be measured over a short 6-week

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window of apple harvest activity in New York State. This process is described in Chapters VI and VII.

Make field measurements of efficacy, acceptance and productivity impacts Chapter VII describes in detail the measurement process and the results obtained for all three variables. Morning and afternoon trunk, shoulder and arm strength measurements were made for 102 workers on one intervention day, one placebo day and for a subset of 20 workers, on a third, "regular equipment" day. Intervention acceptance was ascertained for both conditions via a structured interview on the last day of equipment use. Productivity impacts were assessed by reviewing daily employer records of bushels picked and hours worked during the intervention and placebo weeks, and one week prior to the equipment trial.

Development of alternative measurement methods An alternative effectiveness measure, using EMG amplitude measurement to determine muscle recruitment was also developed subsequent to the field trial. The rationale and development process is described in Chapter VIII.

EMG amplitude measurement Chapter IX describes laboratory measurement of 10 subjects in an apple picking simulation, with EMG amplitude measurements taken at hourly intervals. These data provide belt to no-belt comparisons in terms of muscle recruitment for 15 muscles in 7 different stances.

Synthesize data from multiple experiments and draw conclusions The final step in this evaluation process is to review the results and draw conclusions regarding the readiness of the intervention for use in the orchard. Chapter X provides this concluding discussion, along with identification of areas for future research.

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Chapter IV. PRELIMINARY DEVELOPMENT OF MUSCLE FATIGUE MEASURES

Preliminary design and testing of muscle fatigue measures

To begin the development process, four strength tests that evaluate muscles used in apple picking were selected by a licensed physical therapist (PT), after viewing videotapes of farmworkers picking apples. (See Appendix 3, tests one through four). In order to isolate these muscles, the PT constructed a special table with dynamometer attachments (for measuring pulling strength) in the appropriate positions for each test. The dynamometer (recommended by the PT) measured performance over a five-second interval (providing both a five-second maximum and a mean reading), and the option of storing up to five repetitions within the machine. Therefore the initial testing was done in five-second intervals, with five repetitions for each test. The data collection protocols are included in Appendix 3.

The initial testing was done at a farm in western New York in late August, 2004. The goal of the testing was to determine whether any of the tests show a statistically significant fatigue effect in response to eight hours of apple picking labor, and ideally, a significantly greater decline than that seen in response to eight "non-work" (sedentary) hours.

This particular orchard was selected because it had an early harvest of peaches using the same equipment and picking technique as in apple harvest work. Researchers conducted four consecutive days of data collection. The third day was Sunday, a planned rest day. Each day the workers' pre-work testing began at five A.M. The post-work testing began as soon as each worker returned from the field. At the crew leader's

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suggestion, the testing station was set up at the camp, to be more convenient for workers who might want to shower or cook while waiting to be tested (Figure IV.1). This also made it possible to leave the equipment set-up protected from weather for the entire four days significantly reducing set up time each day.

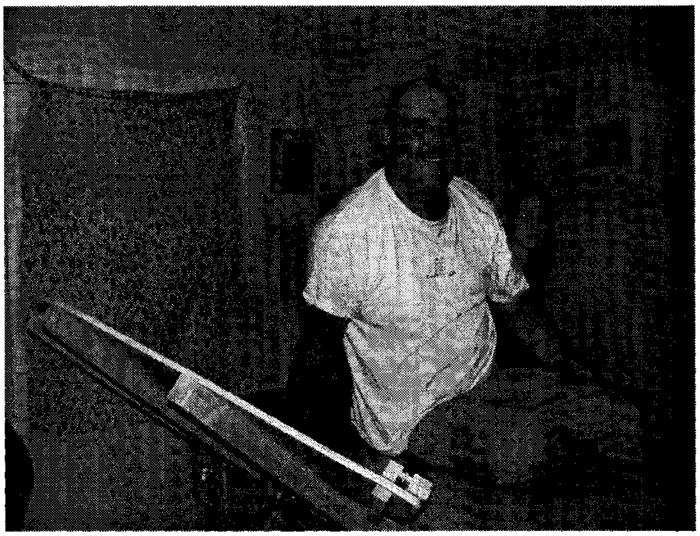

Figure IV.1. Muscle testing table set up inside farmworker housing unit.

The implementation of the muscle tests revealed a number of logistical problems. First, because the testing was being done as part of the subject's workday, the time that testing took reduced their working time, and thus their income. Each test had to be demonstrated and practiced and then performed five times with rest time in-between. Each of the five test also required table adjustments to fit the subject and moving of the dynamometer. On the first day some workers took as much as 35 minutes to complete the test. This made some workers late to work. In addition, testing at an hour when a subject is typically just waking up may have resulted in the muscle being weaker than they would be at the beginning of a typical workday, 2-3 hours later.

In addition to needing time-consuming adjustments, the dynamometer table also presented some other difficulties. Many workers appeared uncomfortable having to lie

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on the table. For example, one of the female workers required that the curtains be drawn and the door to the room in which the testing be done locked before she would consent to be tested.

Furthermore, the size and weight of the table led to the decision to keep it at the camp rather than take it to the worksites. In hindsight, this may have affected the tests' accuracy. In the opinion of the physical therapist, it may be necessary to measure workers in the orchard after some period of muscle warm-up in the morning, and before muscles have a chance to cool down in the afternoon.

Another unanticipated difficulty was that due to the fact that it rained on one of the workdays, workers did not take the entire day off on Sunday. Most of the workers worked only 3-4 hours on the day in which it rained, and then 3-4 hours on Sunday.

Evaluation of muscle fatigue measures

The original intent of the test development trials was to measure a daily fatigue score (pre- to post-work decline in strength), and to compare that fatigue score on a working day to a corresponding one from a resting day within individual subjects. It was thought that the most desirable tests for employment in the main trial would be those that showed large fatigue on working days versus less fatigue on resting days.

For each subject, a difference score defined as each day's maximum morning value minus the corresponding maximum afternoon value was calculated. For example, the maximum of the three afternoon peaks for test one was subtracted from the maximum of the three morning peaks for test one. Difference scores for the mean of this test were calculated in an analogous manner.

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Statistical analyses consisted of a test of the null hypothesis that the fatigue scores for the working condition have mean equal to 0, as opposed to the original working hypothesis that the mean of the working condition fatigue scores was greater than the mean of the resting condition fatigue scores. In addition, in an attempt to assess the presence of a dose-response relationship, the correlation between the hours of worked time and the magnitude of the fatigue score was also considered relevant.

Considerable variability was observed, for both peak and mean readings, within a given set of multiple repetitions of a test. It was agreed by all observers that this variability was largely due to varying degrees of effort put forth by the subject from repetition to repetition. Because of this, it was agreed by the researchers that the best indication of the subject's muscle strength for a given sequence of test repetitions was the maximum of the values observed.

An additional analytic concern relates to the fact that the small sample size makes the Central Limit Theorem relatively untenable for guaranteeing normality of the sampling distribution of the mean. Therefore, in cases where the distribution of individual fatigue scores was found to be non-normal, or those where outliers made the mean a bad estimate of central tendency, non-parametric tests employing the median were used.

As shown in Table IV.1 below, this preliminary analysis indicated that, in fact, workers tended to have better muscle performance at the end of the work day than at the beginning (indicated by a negative fatigue score).

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Table IV.1. Muscle fatigue scores from a four-day trial using table-based muscle tests

Measure	n	Mean Fatigue score*	S.E.	95% C.I. Lower limit	95% C.I. Upper limit
lower arm mean	40	0.96	2.79	-4.50	6.41
lower arm peak	40	-0.49	3.32	-7.00	6.02
upper arm mean	40	-9.80	5.64	-20.86	1.26
upper arm peak	40	-11.70**	4.11	-19.76	-3.63
scapular elevation mean	40	-11.87	7.52	-26.61	2.86
scapular elevation peak	40	-15.12**	6.90	-28.65	-1.59
spinal extension mean	40	-22.01**	11.09	-43.74	-0.29
spinal extension peak	40	-72.43	56.72	-183.60	38.74

* Fatigue score = [(a.m. reading - p.m. reading)/a.m. reading] x 100
** Statistically significant

Two possible explanations were considered by the team: a) possibly the disruption to the work schedule caused by the rain resulted in not enough work being done on working days to move the muscles into a fatigued state; or b) that muscles were measured so early in the morning (the first at 5:00 AM), that they were not warmed up enough to be at peak performance. To minimize the effect of the disruption of work hours during the testing days, a second analysis was done, examining the correlation between fatigue score and hours worked. Table IV.2 below shows the results of this analysis.

As the table shows, no positive correlation was found between fatigue score and hours worked. It was the consensus of the research team that the most likely reason for not detecting differences was the lack of muscle warm-up and too much muscle cool-down time caused by taking measurements at the camp rather than in the orchard. Therefore, the tests were re-designed to be implemented without the table, thus allowing data collection in the orchard when muscles are warm.

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Table IV.2. Pearson correlation between hours worked and fatigue score for each test N=10

Measure	r	p
lower arm mean	-.52	.13
lower arm peak	-.18	.62
upper arm mean	.22	.54
upper arm peak	.14	.70
scapular elevation mean	.14	.71
scapular elevation peak	.10	.78
scapular retraction mean	-.57	.09
scapular retraction peak	-.57	.08
spinal extension mean	-.66	.04
spinal extension peak	.12	.75

Redesign of orchard muscle fatigue tests

Based on these results, the muscle fatigue tests were redesigned. Three modified versions of the original tests were designed, and first tested under controlled, laboratory conditions (Figure IV.2). The two arm tests from the table were replaced with one standing arm test, with the subject holding a ten-pound weight at 120 degrees overhead until failure. The lying latissimus dorsi raise was replaced with a standing latissimus dorsi raise (with one and then two shoulders), and the lying back raise was kept on the table (there was not enough time to construct a standing back pull apparatus before this round of testing), but was changed to a timed (seconds to failure) test. In order to replicate the burden on the muscles creating by apple harvest work, laboratory subjects underwent a "simulated picking" exercise for two hours between morning and afternoon measurements (see Figure IV.2). More detailed methodology and results for this laboratory test are presented in Chapter V. Testing equipment and measurement protocols are provided in Appendix 3.

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Figure IV.2. Laboratory volunteer "picking" apples during simulation

Further testing modifications

In order to reduce testing time to an acceptable length for use in the field, the number of repetitions for each test was reduced from the five to three. Rest periods of fifteen seconds were given between back-extension tests and one minute between arm-hold tests. The rest intervals were established at the recommendation of the physical therapist to maximize muscle recovery between tests without making the testing process unacceptably time-consuming.

These three tests were then pilot tested in the orchard with five workers in a Saratoga, NY orchard early in September 2004, with two further modifications: a standing "dynamometer tower" for the vertical equivalent of the timed spinal extension was constructed, and the timed arm hold was changed from 90 to 120 degrees from the chest to make the posture more similar to overhead picking. The dynamometer tower allowed the subject to pull back while standing. With this change, a measurement table

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was no longer necessary. See Appendix 3 for a photo of the standing dynamometer tower.

An additional procedural modification involved the institution of a "warm up" period. This involved delaying the pre-test observations until the worker had completed a minimum of 30 minutes of picking. This change was implemented on the advice of the study physical therapist in order to reduce the effect that a lack of muscle warm-up might have on the morning versus afternoon comparison.

It was also deemed necessary to complete all post testing at the end of the picking day, but prior to the actual cessation of work. This was done to assure that the subject did not have a muscle recovery period prior to the administration of the afternoon test. The necessity of completing both tests during the actual workday required the testing of subjects in the orchard in a sequential manner. The following chapter contains the more formal development and assessment that followed these initial development steps.

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Chapter V. DEVELOPMENT AND INITIAL ASSESSMENT OF OBJECTIVE FATIGUE MEASURES FOR APPLE HARVEST WORK

Abstract [1]

Previous research has shown that neck, back and shoulder musculoskeletal strain is a major occupational health problem affecting migrant orchard harvest workers. Researchers seek to measure the effect of an ergonomic modification to the apple picking bucket on muscle fatigue, however objective measures for use in the orchard are not yet available.

The purpose of this study is to develop simple back, shoulder or arm strength measures, which detect statistically significant drops in strength over one workday. Candidate muscle strength measures were piloted in the laboratory, adapted for the orchard and evaluated (n=102). Data were analyzed for morning to afternoon fatigue, and for correlation between fatigue score and hours worked.

In the laboratory, the timed arm hold (35.7% time reduction, 95% CI: 21.81-49.61), and the timed spinal extension (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. The potential effect of field conditions and subject motivation on these results needs further exploration.

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[1] Chapter submitted to *Applied Ergonomics*, Accepted December 13, 2005.

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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 these activities is musculoskeletal strain due to stooping (ground crops), reaching (orchard fruit), and carrying of heavy loads. There is some research evidence to suggest that extreme powerlessness among this largely foreign-born, uneducated and sometimes undocumented workforce contributes to injury frequency (Salazar et al., 2005)

Epidemiology of back, neck and shoulder strain among apple harvest workers A number of published studies place musculoskeletal strains among the most frequent injuries for migrant and seasonal farmworkers (Northeast Center for Agricultural and Occupational Health, 2003, unpublished; Villarejo et al., 1999; Osorio et al., 1998; Husting et al., 1997; Ciesielski et al, 1991). One study reported an overall strain/sprain prevalence of 31 percent per season (McCurdy et al., 2003).

Frequent occurrences of muscle pain (a common symptom of strain) have also been found in orchard work. For example, a study in Japan examining musculoskeletal symptoms in apple and pear work found self-reported neck pain and stiffness ranging from 25-50 percent of workers in apples and from 40-60 percent of workers in pears. Sixty-five to 70 percent of workers in both crops reported stiffness in the shoulder, with roughly a third of apple workers and half of pear workers reporting shoulder muscle pain. Similar frequencies of neck pain with motion were reported as well (Sakakibara et al., 1995). Calisto (1999) also found an elevated prevalence of pain among fruit growers in

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the upper and lower back (19% and 57%, respectively), and in the neck and shoulders (both at 38%).

In addition to strain and pain outcomes, long periods of exposure to the ergonomic hazards of awkward posture and weight bearing among orchard workers have been documented (Earle-Richardson et al., 2004; Calisto, 1999). As a proportion of the workday, these periods of exposure are as long, or longer than those found in construction and nursing, two reportedly high-risk occupations (Earle-Richardson et al., 2004).

Prevention of strain through ergonomic intervention Researchers have developed an ergonomic bucket modification to reduce the load borne by the back, neck and shoulders of apple harvest workers, consisting of a supporting hip belt which redistributes weight from the upper back, neck and shoulders to the lower trunk, a preferable vertical height for weight bearing, and also maintains the load close to the body (Waters, 1994; Pheasant, 1991; Page, 1985). The intervention (shown in Figure V.1), is more fully described in a previous issue of this journal (Earle-Richardson et al., 2005), and in a preliminary laboratory EMG study (Earle-Richardson et al., 2006).

Figure. V.1. An apple harvest worker climbs a ladder to pick apples using the intervention belt

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Evaluating the hip belt intervention in the orchard As with the laboratory research, it was necessary to use an intermediate endpoint in the development of musculoskeletal strain because there currently exists no objective physical measure of the outcome. However, because it was not feasible to conduct EMG research in the orchard, the development of mechanical methods that could be used in the orchard environment was undertaken.

Detection of muscle fatigue through measurement of changes in morning to afternoon maximum voluntary contraction was selected as an endpoint. According to a model proposed by Armstrong and colleagues (1993), the development of musculoskeletal strain can be thought of as a sequence of four events: *exposure*, *internal dose*, *capacity* and *response*. In this context, *internal dose* is the body's initial response to a given load. One example of internal dose is muscle fatigue. While other capacity factors, such as rest time and overall condition, may ultimately determine whether an individual with a given internal dose develops muscle strain, an intervention that significantly reduces the internal dose can reasonably be called beneficial in preventing or reducing muscle strain. A number of other studies describe a similar process (Clarkson and Hubal, 2002; Protske and Morgan, 2001; Clarkson and Sayers, 1999; Sjogaard and Sogaard, 1998; Green, 1997; Clarkson and Newham, 1995; Bystrom, 1994; Hagberg, 1981).

Muscle strength measures 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 (Lanza, 1999). Published fatigue studies of this type measure either time holding a posture, one-time attainment of a maximum reading on a dynamometer or

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possibly a dichotomous pass/fail metric for performance of weighted or non-weighted tasks (Lee et al., 2001; Nussbaum et al., 2001; Hughes et al., 1999; Vollestad, 1997; Bloswick and Mecham, 1994).

Initial steps in muscle fatigue measurement instrument development Before being used in a large orchard trial, the sensitivity of each type of performance measure for apple harvest work needed to be evaluated. For the purposes of the current study, a measure deemed effective was one that detected a change in muscle strength occurring over an orchard harvest workday. This methodology is unique in that other published studies take pre- and –post measurements over a relatively short interval of time (no more than 2 hours), whereas this method seeks to measure a real work day of actual farm workers (6-8 hours). Interventions can thus be evaluated on their ability to reduce one-day muscle fatigue.

Methods

Study design The study has two phases: a laboratory phase and an orchard phase. Both phases are experimental in design. Beginning first in the laboratory with volunteers, pre- to post-work muscle strength measures are used to identify extent of muscle fatigue. Successful tests were then subjected to the same study process, using actual farmworkers in the orchard. Table V.1 shows the details of the laboratory and orchard evaluation phases.

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Table V.1. Summary of candidate muscle test trial data used in the current analysis

	n	Measures evaluated*	Hypotheses tested	Statistical analyses
A. Laboratory testing (2 hrs. simulated picking)	8	-standing scapular elev. mean - left -standing scapular elev. peak - left -standing scapular elev. mean - right -standing scapular elev. peak - right -2-shoulder mean -2-shoulder peak -timed arm hold-right -timed arm hold-left -timed spinal extension	"Fatigue score > 0" with 2 hrs. simulated picking	Confidence intervals (T probability density distribution)
B. Orchard testing	102	-timed arm hold -standing spinal extension mean -standing spinal extension peak	"Fatigue = 0" and "Fatigue not correlated with hours worked"	Paired T test, signed ranks; Pearson correlations

*"Mean" and "peak" designations are variations of dynamometer-based tests, the former taking the mean value over a five second contraction, and the latter the peak reading over a five-second contraction.

Laboratory phase Exploratory analysis evaluating differences in morning to afternoon strength. Confidence intervals around the observed differences will indicate certainty of the estimates. A finding of 0 within the 95% confidence interval will indicate no significant drop in strength.

Orchard phase hypothesis One or more musculoskeletal strength (or endurance) measure can be identified that shows a statistically significant fatigue effect of 10 percent or more among seasonal apple harvest workers after eight hours of apple harvest work.

Data collection For both the laboratory and orchard testing, an instructor and a recorder worked at each testing station. The instructor explained the measures to the subject and adjusted the test equipment to the subject's physical dimensions. The recorder assisted in the adjustment process and recorded all data relevant to the test. This included recording the settings for the subject's physical dimensions so that these settings could be duplicated in the afternoon test session.

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Laboratory testing This phase was conducted on eight research staff personnel using two hours of simulated picking conditions and three muscle measures. One day of testing was performed on each subject in this phase.

The first measure, the timed spinal extension, involved timing subjects for how long they could hold a maximum spinal extension lift while lying face down on an examining table. The second measure, the scapular elevation was comprised of three parts: one for both shoulders, and one each for the left and right shoulders. The third measure, the timed arm hold, was also performed separately for both left and right arms.

Each of these measures was administered both before and after two hours of simulated apple picking, which involved having the subject climb a stepladder and fill a standard apple bucket with apples arranged at various heights on a series of shelves. The subject then descended the ladder and released the apples out of the bottom of the bucket (through a recloseable opening) into a bin. This process continued for two hours, after which the post-test was administered.

Peak and mean exertion levels were recorded for maximum exertion measures after each of three repetitions using a dynamometer. Seconds to failure was used as the endpoint for timed endurance measures (timed spinal extension and timed arm hold). Rest periods of fifteen seconds were given between maximum contraction measures using the dynamometer, and one minute between timed maximum endurance measures.

Orchard testing Two of the three laboratory measures were further tested in the orchard. The scapular elevation measure was dropped from further consideration based on laboratory results. The timed arm-hold measure was performed for the dominant arm only. For the spinal extension an upright stand was constructed that

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allowed the subject to perform it standing up. Three repetitions of each measure were performed, with peak and mean exertion values recorded. A fifteen second break was provided between each spinal extension repetition, and one minute between each arm-hold repetition.

An additional procedural modification involved the institution of a "warm-up" period. This involved delaying the baseline observations until the subject had completed a minimum of 30 minutes of picking. These steps were taken on the advice of the study's physical therapist in order to reduce the effect that a lack of muscle warm-up might have on the morning versus afternoon comparison. Similarly, all post-testing was completed at the end of the picking day, but prior to the actual cessation of work, in order to assure that the subject did not have a muscle recovery period prior to the administration of the afternoon test.

A total of 27 apple harvesters were measured. Subjects were tested in two groups (n=7; n=20). Two testing stations were set up and ten subjects were tested at each station. Thus, with two test stations, it was possible to test the 20 subjects in approximately two hours and 30 minutes. This meant that the last subjects tested had been picking apples for approximately 135 minutes before their morning test.

Because of this significant time lag, the order of testing for the subjects was kept the same for the morning and afternoon sessions. This assured that the interval between tests was roughly the same for each subject. To do this, an additional researcher, termed the runner, would go into the section of orchard being harvested and return to the testing site with two workers. This process was repeated until all workers had been cycled through the test session.

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Timed arm hold measure – administration This measure made use of the dynamometer stand (see Appendix 3) to house a vertical pole, and to provide body stabilization during the timed measure. Other equipment included a hand-held dumbbell (4.54 kg for men, 2.27 kg for women) weight, a stopwatch and an adjustable pole with contact light designed to stay lit as long as the hand was in contact with the bar (see Figure V.2).

Fig. V.2. Administration of the timed arm hold in the orchard.

The subject stood on the platform of the dynamometer stand, facing the vertical post, leaning gently against the braces. To perform the test, the subject was instructed to hold the weight in the dominant hand, raise it up and hold it up against the contact pole as long as possible. A timer began when the subject made contact with the bar, and continued until the arm dropped away from the top of the pole arm and the light was no longer lit. Then the subject rested for one minute, and repeated the test and rest cycle two more times.

Standing spinal extension measure – administration This test employed a Chatillon CSD 300 strength dynamometer (see Appendix 3). This portable dynamometer measures pulling force in pounds over a five-second interval. It provides readings on the

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mean and peak pulling force for the interval, storing up to five, five-second intervals and provides a coefficient of variation for all the tests stored in memory. The dynamometer was housed in a stand, which has a brace on which the subject rests the upper back. This brace is also connected to the dynamometer and stabilized by the stand itself. It also has two other adjustable braces, one just below the knee and one at hip height.

The subject was asked to stand on the platform facing the vertical post, with legs and hips just touching the leg and hip braces. The brace was vertically adjusted so that the dynamometer was on the same horizontal line as the subject's sternum, and horizontally adjusted so that when the subject was standing erect, the chain connecting the brace to the dynamometer had no slack. The hip brace was vertically adjusted to the hips, and the leg brace one inch above the knee (see Figure V.3). All adjustments were scaled so that the precise location for a given subject could be recorded and replicated for the afternoon test.

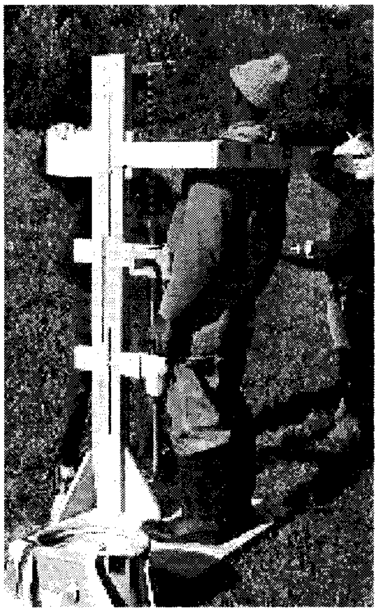

Figure V.3. Administration of the standing spinal extension in the orchard.

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The subject performed the measure by pulling with the upper back as hard as possible (pressing the thighs and hips forward into the stand) until told to stop. After a 15-second rest, the measure was repeated two more times. After three repetitions, mean values and then the peak values for each interval were manually recorded from the dynamometer.

These two measures were administered in an identical manner in the laboratory and the orchard with two exceptions. First, prior to the vertical spinal extension measure in the orchard, the subject performed a practice spinal extension. Since laboratory testing had shown that extremely low scores (11.34 kg or below) occur when the measure is performed incorrectly, proper performance was defined as obtaining a mean dynamometer reading (11.34 kg) as well as visually performing the measure properly. Second, before the first repetition of the arm hold measure in the orchard, the subject was instructed to raise the weight (4.54 kg or 2.27 kg depending on gender) over their head three times for one second in order to loosen the arm muscles and reduce the likelihood of cramping.

Inclusion of data on subjects from an intervention belt trial Subsequent to the orchard testing of the timed arm hold and the standing spinal extension, these two measures were employed in research evaluating the efficacy of the hip belt intervention. Data from the control day measurement (placebo) of this study were added to this evaluation to increase sample size and improve precision. Use of these data for this purpose assumes that the placebo belt was identical to the condition of using their usual equipment. In order to check this assumption, statistical analyses of the difference in fatigue score between a "placebo equipment" workday, and a "regular equipment"

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workday was done on 20 subjects for whom data on both types of days had been collected. No significant differences were found.

Data analyses As stated previously, the intent of the measure development trials was to identify strength measures that change significantly from pre- to post-work. To assess this, the null hypothesis that the fatigue scores for the working condition have mean equal to 0 was tested. The presence of a dose-response relationship was further considered through estimation of the correlation between hours worked and the magnitude of the fatigue scores. In this case, the null hypothesis that the value of this correlation was equal to zero was tested via conversion to Fisher's Z.

An additional analytic concern relates to the fact that the small sample size makes the Central Limit Theorem relatively untenable for guaranteeing normality of the sampling distribution of the mean. Therefore, in cases where non-normality was suspected, non-parametric tests employing the median were used.

Considerable variability was observed due to varying degrees of effort put forth by the subject from repetition to repetition. Because of this, the maximum of the values observed over these repetitions was selected as the best indicator of a subject's muscle strength (Van Dieen et al., 2001).

For each subject, a difference score, defined as each day's maximum morning value minus the corresponding maximum afternoon value, was calculated. For example, the maximum of the three afternoon peaks for a given measure was subtracted from the maximum of the three morning peaks for this measure. Difference scores for the mean of this measure were calculated in an analogous manner.

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In order to increase the interpretability of the results, all difference scores were expressed as a percent of the morning value:

Endpoint = (maximum morning value – maximum afternoon value) /maximum morning value

Laboratory data analyses There were a total of nine difference scores for this trial: six for the latissimus dorsi raise (a mean and peak difference for each arm and for both arms together), and three times to failure results for the two timed arm holds and the spinal extension measure. All nine of these difference scores were expressed as a percent of the morning value.

Plots of the distributions of these percent difference scores were examined for normality and the presence of outliers. Since distributions were found to be normal, confidence intervals, (the mean +/- 1.96 standard errors) were created for the averages of these mean and peak difference scores for each of the nine measures. Statistically significant differences were considered to be present for those intervals that did not contain zero.

Orchard trial data analysis With the addition of the intervention trial placebo data (n=95) to the orchard trial data (n=27), the sample size was 102 subjects. As with the previous analysis, morning-to-afternoon strength differences were used to create fatigue scores, which were expressed as a percent of the morning value. This consisted of a mean and peak difference for the standing spinal extension, and the difference in time to failure for the dominant arm timed arm hold. Normally distributed fatigue scores not having outliers were analyzed using paired t-test analyses. When outliers were present, the median of the distribution of fatigue scores were taken as the measure of

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central tendency. A test of significance in this case was made using the Wilcoxon signed ranks test.

X-Y plots were created for each of the fatigue measures in order to examine the relationship between the magnitude of the fatigue score and the duration of hours worked between tests. Correlations between warm-up duration and fatigue score were also examined.

Results

Laboratory phase In the laboratory, statistically significant fatigue between pre- and post-work measurements was found for two measures: the timed arm hold (35.7% reduction, 95% CI: 21.8-49.6), and the timed spinal extension (31.8% reduction, 95% CI: 23.5-40.0). The other tests were not significant (Table V.2). All subjects had an elapsed time of two hours, and had no warm-up interval.

Table V.2. Pre-work to post-work muscle strength differences for nine laboratory measures

Measure	**n**	**Mean % drop**	**S. E.**	**95% C.I. lower limit**	**95% C.I. Upper limit**
R-shoulder mean	8	3.51	8.46	-13.08	20.09
R-shoulder peak	8	2.81	6.16	-9.27	14.88
L-shoulder mean	8	3.29	2.93	-2.45	9.03
L-shoulder peak	8	1.62	2.39	-3.06	6.30
2-shoulder mean	8	9.35	5.64	-1.70	20.40
2-shoulder peak	8	10.11	5.49	-0.65	20.87
R-arm hold time	8	35.71*	7.09	21.81	49.61
L-arm hold time	7	9.31	8.34	-7.04	25.66
Timed spinal extension hold time	6	31.75*	4.19	23.54	39.96

*Statistically significant

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Orchard phase Table V.3 shows selected demographic and physical characteristics of the study subjects who participated in this phase. The subjects were Jamaicans and Mexicans with varying preferences for bag carrying position (right, left, front). Additionally, there was a wide range of height, weight, and body mass index. However, analyses did not show associations between these variables and fatigue, so they were not considered in further analyses.

Table V.3. Demographic characteristics of 102 subjects in trial four

Characteristic	n	
Mean age	99	42.6
% Male	99	97%
Jamaican	82	80%
Mexican	20	20%
Mean height	100	1.72M (67.8 in)
Mean weight	100	76.86K (169.2 lb.)
Mean BMI	99	26.4
% Bag left side	9	9%
% Bag right side	15	15%
% Bag center	61	61%

Subject warm-up times ranged from 28 to 240 minutes (mean: 97.4 minutes), and elapsed time between baseline and afternoon test ranged from three to 7.25 hours (mean: 5.6 hrs.). Twenty minutes was determined by the study Physical Therapist to constitute sufficient warm-up time. Researchers were concerned that morning strength scores may have been diminished among those with extremely long warm up intervals. However a lack of strong correlations between warm-up time and fatigue indicated that this concern was not warranted. Similarly, correlations between elapsed time and fatigue were not statistically significant.

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The mean fatigue score for the timed arm hold measure was 11.4 percent ($p<.0001$). For the standing spinal extension, median values were used as measures of central tendency for the distribution of both the peak and mean values, rather than means, due to the presence of outliers. A test of these medians employing the Wilcoxon signed ranks test showed neither to be significantly different from zero (Table V.4).

Table V.4. Fatigue scores for three tests among 102 apple harvest workers

		Mean		Median	
		% drop	P*	% drop	p**
Timed arm hold	102	11.38	<0.0001	11.56	<0.0001
Standing spinal ext. mean	101	-8.42	.219	2.32	0.766
Standing spinal ext. peak	101	-.62972	.809	1.7056	0.659

*Paired t-test **Signed ranks test

Discussion

Laboratory phase The laboratory data indicate that two measures are sensitive to two hours day of orchard harvest work among unseasoned subjects: the timed arm hold (35.71% reduction, 95% CI: 21.81-49.61), and the timed spinal extension (31.75% reduction, 95% CI: 23.54-39.96). Thus, the hypothesis that laboratory measures of muscle fatigue could be identified was found to be valid.

Orchard phase In contrast, the orchard workers showed a much smaller fatigue effect for the arm hold (11.4% $p<.0001$) and did not exhibit a significant fatigue effect for either measure (peak or mean) of the standing spinal extension. While the hypothesis for this phase was also not disproven, the results were much less conclusive.

With regard to the timed arm hold, one-day strength losses of between 10 and 30 percent are observed in other studies with moderate activity (Mullaney et al., 2005; Byrne

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and Eston, 2002; Clarkson and Hubal, 2002). Other studies of strenuous activity have documented one-day drops ranging from 50-70 percent (Warren et al., 2002; Rinard et al., 2000; Howell et al., 1993). The results for the timed arm hold are therefore within the expected range for a functional measure of muscle fatigue. Similarly, an orthopedic physician with whom the authors' conferred reported the use of 10 percent strength deficit as the threshold value for being indicative of injury (Jackson LaBudde, MD, personal communication, July 13, 2005).

There were some important differences between the laboratory trial and the orchard trial that may account for the smaller fatigue effect observed in the orchard for the timed arm hold. First, the laboratory subjects were not conditioned farmworkers. As a group, these eight volunteers were unaccustomed to apple harvest work, which would tend to make the fatigue effect more pronounced than it would be with actual farmworkers. This may have resulted in increased muscle fatigue among the laboratory subjects. On the other hand, the fact that the work interval in the laboratory was only two hours (as opposed to five to eight hours in the orchard trial) would have led to less fatigue among subjects. It is difficult to say which is likely to have had a greater influence.

Another potentially important difference between the laboratory subjects and the orchard workers was the likely higher motivation level of the laboratory subjects to maximally exert themselves. As part of the research team, each of the laboratory volunteers was likely to be more motivated to perform the measures correctly and with maximum force. In contrast, some orchard worker subjects expressed concern regarding overtaxing themselves on the measures and a desire not to "tire themselves out," a

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phenomenon that was not encountered in the laboratory. Reduced effort at baseline is likely to have led to an underestimation of fatigue.

The lack of a significant correlation between fatigue score and elapsed picking time between tests indicates that the fatigue effect seen in the timed arm hold does not follow a linear dose-response pattern. Further research would be needed to establish the presence of some non-linear dose response pattern, or alternatively, an all or none response.

The inability of the standing spinal extension to detect fatigue (of 10% or more) in the orchard after a similar test, the timed spinal extension, detected a significant fatigue effect in the laboratory warrants further consideration. While the standing spinal extension measure was kept as similar to the timed spinal extension as possible, there were some major differences that may have affected the result. The fact that the timed spinal extension was held until failure and required the subject to hold against gravity may have been more effective in achieving a state of muscle fatigue where one day differences were observable. In contrast, pulling backwards for five seconds may have relied more on concentric muscle actions, which are much less prone to strain (Proske and Morgan, 2001).

In the literature, endurance-based measures are more commonly seen than those related to maximum strength (Stewart et al., 2003; Keller et al., 2001; Latimer et al., 1999; Bloswick and Mecham, 1994; Biering-Sorenson, 1983). On the other hand, two published studies suggest that maximum voluntary contraction measures (achieving a maximum rating on a dynamometer) are preferable because they are more reliable (Vollestad, 1997; Mayer et al., 1995).

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Furthermore, there are a number of other factors that might affect a given muscle's susceptibility to fatigue and strain: the muscle fiber type, the muscle length, overall size and structural complexity (Brooks, 2003; Proske and Morgan, 2001; Chaffin and Andersson, 1991). In order to fully take advantage of the logistical ease of mechanical field methods, it would be prudent to conduct further laboratory testing using surface electromyography to identify the most sensitive muscles, muscle groups and muscle actions.

Conclusions

Throughout the research, 12 different muscle strength measures were evaluated; four of these were timed endurance measures, and eight were maximum contraction measures (employing the dynamometer). While further research is needed to draw any firm conclusions, these preliminary data seem to suggest that endurance measures may be more effective in this setting than maximum strength measures. The fact that these measures diminished in the extent of fatigue detected from the laboratory (with researcher subjects) to the orchard (with worker subjects) may also be due to limitations of the physical environment, or to subject motivation and performance abilities.

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Chapter VI. IMPLICATIONS FOR MUSCLE FATIGUE MEASURES USE IN AN ORCHARD EVALUATION TRIAL

The muscle fatigue development research described in the previous chapter evaluated a total of 12 different muscle strength measures, and found two that indicated muscle fatigue with apple harvest work in the laboratory, while one did so in the field. The fact that these measures diminished in the extent of fatigue detected from the laboratory (with laboratory volunteers) to the orchard (with farm worker subjects), may be due to limitations of the physical environment, or to subject motivation and performance abilities.

Time constraints did not allow for a more definitive validation of these measures, that is, a comparison of fatigue scores between working days and non-working days. A significantly greater fatigue score on a working day would confirm that the measure was sensitive enough to not only detect muscle fatigue occurring on a work day, but also to distinguish muscle fatigue due to working from that which occurs over the course of any day.

Unfortunately, the short, intense nature of the harvest made it impossible to find true rest days until the end of the harvest season, too late to confirm measures before using them in the season. While orchard owners reported that Sundays were rest days for workers, the reality was that rest days were entirely dependent on the weather and the readiness of the apples for picking. For example, if workers were forced to stop picking due to rain, or because a certain orchard was not quite ready for harvest, then that time would be made up on Sunday. Therefore, it was necessary to proceed without this final validation. Researchers chose to use the two most promising muscle fatigue measures:

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the timed arm hold and the standing spinal extension (this is the field version of the timed spinal extension) in the next phase of the trial.

While the development trial presented in Chapter V found a significant fatigue score for the timed arm hold only when tested in the orchard, there is some, albeit weaker evidence for both the timed arm hold and the standing spinal extension demonstrated in an analysis of a small cohort of workers measured using regular equipment. This is a slightly different assessment from that of the group of 102 workers from Chapter V in that the 102 workers were using a placebo belt, not their regular equipment. The table below shows mean and median values for 27 subjects using the timed arm hold and the standing spinal extension (five-second mean and five-second peaks).

Table VI.1. Mean and median fatigue scores for three tests of workers using regular equipment

	n	Mean	95% C.I. lower limit	95% C.I. upper limit	Median	P (signed ranks)
Timed arm hold	27	4.63	-5.39	14.65		
Mean standing spinal extension	27				7.02	0.10
Peak standing spinal extension	27				6.29	0.09

In this table, the analysis method used depended on whether outliers were found in this small sample. For the timed arm hold, a 95 percent confidence interval was formed around the mean. In the cases of both standing spinal extension measures, medians were used, due to the presence of outliers. Significance was tested using non-parametric methods (signed ranks test). All three tests show non-significant positive fatigue scores at the P=.05, level.

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Similarly, Pearson correlations show some weak evidence for an increasing fatigue score with increasing time worked for the standing spinal extension tests, although not for the timed arm hold, as shown in Table VI.2.

Table VI.2. Pearson correlations between hours worked and fatigue score for each test

		r	p
Timed arm hold	27	-0.1937	0.33
Mean standing spinal extension	27	0.5564	0.003
Peak standing spinal extension	27	0.5304	0.004

These results, which are somewhat more favorable to the standing spinal extension than those presented in Chapter V are based on a much smaller sample size. These data are also different in that the subjects were using their regular equipment rather than a placebo belt and bucket. It is difficult to interpret what importance this might have, but it does support the argument that the standing spinal extension is the second best measure to carry forward into the orchard trial.

Initial steps in the orchard trial

Planning with orchards and workers The first step in moving from instrument development to an actual orchard trial was to meet with orchard owners and review the goals and progress of the research. Meetings with orchard owners and displays at orchard conferences and shows had been ongoing for the previous year, but as the orchard phase of the research drew closer, it was necessary to plan the specifics of the implementation with orchard owners. During the spring and summer of 2004, meetings

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were held with 12 orchard owners and managers, and 14 farmworkers, both Jamaican and Mexican. These meetings made it possible to determine what form of data collection would be acceptable to workers and employers. In addition, study planning updates were sent to all orchards in a newsletter format. This made orchard recruiting much easier and more successful. An example of a communication with orchard owners during this period is included in Appendix 4.

Orchard recruiting Orchards for this phase of the research were selected from a pool of fifteen orchards from around New York State that had volunteered to participate in the study. In order to collect data on such a large number of workers over such a short period of time, it was necessary to enroll two large orchards, with at least 30-50 workers agreeing to participate at each. Depending on the number enrolled and the nationality/ethnicity of the subjects, smaller orchards would then be recruited in order to reach the desired number of workers (100), and representation of at least 2 major nationality/ethnicities.

Geographic location of study orchards As shown in the map below (Figure VI.I), the orchard trial research was conducted in two distinct regions of the state. In the far northeastern corner of the state, two large orchards specializing in the MacIntosh apple variety participated in the study. The hand-harvest workers on these orchards were entirely Jamaican, brought to the farms from Jamaica through a New York State Department of Labor guest worker program. Due to the easy bruising of the MacIntosh apple variety, much of the harvest work is done at an hourly pay rate, rather than by quantity picked (termed piece rate), common with other varieties. The harvest season is

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4-6 weeks, and each of the two orchards employed approximately 150 workers during this time.

In the western Lake Ontario region, workers on the participating farm were all Mexican. Most were part of one extended family. These workers were paid a piece rate, and picked a wide variety of apples. This orchard also grows peaches and pears. The harvest season on this orchard was somewhat longer (8-10 weeks), and employed 20-30 workers.

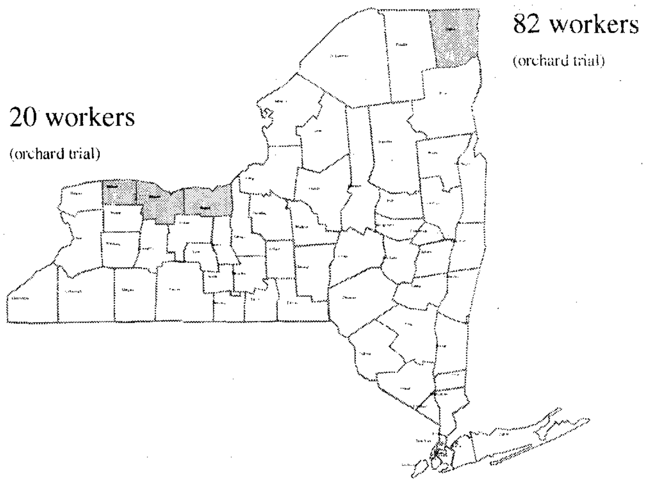

Figure VI.1. Locations of New York orchards participating in the orchard trial

Determining the data experimental design and sample size On the basis of the study goals, and after extensive consultation with orchard workers and employers, a

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three-part data collection plan was designed. As shown in Table VI.3., the general plan was for subjects to use the intervention belt for one week and the placebo belt for one week. Some workers were to receive a third week of muscle fatigue testing using their customary equipment after the trial. Productivity data were collected after the trial through employer records.

Table VI.3. Two-week intervention trial plan

	MON	TUES	WED	THURS	FRI	SAT	SUN
Wk1 50 intervention 50 placebo	Work	Work	Work Subjects receive pre-work strength test; then same evening test	Work	Work	Work	Worker interview
Wk2 Intervention, placebo groups switch	Work	Work	Work Subjects receive pre-work strength test; then same evening test	Work	Work	Work	Worker interview
Post trial week			Subset of workers receive pre-work strength test; then same evening test using regular equipment	Employer records reviewed to collect bushels picked per day and hours worked per day for each subject during WK1, Wk2 and the week prior to WK1.			

Sample size considerations were based on providing adequate numbers of subjects for the comparison of fatigue scores for spinal extension between the treatment and placebo groups, since the prone version of this test (the timed spinal extension, done lying down) is most frequently found in the published literature. Since each subject

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would have fatigue scores for both treatment and control conditions this comparison was made via dependent samples t-test.

Using data from Bloswick and colleagues 1994, and assuming a relatively conservative correlation between the worker's fatigue scores in the control versus intervention conditions of .5, the standard deviation of the difference in fatigue scores is estimated to be 5.58. Further, a mean difference in fatigue scores of 5 seconds is considered to be the minimum relevant amount in this population.

From this, and using a two tailed alpha of .05 (z=1.96), it is estimated that a sample of 65 workers exposed to both treatment and control conditions, would provide power of .90 for the test of the null hypothesis that the control and intervention mean fatigue scores are equal.

In addition to this comparison, it is also necessary to measure the degree of worker acceptance of the new bag with a margin of error (95% confidence interval) of not more than ± 10 percent. In order to place binomial variance at its theoretical maximum of .25, the proportion of workers liking the intervention belt as much or more than the traditional bucket will be assumed to be .50. Therefore, a sample of 100 workers would result in a standard error of this binomial proportion of .05 and yield a margin of error (± 1.96 X se) of .10, or 10 percent. Therefore, 100 subjects was the recruiting goal.

Recruitment, training and compensation of apple harvest workers Before recruiting farm workers, an agreement was made with the farm owner as to the total number of subjects that he was willing to have involved, since data collection would cause a certain amount of disruption to the daily orchard operation. On the two large

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orchards, invitation to participate was limited to two groups of approximately 50 workers in order to prevent participants being scattered across the entire orchard. The study could feasibly accommodate a maximum of 50 workers at any one time, so this limit also prevented having to turn any potential subjects away.

Informed consent was obtained from workers selected for participation. This process involved reading the informed consent script in the subject's first language, assuring that they understood the content, soliciting questions, and obtaining written consent, according to the recommendations of the Bassett Research Institute Institutional Review Board, and the SUNY Albany Institutional Review Board. Sample copies of the approved informed consent forms, English and Spanish are in Appendix 5.

After the first interview, subjects participating in the two-week intervention trial received \$30, and after the second interview \$35. For each day of muscle fatigue testing, the subjects received an additional \$10, as was the practice during the measurement development phase.

Development of the worker interview instrument The worker interview was primarily geared toward measuring worker acceptance of the intervention belt, and to gather detailed information about what might be specific problems with the belt. These questions were modeled after those used in a previous acceptance survey (Earle-Richardson *et al.,* 2005). In addition, questions on farm worker muscle pain were based on a similar pain survey for farmworkers developed by Faucett and colleagues (2001). A copy of the interview instrument, which was administered in both English and Spanish, is in Appendix 6.

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CHAPTER VII. ORCHARD EVALUATION OF ERGONOMICALLY MODIFIED APPLE BUCKET

Abstract[1]

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* The study aims 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.

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Introduction

Figure VII.1. Orchard harvest workers typically combine flexed postures and weight bearing

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 (McCurdy et al., 2003; Villarejo and Baron, 1999; Osorio et al., 1998; Husting et al., 1997; Ciesielski et al., 1991).

Very high rates of muscle pain, a common symptom of strain, have also been documented in orchard work (Calisto 1999; Sakikabara, 1998). 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. VII.1) have been identified (Earle-Richardson et al., 2004; Calisto 1999).

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 VII.2 and Figure VII.3).

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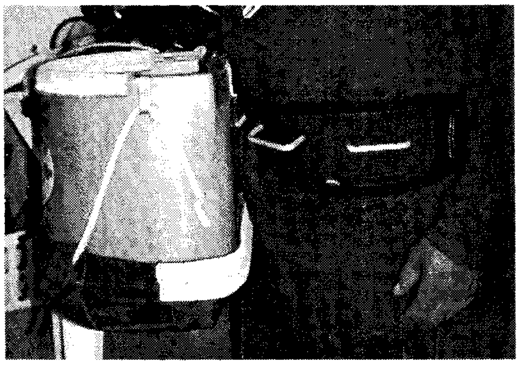

Figure VII.2. Ergonomic intervention belt.

Figure VII.3. Apple worker using intervention belt

A small laboratory study (Earle-Richardson et al., 2006) has demonstrated that the intervention belt reduces load on the mid- and low-back, two site commonly associated with muscle strain. 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, muscle fatigue measurement methods described in Chapter V will be employed to determine whether the beneficial effects seen in the laboratory are also seen in the orchard.

Worker acceptance Pilot research (n=14), indicated that a majority of workers rated the hip belt intervention favorably (79%), after 2-3 one-hour trials (Earle-Richardson et al., 2005). 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

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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 (Clarkson and Hubal, 2002; Jacobson, 1999; Palmer et al., 1999; Deutsch and Mink, 1989). 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 (Faucett et al., 2001; Booth-Jones et al., 1998; Husting et al., 1997; Baron et al., 1996; Ohlsson et al., 1994).

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 (see Chapter V).

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 (Lanza, 1999). Published

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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 (Lee et al., 2001; Nussbaum et al., Hughes et al., 1999; Vollestad, 1997; Bloswick and Mecham, 1994).

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 (Stewart et al., 2003; Keller et al., 2001; Latimer et al., 1999; Bloswick and Mecham, 1994; Biering-Sorensen, 1983). 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 (see Chapter V) 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.

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Methods: implementation

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 use of the placebo, which appeared similar to the intervention, would account for any "placebo effect," that is, any favor given to it by workers because it appeared quite similar to a belt commonly used by weightlifters and manual workers for assisting in lifting heavy objects.

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The subjects were individually fitted and instructed in the use of the intervention belt (Figure VII.4). The use of this placebo was considered important because the typical equipment for apple hand harvest in New York State ("regular equipment") includes the same bucket with no belt at all. This made the intervention and regular equipment conditions extremely different visually, and there was a concern that difference might unduly influence subjects in evaluating the intervention belt.

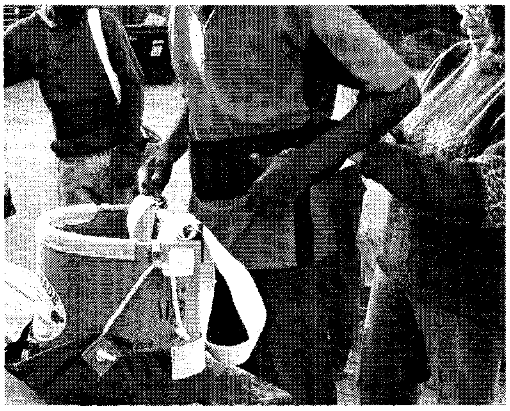

Figure VII.4. Worker is fitted with a placebo belt

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.

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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 the subject 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 VII.5 shows the decision tree for determining intervention compliance.

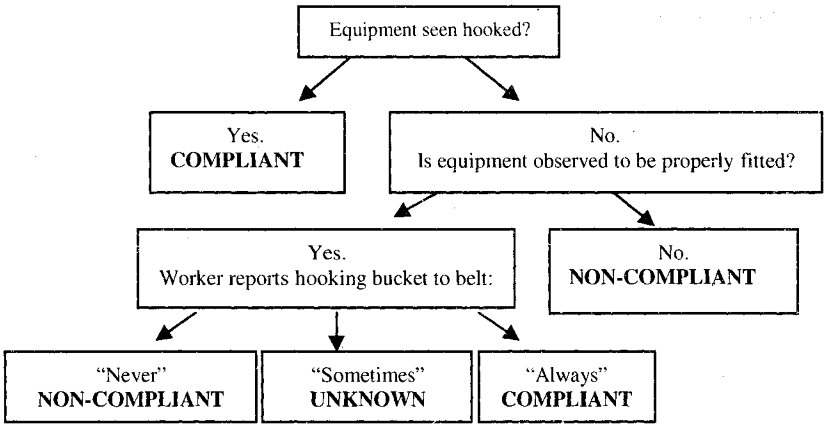

Figure VII.5. Subject intervention compliance decision tree.

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,

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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 benefits to the worker. Researchers believe that a 50 percent 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), divided by the morning value. Therefore, muscle fatigue scores are expressed in percentages. 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 fatigue score (which is a percentage) one-day muscle fatigue minus the intervention day muscle fatigue score.

Methods: 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 (Earle-Richardson et al., 2005), with the questions further tested with 10

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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 their 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

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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

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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 VII.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 in Appendix 3.

Figure VII.6. Subject performing the timed arm hold muscle fatigue test

Methods: statistical analyses

Worker acceptance of the intervention It was hypothesized that at least 50 percent of workers trying the ergonomic belt would state that they would be willing to

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use it for their regular work in the future. A 95 percent confidence interval was created for this proportion.

Intervention impacts on worker productivity Bushels per hour were compared for three conditions: intervention, placebo, and usual equipment conditions using a one by three ANCOVA. In order to control for any effects of 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. This was based on the assumption that any relationship found would be linear, since all subjects met the minimum 20-minute warm-up requirement.

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 "noncompliant + unknown"). The mean difference in fatigue scores was compared between these two groups using an independent samples t-test.

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Results

One hundred and twenty workers were invited to participate in the study; one hundred and two participated, for a participation percentage 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 VII.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.

Table VII.1. Demographic characteristics of orchard trial subjects

	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%
% Bucket right side	12	12%
% Bucket center	82	82%

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

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sparse to make any formal statistical comparisons. Workers' comments about the intervention equipment are summarized in Table VII.2.

Table VII.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

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 hours (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 hours (SD=1.4). Similarly, warm-up time differences within subjects had a mean of –0.15 hours (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 VII.3, employer record review indicated that workers' mean picking speed per hour during their intervention did not differ significantly between

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intervention and placebo weeks. Picking speed for both of these weeks was significantly higher than picking speed during the regular equipment week.

Table VII.3. Comparisons of subject picking speed
(adjusted for total hours picked)
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	<0.001	---

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

Mean timed arm hold values among all subjects were: 41.3 seconds (AM) dropping to 36.1 seconds (PM) in the intervention condition, and 42.8 seconds (AM), dropping to 36.7 seconds (PM) in the placebo condition. As shown in Tables VII.4 and VII.5, muscle fatigue differences between intervention and placebo days within subjects 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.

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Table VII.4. Fatigue score differences between intervention and placebo day: all subjects, and among confirmed compliance only

	n	Mean fatigue score* difference between intervention & placebo day	p
Timed arm hold, all subjects	95	0.13 % difference	.97**
Timed arm hold, only compliance-confirmed subjects	65	1.5 % difference	.72**

*Fatigue score = (AM time to failure -- PM time to failure) /AM time to failure
** Paired t-test for null hypothesis: fatigue difference = 0

Table VII.5. Comparison of intervention-placebo fatigue score difference between the confirmed compliant to all other subjects

Timed arm hold, comparing compliant to non-compliant	n	Mean fatigue difference between intervention & placebo day	p
Compliance-confirmed	65	1.5 % difference	
Compliance unconfirmed	26	-4.1 % difference (indicates greater fatigue on intervention day)	.45*

* Two-sample t-test for null hypothesis: fatigue score difference, compliance confirmed = fatigue score difference, compliance unconfirmed

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

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that at least 50 percent of workers would accept it. Other agricultural studies introducing new equipment to migrant and seasonal farm workers have found varying degrees of acceptance, from none to a majority accepting (McNeill and Westby, 1999; Miles and Steinke, 1996; Sen and Sahu, 1996). 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,"* and, *"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 (Ammendolia, et al., 2005; Wassell et al., 2000; Hodgson, 1996)[2]. 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

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[2] There is some evidence in the literature that the use of back belts can affect worker behavior. In some settings, belt use reduces the frequency and severity of assuming hazardous postures, and thereby may reduce injury (Smith et al., 2004; Willey, 2001; Lavender et al., 2000). However, previous research by the author measuring the impact of belt use on posture (Earle-Richardson et al., 2004), demonstrated that postures and orchard work activities are not affected by belt use.

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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 between .13 and 5.6 percent of the AM value (which are generally less than 60 seconds) are neither statistically significant (p values: .97 - .45) nor biologically meaningful (Clarkson and Hubal, 2002; Mullaney et al., 2005; Byrne and Eston, 2002).

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 (Oberg et al., 1994; Sundelin and Hagberg, 1992; Hammaskjold and Harms-Ringdahl, 1992; Haag and Suurkula, 1991; Hagberg, 1981).

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 previously validated. 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.

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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 (Chapter V), found substantial strength reductions in the laboratory 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 is acceptable to workers and does not negatively impact productivity in the orchard. Current methods were not sufficiently sensitive to determine

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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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Chapter VIII. IMPLICATIONS FOR THE INTERVENTION AND FURTHER RESEARCH

In Chapter VII, it was demonstrated that apple harvest workers overwhelmingly accept the intervention belt and that it does not slow them in their work. However, a significant reduction in muscle fatigue score was not observed. Further evaluation of muscle strength tests with worker resting days at the end of the harvest season revealed that the timed arm hold was not able to identify differences in fatigue between a day of apple hand-harvest work and a resting day. This finding led researchers to conclude that the timed arm hold, while promising in initial development testing, was not sensitive enough to detect the muscle benefit that researchers believed was conferred by the intervention belt.

In this chapter, detailed muscle fatigue results for three tests are presented, as are data from an examination of the relationships of a number of different variables to muscle fatigue score. A brief review of the researcher's past work with electromyography is provided, with commentary on how this research was used to design the final phase of the intervention hip belt evaluation study.

Fatigue score differences for the timed arm hold and the standing spinal extension

The original intention of the fatigue measures development phase was to identify several (at least 3) measures that could be used in the orchard trial. It was believed that this was needed in order to provide a reasonable opportunity of measuring fatigue in the appropriate muscle or muscle group (upper back, shoulder and neck or lower back), where most of the burden is borne. As shown in Chapter V, only the timed arm hold

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performed sufficiently well with 102 subjects to be used in the formal orchard trial. Due to this shortage of validated tests, it is noted in Chapter IV that data were also collected using the next best test, the mean standing spinal extension. Standing spinal extension results are not included in the formal analysis in Chapter VII, but are presented in Tables VIII.1 and VIII.2 below.

In addition, as described in Chapter VII, there were a number of subjects whose use of the intervention belt was not sufficiently appropriate for them to be gaining the anticipated muscle benefit from it. For this reason, additional analyses were done among compliant subjects only (Table VIII.1), and then a third time, comparing compliant to non-compliant intervention-control differences (Table VIII.2). These were done to determine whether poor compliance may have affected the results in the first analysis.

Table VIII.1. Difference in Fatigue Scores between intervention and placebo days, for all subjects, and for compliance-confirmed subjects

	n	**Mean fatigue difference**	**p**
Timed arm hold, all subjects	95	0.13	.97*
Timed arm hold, only compliance-confirmed subjects	65	1.5	.72*

* Paired t-test

	n	**Median fatigue difference**	**p**
Standing spinal extension, all subjects (mean)	93	-4.13	.39**
Standing spinal ext., only compliance-confirmed subjects (mean)	64	-3.08	.54**

* * Wilcoxon Signed Ranks Test

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Table VIII.2. Summary of 1x2 analysis of covariance for difference in fatigue scores by intervention compliance

Response	Compliance Level		Mean	p-value
Timed arm hold	High	(n=63)	+1.8090	
	Med/Low	(n=26)	−4.0507	0.4362
Standing spinal extension (mean)	High	(n=62)	−0.2968	
	Med/Low	(n=25)	−6.7344	0.5017
Standing spinal extension (peak)	High	(n=60)	−3.1040	
	Med/Low	(n=23)	+0.1932	0.6965

As was shown in Chapter VII with regard to the timed arm hold, none of the analyses indicate any significant difference in fatigue score with belt use.

Factors potentially affecting muscle fatigue results

Several additional variables were considered in an attempt to further explain the results.

Length of warm-up interval In order to determine the effect that differing lengths of the warm-up interval between intervention and control days may have had on the muscle fatigue score results, an analysis was made with results stratified by quartiles of warm-up time interval length (see Table VIII.3). Fatigue score differences between intervention and placebo for the timed arm hold decrease between quartile one and two, as well as between quartile three and four. This indicates a general pattern of decreasing pre-work strength as measurement is taken later and later in the morning. However the correlation between warm-up time and fatigue was weak (-.146, p =.14) for this measure. There is no discernable pattern with the two standing spinal extension measures.

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Table VIII.3. Intervention versus placebo difference in fatigue scores by quartile warm-up interval length

Mean Measure	Median n	% Drop	p*	% Drop	p**
Below 1st Quartile Value (1.033 hours)					
Arm Hold	25	+15.96	0.006	+18.61	0.004
Mean Back	25	−02.01	0.725	+01.32	0.685
Peak Back	25	−01.68	0.771	+01.84	0.592
Below 2nd Quartile Value (1.483 hours)					
Arm Hold	26	+11.49	0.025	+16.52	0.018
Mean Back	26	−09.29	0.272	−01.27	0.796
Peak Back	25	−03.95	0.587	+00.00	0.837
Below 3rd Quartile Value (2.000 hours)					
Arm Hold	25	+12.70	0.011	+13.64	0.015
Mean Back	25	−24.39	0.348	+06.88	0.969
Peak Back	24	+02.60	0.458	+03.44	0.618
At, or Above 3rd Quartile Value (2.000 hours)					
Arm Hold	26	+04.65	0.290	+05.47	0.216
Mean Back	25	+02.02	0.562	+03.44	0.556
Peak Back	24	+00.70	0.842	+01.50	0.698

As a last step in this exploration, the fatigue score analysis was done once more, adjusting for both warm-up time and elapsed time spent working between tests. These results are shown below in Table VIII.4.

Table VIII.4. 1 x 2 analysis of covariance for difference in fatigue scores by intervention compliance

Adjusted for difference in elapsed work time and elapsed warm-up time between intervention and control days

Response	Compliance Level		Mean	p-value
Timed arm hold	High	(n=63)	+1.7501	
	Med/Low	(n=26)	−3.9080	0.4503
	(covariates)			
	Elapsed Time		n/a	0.6607
	Warm-up Time		n/a	0.1435
Standing spinal extension	High	(n=62)	−0.2396	
(mean)	Med/Low	(n=25)	−6.8764	0.4926
	(covariates)			
	Elapsed Time		n/a	0.8499
	Warm-up Time		n/a	0.4640
Standing spinal extension	High	(n=60)	−3.0713	
(peak)	Med/Low	(n=23)	+0.1079	0.7094
	(covariates)			
	Elapsed Time		n/a	0.7685
	Warm-up Time		n/a	0.4704

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A number of other subject physical and demographic characteristics were considered. Table VIII.5 below shows the correlations of five additional variables with fatigue score difference between intervention and placebo belt. None were significant. Similarly, Tables VIII.6 and VIII.7 show muscle fatigue score differences between intervention and control stratified by subject nationality and by subject preference as to whether the bucket is carried on the left side, right side or in front.

Table VIII.5. Pearson's Correlation (r) between intervention-control fatigue score difference and other factors

	Timed arm hold			Mean standing spinal extension			Maximum standing spinal extension		
Variable	n	r	p-value	n	r	p-value	n	r	p-value
height (m)	93	−0.0652	0.5346	91	−0.0070	0.9472	87	−0.0269	0.8045
weight (kg)	93	+0.0661	0.5289	91	+0.0822	0.4384	87	+0.1515	0.1614
BMI (kg/m^2)	93	+0.0950	0.3649	91	+0.0940	0.3756	87	+0.1780	0.0991
waist:hip	93	+0.0684	0.5147	91	+0.1575	0.1360	87	+0.1367	0.2067
age (yrs)	92	−0.0043	0.9676	90	+0.0691	0.5174	86	+0.0901	0.4094

Table VIII. 6 Intervention-control fatigue score difference stratified by nationality

Measure	n	Mean	Standard Error	p-value
Timed arm hold				
Jamaican	75	−0.292	3.5234	
Mexican	20	+1.697	7.6482	0.8012
Mean standing spinal extension				
Jamaican	73	−1.435	5.4566	
Mexican	20	+8.261	9.9958	0.4081
Maximum standing spinal extension				
Jamaican	69	−0.236	4.6717	
Mexican	20	+1.159	7.1835	0.8837

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Table VIII. 7 Intervention-control fatigue score difference stratified by side on which bucket is carried - one-way ANOVA by bucket side

Measure	n	Mean	Standard Error	p-value
Timed arm hold				
Center	59	−0.273	3.7214	
Right	12	−3.352	9.9262	
Left	07	−7.775	13.088	
All	15	+9.2261	10.123	0.6105
Mean standing spinal extension				
Center	57	−1.424	6.6037	
Right	12	+13.57	12.918	
Left	07	+9.007	15.750	
All	15	−5.675	9.9826	0.6815
Maximum standing spinal extension				
Center	54	−2.150	5.4121	
Right	12	+4.223	8.0788	
Left	07	+4.847	12.371	
All	14	+1.560	10.994	0.9286

Further evaluation of the fatigue tests employing end of season rest days

As discussed in Chapter VII, after the end of the harvest it was possible to collect muscle fatigue data on subjects in the resting state (Typical activities on these days were washing laundry, cooking, visiting with friends and shopping.) These data indicate that while the timed arm hold showed muscle fatigue with apple harvest work, this fatigue was not distinguishable from the fatigue found to develop over a resting day. This suggests that this test would not be sensitive enough to detect any subtle fatigue differences between intervention use and placebo belt use. Table VIII.8 demonstrates this result, for the timed arm hold and the two standing spinal extension tests. As with previous analyses, the timed arm hold was analyzed with the dependent samples T test, since there were no outliers in the data, whereas the standing spinal extension tests were analyzed with non-parametric methods due to the presence of outliers.

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Table VIII.8. Work day (w) rest day (r), fatigue score differences
N= 27

	Dependent samples t test				Signed ranks	
			95% C.I.	95% C.I.		
	Mean	S.E.	lower limit	upper limit	Median	p
Timed arm hold	-6.26	8.74	-23.4	10.87		
Standing spinal extension (mean)					-2.8	.58
Standing spinal extension (maximum)					-3.31	.81

Implications for intervention evaluation

The failure of any of the strength-based muscle fatigue tests to identify muscle fatigue present on a picking day and not present on a resting day left open the possibility that the negative results obtained by the intervention belt were a result of the poor sensitivity of the measures, rather that the ineffectiveness of the intervention belt. Since this area of muscle fatigue research is relatively new and the science is not well developed, researchers considered using alternative measurement methods.

Alternative methods for outcome measurement

In Chapter II, the literature review identified a second method used by researchers to measure the impact of load on muscles: changes in electromyographic amplitude (see *Other indicators related to the development musculoskeletal strain*).

As described previously, muscle activity generates electrical current, which can be measured non-invasively with surface electromyography (SEMG), by placing two electrical leads per muscle on the skin. The amplitude of this electrical current has been shown to vary with muscle exertion magnitude under controlled experimental conditions

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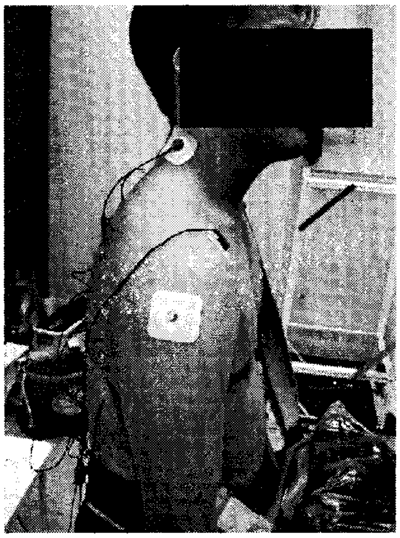
(Bloemsaat et al., 2005; Rolander et al., 2005; Asundi et al., 2005; Alkjaer et al., 2005; Mathiassen et al., 2005; Steingrimsdottir et al., 2005; Dong et al., 2005; Krantz et al., 2004).

The use of EMG was not initially selected due to a number of disadvantages associated with use in the orchard. There are many possible sources of interference, including heat, cold, moisture, and external sources of electromagnetic radiation (Cram, 2004; De Luca, 2002; Lanza, 1999). In addition, SEMG amplitude measurement requires that measurement be taken with the subject standing still, with the joints surrounding the muscle of interest at the same angle in each measurement (see Figure VIII.1, below). In the orchard setting this is difficult due to ground that is not level, and the natural variability of work postures during harvest work. Also, the feasibility of orchard measurement while workers are picking had not yet been evaluated.

However, given the lack of clear results using strength-based muscle fatigue measures, the decision was made to use existing laboratory-based EMG methods with some improvements, based on recent experience.

Figure VIII.1. Laboratory subject holding bucket of apples with EMG leads attached


[redacted]

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Development of EMG methods for evaluation of the intervention hip belt

Pilot methods Previously, a comparison of muscle exertion (using electromyography [EMG]) of four key back and shoulder muscles was made among 10 laboratory volunteers under intervention and control conditions, in two postures (standing erect [0°]) and flexed [45°]) (Earle-Richardson et al., 2006). Ten student volunteers participated in a laboratory measurement of EMG amplitude, standing while holding a full bucket of apples, one time wearing the intervention hip belt, and one time not wearing it. EMG electrodes were placed on four muscle locations: trapezius, latissimus dorsi, erector spinae (L2) and erector spinae (L5).

Subjects were randomly assigned as to the order of the four conditions. As described above, these were: no belt—erect; no belt—45° flexion; belt— erect; belt— 45° flexion. For each of the four experimental conditions, observations were made from each of the four electrodes and also from the pressure sensor located under the shoulder strap. Each measurement was repeated after a two-minute rest period for each condition.

Significant interactions were seen between trunk angle and intervention-control difference. Therefore, separate analyses were made at 0 and 45 degrees. See Table VIII.5. Three of four muscles showed significant declines 45 degrees flexed posture with the intervention. One of four measures showed a significant reduction in the erect posture. This was considered to be evidence that the hip belt intervention was able to significantly reduce exertion in certain muscles while in certain postures.

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Table VIII.9. 1 x 2 analysis of variance for EMG muscle activity by trunk flexion angle

	0° flexion			45° flexion		
	no belt	belt	p	no belt	belt	p
EMG upper shoulder (trapezius)	27%	18%	0.38	44%	34%	0.30
EMG shoulder (latissimus dorsi)	7%	9%	0.76	40%	26%	0.02
EMG mid back (erector spinae)	17%	20%	0.59	66%	42%	0.0001
EMG low back (erector spinae)	18%	24%	0.08	66%	54%	0.004

Implications for current study

The fact that results differed so much between different muscles and different trunk posture suggested that the ranges of both should be expanded. Therefore the first modification to the previous methodology was to substantially increase the number of muscles being measured, as well as the postures assumed by subjects. Eight muscles were selected, (some with both right and left side measurement), based on previous visual job analysis by the study Physical Therapist. In addition, several more trunk postures were included, as well as the standing erect, one arm up and two arm up postures. These were postures that had been demonstrated to be commonly assumed postures in apple harvest work (Earle-Richardson et al., 2004). In addition, all eight muscles were tested in all seven postures and under two different bucket wearing methods (front carry and side bucket carry).

Other improvements were made to the study protocol. Because of the larger number of muscles and postures, a more complex randomization scheme was utilized, which resulted in a completely randomized order of all conditions for each subject. Also, maximum exertions for each muscle and each subject were recorded at the beginning of the measurement session to provide a highly accurate maximum contraction against

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which to calculate percentage of maximum exertion results. Previously, these maximums used to calculate "percentage of maximum exertion" calculations were simply each individual's highest value recorded during the experiment.

It was still necessary to conduct the EMG amplitude measurement in the laboratory using student volunteers, since field methods have not yet been developed. Results will be, in a sense, one step removed from what they would have been in the orchard. However, given the state of the science at this point, this is a necessary limitation. Going back to the model of muscle strain in Chapter II, one can see that muscle activity, while still in the category of "internal dose," is somewhat earlier in the chain of events resulting in muscle strain than is muscle fatigue. This is also less desirable, since the better endpoint is the one closest to the injury outcome.

The decision was made at this point to return to the earlier laboratory study's use of the "usual equipment" (no belt at all) as the control condition rather than the placebo belt, for two reasons. First, as discussed in previous chapters, some data suggested the possibility the belt itself, independent of its hooking to the bucket, might have some exertion-reducing effect. Use of the no-belt condition eliminates this possibility. Second, in this phase of the study, worker interview was not a component of the data collection, so the fact that the hip belt might be more visually appealing than usual equipment was not a concern.

In the next chapter, this modified EMG protocol is described in detail along with study results and implications for the intervention evaluation.

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Chapter IX. ELECTROMYOGRAPHIC ASSESSMENT OF APPLE BUCKET INTERVENTION DESIGNED TO REDUCE BACK STRAIN

Abstract[1]

Researchers previously developed an apple bucket that was modified to reduce muscle fatigue. The intervention 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. Our purpose was to evaluate the intervention's effect on back neck and shoulder muscle activation employing surface electromyography. 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. Subjects were measured in these conditions both with the bucket carried in front and with the bucket carried to the side. Significant reductions in amplitude favoring 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

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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.

Introduction

Migrant and seasonal farmworkers 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 (McCurdy et al., 2003; Ciesielski et al., 1991; Husting et al., 1997; Osorio et al., 1998; Villarejo et al., 1999). 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 ergonomic 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 back, neck and shoulder strain, the authors have developed a simple belt that hooks to the apple harvesting bucket (Figures IX.1-IX.2) (Earle-Richardson et al., 2004; Earle-Richardson et al., 2005).

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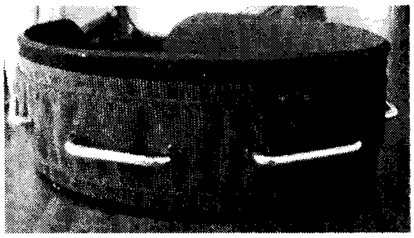

Figure IX.1. Intervention belt

Figure IX.2. Apple harvest worker using intervention belt

In order to evaluate the intervention's effectiveness, researchers compared muscle fatigue effects between the intervention and a placebo (Chapter VII). 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 one week. In a second week, all workers switched conditions. Subjects 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 ergonomic 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 one day 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. This suggests that these methods were not a good means for measuring musculoskeletal exposure to the hazards of posture and load experienced during apple harvest work.

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For this reason, the current study evaluates the physiological effects of the hip belt intervention using surface electromyography (EMG) 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 repeated and prolonged muscle exertion is related to muscle strain, it is reasonable to assume that reduced exertion would be beneficial in reducing the frequency and severity of strain of the muscles involved in the exertion. EMG is one of the most widely used measurement instruments for evaluating muscle activity in the occupational setting (Bloemsaat et al., 2005; Rolander et al., 2005; Asundi et al., 2005; Alkjaer et al., 2005; Mathiassen et al., 2005; Steingrimsdottir et al., 2005; Dong et al., 2005; Krantz et al., 2004).

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).

Other studies since 1997 also support this finding of association (Carrivick et al., 2005; Holmberg et al., 2003; Village et al., 2005; Sbriccoli et al., 2004; LaBry et al.,

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2004). 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., 2006). 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.

Materials and methods

Subjects Ten 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.

Apple picking equipment Subjects were measured while carrying a semi-circular plastic apple bucket (Wells & Wade Harvest Bucket™, Superior Fruit Equipment, Wenatchee, Washington, USA) in front, with one strap over each shoulder, (Figure IX.3), and also when carrying to one side, with both straps over one shoulder (Figure IX.4). This bucket contained 17kg (38lbs.) of apples for all measurements.

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Figure IX.3. Front carry, two strap

Figure IX.4. Side carry, one strap

Target muscles Target muscles for measurement were identified by a licensed physical therapist while observing a subject 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 IX.5). To minimize the chances of electrical interference from one lead to another, the muscle groups were chosen in such a way as to maximize the distance between attached EMG leads on the body. For certain muscles having a greater potential to be 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 centerline as possible without reference to handedness.

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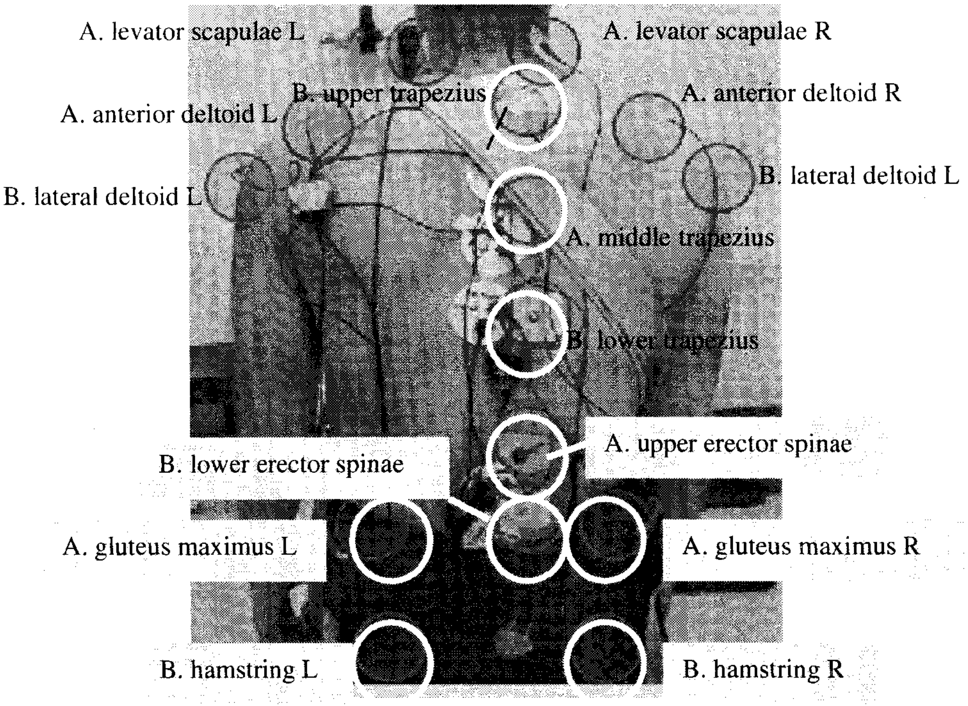

Figure IX.5. EMG placement for muscles in muscle test sets A and B. Muscles for which significant amplitude reductions were found with intervention use are circled in white

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 subjects 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 subject's vertical trunk.

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 subject was right- or left-handed, all measurements were recorded in terms of 'dominant hand side' and 'non-dominant hand side.' For example,

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data from a left-handed subject raising his left arm and data from a right-handed subject raising his right arm would both be categorized as 'dominant hand side arm raised.'

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

Experimental procedure Randomization of testing order was utilized for all four repeated measures variables. These were: muscle testing sets A and B (Figure IX.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-subjects effect. This related only to situations where the bucket was carried to the side. In these cases, five subjects were randomized 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 subject, the following randomization and testing protocol was applied:

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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 carry	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 carry	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

*Four trunk postures and three arm-raised positions: 0 arms up, 1 arm up, 2 arms up, 0° trunk flexion, 20° trunk flexion, 45° trunk flexion, 90° trunk flexion.

Attachment of the EMG 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).

Establishment of maximum muscle amplitude For each muscle, a maximal exertion motion was identified (Cram et al., 1998) to obtain the subject's maximal contraction reading for that muscle. Before beginning data collection, the subject 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.

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Subject measurement for assigned postures All seven of the postures and arm positions were demonstrated for the subject and then evaluated for correctness using a goniometer. The subject was asked to hold the posture for 5 seconds, during which the EMG was recorded, and then given 2 minutes to rest. Each posture was assumed three additional times for a total of four repetitions.

Data processing The raw microvolt data, which constitutes 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-second time sample (and three repetitions) (DeLuca 1997; 2002; Cram et al., 1998).

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 analyzed 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 analyzed using two (intervention/control) by four (0°, 20°, 45°, 90°) analysis of variance (ANOVA). The arm-raised position data were analyzed via a two by three (dominant, non-dominant, both arms) model. All effects in these models were within-subject effects, except for subject effects.

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

Results

The 10 male subjects had a mean age of 28.7 years. Mean height and weight were 172 centimeters (67.8 in.) and 70.7 kilograms (155.5 lb.), respectively. Eight subjects were right-handed, two were left-handed.

Summary of overall levels of exertion Table IX.1 shows the mean muscle exertion (as a percentage of the subject's initial maximum contraction) 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.

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Table IX.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.

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Intervention effects Four types of analysis of variance models were considered, two types involving trunk flexion (2 by 4 models), and two involving arm-raising stances (2 by 3 models). The four types are:

<u>Trunk flexion:</u>

1. Front bucket carry, belt vs. no belt, with 0°, 20°, 45°, and 90° trunk flexion
2. Side bucket carry, belt vs. no belt, with 0°, 20°, 45°, and 90° trunk flexion

<u>Arm raising:</u>

3. Front bucket carry, belt vs. no belt, with dominant arm up, non-dominant arm up, or 2 arms up
4. Side bucket carry, belt vs. no belt:, with dominant arm up, non-dominant arm up, or 2 arms up

As shown in Table IX.2, no significant effects were seen for model type 3, bucket in front, arm raise stances.

Table IX.2. Intervention-control differences in muscle-specific recruitment (% of maximum), by bucket carrying styles, for trunk flexion and arm raise stance

D = dominant hand side, ND= non-dominant hand side

	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 arm raise**	**-/+**	***p***	***p* interaction with posture**	**- / +**	***p***	***p* interaction with which arm is raised**
Neck, shoulder, upper back												
Levator scapulae D		.94	.71		.09	.47		.24	.20	+	.02	.34
Levator scapulae ND		.38	.47		.28	.98		.08	.68		.84	.42
Lateral deltoid D		.27	.47		.74	.53		.92	.70		.08	.33
Lateral deltoid ND		.13	.50		.83	.58		.41	.61		.57	.48
Anterior deltoid D		.14	.09		.48	.89		.07	.58		.69	.47
Anterior deltoid ND		.33	.40		.88	.82		.06	.77		.67	.44
Upper trapezius (D side only)	-	.04	.89		.58	.87	-	.05	.97	-	.04	.15
Middle back												
Middle trapezius (D side only)	-	<.0001	.03		.84	.85	-	.03	.01		.41	.93
Upper erector spinae (D only)	-	.04	.24		.19	.94	-	.03	.29		.19	.28
Lower back												
Lower trapezius (D only)	-	<.0001	<.0001		.73	.34	-	.003	<.0001		.18	.73
Lower erector spinae (D only)	-	<.0001	.01		.37	.32	-	.01	.07		.86	.18
Gluteus maximus D	-	.18	.04		.27	.98	-	.02	.004		.98	.99
Gluteus maximus ND	-	.01	.0003		.98	.20		.84	.03		.07	.24
Hamstring D		.50	.26		.11	.40	-	.01	.11		.95	.87
Hamstring ND		.20	.16		.61	48	-	.01	.23		80	.24

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Among the remaining three types of models, 16 significantly favor intervention, 1 favors the control condition. As shown in Table IX.2, 15 of these 16 are trunk flexion models, and 10 have significant interactions with trunk angle.

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 reanalyzed without it.

Significant ANOVA models – response patterns by flexion angle Among the ANOVA models considering trunk flexion (models types 1 and 2, above), there were a number of common patterns observed, both among those with significant interactions, and those without. Figures IX.6 through IX.10, which follow, show these patterns, in order of descending frequency of occurrence.

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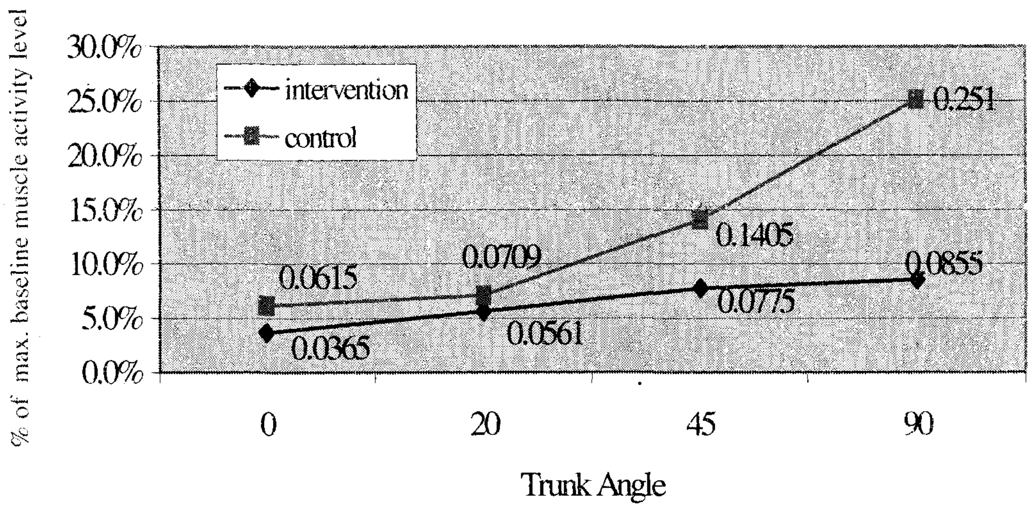

Figure IX.6. 6 muscles: increasing benefit with increased angle (lower trapezius, front bucket). Other muscles with this pattern: *Front bucket:* middle trapezius, upper erector spinae; *Side bucket:* both hamstrings and the upper erector spinae Significant interaction between amplitude change and body angle

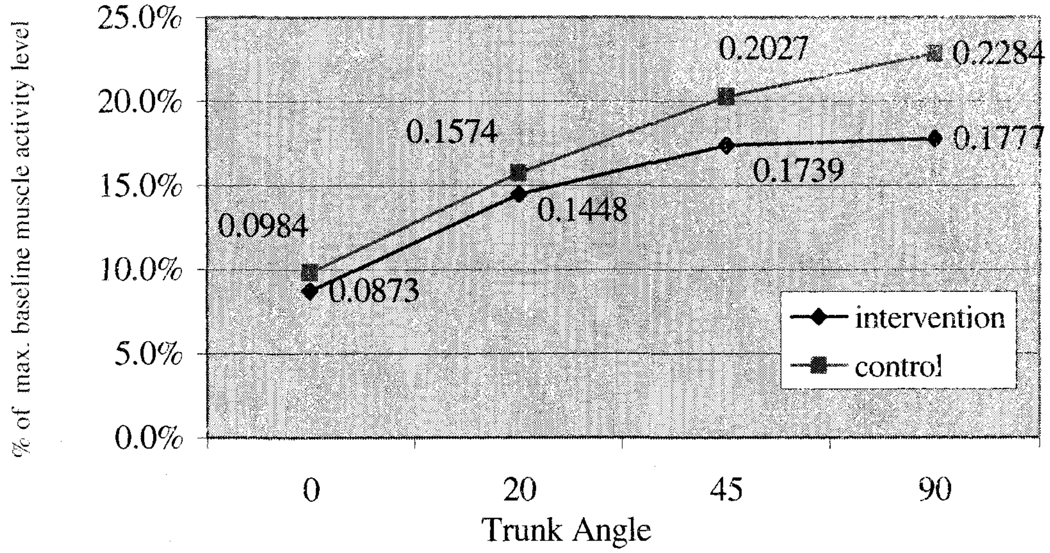

Figure IX. 7. 4 muscles: slight increase in benefit with increased angle (upper erector spinae, side bucket). Other muscles with this pattern: *Front bucket:* upper erector spinae, hamstrings (dominant, non-dominant) No significant interaction between amplitude change and body angle

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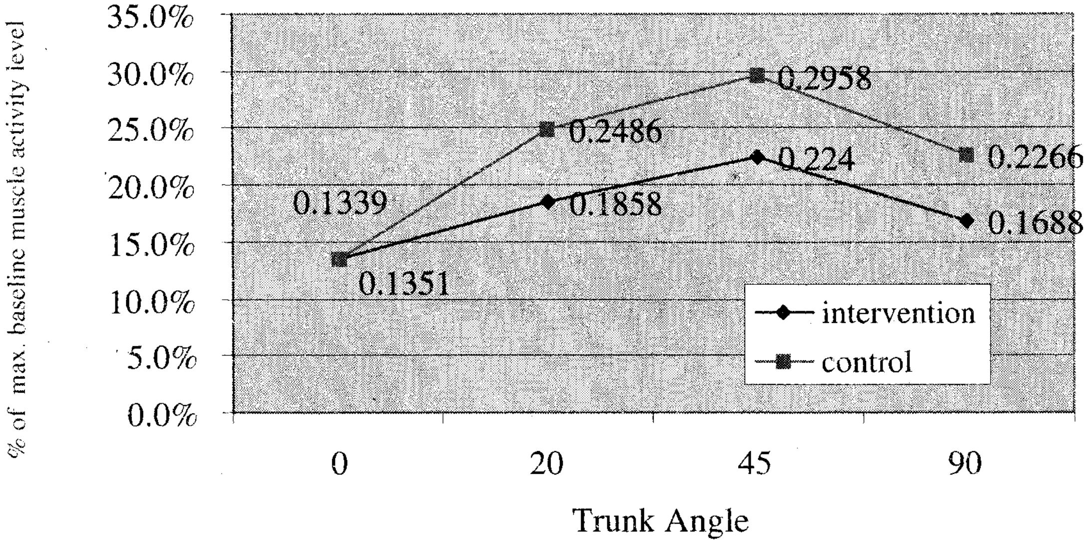

Figure IX.8. 4 muscles: slight disadvantage changing to significant benefit with increased angle (gluteus maximus, front bucket, non-dominant). Other muscles: *Front bucket*: gluteus maximus, dominant.* *Side bucket:*gluteus maximus, (dominant, non-dominant**). Significant disordinal interaction between amplitude change and body angle

*NS main effect, p=.18

**trend lines for these 2 models cross between 0° and 20°.near .06 -.08

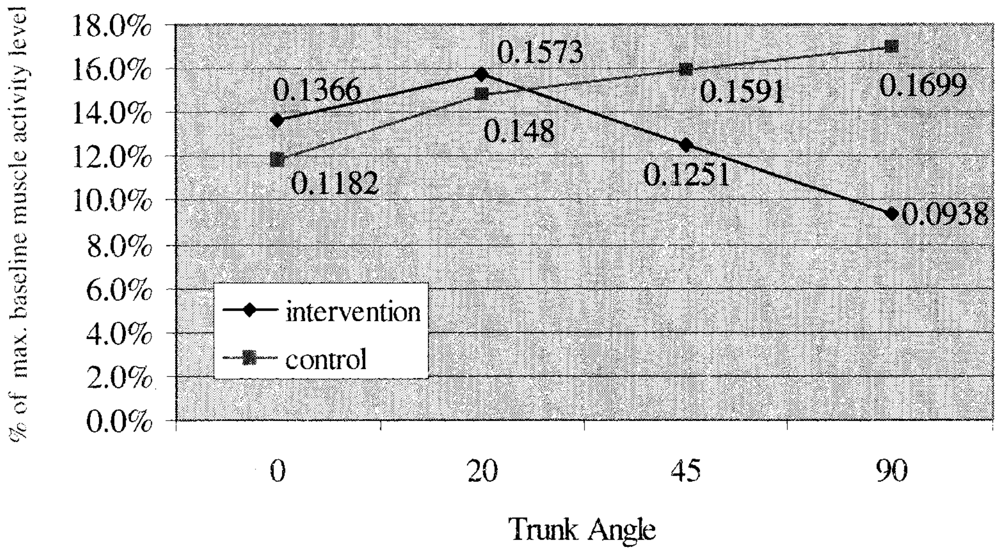

Figure IX.9. 3 muscles: no difference at 0°, consistent benefit across other angles* (levator scapulae, side bucket, non-dominant). Other muscles: *Side bucket*: anterior deltoid (dominant, non-dominant). No significant interaction between amplitude change and body angle

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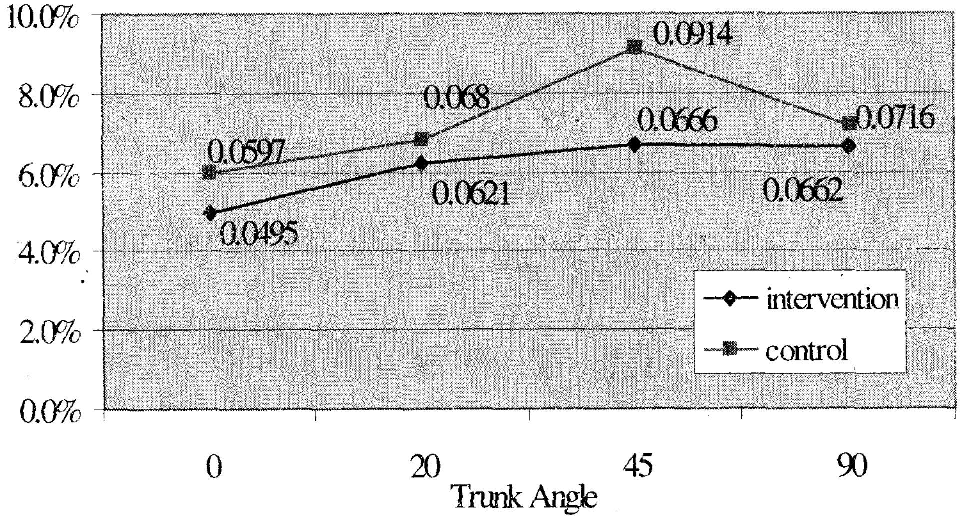
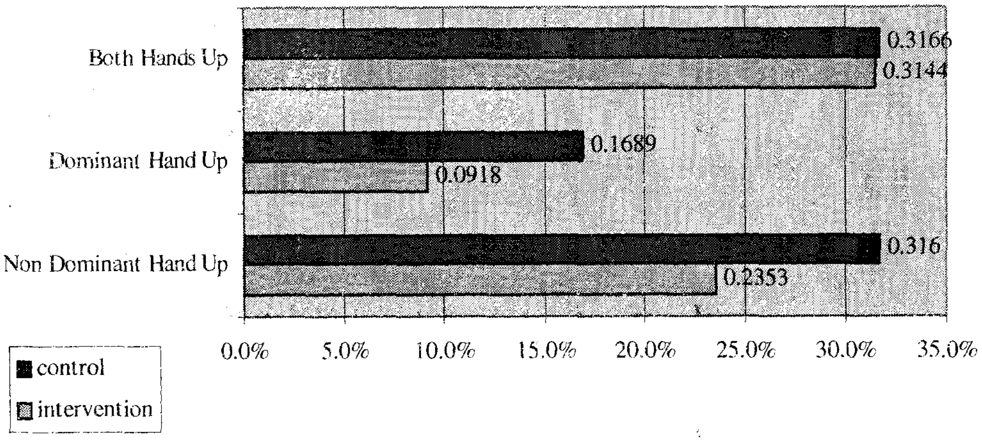


% of max. baseline muscle activity level

Figure IX.10. 2 muscles: greatest benefit at 45° (lower erector spinae, side bucket). Other muscle: *Front bucket*: upper trapezius. No significant interaction between amplitude change and body angle

* Overall ANOVA main effect near-significant (p values range from .06 -.08).

Significant ANOVA models – response patterns by arm raise stance There were notably fewer significant main effects or interactions between change in EMG amplitude and stance in the arm raise models. Figures IX.11 and IX.12 show these results.



% of max. baseline muscle activity level

Figure IX.11. 1 muscle: no difference with both hands up, consistent benefit for other 2 arm positions (upper trapezius, side bucket). No significant interaction

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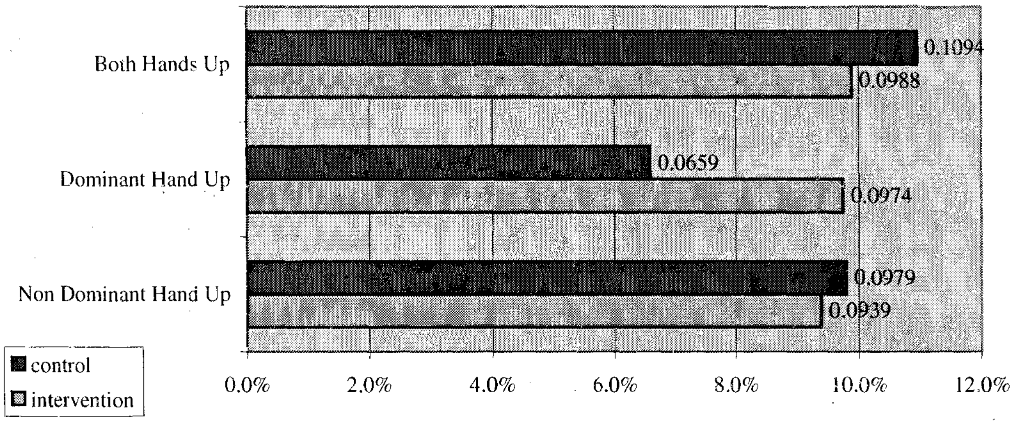

between amplitude change and arm posture

Figure IX.12. 1 muscle: belt disadvantage for dominant hand up, slight benefit for other 2 arm postures (levelator scapulae, dominant, side bucket). No significant interaction between amplitude change and arm posture

Discussion

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 maximized 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 (Punnett et al., 1991; Madeleine et al., 2003; Burdorf et al., 1991; Toroptsova et al., 1995, Skov et al., 1996, Magora 1972; Bergenudd and Nilsson 1988, Jensen et al., 1993) 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

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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.

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 the ANOVA models considered, only one showed a significant main effect that favored the control condition. The dominant levator scapulae had significantly increased mean amplitude for the intervention condition versus the control when pooled

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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).

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.

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 (Anders et al., 2005; Dainoff et al., 2005; Matern et al., 2004; Nevala et al., 2003; Peper et al., 2003; Mathiassen et al., 2003; Roquelaure, 2002). 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 hours, 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.

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One study by Village and colleagues (2005) quantifies median peak neck/shoulder muscle activity (as a % of baseline maximum contraction) between health care facilities with high and low injury rates. The four higher injury rate facilities have an average median trapezius amplitude of 18.5% of maximum, whereas the four with lower injury rates have an average median trapezius amplitude of 11.3%. While not statistically significant ($p = 0.18$), highly significant correlations between injury and a similar indicator, spinal compression, were found (Spinal compression is slightly different in that EMG amplitude readings are normalized to maximum voluntary contraction at a 60° angle). This provides some evidence that differences found in the current study are large enough to result in injury reduction. However, it must be kept in mind that 23% of the time apple harvest work involves moderate to severe forward flexion. The above research would only apply to that portion of the work time.

There is additional published data that find quantitative relationships between ergonomic exposures (load, duration, and body angle) and musculoskeletal strain (Village et al., 2005; Herrin et al., 1986, Bringham and Garg 1983; Anderson 1985, Chaffin and Park, 1973); however, the correspondence between these exposures (e.g., compressive forces, load in kilograms, 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 kilograms, but also such factors as horizontal distance of the load from the spine, body angle, and emotional factors (Rissen et al., 2000; Chaffin, 1969; Mientjes et al., 2003; van den Bogert, 1994; Wells et al., 1994). In the present study, the fact that data was analyzed within subjects and collected in the

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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.

Conclusion

The intervention resulted in substantial reductions in muscle recruitment of the middle and lower back muscles for subjects 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 among 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.

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Chapter X. SUMMARY DISCUSSION AND STUDY CONCLUSIONS

Implications of the positive EMG results for the intervention belt

The results of the EMG laboratory testing presented in Chapter IX demonstrate reduced exertion of certain key muscles in response to a standard load when wearing the intervention belt. While this would ideally have been measured in the orchard, the fact that the belt changes the electrical activity level of key muscles to a given weight does not seem likely to change whether indoors or out.

The reduction of electrical activity, and by extension, muscle exertion resulting from the intervention belt, has been demonstrated. However, drawing definitive conclusions about how this translates in terms of frequency or severity of back, neck or shoulder strain is more difficult. Unfortunately, there is little currently published research quantifying the dose-response relationship between EMG amplitude and muscle strain incidence or duration (Village et al., 2005; Westgaard et al., 1993,1986; Aaras, 1987; Jonsson, 1982). Some of the lower trunk muscles show dramatic drops in muscle activity with intervention belt use: the lower trapezius (over 50% drop from exertion in the no-belt condition), the lower erector spinae and gluteous maximus, (dominant side in the side bucket carry, drops of about one-third). However, we cannot assume that the muscle activity-muscle strain relationship is directly linear, that is, that it would result in a reduction of one-half to one third of strain cases. It is possible that the majority of strain cases occur at one end or the other of the exposure spectrum. So, we do not know whether this reduction results in the elimination of all, some or none of the orchard worker back, neck and shoulder strain.

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However, we can say with confidence that there is a substantial reduction in muscle exertion among muscles of the mid and lower back, which are common sites of muscle strain. Given the somewhat undeveloped state of the science at this point, this may have to be a sufficient conclusion for this evaluation, that hip belt use does reduce exertion in several mid- and lower back muscles when holding a 17-19 kilogram load, as is commonly handled by apple harvest workers.

It seems reasonable, given this result in combination with the high level of intervention belt acceptance and the neutral impacts on productivity to conclude that the intervention belt is effective, at least insofar as current research methods can demonstrate. The author and colleagues believe that this is sufficient evidence to introduce the intervention belt into use. Further evidence will come to light once it is introduced into wide use on all three of the evaluation factors.

Information provided by the orchard trial

Two other important outcomes, worker acceptance and neutral impacts on productivity were demonstrated with this large sample of workers. Not only was the intervention hip belt popular among workers (90% report that they would use it in the future), but the placebo hip belt was equally popular. Researchers had not anticipated that the concept of the hip belt would be so well known among migrant and seasonal farmworkers and so popular. This raises both questions for further research as well as an opportunity for promoting the intervention hip belt to farmworkers. While we seek to understand better whether any physiological benefit is provided by the belt alone, or whether it is simply perception, while at the same time allowing the "back belt" appeal to

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encourage workers to try the intervention hip belt, which, when engaged appears to provide a benefit to several middle and lower back muscles.

The orchard measurement component of the research also provided an invaluable opportunity to gather informal feedback from the workers regarding the intervention belt, how it might be improved, and what issues need to be clarified for them in terms of proper use. For example, suggested changes to the intervention belt included: an attachment mechanism that detaches more easily, putting the belt clip on the front of the belt instead of the back, and making the bucket attachment height adjustable. It was also apparent from observing and speaking with farm workers that the necessity of maintaining balanced tension between the shoulder straps and the hip belt was not obvious, and that this needs to be emphasized when giving the belt to workers. Also, more generally, it was extremely useful to gain an understanding of the orchard harvest working environment through first-hand observation.

It is also notable that new occurrences of back, neck, or shoulder pain were reported by three workers during the intervention week, and four workers during the placebo week. This *suggests* a incidence of musculoskeletal strain of roughly 3-4 percent (although it must be remembered that not all pain is muscle strain) per week. Hypothetically, if this weekly rate were extended to a 12-month period, one would expect to see the 30% incidence (perhaps more) that was reported by McCurdy and colleagues. While realistically, this one-week interval at the height of the harvest season cannot be extended to an entire year, it does show that the two figures are plausibly consistent.

The 3-4 percent per week is a great deal higher than the 2.1% cumulative incidence (over a roughly 10-12 week season), found among New York orchard workers

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obtained in previous health center record research by the author (Earle-Richardson et al., 2003, unpublished). This seems most likely due to the fact that the majority of cases of musculoskeletal strain symptoms will not be seen at a medical care facility. Because data was collected at the worksite, and the reporting interval was short, researchers did not expect to obtain a large number of musculoskeletal symptom reports. A longer reporting interval in future research could be a useful confirmatory step for this evaluation.

In addition, the field trial provided important methodological information. This was the first agricultural trial of its kind, where 100 migrant and seasonal workers were physiologically monitored while working. This demonstrates that it can be done, and will hopefully encourage other researchers to undertake worksite monitoring with this population. The orchard research process revealed that measurement can be integrated with the workday, and is best done in the field, close to where work is done. It was the observation of the research team that testing done in or near living quarters was chaotic and more difficult to complete successfully. However, worker monitoring is best done in a manner that does not depend on subject performance the way muscle fatigue measurement was. Biological monitoring that is passive could be more successful with a subject population with low levels of education because it would not require an understanding of abstract concepts such as maximal exertion, consistency of stance and movement, and relaxation and rest between efforts.

Another methodological lesson learned from this research is that muscle fatigue measurement is optimally done when job tasks are of high intensity and short duration. Several published studies refer to a cut-off level of 80 percent of maximum voluntary

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contraction (cite). In future research, investigators could use the EMG methods described in Chapter IX to determine mean exertion levels of common work activities before choosing muscle fatigue measurement as an evaluation endpoint.

Methodological results: optimal study endpoint and measurement method

One of the main challenges facing this evaluation research has been identifying a valid measurement instrument for the main outcome: muscle strain. In the absence of a definitive clinical indicator of muscle strain, researchers initially considered three outcomes with very different measurement methodologies: self-reported muscle pain, muscle fatigue measured with before and after strength/endurance tests, and muscle electrical activity measured with electromyography.

Self-reported pain The decision was made not to use this indicator for two reasons. First, the Mexican workers with whom researchers spoke in focus groups indicated that they and their coworkers never experienced muscle pain, whereas the Jamaican workers said that muscle pain was a common occurrence. This, combined with previous research data indicating that muscle pain and strain is common, cast doubt on the Mexican workers' willingness to freely report pain. Secondly, identifying strain cases through self-reported pain would have required weekly interviewing of 100 workers for 8 –10 weeks. It was not clear that the farms would have consented to such a long period of intervention in their harvest work.

To find other muscle strain indicators, researchers had to go outside of the ergonomic literature in crop agriculture. As shown in the literature review in Chapter II, published studies of crop hand-harvest interventions focused on the endpoints of

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intervention acceptance, productivity, overall metabolic energy expenditure, and in a few cases, force requirements. None of these suited the goals of the current research.

More appropriate measurement methods were found in a broader review of the ergonomic literature: muscle fatigue measurement using strength testing, and electromyographic measurement of muscle activity. However, both of these methods required substantial adaptation and development before they could be used in the orchard. The challenge for researchers, then, was to develop valid measurement methods for an orchard intervention and to use them to evaluate the hip belt intervention over a relatively short period of time.

Researchers first looked to muscle fatigue measurement using muscle strength changes (morning versus evening), primarily because it appeared to be more easily adaptable to the orchard. One test that was documented in the ergonomic literature that appeared promising was the Sorensen Prone Test, used by Bloswick (1994), in his evaluation of a hip belt for letter carriers. In fact, a very similar test ("timed spinal extension") was successful in the initial round of testing, but it was not feasible to use in the orchard because it necessitated having subjects lie on a measurement table. This appeared to make a number of workers uncomfortable, and was not logistically feasible for data collection in the orchard, since the table was difficult to move and unstable on uneven ground.

This was just one of several challenges presented by the outdoor environment and by attempting to collect data on working subjects. Other difficulties included the lack of level ground on which to place measurement instruments, and the uncertain willingness of workers to maximally exert in the tests in the morning, when they had a

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full work day ahead of them. One recommendation for the future that has some potential is to outfit a small truck or van with testing equipment and two-directional levels (much like mobile medical units and hearing testing vans currently in use) for data collection. This would provide a private, level, comfortable space for measurement, and this vehicle could be driven through the orchard with relative ease. This would not address the issue of subject motivation to exert maximally, however.

There is another difference between what researchers have attempted to do in the past with this type of measurement and what researchers were seeking in the current study that may further explain the lack of success. In past research, most measurement of this type was conducted with very short work intervals in between measurements, on the order of one to five minutes (Lanza, 1999; Vollestad, 1997; Bloswick, 1994; Nussbaum et al., 2001), and had not been applied to beginning and end of day measurement protocols.

This may be an important difference from the current research methodology. When measuring a short interval of work, one can make a measurement before any rest interval occurs, whereas when measuring at the end of the day, one is measuring the accumulated fatigue, which is the fatigue that remains after several work-rest intervals.

It has been suggested by some workers and also some farm owners that this type of measurement might be successful if done in the first week of picking, before muscles have the opportunity to acclimate to the work-rest pattern of the job. This seems to indicate that for many workers the recovery and conditioning process may make it difficult to measure the benefit of the intervention belt with this method. However, given the epidemiologic evidence that muscle strain does occur frequently in this

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population, it is reasonable to assume that the recovery and conditioning mechanism is frequently not sufficient to protect the individual from injury.

Another potentially important factor is the fact that muscle exertions in apple hand harvest work are relatively low-level exertions. Baseline muscle exertion results obtained in the third phase of the research (see Table IX.1) indicate that none of the muscle exertions during harvest work rose above 35 percent of maximum (the mean exertion was 12%). While the demands on the back muscle of apple picking work are sufficient to cause muscle strain, the exposure appears to be of moderately low intensity over a long period of time. This makes detection of muscle fatigue over one day difficult.

In moving to electromyographic methods, researchers proceeded somewhat more cautiously, retaining the laboratory setting, while making methodological adaptations to more closely resemble orchard activities. This required a process of selecting specific muscles and postures most commonly involved in apple harvest work. This methodology was more labor-intensive, and so an initial sample size of 10 was selected. Because the data collection was undertaken in the laboratory with volunteers, there was the option of increasing the sample size if power appeared to be a problem in the initial analysis.

This study phase was more successful. Significant reductions in amplitude favoring the intervention were seen for 11 of the fifteen muscles in models considering the four body flexion angles. Ten of these were of the mid- and lower back. These control-intervention differences were seen with both bucket carrying positions (front versus side) and tended to increase with increasing flexion angle.

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However, as described above, important quantitative and qualitative data was also gathered in the orchard phase of the study, even though the muscle fatigue measurement component was not successful. Had researchers employed EMG laboratory methods initially, these two factors could not have been evaluated. Until orchard methods of electromyographic measurement are developed and validated, a combined study protocol of both laboratory and orchard data collection will be necessary.

Areas for future research

In addition to providing information and insight into a number of different important results and methodological insights, the study has raised a number of new questions for future research.

Orchard EMG methods Because of the positive results obtained in the laboratory with electromyographic measurement, a key area for future research is certainly EMG methods in the orchard. This would permit researchers to attempt to replicate the laboratory results in the orchard. A great deal has been learned about orchard research methods from the current orchard trial that can be applied to conducting EMG research in the orchard. For a simple orchard replication of laboratory measurement, researchers will need to overcome some logistical issues, as well as develop a measurement protocol that permits measurement in static, prescribed postures during subjects' harvest work day.

However, the ultimate goal in EMG orchard research should be to develop a means by which measurement can be taken while subjects are moving (rather than in a static posture), and having some means to compare work intervals with the intervention belt with no-belt intervals. Some progress has been made in this are using remote sensing

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(wire free) telemetry units (Bio-medical.com, 2005; Rolander et al., 2005; Nordstrom et al., 1998), but further research is needed.

Dose-response relationship between muscle electrical activity and muscle strain When this methodological milestone has been achieved, several studies that correlate EMG changes with self-reported symptoms or with days lost or other indicators of injury are likely to follow, at least in populations where these self-reported indicators are reliably reported. Currently, there is little data available on this critical point (Village et al., 2005; Simoneau et al., 2003; Jonsson, 1982; Westgaard et al., 1986, 1993). This will provide dose-response data that is currently needed in order to correlate EMG changes with muscle strain outcomes.

Popularity of the placebo belt A key question for future research is whether the popularity of the placebo belt is due to some physical benefit conferred, or whether it is purely a popular perception that belts are protective. Some simple electromyographic tests could provide important data on this question. Previous job cycle analysis of workers wearing the intervention hip belt did not reveal any postural or work task differences, so it is unlikely that work practices would be different (i.e., protective) with the placebo belt.

In addition to specific questions raised by the study results, the research has pointed out certain shortcomings in the broader area of the physiology of muscle strain.

Specification of muscles involved in "back strain," and "back pain" One particular weakness in the published literature with respect to back strain is the failure of researchers to distinguish between different muscles. Instead, they report on the back as though it were one organism. The difficulty this presents for the current research using

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electromyographic methods is that it makes it more difficult to identify those muscles at highest risk for strain, and consequently those that should be studied.

Basic mechanisms of musculoskeletal strain One of the primary difficulties of conducting the current research is the lack of basic science surrounding muscle strain: a common definition, its natural history, common metrics of severity. One researcher (Melhorn, 1998), eloquently describes the irony of the recent recognition of repetitive motion injuries as one of leading occupational conditions in the United States, yet relatively little research has been conducted to date that would establish a detailed working model of the mechanism:

> Cumulative trauma disorders account for 56% of all occupational injuries. Currently, occupational injuries affect 15% to 20% of all Americans. The United States government predicts that by the year 2000, 50% of the American workforce will have occupational injuries annually and 50 cents of every dollar will be spent on cumulative trauma disorders. There is common agreement on the need for reduction of cumulative trauma disorders in the workplace. However, there is little agreement on the appropriate definition for musculoskeletal pain that occurs in the workplace, or the ergonomic and epidemiologic model for cumulative trauma disorders, or on the specific exposure relationships of the individual, by the job, and occurring in the workplace.

Several other authors make similar statements regarding a lack of an established mechanism (Sbriccoli et al., 2004; Lieber and Friden., 2002; Barr and Barbe, 2002; McHugh et al., 1999; Armstrong, 1990). Some partial models have been proposed, but more research is needed to fully describe the biological mechanisms involved (McHugh et al., 1999; Armstrong, 1990).

As described in Chapter II, some very basic descriptive data regarding how muscle strain occurs exists with experimental support. However, quantified relationships that would allow more definitive assessment of preventive interventions are not yet available. A few animal studies have begun to examine these mechanisms (Sbriccoli et

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al., 2004; Lieber, 2002; Barbe et al., 2003; Solomonow et al., 2003; Barr and Barbe, 2002; Uchiyama et al., 2001). Further knowledge in this are would be very valuable to ergonomic researchers because it would provide a scientific basis upon which to select outcomes relevant to musculoskeletal strain.

MRI technology Currently, MRI technology is cumbersome and expensive. Further research into developing a smaller and less expensive technology might allow this diagnostic test to be used in field research. With this tool, effects of interventions such as the intervention hip belt on key muscles could potentially be observed directly with pre- and post-season imaging studies.

Limitations of study results

Laboratory EMG results In the laboratory EMG data collection it was necessary to use student volunteers rather than actual farmworkers. This may have affected the subjects' overall muscle tone, and general fatiguability. Increased muscle recruitment resulting from a less conditioned subject could possibly have increased the observed benefit provided by the intervention.

The dose-response relationship between EMG muscle activity and muscle strain is unknown While it has been established that increasing loads results in increased EMG electrical activity in the muscle, and that exposure to greater loads results in greater frequency of muscle strain, there are little data that quantify the relationship between load and muscle strain (Melhorn, 1998). Therefore, it is not possible to determine the extent of reduction of strain resulting from the reduction in load.

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Orchard intervention acceptance results In the orchard research every attempt was made to include a broad spectrum of farmworkers. The two main nationalities in New York orchard work, Mexicans and Jamaicans, were represented. These two groups represented both front and side bucket carriers, and employment on both large and small farms. However, it must be acknowledged that farms volunteering to be a study site for this relatively intrusive research are, by definition, the most enlightened and safety-conscious of farms. These farms may not represent New York orchards as a whole. It seems likely that participating farms enjoy better relations with harvest workers than the average farm, and are more concerned about issues such as worker comfort. Therefore, worker intervention acceptance results may not generalize to all New York farms. It should also be noted that since both the intervention and the placebo belt were equally popular, there is no way to judge what effect a desire to please interviewers may have influenced these responses.

Intervention impacts on productivity Productivity was assessed by reviewing employer records from the two large farms in the study. The smaller farm, employing the 20 Mexican workers, was unable to provide the level of detail needed for this analysis. The larger orchards pay an hourly rate more often (both large and small farms pay a mixture of hourly and piece rate), due to the fact that their apple varieties are more delicate and prone to bruising. This means that these workers may pick more slowly in general. If they do, it is possible that the intervention would have less of an impact on picking speed than at other farms where the average picking speed were faster due to piece rate payment. Further research is needed to determine if this is the case. There were no differences in intervention acceptance between small and large farms. This

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suggests that there are no productivity impacts (that the workers notice) of using the intervention.

Final Conclusions

The intervention hip belt is effective in reducing the electrical activity of several muscles of the mid- and lower belt during apple harvest activities. Muscle activity in response to weight-bearing and awkward postures has been associated with muscle strain, although not clearly quantified. Although rough, this is best currently available indicator that the intervention hip belt has a beneficial effect with regard to back strain. Furthermore, the intervention is well accepted by workers and appears to have no negative effects on worker productivity.

Future research should test this intervention under different conditions: with different nationalities of worker, different apple varieties and using different bucket types, such as those in different regions of the U.S. In addition, future research should endeavor to develop EMG methods for use in the orchard setting, to confirm the results found in the laboratory.

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APPENDICES

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Appendix 1. Possible apple harvest ergonomic interventions
(suggested by consulting ergonomist)

Intervention	Risk factor reduced	Worker acceptability factors	Employer acceptability factors	Possible risk factors introduced
Apple picking tool	overhead work	time to learn new tecnique	ladder cost, training	falls
Automated picker	all hand-harvest work	eliminates jobs,	cost	machine safety
Ergonomics training	worker identifies risks, recommends work changes	fear of being critical; takes time	time, productivity effects	language, time
Folding bin/trailer	forward flexion	small amount of new learning	crew management, cost	machine safety
Hip support belt	load on back, shoulder	comfort, picking speed	may be cost issue	ladder stability
Ladder redesign	forceful, awkward lifts;	comfort; better balanced, overall weight to carry	may be cost issue	ladder safety
Ladder use rotation	forceful, awkward lifts;	relearning, issues regarding dividing earnings	time investment to reorganize workers	possibly ladder safety
No piece rate	repetition	earing potential unclear	possibly better quality apple, but decreased production	none
Padding of shoulder straps	impact on shoulder, ribs	comfort	none	slipping and pinching

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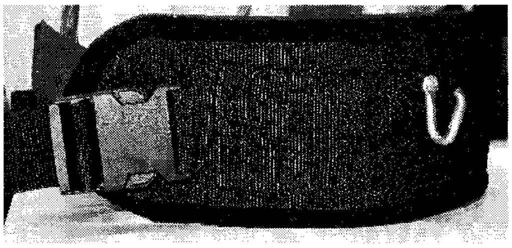
Appendix 2. Stages of development of the hip belt intervention

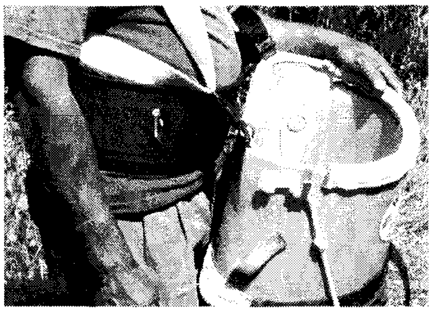
1. Bucket with belt permanently attached

The first prototype that came from the ergonomic discussion group process was the belt shown here at the left. The belt wrapped around the back and hips and then was fastened to the front of the bucket.

Farmworkers immediately rejected this idea, because it made it nearly impossible to move the bucket away from the body, as is commonly done when empty the apples out the bottom of the bucket. This motion is shown in the photo at the left.

2. Detachable belt





The next design made it possible to easy remove the bucket from belt at will. This was much more popular with workers. Three hooks were placed on the belt: one in the center front and one on each side to accommodate different bucket carrying styles.

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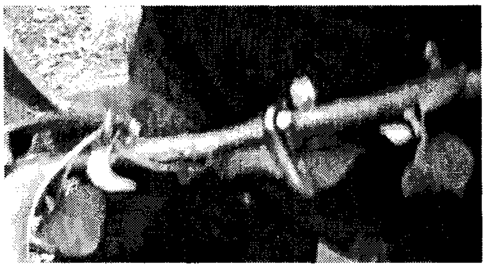
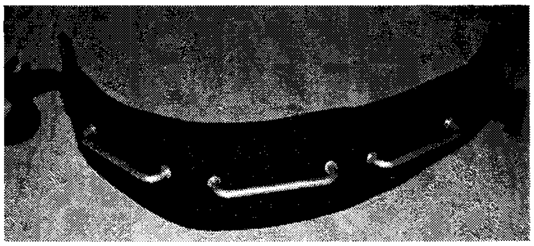


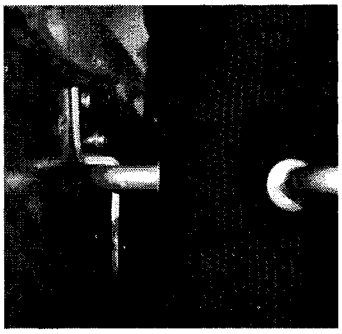
2. Detachable belt (continued)

However, there was a different problem with this prototype. As shown at the photo at left, some workers complained that the hooks got caught on branches when not engaged with the bucket.

3. Belt with hooks that protrude less

In response to this concern, researchers modified the hooks so that they would protrude significantly less. The disadvantage of this modification, shown at left, was that it then became more difficult for workers to hook and unhook belt.





4. Belt with eyes rather than hooks

A major change was introduced at this point that solved the problem of the belt hooks catching on branches. The hook was moved to the bucket, and eyes were moved to the belt. This model is shown above left. The hooking mechanism is shown in the photo at left.

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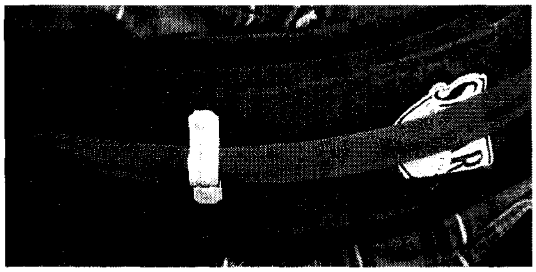

5. Belt with continuous cable attachment

One additional consideration that arose when the hook was moved to the bucket was the question of how wide to made the eyes, now on the belt. In the prototype shown here, at left, eyes were replaced with one continuous cable. This offered unlimited possibilities for where the bucket could be placed, while the fabric coating kept the bucket from sliding sideways.

The difficulty with this model had to do with a lack of stability of the cable when bearing weight.

6. Belt with five eyes across it

A more popular alternative to the cable was to outfit the belt with several (5), wide eyes that would offer a range of placement sites. This model is shown at left. One difficulty that can be observed in this photo is poor horizontal stability of the eyes.

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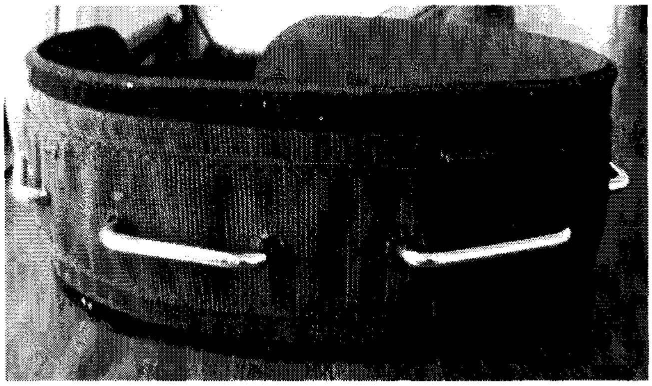

7. Final design: belt with five eyes, shortened protrusion out from the belt

The final design resolved this last problem with shorter length of the horizontal bar on each eye, as well as larger anchoring washers inside the belt.

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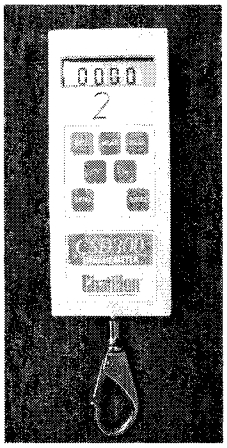
Appendix 3. Ergonomic orchard study muscle strength testing - equipment and test protocols

Part I: Equipment

Dynamometer



The Chatillon CSD 300 strength dynamometer manufactured by: Ametek Test and Calibration Instruments Division, 8600 Somerset Drive, Largo, FL 33773, (727) 536-7831. The dynamometer measures pulling force in pounds over a five-second interval. It provides mean and peak pulling force for the interval. It stores mean and peak values for five, five-second intervals and provides a coefficient of variation for all the tests stored in memory.

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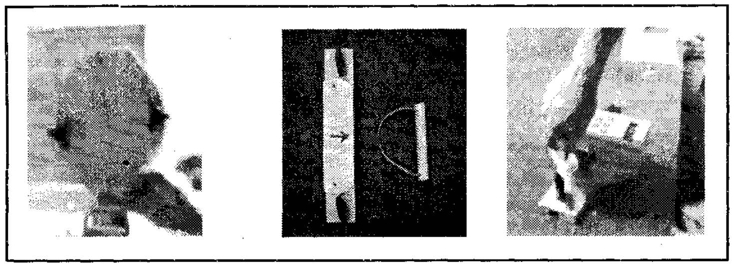
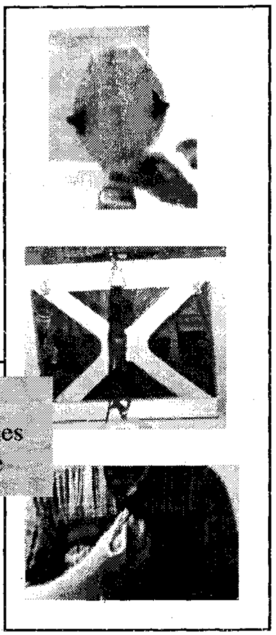
Dynamometer table

The dimensions of the custom made table are: 36.5" tall by 24" wide by 78" long. The following photos illustrate the table design and the attachments for each test.

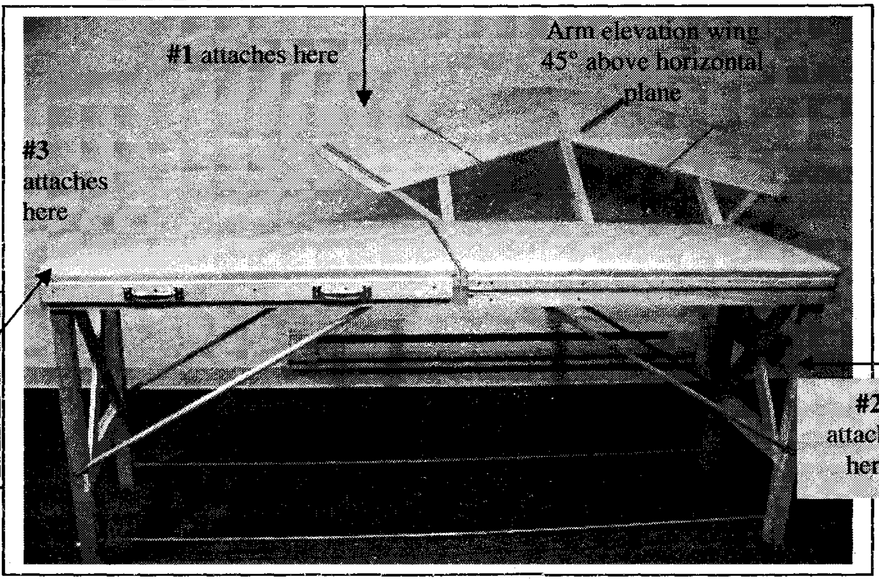
Dynamometer table attachments for test #1: humeral elevation in the scapular plane at 45° – 2 mounting plates (circular plate and sliding rectangular plate) and handle



Dynamometer table attachments for test #2: humeral elevation in the scapular plane at 135 degrees – 2 mounting plates, handle



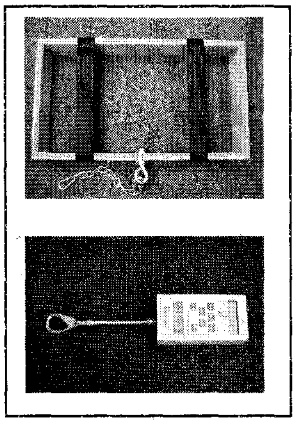
Dynamometer table attachments for #3: scapular elevation – foot board, mounting plate, adjustable strap, handle

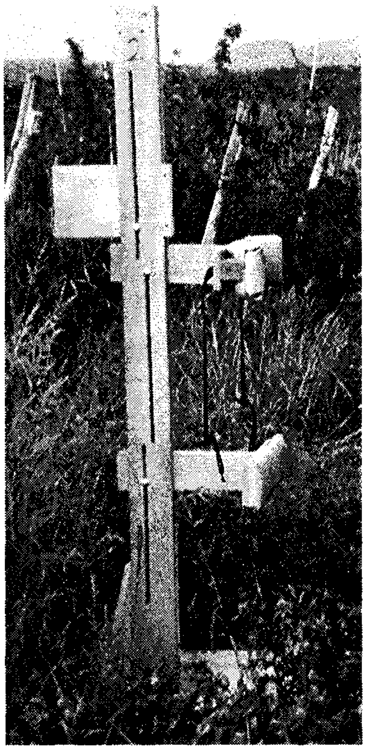


Dynamometer table attachments for test #4: spinal extension – mounting plate, dynamometer connector strap, and chest strap

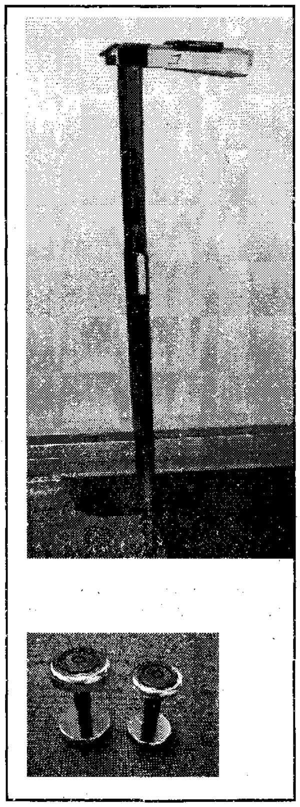
Dynamometer Tower

Dynamometer attachments for test # 10: standing back pull – shoulder girdle, and dynamometer extension pin





Dynamometer attachments for test # 9 timed arm hold, single arm – adjustable pole with contact light, 10 and 5 lb. weights



This apparatus was custom-made by researchers to house the dynamometer for standing muscle tests. The tower is 72 inches tall. The base is 26 inches deep by 30 inches wide. The tower has an adjustable dynamometer housing, so that the dynamometer can be located at the height of the subject's sternum, allowing for varying subject heights. In addition, the hip brace and knee brace are adjustable.

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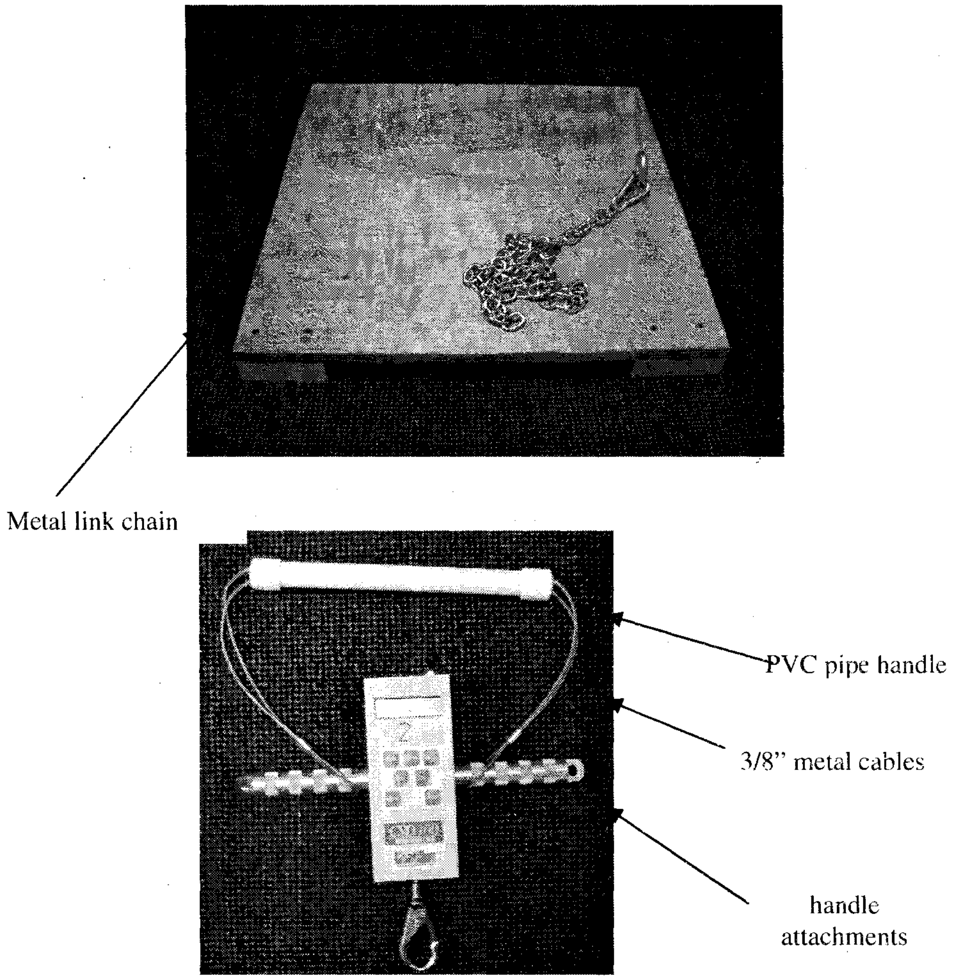
Dynamometer platform & handle



The platform and handles were used in muscle tests # 7 and #8: two-arm and one-arm scapular elevation.

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Part II: Muscle Tests

Muscle test #1 (Humeral Elevation in the Scapular Plane at 45°)
Used: first pre-test: table-based testing in Appleton, NY (n=10)

Equipment: Table, dynamometer, circular plate, rectangular plate, handle, elevation wing, and waist stabilization belt

Dynamometer Positioning: Dynamometer attached to shoulder wing attachment, which is set at 45° from the horizontal plane of the table. Sliding dynamometer mounting is adjusted so that the handle and cable are 90° to the subject's arm.

Subject positioning: Subject lies on the table, supine (face up), body parallel to the table edge. The shoulder is aligned with the edge of the table on the side to be tested. The shoulder (acromion process) is aligned with center support of the shoulder wing attachment. Subject grasps handle in a palm down position. Stabilization belt is across the subject's chest, just below the sternum.

Muscle action: Subject is instructed to pull up on the handle with maximum force during a count of five seconds, and to stop when instructed. After each five-second interval, the subject rests for fifteen seconds. This is repeated five times. The subject is instructed to keep the elbow straight, and to keep the handle in contact with the wood at all times without pushing down on the wood.

Data recording: After five repetitions, mean and peak values for each five-second interval is retrieved from the dynamometer and manually recorded.

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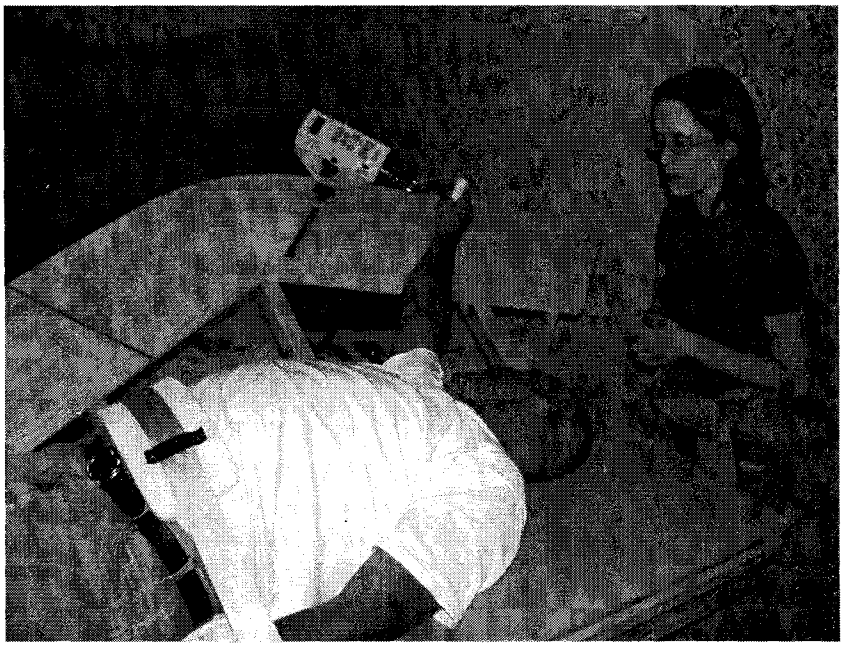

Muscle test #2 (Humeral Elevation in the Scapular Plane at 135°)
Used: first pre-test: table-based testing in Appleton, NY (n=10)

Equipment: Table, dynamometer, circular plate, rectangular plate, handle, elevation wing, and waist stabilization belt

Dynamometer Positioning: Attached to shoulder wing attachment, which is set at 135° from the horizontal plane of the table. Sliding dynamometer mounting is adjusted so that the handle cable is 90° to the subject's arm.

Subject positioning: Subject lies on the table, supine (face up), body parallel to the table edge. The shoulder is aligned with the edge of the table on the side to be tested. The shoulder (acromion process) is aligned with center support of the shoulder wing attachment. Subject grasps handle in a palm down position. Stabilization belt is across the subject's chest, just below the sternum.

Muscle action: Subject is instructed to pull up on the handle with maximum force during a count of five seconds, and to stop when instructed. After each five-second interval, the subject rests for fifteen seconds. This is repeated five times. The subject is instructed to keep the elbow straight, and to keep the handle in contact with the wood at all times without pushing down on the wood.

Data recording: After five repetitions, mean and peak values for each five-second interval is retrieved from the dynamometer and manually recorded.

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Muscle test #3 (Scapular Elevation, Supine)
Used: first pre-test: table-based testing in Appleton, NY (n=10)

Equipment: Table, dynamometer, handle with cable, webbing strap, footplate, circular plate, rectangular plate, and waist stabilization belt

Dynamometer Positioning: Attached to footplate table attachment, parallel to the surface of the table, six inches above the table. Cable and strap adjusted so the handle reaches the palmar crease of the subject's hand.

Subject positioning: Subject lies on the table, supine (face up), feet flat against the footplate. Stabilization belt is across the subject's chest, just below the sternum.

Muscle action: Subject is instructed to pull up with the shoulder (in a "shrugging" motion) with maximum force during a count of five seconds, and to stop when instructed. After each five-second interval, the subject rests for fifteen seconds. This is repeated five times. The subject is instructed to keep the elbow straight, lift only with the shoulder, and to keep head on the table.

Data recording: After five repetitions, mean and peak values for each five-second interval are retrieved from the dynamometer and manually recorded.

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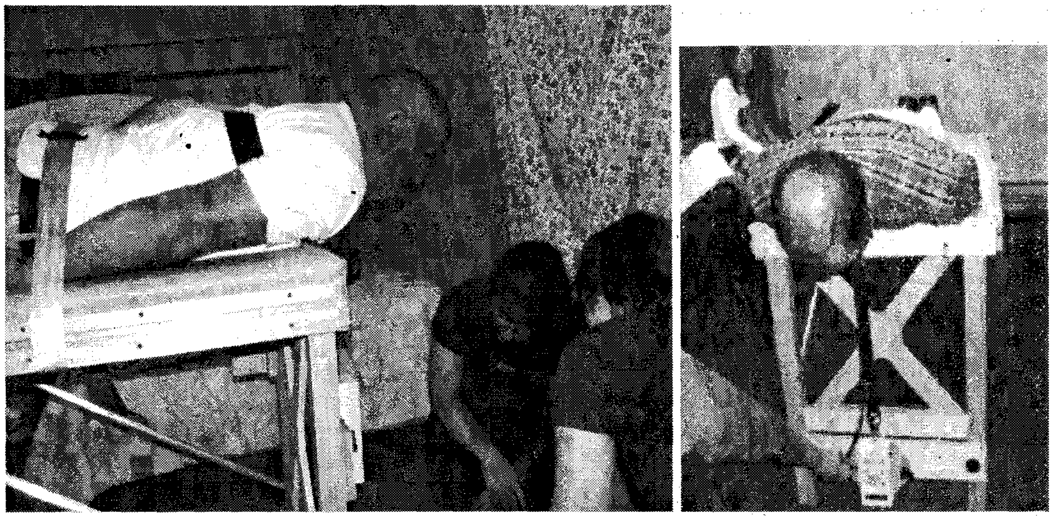

Muscle test #4 (Spinal Extension)
Used: first pre-test: table-based testing in Appleton, NY (n=10)

Equipment: Table, circular plate, rectangular plate, dynamometer, adjustable strap, waist stabilization belt, and back belt.

Dynamometer Positioning: Mounted on extensor attachment on legs of the table at the head. Large Velcro strap hooked to the dynamometer.

Subject positioning: Prone with entire sternum/breast over the end of the table. Subject has Velcro strap snugly wrapped around shoulders. Stabilization belt is across the sacrum.

Muscle Action: Subject is instructed to pull the chest away from the table with as much force as possible when the instructor says, "go," and to continue pulling until the instructor says, "okay." This is repeated five times, with a 5-second rest in between each repetition. Subjects are instructed to keep the head/face looking at the floor at all times during the testing intervals.

Data Recording: After five repetitions, mean and peak values for each five-second interval are retrieved from the dynamometer and manually recorded.

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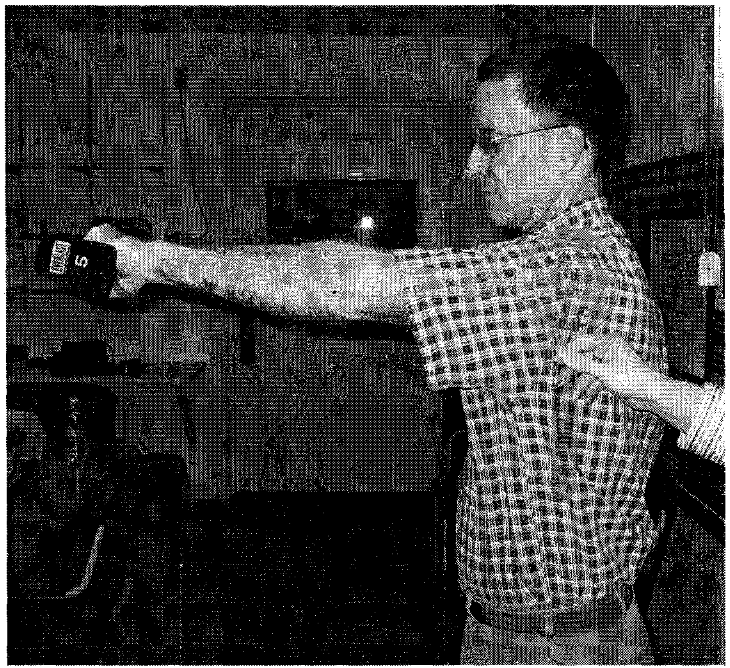

Muscle test #5 (timed arm hold, single arm, 90°)
Used: Laboratory muscle testing (n=8)

Equipment: Stopwatch, five lb weight, and goniometer.

Dynamometer positioning: N/A

Subject positioning: Subject is standing looking forward, feet together, with dominant arm raised so it makes a 90° angle, while holding a five lb weight.

Muscle Action: Subject is instructed to hold the five lb weight in their dominant hand and raise their arm. 90° is measured with the goniometer. The subject is instructed to hold this position as long as they possibly can. As soon as their arm drops, the test is stopped. After each test the subject will rest for one minute. The test is repeated three times. It is very important that the subject hold the position as long as they can, but do NOT use any other muscles, and do NOT move their head any way. Try to maintain the subject looking straight ahead.

Data Recording: The time the arm is held up for is manually recorded after each of the three repetitions.

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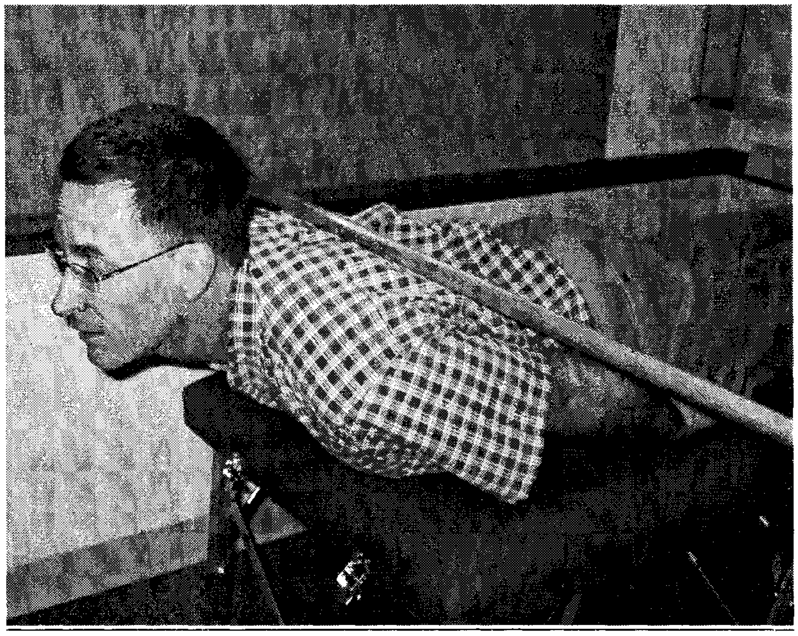

Muscle test #6 (timed spinal extension)
Used: Laboratory muscle testing (n=8)

Equipment: Portable exam table, metal pole, and stopwatch.

Dynamometer positioning: N/A

Subject positioning: Prone with entire sternum/breast over the end of the table.

Muscle Action: Subject is instructed to lift chest off the table as high as possible. A contact bar set at that maximum lift height, and a timer starts recording. The subject is instructed to hold the maximum lift as long as possible. Once the subject loses contact with the bar, the test is stopped. The subject rests for one minute and then repeats the test, using the original maximum lift point. The maximum hold interval is timed again, followed by another one-minute rest. A third and final timed back raise is then done.

Data Recording: The time the back position is held is manually recorded after each of the three repetitions.

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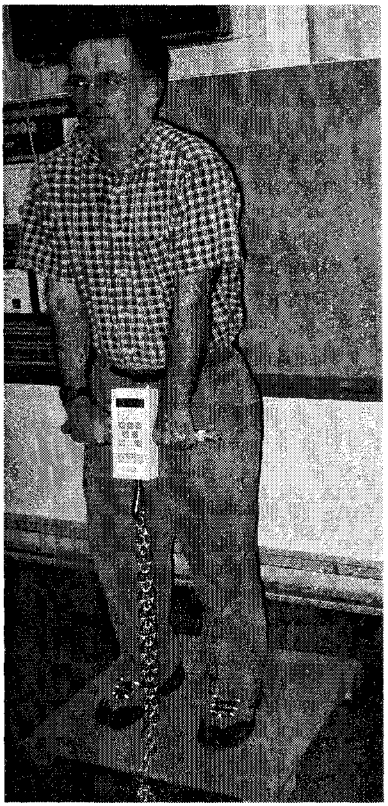

Muscle test #7 (scapular elevation, vertical, both arms)
Used: Laboratory muscle testing (n=8); Saratoga Orchard pre-test (n=5)

Equipment: Dynamometer, wooden platform, dynamometer handle minus the white handle (see photos on page 4), metal link chain.

Dynamometer positioning: Screw the two metal handles on either side of the dynamometer and subject will hold a metal handle in each hand.

Subject positioning: The subject is standing on the wooden platform (the platform should be positioned where the metal loop is directly in front of the subject) with the balls of their feet equal with the metal loop. The subject should be standing comfortably, looking straight ahead.

Muscle Action: The subject is instructed to raise both shoulders straight up, by pulling on the handlebars. It is very important that the subject pulls as hard as they possibly can, does NOT use any other muscles and does NOT move their head in any way. Try to maintain that the subject looks straight ahead.
The subject will maintain this position for five seconds. After five seconds the subject will rest or shake out their muscles for five seconds. This will be repeated fives times.

Data Recording: After five repetitions, mean and peak values for each five-second interval are retrieved from the dynamometer and manually recorded.

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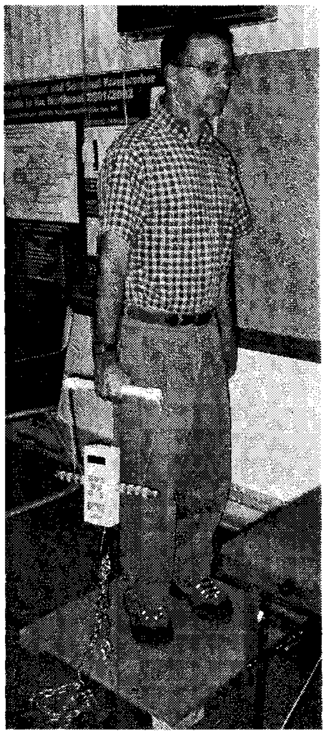

Muscle test #8 (scapular elevation, vertical, one arm)
Used: Laboratory muscle testing (n=8); Saratoga Orchard pre-test (n=5)

Equipment: Wooden platform, dynamometer handle with white handles/metal cable (see photo on page 4), dynamometer, metal link chain.

Dynamometer positioning: Screw the two metal handles on either side of the dynamometer and attach the white handle with metal cables. Have the subject hold the white handle in their dominant hand.

Subject positioning: The subject is standing on the wooden platform. The subject should be positioned where the metal loop is directly to their dominant side, inline with their dominant shoulder. The subject should be standing comfortably, looking straight ahead.

Muscle Action: The subject is instructed to raise their dominant shoulder straight up by pulling the handlebar. It is important that the subject understands to pull as hard as they possibly can, but does NOT use any other muscles and does NOT move their head in any way. Try to maintain that the subject looks straight ahead. The subject will maintain this position for five seconds. After five seconds the subject will rest or shake out their muscles for five seconds. This will be repeated fives times.

Data Recording: After five repetitions, mean and peak values for each five-second interval are retrieved from the dynamometer and manually recorded.

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Muscle Test #9 (Time arm hold at 120°)
Used: Saratoga Orchard pre-test (n=5); final orchard pre-test (n=14)

Equipment: 10 or five lb weight, stopwatch, adjustable pole with contact light, dynamometer tower and goniometer.

Dynamometer Positioning: N/A

Subject Positioning: The subject is standing on the platform of the testing tower, facing the tower. Position the middle arm so it is at chest height, just below the arms. Secure the stabilization belt securely, but comfortably around the subject's chest and back. Adjust the pole height so when the subject raises his/her arm it makes a 120° angle to the top of the pole arm.

Muscle Action: Subject is instructed to take the 10 lb weight in their dominant hand and touch their hand to the top of the pole arm. 120° is measured with the goniometer. Subject is instructed to hold the position as long as they can, but NOT to use any other muscles, and NOT to move their head in any way. The subject should look straight ahead. As soon as the arm drops away from the top of the pole arm, the test is stopped. After each test the subject will rest for one minute and the test will be repeated two more times.

Data Recording: Time is recorded for each of the three repetitions per arm.

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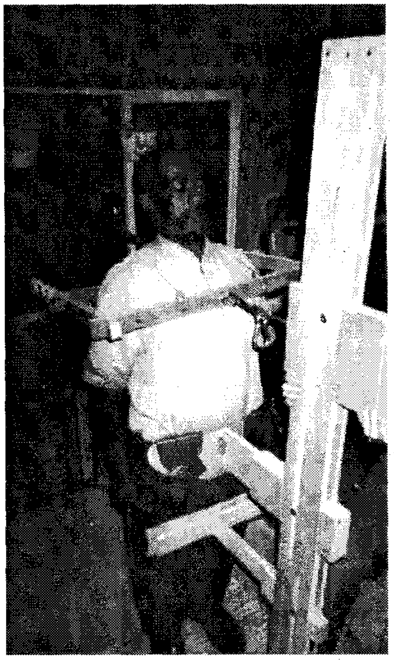

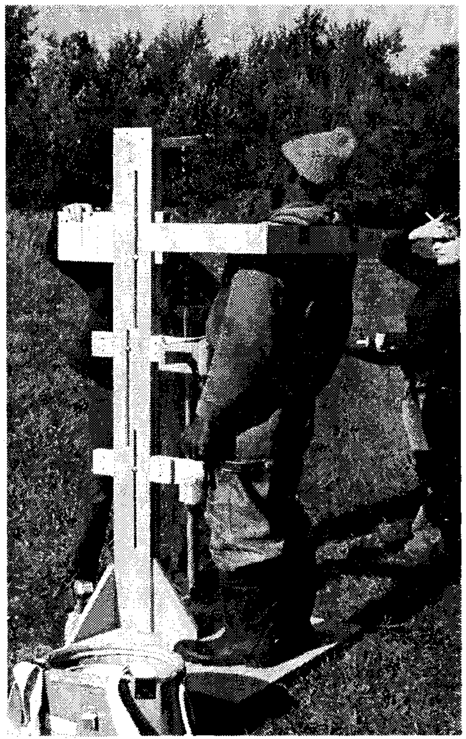

Muscle Test #10 (Standing spinal extension)
Used: Saratoga Orchard pre-test (n=5); final orchard pre-test (n=14)

Equipment: Dynamometer tower, shoulder girdle, dynamometer, extension pin.

Dynamometer Positioning: Secured in slot on the uppermost perpendicular arm of the testing tower. The tower arm is adjusted so that the dynamometer is level with the midpoint of the subject's sternum. Adjust the chain links or carabineers, which attach the dynamometer to the shoulder harness, so they are not loose.

Subject Positioning: The subject is standing on the wooden platform of the tower facing the tower. Adjust the lowest perpendicular arm so it rests just above the subject's kneecap. Position the middle arm so it rests at the subject's hips. .

Muscle Action: Subject is instructed to press their thighs and hips forward, and pull back with their shoulders as hard as they can. Subject will continue pulling back for five seconds. After 15 seconds of rest this test is repeated two more times.

Data Recording: After three repetitions, mean values and then the peak values for each interval are retrieved from the dynamometer and manually recorded

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Appendix 4. Communication with orchard owners

NYCAMH Apple Bag & Belt Study
Summer/Fall 2004 Planning

Reducing Back Strain with Hip Belt

As many of you know, NYCAMH has been working on improving the apple picking bucket/strap system currently used in hand harvesting throughout orchards in the Northeast. By adding a hip belt to the bucket to transfer some of the weight, we think we can reduce back and shoulder strain.

Many of you have been involved in this project, giving us input, ideas, and even letting us onto your orchards for testing of the revised equipment.

Workers who have tried the new equipment find it to be comfortable, and lab tests have shown a reduction in weight-bearing on the shoulders and back. With your help, we are continuing to improve the design.

We are working hard towards getting a workable product available to the orchards as soon as possible. More research is needed to make sure it will work over a whole season and be comfortable to workers.

We put this newsletter together to tell you about the next steps in the study, and how your orchard can participate. We'd like to give you a call in a few days to get your feedback!

Giulia Earle-Richardson, Project Director (L) & Christine Mason, Project Coordinator

Over this Spring we have talked over several research ideas with you and other apple industry experts. The best way of studying the apple bag and belt seems to be having workers try it and then measuring the differences in muscle fatigue after using it, compared to muscle fatigue after using their regular equipment. **See top page 4 for an explanation of MUSCLE FATIGUE and how it is measured**

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How the study will work

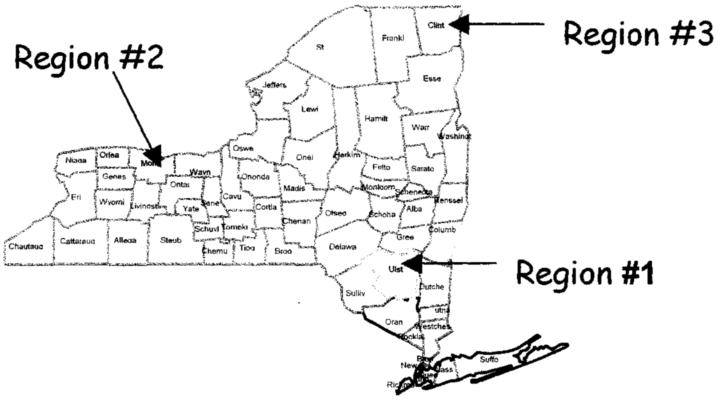
The study has three parts:

- Practice test of measuring muscle fatigue (10 workers)
- Two-week trial of worker opinion of bags (100 workers)
- Measuring differences in muscle fatigue when using hip belt (65 workers)

Part one; practice test of measuring muscle fatigue will be done on orchards picking fruit in July. During this part, several different muscle fatigue tests will be tried to see which ones work best.

Parts two and three will be done at the same time. Workers will use bags with belts for two weeks, and during those two weeks, muscle fatigue measurements will be made early in the morning and after work on some of the workers.

Study locations



How you can help...

We need your help in moving forward with our plan.

Please look at the map and calendar. When we call you, we will ask the following questions:

Can your orchard participate in the study during the period :______ to ____?

1. We are estimating that your orchard would have _____ workers participating. Is this feasible for you?
2. Can you tell us the following things about your workers and work schedule
    a. Native language
    b. usual beginning and end to work day (time?)
    c. type of bucket used
    d. usual day off (Sat? Sun? other?)

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3. ***Compensating workers and orchards.*** We are trying to develop a fair method of compensating workers who participate in different parts of the study, and also a way of showing our appreciation to participating orchards. With such a large study, this is quite challenging, since large sums quickly put us over our research budget. Here is a plan we are considering. We would like you to look it over and tell us if you think is appropriate, or whether it should be changed:

e. **Farmworkers participating in muscle fatigue practice test** - These workers will be tested early in the morning and after work on approximately six days. They would be compensated $10 each day for a total of $60. We will try to make the measurement take no longer than 45 minutes.

f. **Farmworkers participating in two-week orchard trial** - These workers will wear a trial bag for two weeks, and be interviewed for 15 minutes at the end of each week. They will receive $30 after the first interview, and $35 after the second.

g. **Farmworkers participating in muscle fatigue final tests** - These workers will already be part of two-week orchard trial, and in addition to the interviewing, will participate in muscle fatigue tests early in the morning and at the end of the work day on between 3 and 6 days. These tests should take about 20 minutes. Workers will be compensated $10 for each day of testing.

h. **Any worker wishing to participate but not selected** for any reason will receive a $5 calling card in appreciation.

i. **If in the course of the study, any worker** should experience a more than 10% loss in wages, the owner will notify the research team, and we will do our utmost to compensate that loss.

j. **Collaborating orchards** - The research team recognizes that the value of each orchard's participation is way beyond any financial compensation. We understand that orchards participate because they care about their workers and promoting the New York Apple industry. In recognition of this outstanding commitment to worker health and safety, participating orchards will receive the following at the conclusion of the research.
    - They will be listed as a collaborating orchard in all product development announcements and documents (if desired)
    - They will be featured (if desired) in all news coverage of the project and product promotion
    - When product testing is complete, any remaining study buckets and belts will be distributed among the orchards

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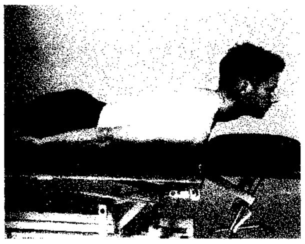
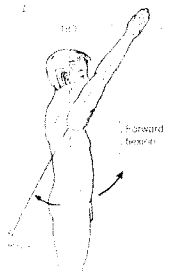
Measuring muscle fatigue

In this study, FATIGUE just means how much less work a muscle can do after 8 hours of picking. Looked at this way, we can measure FATIGUE by measuring strength before and after 8 hours of picking. Here are two examples of muscle fatigue measures:



Upper back lift
subject lies on table, facing down subject lifts head and shoulders off the table for as many times as possible. Researchers count the number of times.



Forward flexion of arm subject lifts and holds picking arm overhead (maybe with small barbell) as long as possible. Researchers time how long worker holds before stopping. This tests arm muscles involved in picking.

Where's Richard?

Rich & Giulia

Many of you first heard about the orchard study from Richard Smith, NYCAMH's Safety Education Specialist. In May of this year, Richard moved on to a position with the Saratoga County Cornell Cooperative Extension as Farm Management/Dairy Educator Agent. In his new position, Richard continues as a collaborator, and most of all, as a friend. We would like to take a moment to thank Rich for all the help, support and wisdom he provided to us on the Orchard Ergonomics/ Apple Bag/Belt Study. Rich can be reached at (518) 885-8995 ext. 229, and his e-mail is rcs39@cornell.edu.

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Appendix 5. Orchard Worker Consent From (to be read to participants) (provided in English and Spanish)

You, ________________________________ have been asked to take part in a research study. The study will try a different kind of picking bucket to see if it makes you less tired. It may be possible to make picking less tiring and painful. You will be given a picking bucket and hip belt to wear for one week. During the next week, the bucket and belt will be a little different. At the end of each week, we will ask you questions about the bucket and belt.

You may also be asked to do a number of different simple exercises. These will measure muscle strength in your arms, shoulder, back or neck. We will show you how to do each one before asking you to do it. For each exercise, researchers will write down how you do. Following eight hours of work, we will ask you to do these same exercises again. During any of these exercises you will be told to stop if you feel pain at any time.

You will receive a money order for $30.00 after the first week, for answering the questions. At the end of the second week, you will receive a money order for $35.00. If you are asked to do the muscle test, you will receive an additional money order for $10.00 for each day you do the muscle tests. If you are not selected to do the muscle tests, you will receive a phone card for $5.00.

Benefits of this study include finding new ways to pick more comfortably, have less pain, and not be as tired. This would help you and other apple pickers in the future.

Your boss knows about the study. It is OK with him if workers are in the study. It is also OK with him if you decide not to be in it. No one will hear anything about your testing or comments about the belt except the researcher. The interviewer will write down the answers. He or she will not share your answers with anyone else on the farm. The results of the research will never use your name or the name of the farm you work on. No one will ever say anything publicly about you or your boss. No one will ever share your name or the name of your boss with the government.

Your participation is voluntary and you may quit the study at any time. If you should be injured because of this study, treatment is available at the hospital's regular charges. The costs of this care can be billed to medical insurance. Financial compensation for such things as lost wages, disability, or discomfort due to this type of injury is not routinely available. Further information may be obtained from the Office of Risk Management of Bassett Healthcare at (607) 547-6960.

This project has been approved by the Institutional Review Board of The Mary Imogene Bassett Hospital. Any questions about your rights as a research subject may be directed to the Chairman of that board at the Research Institute Office (607) 547-3670.

By signing this form you indicate that you willingly agree to help in the study as described above. You understand that you can change your mind any time and quit the study if you want to. You have had a chance to ask questions, and they have been answered so that you understand. You can ask more questions about the study at any time by calling Giulia Earle-Richardson at 607-547-6023. If you experience pain after wearing the equipment or doing the exercises, you should contact the study staff immediately.

This is to certify that you consent to participation as a volunteer in this research study. You understand that you will receive a signed copy of this consent form. You have read this form, or had it read to you, and understand what it says.

Name: ____Date: ________

I, the undersigned, have defined and explained the studies involved to the above volunteer.

Name: ____Date: ________

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Appendix 6. First Farmworker Intervention Interview
(to be read to the farmworker)

Subject ID#____________ Subject name: __________________________

Data Collector's Initials:______ Date of interview:____________

Farm/Orchard:____

1. Can you tell me which days you picked this week, and for how many hours each day?

Mon	Tues	Wed	Thurs	Fri	Sat	Sun

I would like to ask you some questions about the hip belt you have been using this week.

2. Did you wear the hip belt the whole time you were picking?
   1) Yes
   2) No If no, when did you not wear it? ________________________
   Can you tell me why you did not wear it at that time?___________

   2a. (If hook belt): how much of the time did you hook the belt when you had a full bucket of apples?

   Never once in a while usually always

   (if never/rarely) Can you tell me why?___________

3. Were there any problems using this equipment? Y N

   3a. If yes, please describe:_______________________________________

4. How well did you like this bucket compared to your usual equipment?

This bucket is: much worse a little worse the same a little better much better

5. How well did you like this belt compared to not wearing any belt?

This belt is: much worse a little worse the same a little better much better

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6. 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 YES, answer 6a-6e.

IF NO, skip to question 7

6a. If yes, where was this pain?

_____neck _____R shoulder ____L shoulder ____upper back

____lower back __other____________

6b. How bad was the pain?

Neck :	_______mild	______moderate	______severe
Shoulder (R)	_______mild	______moderate	______severe
Shoulder (L)	_______mild	______moderate	______severe
Back:(upper):	_______mild	______moderate	______severe
Back:(middle):	_______mild	______moderate	______severe
Back:(lower):	_______mild	______moderate	______severe

6c. When did the pain start? __________________________

6d. Did the pain interfere with your work in any way? Y N

If yes, describe____

____

6e. did you have any kind of accident that caused the pain?

Y N describe:__________________

7. If this belt were provided by your employer, would you be willing to use as part of your regular work?

Yes No

8. Did using this belt make your body feel different from how it usually feels in any way? Y N

9. If yes, how is it different?____

____

10. Is there anything else you would like to say about trying the new equipment today?

____

Thank you very much!

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