ERGONOMICS PARTNERSHIP TO ADDRESS TREEFRUIT WORKER INJURY

PREVENTION OF MUSCULOSKELETAL DISORDERS IN HAND-HARVESTED TREEFRUIT CROPS

FINAL REPORT

UNIVERSITY OF CALIFORNIA
AGRICULTURAL ERGONOMICS RESEARCH CENTER

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PREFACE

This is a report on the goals, methods, implementation and results of the Ergonomics Partnership to Prevent Treefruit Injury Project of the University of California as proposed to and funded by the National Institute for Occupational Safety and Health in Continuing Agreement U05-CCU911435.

This report is intended to serve as the final project report.

The principal investigators, staff, and cooperators involved express their appreciation to the NIOSH Community Partners for Healthy Farming program and to Ms. Terry Palermo and Ms. Janet Ehlers of NIOSH for their unstinting support in making the project possible and successful.

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EXECUTIVE SUMMARY

The Ergonomics Partnership to Prevent Treefruit Injury Project of the University of California was funded by the National Institute for Occupational Safety and Health Continuing Agreement U05-CCU911435 under the Community Partners for Healthy Farming program.

The project's proposed specific aims were to:

1) To scientifically document and describe ergonomics risk factors involved in hand harvest of treefruit.
2) To develop and evaluate field practical applications of known controls that eliminate or significantly reduce targeted hand harvest risk factors.
3) To scientifically test the impact of selected interventions combined together on targeted hand harvest risk factors.
4) To improve community-based understanding of ergonomics methods and improve intervention practices in hand harvest of treefruit.

All but one of the project's specific aims were successfully achieved. The project described the ergonomics risk factors associated with hand harvest of 10 different crops then focused intervention efforts on three specific crops with high priority exposures: Pomes-pears, Citrus-lemon, and Stone Fruit-peaches.

As a result of analysis of ergonomics risk factors associated with these jobs and information provided by both cooperating workers' compensation insurers and cooperating treefruit employers, the project was focused on hazards of ladder design and use and manual handling of awkward and heavy loads. The hazards of highly repetitive hand picking is of equal concern, but no tools offering alternative practices were identified or accepted as satisfactory by cooperating growers and workers.

Ten growers and nearly 1400 workers directly participated in at least one phase of the project as hand harvest job descriptions were developed for ten different treefruit crops. These growers and their workers were provided information on MSDs, their causes and symptoms, and strategies for their prevention.

Cooperative trials were conducted of: A) smaller picking bags in lemon harvest, B) powered harvest platform in pear harvest, and C) use of ladders with alternate step spacing and design in peach harvest. All of these interventions were well accepted by workers and growers participating, and all demonstrated reduction in targeted risk factor exposures.

SMALLER PICKING BAGS

Reducing the loads of lemon picking bags from an average of 74# to an average of 57# was shown here to demonstrate trends toward reduced levels of self reported fatigue and MSD symptoms, but these did not reach the level set for significance.

In reflection, we believe that the failure of this comparison to achieve statistical significance may have been due to the fact that experimental loads were not reduced below 55#. Smaller picking loads (average 47#) were previously studied by the AERC in winegrape harvest and were found to be effective in reducing priority ergonomics risk factors and statistically significant in reducing pain and MSD symptoms (Meyers et al. 2005). That trial was based in part on findings reported by Davis and Marras (2000) of evidence of a threshold on the effects of spinal loading of weights above and below 55#.

The failure to reach levels of statistical significance might well be due to the fact that the smaller bags used in the treefruit trial did not reduce average loads below the predicted 55# threshold. While this remains conjecture at this stage, the juxtaposition of results from the two studies seems to support the effect of a threshold factor. Further study will be required to prove the existence of such a spinal loading threshold and at what load levels it and how it comes into effect on factors such as fatigue and injury symptoms.

It is also possible field setting factors, including unpredictable weather and harvest production, and the worker population under study added difficulties which may have negatively influenced findings. The nature of the field settings and worker populations studied here present considerable challenges for traditional methods of research. These initial studies in treefruit demonstrate interventions that promise reduction of injuries and musculoskeletal disorders among farm workers performing hand harvest of treefruit, but further studies are needed to examine these under varying conditions.

POWERED HARVEST PLATFORMS

Powered harvest platforms are commercially available and have been used and studied for productivity effects (especially in apple harvest) in other crops (Baugher, 2009). For the pear harvest platform trial, a Spanish built Argiles self-powered platform was provided by BlueLine Manufacturing of Yakima, WA. The machine required extensive modification by UC AERC staff to meet the demands of pear harvest.

The application of the powered platform to fresh pear harvest met the goals of eliminating ladder use in harvest, replacing them with an improved working platform with significantly reduced risk of falls. In addition, workers on the platform did not have to use heavy bags as they were able to readily deposit fruit in conveyors.

Requiring a crew of from 5 to 9, the platform was able to achieve harvest productivity levels ranging up to equal those of ladder crews of the same size. Platform harvested pears arriving at the packing house showed less harvest damage than those from ladder crews and worker and owner/operator response was uniformly positive. Additionally, the platform can be used in annual pruning and other tasks. Washington State University researchers reported a 30% labor cost reduction for pruning using a similar powered platform in apple orchards.

Cooperative research on the use of powered harvest platforms was continued after the end of this study by participating growers and Cooperative Extension staff with support from local workers compensation insurers and the California Pear Advisory Board.

MODIFIED LADDERS

In a further effort to reduce risk of falls, an approach to ladder design featuring alternative rung spacing was given review. From a wide range of rung spacing alternatives, laboratory kinematic studies suggested that most ergonomic improvements for this population would be achieved using rungs spaced 10 and 11 inches apart, as opposed to the current standard of 12 inches. Field trials by workers over a 5 week period showed significant worker preference for the shorter rung spacing. Workers reported less fatigue and increased ladder stability. It should be noted that commercial progress on this approach is severely inhibited by ladder producers concerns for potentially increased liability in the absence of published and accepted scientific support for changes to current ladder design. This suggests that little progress is likely without increased public funding for ladder ergonomics research.

Specific Aim 3, involving assessment of the combined effect of smaller picking bag use in lemon harvest combined with a rest break protocol was dropped from the project in the face of difficulties in maintaining adequate sample populations due to weather effects on harvest demands during the planned experimental period.

In sum, this project’s goals of identifying and describing ergonomics risk factors involved in hand harvest of treefruit; of developing and evaluating controls that eliminate or reduce targeted risk factors, and of scientifically assessing the impact of interventions were met. Important information on the development and use of alternate work practices and technologies was demonstrated to both the industry and to interested professionals. This study also demonstrates that additional funding is needed to support and evaluate technological modifications of innovations on the market that have not been fully assessed for ergonomic or occupational health consequences.

INTRODUCTION

The UC Agricultural Ergonomics Research Center (AERC) is a multi-disciplinary team of UC researchers dedicated to application of ergonomics methods to the identification, analysis and prevention of MSDs in agricultural work. The AERC has received numerous NIOSH awards over the past decade to investigate work-related musculoskeletal disorders and ergonomics in diverse agricultural commodities. In those projects, the AERC focused on commodities that were both large and growing in acreage and labor use (plant nursery production and wine grapes). Orchard products stand third among California agricultural commodities that are increasing in acreage and employment. California hand-harvested treefruit commodities include citrus, stone fruits, and pomes. California is ranked either first or second in the nation for production for all but two of these treefruit crops with a 2001 value exceeding $1.6 billion. California treefruit production involves approximately 600 thousand acres and more than 50,000 workers.

Nationally, treefruit harvest research has focused on development of fully or partially mechanized harvest equipment. This work has continued for citrus crops in Florida, where most producers target juice processing and cosmetic damage is not a concern. Because California treefruit producers specialize in fresh market products, where cosmetic damage is a significant marketing factor, hand harvest and cultivation practices have remained the norm for these commodities. For hand harvested fresh market crops, equipment and practices are virtually the same as they were at the turn of the 20th century, with the same attendant risks and hazards for workers.

Research previously completed by the UC AERC documented that hand harvest places workers at high risk for back strain and other musculoskeletal problems. AERC staff also undertook prior planning discussions with a diverse range of industry groups, which led to the priorities reflected in the original proposal. Participants included treefruit growers, workers, farm labor contractors, workers' compensation insurers, safety practitioners and others. Findings from those interactions focused concern on the elevated risk for injury from falls, usually involving ladders.

PROJECT GOALS AND OBJECTIVES

The ultimate goal of all UC AERC research is to significantly reduce or eliminate targeted ergonomic risk factors and the resulting probability of injury. Because this cannot always be effectively assessed during the short term of most funded projects, we look to specific indicators including: effects on identified ergonomics risk factors and symptoms consistent with development of MSDs.

The project specific aims included:

1) Scientifically document and describe ergonomics risk factors involved in hand harvest of treefruit:
   a) develop detailed ergonomics job descriptions of hand harvest in 12 commodities;
   b) utilize biomechanical, metabolic, and postural stress measures to describe ladder use, manual load handling, and repetitive picking in detail;

   c) assess the incidence and types of injuries associated with hand harvest risk factors.

2) Develop and evaluate field practical applications of known controls that eliminate or significantly reduce targeted hand harvest risk factors:
   a) share proven concepts with cooperating workers, growers, contractors, safety practitioners, and interest groups making up the treefruit community;
   b) modify effective intervention applications to ensure field practicability;
   c) conduct cooperative controlled field trials of cooperatively selected intervention applications;
   d) statistically compare individual intervention and control conditions.

3) Scientifically test the impact of selected interventions combined together on targeted hand harvest risk factors:
   a) conduct cooperative hand harvest intervention trials with treefruit production partners;
   b) compare combined intervention conditions and control conditions in terms of ergonomics, injury symptoms, and productivity measures.

4) Improve community-based understanding of ergonomics methods and improve intervention practices in hand harvest of treefruit:
   a) provide training and workplace experience with ergonomics methods to cooperating partners;
   b) provide community ergonomics information and training;
   c) assess perceived adoptability of interventions;
   d) communicate project findings to treefruit and other agricultural industry groups, to workers and community interest groups, and other safety and injury researchers.

PROJECT COOPERATORS

Ten growers and nearly 1400 workers directly participated in at least one phase of the project as hand harvest job descriptions were developed for ten different treefruit crops. These growers and their workers were given summary information on MSDs, their causes and symptoms, and strategies for their prevention.

Three pear growers, one lemon harvest labor contractor, and one peach grower and their workers directly participated in conduct and evaluation of intervention trials. The wider community of treefruit growers was involved in setting intervention priorities, reviewing and advising on interventions, and receiving and evaluating results. More than 200 workers directly participated in the conduct and evaluation of intervention trials. All participating workers were provided training and information on MSDs, their symptoms and causes, and strategies for their prevention.

AERC staff undertook pre-submission project planning discussions with representatives of interested groups, which led to the informal Treefruit Safety Research Group. Participants include treefruit growers, workers, farm labor contractors, workers' compensation insurers, safety practitioners and others. This group was subsequently subsumed by a permanently standing University-Industry group, the Pomology Extension Continuing Conference which has larger and more diverse industry participation.

The growers involved in the project were all considered mid-size by California standards. The harvest jobs are all seasonal, although season lengths vary by crop. The industry is almost completely non-union in California and there was no active union representation at any of the cooperator sites. All of these cooperators have active injury and illness prevention programs. Provision of worker's compensation insurance benefits is required in California.

The majority of workers in these operations are Spanish-speaking, from Mexico. Treefruit harvest work is considered a “skilled” job by most California farmworkers and is relatively well paid. Workers earn on average $15 per hour during harvest, and accumulating up to 40% of their annual income during this period.

SPECIFIC AIM 1

To scientifically document and describe ergonomics risk factors involved in hand harvest of treefruit.

METHODS

Aim 1 was accomplished using an observational longitudinal design: we followed a cohort of 10 harvest crews (i.e., one for each of the 10 crops involved) over at least one full work week to develop harvest job descriptions and conduct risk factor job screening on each job. NOTE: While the original proposal called for survey of 12 commodities, two were judged duplicative and unnecessary based on interactions with growers (tangerines, grapefruit) and so were dropped. Ergonomics risk factor assessments were completed for the remaining 10 commodities as planned (apples, apricots, pears, peaches, nectarines, cherries, figs, plums, oranges, and lemons).

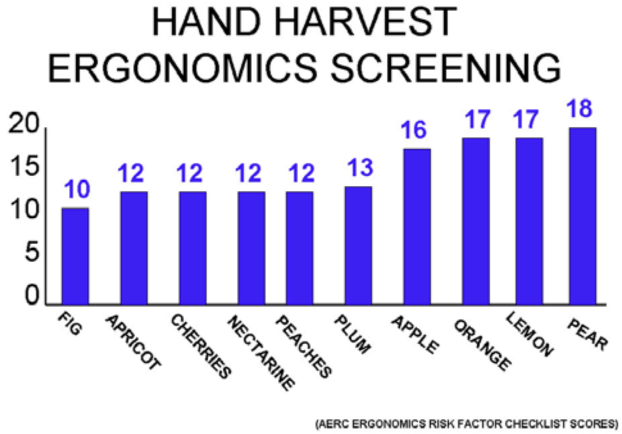
We also assessed incidence, types and causes of injuries for each crop based on cooperator’s reported injury records and first aid logs, and summarized public workers compensation insurance data. Following completion of this work, three target crops were selected by the research team in conjunction with the project advisory group based on relative severity and incidence of injuries and ergonomics risk factor exposures. The selected target crops were: Pomes – pears, Citrus – lemons, and Stonefruit – peaches (and nectarines).

Detailed descriptive ergonomics data were then generated for each of the three target commodities. These data helped identify priority risk factors for intervention, guide engineering design, and assess risk factor reduction efficacy of interventions.

RESULTS

Job descriptions and ergonomics risk factors associated with the hand harvest of each of 10 treefruit commodities were documented. These were then ranked according to their ergonomics checklist scores as Table 1, below, shows.

Table 1, Total ergonomics risk factor screening scores for 10 treefruit crops.



Detailed job descriptions for the three crops selected for intervention were very similar, differing mostly in the use of small plastic tubs supported by a strap around the neck for receiving and carrying peaches as opposed to use of large bags suspended over the shoulder for pears and lemons.

Lemons/Pears Job Description

1. Place Bag over shoulder and diagonally across trunk (adjust strap as needed)
2. Carry ladder to tree
3. Place ladder in tree
4. Climb ladder to top level of fruit and fill bag to approximately half capacity
5. Descend ladder, picking fruit from lower levels of tree. From ground level, pick fruit from ground level until bag is full
6. Carry bag to box & unclip to dump

Lemons

Pears

Peaches Job Description

1. Carry ladder to tree
2. Position ladder
3. Climb the ladder with tote
4. Pick peaches with both hands
5. Place in tub until full
6. Descend ladder
7. Carry tub to trailer
8. Remove tub and get new one

Peaches

Ergonomics risk factors recorded for all three jobs were similar including:

1. High Force/Weight
   Filled bags weigh from 70 to 80 lbs, suspended from one shoulder by a web strap
   Weights for peaches were much less (10#) due to use of small picking tubs
   Carrying and setting 30 # ladder
   Hand clippers 2-5# force (not used on peaches)
2. Contact Stress
   Continuous from bag (tub) straps
   Continuous to hand from holding clipper
   Continuous to feet from standing on ladder rungs
3. Very High Repetition
   Up to 100 “picks” per job cycle
   Up to 2-3 ladder moves per job cycle
4. Awkward Postures
   Awkward hand/wrist, back/neck postures in picking
   Repeated shoulder/trunk extensions to reach to pick
   Hunched shoulder positions from suspended weights
   Shoulder elevations to carry ladder
   Trunk flexion to empty bag

Citrus hand harvest (oranges, lemons) was subjected to analysis using the REBA (Rapid Entire Body Assessment, Hignett and McAtamney 2000) program. This is a commonly used, standardized ergonomics risk job assessment. The results, displayed on Table 2 below, show which tasks within the overall hand harvest job should have highest concern.

Table 2. REBA scores for citrus hand harvest job tasks

REBA Analysis of Citrus Hand Harvest Job Tasks

TASK	REBA SCORE	CONCERN LEVEL
Lift Ladder	8	High
Carry Ladder	11	Very High
Pick from Ladder	10	High
Descend Ladder	8	High
Pick from Ground	11-12	Very High
Carry full bag to Bin	3	Low
Empty bag into Bin	5	Medium

Injury data from workers’ compensation insurance system supported cooperators experience that falls are the most common and most expensive reported treefruit hand harvest injuries and that ladders were highly implicated in these falls.

SPECIFIC AIM 2

To develop and evaluate field practical applications of known controls that eliminate or significantly reduce targeted hand harvest risk factors.

OVERVIEW

Aim 2 was accomplished using a modified participatory action research model to work with growers and workers to design and evaluate modifications of tools and work practices. Discussions with growers and workers about hazards and injuries, worker compensation data and existing engineering approaches were a central part of this process. This approach has been successfully applied in all previous projects.

Priority ergonomics risk factors involved in hand harvest of treefruit include: 1) Very high repetition of hand closure for cutting; 2) awkward postures from picking at heights with loads: and 3) high forces and awkward postures while ascending and descending ladders with loads. Even after extensive review, there are no practical cutting tools for hand harvest of treefruit that do not involve forceful hand closure. Powered cutters are too slow, too awkward and field power source options either add too much weight or involve entangling cords, etc. Hence no intervention could be given trial to address this high priority risk. That left the two high priorities dealing with heavy loads and ladders. After extensive consultation with cooperators, three different interventions were decided on.

We developed specific intervention concepts for each of three selected trial crops (pears, lemons, and peaches). These were: lemons – smaller picking bags, pears – a mechanized harvest platform, and peaches – alternate ladder designs. These interventions were worked out in full cooperation with participating workers and growers and subjected to repeated field tests to ensure practical efficacy and worker acceptance.

Once acceptable interventions were finalized for each crop, separate field trials for each were cooperatively conducted. Because only one harvest platform and a limited number of ladders were available, these intervention trials could not involve a sufficient sample size during the normal course of the harvest period for statistical testing. Therefore, these two interventions were subjected to less formal evaluations emphasizing effects on targeted ergonomics risk factors and workers' expressed preferences.

SMALL HARVEST BAGS (LEMONS)

Previous AERC research in orange harvest suggested that use of smaller bags could significantly reduce MSD pain and symptoms. Commercially available harvest bags were used. In 2006, we found that our two collaborating labor contractors were offering two different bags to workers to carry the lemons that were harvested, and we determined that we could take advantage of this "natural experiment." Historically, a "large bag" was the most common bag in California used for carrying lemons; it was possible to carry up to 85 pounds of lemons in this bag. Recently, contractors had begun to introduce a “small bag” that held up to 65 pounds of lemons, but is not the industry standard.

Lemon harvest using the two types of bags was investigated twice, in 2006 and 2007. As our initial investigation into lemon harvest, we elected to describe the symptom experience of harvesters, and to compare the effects of the small vs. large bags over the season. The 2006 investigation took place from mid-January to late May, enrolling workers as they were engaged to work by two contractors, and randomly assigning them to one of the two bags. In 2007, 104 workers were enrolled over three weeks in March and most were retained until the end of the study in April.

The 2006 Lemon Harvest Trial

Sample**.** Table 3 provides descriptive information about the workers who completed the 2006 baseline interviews (n=137). We have only had 2-3 refusals per year over the 14 year course of this study; in this study, our enrollment continued to be quite successful. The majority were men in their 20’s and 30’s, with less than primary school education. Over half had 10 years of experience or more in California agriculture and 8 years or more in treefruit specifically. Most reported themselves to be in good to very good health.

Table 3: Baseline demographics about 2006 lemon harvest crew members (n=137)

	Number responding	Frequency Number (percent)	Mean - SD - Median
Age (years)	136		
<20		11 (8.1)	
20-29		49 (36.0)	
30-39		31 (22.8)	
40-49		22 (16.2)	
50-59		15 (11.0)	
60-69		8 (5.9)	
Gender	137		
Male		132 (96.4)	
Female		5 (3.6)	
Education (years)	137		Mean 6.3 SD 3.0 Median 6.0

Length of experience: in California agriculture	137		Mean 12.4 SD 11.0 Median 10.0
Length of experience: in treefruit	137		Mean 11.1 SD 9.9 Median 8.0
Length of experience with this employer	136		Mean 4.6 SD 5.3 Median 3.0
Height (inches)	82		Mean 66.7 SD 2.4 Median 67.0
Weight (pounds)	100		Mean 165.5 SD 21.6 Median 163.0
BMI	82		Mean 26.0 SD 3.0 Median 26.0
How many hours did you work last week? (A7)	130		Mean 30.3 SD 11.9 Median 32.0
How good is your health? Excellent Very good Good Fair Poor	136	 11 (8.1) 22 (16.2) 56 (41.2) 47 (34.6) - -	

Information for the 76 workers who participated in both baseline and exit interviews is shown in Table 4. Workers using the large bags tended to be slightly younger and had had less experience with their current labor contractor.

Table 4: Demographics comparing workers using small (n=39) v. large (n=40) bags for harvesting lemons (2006), at baseline and at exit surveys.

(a) Age at baseline for workers using small and large bags

Age (years)	Small bag (n = 39)	Large bag (n = 40)
<20	4 (10.3)	3 (7.5)
20-29	11 (28.2)	16 (40.0)
30-39	6 (15.4)	10 (25.0)
40-49	6 (15.4)	4 (10.0)
50-59	7 (17.9)	4 (10.0)
60-69	5 (12.8)	3 (7.5)

(b) BMI and experience of workers using small and large bags, at baseline and exit.

	Baseline		Exit	
	Small bag (n = 39)	Large bag (n = 40)	Small bag (n = 39)	Large bag (n = 37)
BMI	(n = 37) 26.0 3.0 26.3	(n = 35) 25.9 3.0 25.5	(n = 36) 26.3 2.9 26.2	(n = 36) 26.0 3.1 25.6
Length of experience: in California agriculture	(n = 39) 13.9 12.0 10.0	(n = 40) 12.5 11.4 8.5	(n = 23) 14.3 13.0 11.0	(n = 16) 14.9 13.5 10.0
Length of experience: in treefruit	(n = 39) 12.0 9.8 8.0	(n = 40) 11.2 10.0 8.4	(n = 23) 12.2 10.0 8.0	(n = 16) 13.7 10.6 10.0
Length of experience: with this employer	(n = 39) 6.3 6.2 4.0	(n = 40) 3.6 3.8 2.1	(n = 23) 6.2 4.7 5.0	(n = 16) 4.8 5.1 3.5

Symptom survey measure. We utilized an adapted version of the survey we have used for 14 years with agricultural workers in California (Faucett, Meyers, Tejeda et al. 2001). The survey has demonstrated sound reliability and validity among California farm workers. The survey provides data on job characteristics, symptom experiences, and demographics. Face to face interviews are conducted using bilingual, bicultural interviewers. In the 2006 study of lemon harvest, workers were interviewed periodically throughout the season (see Table 5 for dates).

Analyses**.** We compared the effects of the two bags on changes in symptoms (musculoskeletal discomfort and fatigue) over the main lemon harvest season. For the workers who were assigned to use the small or the large bag over the course of the study, the baseline and exit scores of musculoskeletal symptoms by body region were obtained and summarized: Upper and lower extremities (UE and LE), both right (R) and left (L) sides; low and mid back, neck and shoulders; and by composite musculoskeletal symptom scores; as well as fatigue severity scores.

To utilize data provided by the entire sample, we used mixed model, multilevel regression analyses to assess the effects of the small bag and the large bag on changes in workers' reports about musculoskeletal symptoms and fatigue severity over the course of the season (SPSS, version 15.0; STATA, version 10). We also assessed changes in the frequencies of reporting musculoskeletal symptoms in each of the four body regions using multilevel logistic regression analyses (STATA, version 10). Each worker contributed data on symptoms for the amount of time he used each bag (i.e. exposure to the bag). Thus, workers who remained in the study since January and who were interviewed at each data collection point provided more data for analyses than workers who entered towards the end of the study. We examined the contributions to these multilevel regression equations of time and bag, and also the quadratic of time to identify significant variations in the strenuousness of the work as the harvest waxed in mid-season and waned toward the end. We also examined the impact of individual differences in bag handlers, using age, experience with treefruit, and BMI as covariates.

2006 Results.

Acquisition and retention of subjects. Workers were enrolled between January and April, and were repeatedly interviewed until the end of May. A substantial number of workers, however, dropped out of the study or were not available for interviews when the research team members were on site. Table 3 demonstrates the numbers of workers who were enrolled, retained and followed up by the research team interviewers at the various weeks of the study, and their bag assignments.

Our initial trial of bag size made several assumptions. Our original design assumed that exposure to the small bag over a period of two weeks would be sufficient to detect a significant change in symptoms. Further we anticipated that most workers would be available for study for a minimum of six weeks. Finally, although we expected attrition in late January after the more lucrative jobs in avocado harvest became available, we anticipated that many workers would stay for the entire lemon harvest season.

Table 5 demonstrates attrition after the end of January, as many workers left for better paying jobs in the avocado harvest. Table 5 also demonstrates the challenges faced in getting follow up interviews in this setting with workers, and in retaining workers through the course of the study. Of 78 workers enrolled in mid-January, only 7 were successfully interviewed in March, 41 missed their follow up interviews and a further 40 had left their jobs. In March and April, we enrolled an additional 51 workers for a total of 96 workers enrolled for the early May follow up interviews. Of these 96, only 12 missed their follow up interview and 5 dropped out. At the end point of the study, 76 workers were still enrolled out of 87 at the preceding interview; and 11 had dropped out. Of those 76, 39 had been assigned to the small bag and 37 had been assigned to the large bag. Our inability to follow workers after they had left the work setting makes it impossible to define any 'healthy worker' effect, or determine whether workers left because they had sustained new injuries or found more lucrative jobs.

Table 5: Enrollment, retention and bag assignment of sample (n = 137) over 2006 lemon harvest season.

Interview times and dates	T0 January 12-18	T1 March 23-24	T2 April 6-9	T3 April 19-20	T4 May 4	T5 May 17-18	Exit June 1-2
Total enrolled*	78	66	97	96	99	87	76
Newly enrolled		18	32	1	8	-	-
Followed up		7/78	50/66	78/97	79/96	79/99	76/87
Missed F/U		41/78	15/66	19/97	12/96	8/99	-
Drop-out		30/78	1/66	2/97	5/96	12/99	11/87
Total interviewed	78	25	82	79	87	79	76
Small Bag assignment	10	N/A	41	37	38	37	39
Large Bag assignment	17	N/A	41	42	45	42	37
Unknown assignment	51	N/A	0	0	4	0	0

Excluding drop-out cases

Symptom reports. Given the constraints of our sample as described above, we compared the effects of the two bags on changes in symptoms (musculoskeletal discomfort and fatigue) over the main lemon harvest season. For the 76 workers who remained in the study until the exit interview and who were assigned to use the small or the large bag over the course of the study, Table 4 shows the baseline and exit results for the reports of musculoskeletal symptoms by body region (upper and lower extremities – both right and left sides, low and mid back, neck and shoulders) and by composite musculoskeletal symptom scores, and also the fatigue severity scores. Fifteen of the 39 workers using the small bag (38%) reported some type of injury during the study period as did 13 of the 37 workers using the large bag (35%).

In our first model, entering time, bag type, and their interaction only, time made a significant unique contribution to workers' reports of fatigue (F=38.59, p<.01), bag type did not. This contribution of time held in the computations that included the quadratic for time, but time did not demonstrate significant variations in its impact on fatigue over the course of the season. The interaction term of time and bag type also did not make a significant contribution to fatigue over the season.

Table 6: Symptom reports for workers who remained in the study for the exit interview, and who used small (n=39) v. large (n=40) bags for harvesting lemons (2006).
(a) Symptoms by body region, listed as number reporting (percent)

	Baseline		Exit	
Symptom reports	Small bag (n = 39)	Large bag (n = 40)	Small bag (n = 39)	Large bag (n = 37)
- UE symptoms	3 (7.7)	1 (2.5)	2 (5.1)	2 (5.4)
- LE symptoms	8 (20.5)	3 (7.5)	5 (12.8)	2 (5.4)
- Back symptoms	10 (25.6)	10 (25.0)	13 (33.3)	14 (37.8)
- Neck/shoulder	5 (12.8)	7 (17.5)	9 (23.1)	10 (27.0)
- Rt UE symptoms	3 (7.7)	1 (2.5)	2 (5.1)	1 (2.7)
- Lt UE symptoms	1 (2.6)	- (-)	1 (2.6)	2 (5.4)
- Rt LE symptoms	7 (17.9)	3 (7.5)	3 (7.7)	1 (2.7)
- Lt LE symptoms	7 (17.9)	3 (7.5)	4 (10.3)	1 (2.7)

(b) Scores for musculoskeletal symptoms and fatigue, listed as mean, standard deviation, and median.

	Baseline		Exit	
Symptom reports	Small bag (n = 39)	Large bag (n = 40)	Small bag (n = 39)	Large bag (n = 37)
Composite symptom score	15.8 36.9 0.0	8.8 16.9 0.0	35.2 82.6 0.0	19.3 28.2 7.0
Fatigue score	2.5 0.9 2.0	2.3 1.3 2.0	3.1 1.2 3.0	3.1 1.2 3.0

The addition of covariates, and their interactions with time, however, suggested that the smaller bag had a differential impact over time for older, less experienced workers and those with a greater BMI. When them impact of age, and age over time, were accounted for, the interaction of time with bag became significant; similar results were found for experience and BMI (Table 7a-c).

For the musculoskeletal symptoms composite score, neither time nor bag made a significant contribution to the changes in symptom scores in the model that just included these and their interaction term. This was true for the model testing the quadratic form of time as well. In the models that included age, experience with treefruit, and BMI as covariates, the impact of including these terms and their interactions with time also did not produce significant results for any of the terms included. We also included fatigue as a covariate, this term also did not produce significant results. Thus, none of these models showed that the two types of bag differed in their impact on musculoskeletal symptoms.

Table 7: Multilevel regression final models for fatigue scores, using time, bag type, binomial interaction terms, and covariates.
(a) Age as a covariate

Parameter	Estimate	Std. Error	df	t	Sig.
Intercept	2.3024	.1476	263.843	15.596	.000
Time	.0582	.0120	224.805	4.842	.000
Bag	.3043	.1993	340.535	1.527	.128
Age	.1168	.0766	187.296	1.525	.129
Timexbag	.0349	.0171	253.208	-2.044	.042
Timexage	.0029	.0062	207.943	.467	.641

(b) Experience with treefruit as a covariate

Parameter	Estimate	Std. Error	df	t	Sig.
Intercept	2.2916	.1484	261.232	15.441	.000
Time	.0592	.0120	226.980	4.942	.000
Bag	.3246	.1985	338.646	1.635	.103
Exper	.0166	.0115	192.345	1.436	.153
Timexbag	-.0360	.0170	253.555	-2.115	.035
Timexexper	-.0014	.0009	224.196	-1.550	.123

(c) BMI as a covariate

Parameter	Estimate	Std. Error	df	t	Sig.
Intercept	2.3030	.1566	226.016	4.711	.000
Time	.0600	.0124	197.727	4.809	.000
Bag	.3048	.2053	300.532	1.485	.139
BMI	-.0142	.0398	164.513	-.358	.721
Timexbag	-.0301	.0176	223.807	-1.709	.089
TimexBMI	.0036	.0031	189.683	1.159	.248

We also tested models for changes in the frequency of reporting back pain and neck and shoulder pain, using time, bag type, the quadratic form of time, and their interaction terms. None of these models produced significant results.

Summary 2006*.* In 2006, we tested two types of bag used for harvesting lemons. We documented the demographics and work and symptom experiences of these workers, for comparison with work crews in other commodities in California agriculture. We were unable, however, to demonstrate significant differences for these two types of bag over the course of the season in terms of the severity of fatigue and musculoskeletal symptoms, with the exception of vulnerable workers. Nor did we see significant differences in changes in the prevalence of symptoms in the back and neck and shoulder regions related to bag type. We were challenged by the changing nature of the sample, as workers were hired, left the job for other settings, and returned intermittently for follow up interviews.

The 2007 Lemon Harvest Trial

Instead of pursuing the trial of combined interventions proposed in Specific Aim 3 (see below), we elected to put our efforts into refining the quality of the 2006 lemon study. Reasons for this modification included: (1) due to the winter storms, the lemon harvest started late and was unpredictable in its course and robustness, and (2) workers returning after the winter holiday were felt threatened by the national and statewide controversies over immigration legislation and surveillance. Many did not return to California after the holiday season, changing the overall industry dynamics of agricultural labor, employment practices, and compensation.

We employed the small bag again, and tested it against the larger, more standard bag. Bags were randomly assigned to volunteering workers and they were asked to retain and use these bags throughout the season.

<u>Sample.</u> Table 8 provides descriptive information about the workers enrolled in the study (n=104) at their baseline interviews. The majority were men with less than primary school education. Over half had 10 years of experience or more in California agriculture and 6 years or more in treefruit specifically. Most reported themselves to be in very good to excellent health. Information from workers participating in the baseline and exit interviews is shown in Tables 8 and 9. Workers using the large bags tended to be slightly younger and had had less experience with California agriculture and treefruit (Table 9).

<u>Symptom survey measure.</u> In 2007, we again utilized an adapted version of the survey we have used for 14 years with agricultural workers in California (Faucett, Meyers, Tejeda et al. 2001). Face to face interviews were again conducted using bilingual, bicultural interviewers. In the 2007 study of lemon harvest, workers were interviewed approximately weekly for the duration of the study (see Table 8 for dates).

<u>Analysis.</u> As in 2006, to utilize data provided by the entire sample, we used mixed model, multilevel regression analyses to assess the effects of the small bag and the large bag on changes in workers' reports about musculoskeletal symptoms and fatigue severity over the course of the season (SPSS, version 15.0; STATA, version 10). We also assessed changes in the frequencies of reporting musculoskeletal symptoms in each of the four body regions using multilevel logistic regression analyses (STATA, version 10). Bag use was tracked weekly. There was some exchange of bags among the workers, despite our efforts to reinforce the importance of the study; most workers, however, used the bags for a sufficient level of exposure to assess the outcomes. Each worker contributed data on symptoms for the amount of time he carried each bag (i.e. exposure to the bag). Thus, workers who remained in the study since early March and who were interviewed at each data collection point provided more data for analyses than workers who entered towards the end of the study. We examined the contributions

to these multilevel regression equations of time and bag, and also the quadratic of time to identify significant variations in the strenuousness of the work as the harvest waxed in mid-season and waned toward the end.

Table 8: Baseline demographics about 2007 lemon harvest crew members (n=104)

	Number responding	Frequency Number (percent)	Mean - SD - Median
Age (years)	103		
<20		9 (8.7)	
20-29		35 (34.0)	
30-39		14 (13.6)	
40-49		24 (23.3)	
50-59		14 (13.6)	
60-69		7 (6.8)	
Gender	103		
Male		101 (98.1)	
Female		2 (1.9)	
Education (years)	91		Mean 6.1 SD 3.4 Median 6.0
Length of experience: in California agriculture	101		Mean 12.3 SD 9.5 Median 10.0
Length of experience: in treefruit	101		Mean 10.2 SD 8.9 Median 6.5
Length of experience with this employer	101		Mean 5.9 SD 6.7 Median 3.0
Height (inches)	102		Mean 67.3 SD 1.9 Median 67.0
Weight (pounds)	102		Mean 164.9 SD 15.4 Median 165.0
BMI	102		Mean 25.6 SD 2.1 Median 25.1
How many hours did you work last week?	99		Mean 32.2 SD 4.7 Median 32.0
How good is your health?	102		
Excellent			40 (39.2)
Very good			44 (43.1)
Good			17 (16.7)
Fair			1 (1.0)
Poor			- (-)

Table 9: Demographics comparing workers using small (n=56) v. large (n=44) bags for harvesting lemons (2007), at baseline and at exit surveys.

(a) Age at baseline for workers using small and large bags

Age (years)	Small bag (n = 56)	Large bag (n = 44)
<20	4 (7.1)	5 (11.4)
20-29	10 (17.9)	22 (50.0)
30-39	8 (14.3)	6 (13.6)
40-49	20 (35.7)	4 (9.1)
50-59	9 (16.1)	5 (11.4)
60-69	5 (8.9)	2 (4.5)

(b) BMI and experience of workers using small and large bags, at baseline and exit.

	Baseline		Exit	
	Small bag (n = 56)	Large bag (n = 44)	Small bag (n = 49)	Large bag (n = 31)
BMI	(n = 55) 25.7 2.5 25.4	(n = 44) 25.3 1.5 25.1	(n = 48) 25.8 2.5 25.5	(n = 31) 25.2 1.3 25.1
Length of experience: in California agriculture	(n = 55) 15.0 9.9 15.0	(n = 43) 9.2 8.1 6.0	(n = 48) 15.8 10.2 15.0	(n = 31) 8.4 7.6 6.0
Length of experience: in treefruit	(n = 54) 12.5 9.6 10.0	(n = 44) 7.7 7.5 6.0	(n = 47) 13.0 10.0 10.0	(n = 31) 6.5 6.3 6.0
Length of experience: with this employer	(n = 54) 7.7 8.1 5.0	(n = 44) 3.9 3.9 3.0	NA	NA

Results.

Acquisition and retention of subjects. Workers were enrolled over three weeks in March and most were retained until the end of the study in April. Twenty-two were lost to the exit interviews; most of whom, anecdotally, had gone on to other jobs because of the unpredictable waning of the lemon harvest season. Table 10 demonstrates the numbers of workers who were enrolled, retained and followed up by the research team interviewers at the various weeks of the study, and their bag assignments.

As in the 2006 lemon study, we assumed that exposure to the small bag over a period of two weeks would be sufficient to detect a significant change in symptoms and most workers in the 2007 study participated for at least that length of time. Again, however, our inability to follow workers after they had left the work setting makes it impossible to define any 'healthy worker' effect, or determine whether workers left because they had sustained new injuries or found more lucrative jobs. It is notable that more subjects were lost to the large bag than the small bag condition.

Symptom reports. We compared the effects of the two bags on changes in symptoms (musculoskeletal discomfort and fatigue) over the main lemon harvest season. For the workers who were assigned to use the small or the large bag over the course of the study, Table11 shows the baseline and exit results for the reports of musculoskeletal symptoms by body region (upper and lower extremities – both right and left sides, low and mid back, neck and shoulders) and by composite musculoskeletal symptom scores, and also the fatigue severity scores.

In our first model, entering time, bag type, and their interaction only, time demonstrated a slight, but not significant, contribution to workers' reports of fatigue (F=2.79, p=.097), bag type was also not significant. The final model for fatigue, with the quadratic term included, is shown in Table 12. Time, as both the original term and the quadratic term, demonstrated trends for impact on fatigue, and fatigue also varied significantly by bag group. As demonstrated by the lack of significant outcomes for the interactions of bag and time, the progression of symptoms over the season did not vary with bag type.

Table 10: Enrollment, retention and bag assignment of sample (n = 104) over the course of the 2007 lemon harvest season.

	T0 March 6-9	T1 March 14-15	T2 March 20-23	T3 March 27-30	T4 April 3-6	Exit April 17-19
Total enrolled*	30	57	103	102	102	81
Newly enrolled		27	46	-	-	1
Followed up		30	57	100	97	80
Missed F/U		-	-	2	5	-
Drop-out		-	-	1	-	22
Total interviewed	30	57	103	100	97	81
Small Bag assignment	15	33	56	56	54	50
Large Bag assignment	15	24	46	43	43	31

* Excluded drop-out cases

Table 11: Symptom reports for workers who remained in the study for the exit interview, and who used small (n=56) v. large (n=44) bags for harvesting lemons (2007).

(a) Symptoms by body region, listed as number reporting (percent)

	Baseline		Exit	
Symptom reports	Small bag (n = 56)	Large bag (n = 44)	Small bag (n = 49)	Large bag (n = 31)
- UE symptoms	- (-)	- (-)	1 (2.0)	- (-)
- LE symptoms	7 (12.5)	1 (2.3)	5 (10.2)	1 (3.2)
- Back symptoms	23 (41.1)	11 (25.0)	7 (14.3)	7 (22.6)
- Neck/shoulder	12 (21.4)	8 (18.2)	3 (6.1)	6 (19.4)
- Rt UE symptom	- (-)	- (-)	1 (2.0)	- (-)
- Lt UE symptoms	- (-)	- (-)	1 (2.0)	- (-)
- Rt LE symptoms	6 (10.7)	1 (2.3)	2 (4.1)	1 (3.2)
- Lt LE symptoms	5 (8.9)	1 (2.3)	3 (6.1)	1 (3.2)

(b) Scores for musculoskeletal symptoms and fatigue, listed as mean, standard deviation, and median.

	Baseline		Exit	
Symptom reports	Small bag (n = 56)	Large bag (n = 44)	Small bag (n = 49)	Large bag (n = 31)
Composite symptom score	11.5 15.2 4.5	5.6 12.0 0.0	6.6 17.7 0.0	5.1 9.9 0.0
Fatigue score	1.9 0.7 2.0	2.2 0.6 2.0	2.2 1.0 2.0	2.3 0.5 2.0

Table 12: Final model of fatigue, using time, bag type, their interactions and quadratic terms.

Parameter	Estimate	Std. Error	df	t	Sig.
Intercept	2.1147	.0711	341.909	29.748	.000
Time	-.1696	.1040	401.150	-1.631	.104
Time2	.0513	.0262	388.609	1.959	.051
Bag	-.4456	.1306	395.466	-3.413	.001
Timexbag	.2038	.1329	408.159	1.533	.126
Time2xbag	-.0427	.0292	393.217	-1.463	.144

The final model for the random effects negative binomial regression for the musculoskeletal symptoms composite score, including time, the quadratic of time, bag type, and their interaction terms, is shown in Table 13. Time and its quadratic term showed significant findings, demonstrating the rise and fall of symptoms over the course of the season, regardless of bag type. In these equations, there is a trend for bag type to modify that symptom course, but this did not reach significance.

Table 13: Final model of the composite musculoskeletal symptoms score, using time, bag type, their interactions and quadratic terms.

(a) including the quadratic time by bag interaction term and the constant:

Parameter	Coef.	Std. Error	z	Sig.
Time	-.2481	.0576	-4.31	.000
Time2	.0961	.0409	2.35	.019
Bag	-.3280	.2917	-1.12	.261
Timexbag	-.1953	.1169	-1.67	.095
Time2xbag	.1233	.0843	1.46	.144
Cons.	-1.2009	.1562	-7.69	.000

(b) adjusting for the quadratic interaction term and the constant:

Parameter	Coef.	Std. Error	z	Sig.
Time	.8018	.0440	-4.03	.000
Time2	1.1056	.0473	2.34	.019
Bag	.9642	.2102	-0.17	.867
Timexbag	.8135	.0935	-1.80	.072

No significant findings were obtained for the multilevel logistic regression analyses of the frequency of back pain reports over the season or for the frequency of neck and shoulder pain reports over the season. Given the modest nature of these findings, we did not pursue further investigations of potential covariates.

Summary. Despite or because of the challenges of the unique employment environment in 2007 for these immigrant workers, we were better able to retain subjects in this second trial of the bag type. We again documented the demographics and work and symptom experience of this worker pool, modified somewhat from the previous year. Furthermore, we demonstrated significant variation in symptoms over the course of the lemon harvest season, although more so with musculoskeletal symptoms than with fatigue. We were unable, however, to demonstrate significant differences between the bag types in terms of their effect on the course of musculoskeletal or fatigue symptoms over harvest season, although trends were demonstrated for fatigue.

POWERED PLATFORM (PEARS)

California pear trees are among the tallest and largest of hand-harvested tree crops, often requiring 14-16' ladders. The intended advantage of the powered platform is to completely eliminate ladder use and risk altogether. For the pear harvest platform trial a Spanish built Argiles self-powered platform was provided by BlueLine Manufacturing of Yakima, WA. The machine required extensive modification by UC AERC staff to meet the demands of pear harvest.

Modifications included addition of hydraulically controlled vertically elevation power to increase maximum platform height, replacement of the dual front feeder conveyors with a single conveyor as wide as the main elevator, and modification the full-bin discharge system for use with plastic bins as opposed to the European standard wooden bins. When the machine arrived after being modified, initial pretrial tests mandated additional changes to the front conveyor and the addition of backside handrails on the up-down platforms. An additional emergency stop was also installed.

The machine crew number varied somewhat depending on the fruit load presented in each orchard. The machine had 6 picking positions, and a driver (who also managed replacement of filled bins). The crew also employed 1 to 2 pickers on the ground, again depending on fruit load presented. So, the machine can be operated with as many as 9 and as few as 4 crewmembers depending on orchard style and fruit load presented. In practice the machine varied between 4 and 6 pickers on the machine. Because of a late start to the harvest the machine crew could only be followed for 17 days. The machine was evaluated for ergonomics effects, productivity and fruit quality effects and worker/owner assessment of adoptability.

Orchard Characteristics

The machine operated in a total of four different orchards in the Kelseyville and Lakeport areas of Lake County. The orchards were dissimilar, as the following table suggests. The orchards of primary interest, numbers 1 and 2, had the most days.

Table 14. Orchard Characteristics

Orchard Characteristics	**1**	**2**	**3**	**4**
Distance between tree rows (feet)	17	12.5	12.5	14.5
Distance between trees (feet)	10	12.5	12.5	9
Maximum depth of foliage (feet)	4 to 5	2 to 3	3 to 4	4 to 5
Maximum height of fruit (feet)	13 to 14	14 to 15	16 to 17	14 to 15
Number of trees in a row (feet)	122	68	90	132
Number of breaks within tree row	2	1	1	3
Total length of row (feet)	1232	850	1125	1206
Drip irrigation	yes	no	no	no
Sprinkler irrigation	yes	yes	Yes	yes
Days worked in this orchard	7	7	2	1

Orchard pruning style made a significant difference in machine productivity performance. In most orchards trees were allowed to grow in a fully round shape. However in one orchard (2) trees had been pruned for several years to present a “fruit wall” facing the row. These trees had less foliage depth and fruit was much more readily accessible to pickers.

Fruit Wall Pruning

Productivity
There were significant grower concerns about the machine's speed and harvest productivity compared with experienced ladder crews. Comparable measures below for full strip picking compare the machine with 6 crewmembers to an experienced ladder crew of 11 members.

The ladder crew averaged 7.27 bins per picker per day or 10 bins per hour for the crew of 11. On the same task the machine crew averaged 5.46 bins per picker per day or 4.1 bins per hour for the crew of 6. In one orchard the ladder crew worked for 9 days, picking 720 bins. Applying the daily rates of 72 bins/day for the ladder crew and 32.8 bins/day rate above it would have taken the machine crew just about twice as long to complete the 720 bin total.

It must be kept in mind that the machine crew was approximately half the size of the ladder crew in this example. So harvest costs would be about the same as having half as many ladder crew workers do the job. Looked at on a worker per day basis this level of productivity makes the machine quite comparable to ladder crews in terms of harvest cost.

Two other factors enter the calculation for growers. The first involves the harvest period. Obviously, added ladder crews can reduce the time period involved for any given orchard, while adding machines where harvest period is a concern would increase costs in initial years. This issue made improving machine pacing a concern expressed by some growers.

Secondly, the high initial cost of the machine adds to cost figures for early harvest seasons. This cost would decline as the purchase cost is amortized. However, the cost situation is improved for the machine when use in annual pruning is added to the equation. Washington State University researchers reported an annual pruning labor cost reduction of 30% using a similar powered platform in apple orchards.
In addition to pruning, the platform can be used for other tasks in pear cultivation such as hanging pheromone ties and cutting out fire blight.

Night Harvest Trial
The machine was fitted with lights and operated at night for two night shifts. As with grape harvest, night operation proved quite successful and demonstrated some advantages over day harvest including: cooler fruit delivered to packing house, somewhat improved fruit quality, and extends machine operation time per day. Both workers and owners reported favorably on night operations.

Fruit Quality
Despite concerns about machine handling having negative effects on fruit quality, fruit quality results (summarized below) for pears indicate a very positive outcome:

- Machine had fewer punctures (6% vs. 14%)
- Machine and ladder scratches equal
- Most damage occurred in the packing house.

Ergonomics
The intent of the powered platform is to completely eliminate the use of ladders. This makes ergonomics comparisons with ladder work difficult, in that we are concerned for any new or newly emphasized risk factors presented to machine workers which might equal or exceed those presented by the ladder. In fact, the picking task on the machine is virtually the same, except for the elimination of the ladder and bag. Although pickers must still work at elevation, they are provided with fall barriers. The only two new risk factors resulting from machine assisted harvest are 1) vibration from the machine itself, and that 2) picking is now machine paced. These are not considered significant in the face of hazards removed or reduced through elimination of ladders and picking bags.

Ergonomics assessment of the machine harvest job compared with results for the ladder harvest job shows these differences in risk factor exposures.

Observed ergonomics risk factors recorded for ladder harvest include:
1. High Force/Weight
   Filled bags weigh from 70 to 80 lbs, suspended from one shoulder by a web strap
   Carrying and setting 30 # ladder
   Hand Twist/Pick 2-3# force
2. Contact Stress
   Continuous from bag straps
   Repetitive to hand from grasping pears
   Continuous to feet from standing on ladder rungs
3. Very High Repetition
   Up to 10-12 "picks" per minute, 100 per job cycle
   Up to 2-3 ladder moves per job cycle
4. Awkward Postures
   Awkward hand/wrist, back/neck postures in picking
   Repeated shoulder/trunk extensions to reach to pick
   Hunched shoulder positions from suspended weights
   Shoulder elevations to carry ladder
   Trunk flexion to empty bag.

Observed ergonomics risk factors recorded for machine assisted harvest include:
1. Low Force/Weight
   Lift/transfer pears to conveyer 2-4# force
   Hand Twist/Pick 2-3# force
2. Contact Stress
   Continuous to thighs or abdomen from leaning over fall barrier
   Continuous to feet from standing on platform
   Repetitive to hand from grasping pears
3. High Repetition
   Continuous but variable pick rate (range from 10-20 per minute to 5-6 per minute)
   Continuous but variable transfer to conveyor rate (parallels above rates)
   Machine determined pace

4. Awkward Postures
   Awkward hand/wrist, back/neck postures in picking
   Awkward whole body posture (twist) when transferring pears to conveyor
   Repeated shoulder/trunk extensions to reach to pick
5. Vibration
   Continuous vibration to feet, ankle, knees from machine floor

This comparison makes clear that there are significant reductions in Force/Weight and Contact Stress and Trunk Flexion exposures through eliminating the bag. Similarly elimination of the ladder reduces loads to carry ladder and Awkward Postures from eliminating need to "set" and remove ladders in tree foliage. There is a change from a voluntary repetitive pick rate to a machine paced rate. However, the fruit load facing workers on the machine varies, thus varying their rate of picking as the machine passes. There is an added Contact Stress exposure of some concern on the machine as workers lean out against the fall barriers to reach fruit. And there is an added Vibration exposure when working on the machine.

We believe, and workers and owner/operators agree, that the serious reduction of fall hazard from elimination of the ladder and elimination of high forces and awkward postures needed to manage picking bags are major injury prevention advantages.

Workers Adoptability Questions
Eighteen workers with extended experience on the machine were asked to respond to a series of adoptability questions used in previous projects. As Table 15 shows, their responses were quite favorable, with some concern for picking speed given that they often are faced with piece rate compensation. The interviews were conducted in Spanish by the same staff who conducted pain and symptom surveys.

Table 15. Worker Adoptability Responses (N=18)

	YES	NO
1. Do you think the machine is practical?	18	0
Advantages cited by these workers for the machine: feels more stable, don't get as tired, seems faster, don't have to carry ladder and bag.		
2. Is the machine better or are ladders better?	15	3
Workers citing preference for ladder system cited concern for speed combined with likely piece rate pay.		
3. Does the machine need changes?	14	5
Changes needed noted by workers: Needs a higher picking level, needs more vertical elevation on picking station, bin changing is cumbersome and slows progress, does not turn well slowing progress.		

Continuation
It should be noted that research on the use of the powered platform in harvest of fresh pears was continued after the end of this NIOSH funding with support from one of California's largest worker's compensation insurers and California Pear Advisory Board.

LADDER TRIALS (PEACHES)

Methods

Peach harvest differs from that of lemons or pears in terms of fruit handling. Peaches, being a soft fruit, must be harvested with extra care for bruising. As a result, no clippers are used. The peach is simply pulled off the branch. Additionally, peaches are carried in a small plastic bin or tub (approximately 10# filled) which is hung either around the neck or over one shoulder. The filled tub is usually left at a central point (usually a truck or trailer bed) and a new tub is attached to the shoulder strap. Otherwise the harvest work is similar requiring very similar ladder work.

Nearly all orchard ladders in use in California are industry standard 10 foot tall designs with 12 inch spacing between rungs. After a literature review of the mechanics of ladder use we decided to explore the effects of different rung spacing on worker ergonomics. In 2006, ladders were built with 8-inch, 9-inch, 10-in, 11-inch, as well as one with 13-inch rung heights, to compare against the 12 inch standard rung spacing.

Before alternative designs were evaluated by workers, a study of ladder kinematics was performed in the lab. The objective of the study was to evaluate selected body segment motions associated with ascending ladders having rung separations of 10, 11, 12 (standard), and 13 inches. The specific kinematics studied included: maximum ankle-shank angle, minimum thigh-trunk angle, range of lateral spinal bending, maximum sagittal spinal bending, and range of spinal twisting. Two standardized instruments were utilized to gather this information. The Motion Analysis Expert Vision software was used with Falcon high speed video cameras to describe kinematics as above. At the same time the Lumbar Motion Monitor was employed to assess the range of motion, and velocity and acceleration, placed on the spine as subjects climbed and descended each ladder. Data were taken from two subjects.

After laboratory evaluation the 10 and 11 inch rung spacing ladders were taken to the field (peach harvest) where 24 volunteer workers performed supervised sets of ascents and descents with and without loaded bags.

Based on results of this trial, in 2007 we conducted a field trial with 38 volunteer subjects using alternative ladders divided evenly between the 10-inch and 11-inch rung spacing designs. Workers used the same ladder during the course of a five week period and were not allowed to change ladders during the study, partially as a safety measure to protect against missteps resulting from different rung spacing. Worker feedback was collected each week for five weeks.

Results.
<u>2006 Preliminary inquiry</u>. In-lab studies of the kinematics of different ladder rung spacings were conducted using Motion Analyses and the Lumbar Motion Monitor. Results for minimum thigh trunk angle (Table 15) showed show a nearly linear decrease in angle between the 10 and 12 inch ladders, followed by a greater incremental drop for the 13 inch ladder. This indicates that either the torso is rotating further forward or that the knee is moving up higher or both.

Table 15. Minimum Thigh Trunk Angle

The ankle angle results in Table 16 below represents the angle included between knee joint center, the ankle joint center. The number specifically is the maximum included angle, which occurs right at the time of toe-off (or momentarily afterward actually as the gastrocnemius muscle is still contracting for ankle extension but load has been removed). The results show a highly linear increase in maximum angle, with an overall range of average maximums of approximately six degrees. This shows that for increasing rung separation, i.e., larger vertical step, there is increasingly more contribution to overall vertical motion by the ankle.

Table 16. Maximum Ankle Angle

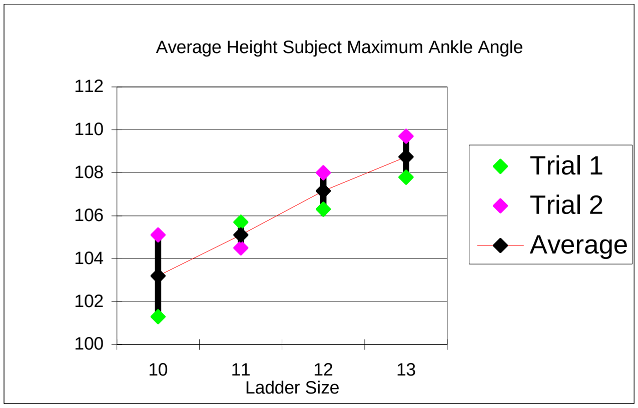
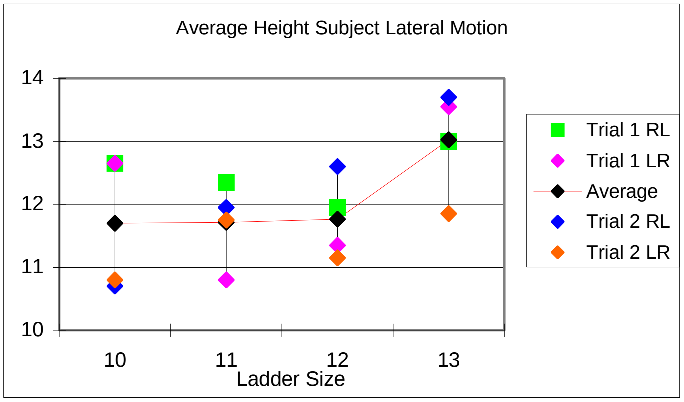


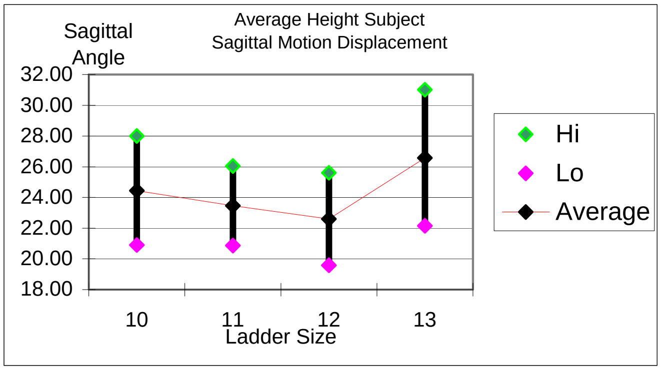
Table 17 below suggests that the amount of lateral bending as measured by the LMM is approximately the same for the 10, 11, and 12 inch ladders but is greater for the 13 inch ladder.

Table 17. Range of Lateral Angle



Sagittal bending of the spine is defined as the angle created between the L5/S1 joint and the T9 to T12 area on the upper back. This is different than trunk bending, and has different implications on vertebral loading. Table 18 below shows the average as well as the +/- one standard deviation (denoted by Hi and Lo) for each ladder. The chart shows an overall average spinal bending of 24 degrees, which could be considered significant bending, especially if maintained for a prolonged period. Of significant interest is the downward trend in maximum sagittal angle from the 10 inch ladder toward the 12 inch ladder and then followed by a large rise for the 13 inch ladder, which average is higher than the ‘Hi’ for both the 11 and 12 inch ladders.

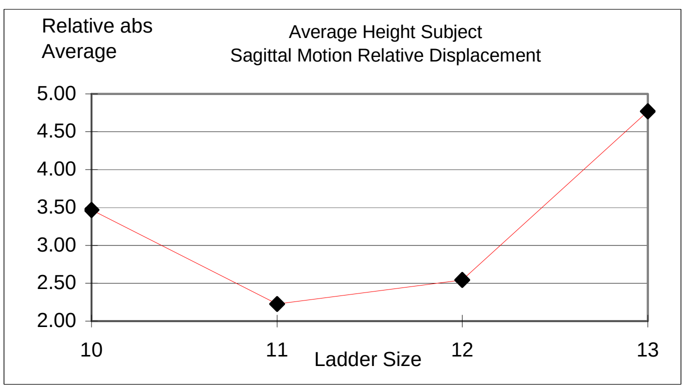
Table 18. Sagittal Motion



In order to try to further interpret the sagittal bending data, we calculated range of motion between the peak fluctuations, plotting the average range of motions for each ladder in the figures below. Table 19 below shows lower relative fluctuations for the 11 and 12 inch ladders at about 2.5 degrees, with the 13 inch ladder producing the largest fluctuation with a value of about 4.7 degrees.

The in-lab evaluations and initial feedback from our cooperators suggested that the 8-inch, 9-inch, and 13-inch designs should not be pursued. The 10-inch and 11-inch designs were selected, including an 11-inch design that included modified rung front-side edges that were bent so that their orientation was approximately vertical when the ladder was set for use.

Table 19. Sagittal Motion Relative Displacement



Field tests were conducted with 24 interested workers to ascertain if enough workers at our cooperating orchard company were willing to use an alternative ladder for a one-month long in-harvest study during the following season. Workers performed sets of supervised climbs and descents on a 10-inch, an 11-inch, an 11-inch with modified rung front-sides, and a standard 12-inch ladder in the orchard but away from the immediate area of harvest activities. Of the 24 workers who participated in the 20-minute long sessions, one worker preferred the standard 12-inch style, four workers preferred any of the four styles, four preferred the 11-inch style, six preferred the 11-inch style with modified front-side, seven preferred the 10-inch style, and two could not decide between 11-inch and 10-inch styles.

Results from weekly interviews with trial workers showed no negative feedback from any trial participants during the five-plus weeks of the study. Feedback from all participants was positive, with comments focused on reduced discomforts on the back and knees, and on improved stability. At the end of the trial only one worker indicated a preference for the standard 12 inch rung spaced ladder. The other workers voiced concern about was about returning to using the standard ladders after the trial was completed. One older worker with knee problems was particularly distraught one day near the end of the season when the ladders got mixed up and he had to use a standard ladder.

Increased ladder weight was not cited as a negative factor by any workers. In fact, one female worker, who was less than 5-feet tall, said she preferred to manage the extra weight of the ladder in exchange for having shorter rung distances. Workers noted a sense of improved stability on the trial ladders. This may result from reduced knee and hip flexion when stepping from one rung to another when either ascending or descending. Reduced flexion can result in reduced muscle exertions as a percent of maximum voluntary contraction. Such reduced flexion may provide a greater sense of control of movement. It also reduce the amount of hand pull a worker must exert on the side rails to help stabilize and support the body. It is also likely that the additional one or two rungs add to the ladders structural stiffness.

SPECIFIC AIM 3

We will scientifically test the impact of selected interventions combined together on targeted hand harvest risk factors.

Aim 3 was to have been achieved by assessing the combined effect of smaller picking bag use in lemon harvest combined with a rest break protocol previously shown to have positive effect on MSD pain and symptoms. However, maintenance of a satisfactory sample of farm workers in the course of work that is directly affected by weather is always a difficulty matter. We had experienced serious difficulties in 2006 in maintaining a statistically significant sample group together in the face erratic harvest demands raised questions about adding an additional sample. Discussions with cooperators as the 2007 season began made it clear that it would not be practical to proceed with the dual study. As a result the project plan was amended to focus only on securing and maintaining a significant sample for the bag study.

SPECIFIC AIM 4

To improve community-based understanding of ergonomics methods and improve intervention practices in hand harvest of treefruit.

METHODS

Aim 4 was achieved through ongoing communication with cooperators and their workers, through occasional news coverage, through regular reports to the Treefruit Safety Research Group (later subsumed by the Statewide Pomology Extension Continuing Conference), and through professional reports and papers presented by project investigators.

RESULTS

During the coarse of this project more than 1600 persons engaged in treefruit work participated in some aspect of this project and were provided information on MSDs, risk factors involved in their work and information about risk factor reduction. This audience included farm workers, owner/operators, and managers and supervisors.

Cooperators

The project's cooperators and their workers received the most information and had the additional opportunity to participate directly in project development and implementation. At minimum, participants received basic information on MSDs in the workplace and California OSHA's regulation applying to repetitive injuries. Those participating in intervention development and trials received training and information on MSD risk factor evaluation and control through direct participation in project implementation and decision-making with respect to their operations. They participated in regular direct interaction with project staff in both field settings and in regular cooperators meetings. Both directly participating workers and managers demonstrate understanding of these issues at a level beyond that one would expect of an "informed" practitioner.

Industry Community

The statewide treefruit industry community was provided with regular updates on the project by the project staff and investigators on both individual and community scales. Project investigators also participated annually at regional industry meetings. Other state and national industry presentations included:

Industry presentations

Duraj, V. Ag Engineering Developments, Western Center for Agricultural Equipment (program for group of 20 Chinese governmental and academic leaders), University of California, Davis, Dec 2009.
Duraj, V, Miles, J, Meyers, J, Faucett, J, Fathallah, F, Elkins R, Tejeda, D. "Harvesting Aids for Reducing Ergonomics Risk Factors in Fruit Orchards. Annual International Meeting, American Society of Agricultural and Biological Engineers, Reno, NV, June 23, 2009.
Elkins, R. Platform Harvester: Mechanical Harvest Aid for Labor Intensive Orchard Systems, California Pear Advisory Board, 2008
Elkins, R. Pear Platform Research Update. 2008 Sacramento River District Pear Research Meeting, Walnut Grove, CA. Feb. 14, 2008
Elkins, R. Pear Platform Research Update. North Coast Pear Research Meeting, Lakeport, CA. Feb.11, 2008
Elkins, R. Mechanized Platform Use in California Pear Harvest. 2008 Hood River Winter Horticulture Meeting, Hood River, OR. Feb. 6, 2008
Duraj, V. Agricultural Ergonomics, Western Center for Agricultural Equipment (program for group of 14 Chilean agronomists/growers), University of California, Davis, Aug 2007.
Duraj, V, Tejeda, D. Ergonomics 101, National AgrAbility Workshop, Oct 2007.
Duraj, V. Tree Fruit Orchard Ergonomics, Agricultural Safety Institute, Aug 2007.
Elkins, R, Glozer, K, Ingels, C. Modernization of California European Pear Orchard Systems,
Elkins, R. Modernizing California Pear Production To Meet Increasing Economic Challenges, California Pear Advisory Board, 2007
Elkins, R. Pear Platform Research Update. El Dorado & Amador County Growers Winter Tree Fruit Meeting, Placerville, CA. Mar. &, 2007
Elkins, R. Mechanized Platform Use in California Pear Harvest. Ontario Fruit and Vegetable Convention, St. Catherines, Ontario, Canada Feb. 21, 2007
Meyers, J. Ergonomics Job Analysis, Monterey, CA, AgSafe, Feb. 2007

Elkins, R. Pear Platform Research Update. North Coast Pear Research Meetings - 2 meetings - indoor and field meetings. Ukiah, CA. Feb. 15, 2007
Elkins, R. Pear Platform Harvest Research. 2007 Sacramento River District Pear Research Meeting, Courtland, CA. Feb. 5, 2007
Elkins, Rachel and Diana Tejeda. " The Platform Harvester: a Potential Labor-Saving Device for Labor Intensive Orchard Systems" presented on December 12, 2006 at the North San Joaquin Valley Cling Peach Seminar.
Elkins, R. Platform Harvester Research Update. Orchard Modernization Roundtable, Williams, CA. Dec. 2006
Duraj, V. Agricultural Ergonomics (program for group of Chilean agronomists/growers), Western Center for Agricultural Equipment, Nov 2006.
Elkins, R, Pear Platform Project Update. Sacramento Delta Pear Field Meeting, Courtland, CA, Oct. 2006
Duraj, V. Practical Ergonomics in the Packing House, UC Cooperative Extension, May 2006.
Meyers, J. Fathallah, F. Treefruit Hand Harvest Injury Prevention, Pomology Extension Continuing Conference, Davis, March, 2006
Meyers, J. Avocado Hand Harvest Injury Prevention, California Avocado Research Symposium, Keynote Presentation. Riverside, October 2005
Meyers, J. Platform Pear Harvest Trial, California Pear Advisory Board, Williams, April 2005
Meyers, J, Fathallah, F. Report on Treefruit Hand Harvest Injury Prevention, Pomology Extension Continuing Conference, Davis, March, 2005
Meyers, J. Treefruit Hand Harvest Injury Prevention, Citrus Research Board, Visalia, 2005
Meyers, J. Miles, J, Faucett, J. Progress on Treefruit Hand Harvest Project, Treefruit Safety Research Group, UC Davis, 2005
Meyers, J. Miles, J, Faucett, J. Establishment of the Treefruit Hand Harvest Project, Treefruit Safety Research Group, UC Davis, 2004
Meyers, J. Proposed Treefruit Hand Harvest Injury Prevention Project, Treefruit Safety Research Group, UC Davis, 2003

Industry articles

Mulhern, B. May 2007 – *California Fresh Fruit and Raisin News* – Clearly Communicating Hazards to Your Hispanic Workers
Mulhern, B. Oct. 2006 – *Growing* – Ergonomic Injuries: Reducing the risk among your hand-harvest workers
Mulhern, B. Sept. 2006 – *California Fresh Fruit and Raisin News* – Hand-Harvest Workers at High Risk of Ergonomic Injuries
Meyers, J. August 2006, California Farm Equipment, Farmers and Their Workers at High Risk of Back Injuries
Meyers, J. July 2006, Yuma Sun, Prevent Disabling Injuries in Citrus Hand-Harvesters
Mulhern, B. July 2006 – *The Harvester* – Identification of Hazards Key to Reducing Ergonomic Injuries
Mulhern, B. June 2006 – *American/Western Fruit Grower* – Micro Ergonomics: Researchers work to reduce costly injuries among tree fruit workers
Mulhern, B, June 2006, American Fruit Grower, Reducing Costly Injuries Among Tree Fruit Workers
Mulhern, B. June 2006, California Fresh Fruit Grower, Hand Harvest Workers at High Risk of Ergonomics Injuries
Meyers, J. June 2006, Capital Press Agriculture Weekly, California Agricultural Workers at risk of Lifting Related Injuries

Professional Papers

Faucett, J. Keynote. California State Association of Occupational Health Nursing, San Francisco, 2005.
Meyers, J. Ergonomics in California Agricultural Production, Actualizacion Tecnica en Prevencion de Riesgos Laborales para el Sector Fruitocola, Santiago, Chile, June 2006
Meyers, J. Ergonomics in California Agricultural Production, Asociacion Chilena de Seguridad, Santiago, Chile, June 2006
Fathallah, F. California Labor-Intensive Agriculture: Health Effects and Interventions, American University of Beirut, Beirut, Lebanon, October 2006

Fathallah, F. Keynote Presentation: Ergonomic Interventions in California Intensive Agriculture, Omaha, Nebraska, November 2007
Fathallah, F. Keynote Presentation: Overview of Agricultural Ergonomics Activities in California and the US, Agricultural Ergonomics Development Conference- 2007. Kuala Lumpur, Malaysia, November 2007.
Miles, JA, Meyers JM, Faucett JA, Fathallah F, Elkins R, Tejeda DG. Harvesting Aids for Reducing Ergonomics Risk Factors in Fruit Orchards. American Society of Agricultural and Biological Engineers Annual International Meeting, Reno, Nevada, USA, June 21-24, 2009.
Fathallah, F. Agricultural Ergonomics Research at UC Davis: Past, Present, and Future, Western Center for Agricultural Health and Safety, Davis, CA, May 2008.
Fathallah, F. Ergonomic Interventions in California Labor Intensive Agriculture, American University of Beirut, Faculty of Health Sciences; January 2008.
Fathallah, F.A. (2008). University of Iowa College of Public Health-Great Plains Center for Agricultural Health. Web-based seminar on: “Ergonomic Interventions in California Labor Intensive Agriculture.” October 7.

Publications
Fadi A. Fathallah, Meyers JM, Faucett J, Miles JA, Duraj V, and Janowitz I. Three Approaches to Reducing Musculoskeletal Symptoms in Hand Harvest of Treefruit. The 17th Congress of the International Ergonomics Association, Beijing, China, August 9-14, 2009.

Fathallah, F.A. (2009). Agricultural Ergonomics and Musculoskeletal Disorders: Historical and Future Perspectives. Keynote Presentation Paper in Proceedings of the International Ergonomics Association 17th World Congress on Ergonomics. Beijing, August 9-14.

Fathallah, FA, Meyers JM, Chapman LJ, and Karsh B-T (2006). Ergonomic Industrial Interventions: Agriculture. In Marras, W.S., and Karwowski, W. (Eds), the Occupational Ergonomics Handbook: Second Edition. London: Taylor and Francis CRC Press.

CONCLUSIONS

This project’s goals of identifying and describing ergonomics risk factors involved in hand harvest of treefruit; of developing and evaluating controls that eliminate or reduce targeted risk factors, and of scientifically assessing the impact of interventions were met. Important information on the development and use of alternate work practices and technologies was demonstrated to both the industry and to interested professionals.

Priority ergonomics risk factors involved in hand harvest of treefruit include: 1) Very high repetition of hand closure for cutting; 2) awkward postures from picking at heights with loads: and 3) high forces and awkward postures while ascending and descending ladders with loads. Of these, both owner/operators and workers’ compensation insurers rate work on ladders by far the most serious in terms frequency, severity and cost of serious work related injuries. This should put development of practical means of preventing falls from ladders higher on the list of priorities for both equipment and safety researchers.

As with other hand harvest California commodities, there is little in the way of readily applicable alternatives to the ubiquitous hand clipper. While powered clippers exist, none are small enough or nimble enough for use in most hand harvest work. Further there appears to be little research on small powered clippers for highly repetitive cutting tasks that are not assembly line based. There is also reason to suggest additional research into new alternative cutting technologies such as vibrating cutters, new ceramic cutters, etc.

Initial research reported here and elsewhere on ladder design, especially alternative rung spacing, shows promise of both improving ladder stability and of reducing stress on vulnerable joints. This is work that needs additional applied research funding since it is unlikely that private concerns will undertake it due to the liability issues involved. This project reported clear benefits to workers of average size from use of ladders with alternative rung spacing (10" and 11"). Those benefits included: improved kinematics, reduced stress on joints (knee, ankle), and improved stability.
This study, combined with existent research, makes clear that there is good reason for new research on ladder design. As noted above, liability risks militate against ladder producers undertaking the work or even adopting new designs without clear scientific evidence of their superiority. The need for this work goes well beyond agricultural work to a wide range of industries.

Powered platforms are used widely in Europe for a variety of tasks including harvesting, pruning, and other tasks. In the US, they have been developed in larger sizes for specialty crops like lettuce, strawberries, apples, etc. Northern California fresh market pear growers face a difficult situation combining unpredictable harvest labor shortages and the use of very tall ladders (14'-16'). Use of a specially adapted powered platform was intended to completely eliminate ladder use and risk altogether.

The platform machine functioned as designed throughout several pear harvest seasons. The platform achieved its primary goal of enabling a practical means of harvesting fresh pears without the use of ladders. While workers are still working at an elevation, their footing is much improved and anti-fall measures (barriers) were applied. The platform also enabled achievement of the project's secondary goal of eliminating the necessity of using large and heavy harvest bags. Instead, easily reached conveyors are placed between workers for depositing fruit as it is picked. Elimination of these two significant risk factors virtually transforms the job. High rates of repetitive hand work remain as do awkward postures from reaching into trees, but the risk of falls is significantly reduced.

Requiring a crew of from 5 to 9, the platform was able to achieve up to equal harvest productivity levels of those of a ladder crew of the same size. At the same time, platform harvested pears arriving at the packing house showed less harvest damage than those from ladder crews. Additionally, powered platform use in annual pruning has demonstrated significant labor cost reductions. Finally a majority of workers generally liked the platform and expressed a preference for being able to work without ladders.

With an estimated commercial cost of $60,000 to $80,000, most participating growers felt that improving platform field speed would be important to widespread adoption. However, given California's uncertain farm labor market, a significant harvest labor shortage could overcome these concerns. An important outcome is the fact that continued research and development of the powered platform project was funded by local worker's compensation insurers and the California Pear Advisory Board.

The major element in this overall project was the trial of smaller picking bags in lemon harvest. The AERC had shown significantly reduced MSD pain and symptoms with substitution of smaller picking tubs in grape harvest work in an earlier NIOSH-funded study. In that study, the experimental tubs averaged a weight of 46# while traditional larger tubs averaged a weight of 57#. In field practice, lemon harvest bags proved to be significantly larger and heavier averaging some 85# when filled. Smaller bags in use by some labor contractors and growers were found to average 65# when filled. Actual field measurements showed that the bags' average weights were somewhat less, averaging 74# and 57#, respectively. While these bags were still significantly heavier than those used in the previous study, they were adopted for this trial given their acceptability by both cooperating employers and workers.

Results for the field trial suggested a reduction in reported fatigue using the smaller bag, (especially for vulnerable workers in 2006), but which was not consistently statistically significant. In an analysis using a model including negative binomial regression for the composite symptom score, including time, the quadratic of time, bag type, and their interaction terms, time and its quadratic term showed significant findings, demonstrating the rise and fall of symptoms over the course of the season, regardless of bag type. In these equations, there is a trend for bag type to modify that symptom course, but this did not reach significance. No significant findings were obtained for the multilevel logistic regression analyses of the frequency of back pain reports over the season or for the frequency of neck and shoulder pain reports over the season.

While these results would seem to run contrary to those of our earlier work with smaller orange harvest picking bags, we believe that there is another factor at work. Our previous study was initiated by research published by Davis and Marras (2000) suggesting that loads at or exceeding 55 pounds were found to cause significantly more spinal loading and physical stress. In their words, "there appeared to be a weight threshold at 25 kilograms [55 pounds] at which spinal loads became increasingly risky."

This current study using lemon bags showed distinct movement in reported levels of fatigue and for MSD symptoms toward reductions when using the smaller bags. However, the failure to reach levels of statistical significance might well be due to the fact that the smaller bags did not reduce average loads below the predicted 55# threshold. While this remains conjecture at this stage, the juxtaposition of results from the two studies seems to support the effect of a threshold factor. Further study will be required to prove the existence of such a spinal loading threshold and at what load levels it and how it comes into effect on factors such as fatigue and injury symptoms. In the final analysis, we believe that this study adds further, if small, support to the idea that reducing loads (especially those over 55#) will result in reduced MSD risk.

It is possible that in the lemon trials we failed to identify realistically the balance of rest and work during the daily shift, to appreciate the variations in workload across a given day, or to understand the attrition of workers and the potential of the healthy worker effect to impact our findings over the whole study period. Any of these would have altered our results on symptom outcomes. More research should be pursued to better document the course of symptoms over the waxing and waning season of lemon harvest and to identify how workers manage their fatigue and musculoskeletal symptoms to sustain their work.

Furthermore, we attempted to maintain bag assignments, but could not force workers to stay with their assigned bags; a minority changed bag types several times. Thus, we analyzed data based on exposure to bag type rather than on random assignment. Although it is reasonable to assume that bag changes were often due to variations in symptom severity, there may be other reasons that workers elected to use one bag over another on any given day. It is also possible that contractors retained workers that they might otherwise have let go because of the tenuous nature of the labor environment in California agriculture in early 2007. Despite our many years of ergonomics research in the agricultural industry of California, we have gained a great respect for the unique labor environment of tree fruit harvest and the challenges it presents for traditional research intervention trials.

FUTURE RESEARCH

Future research needs fall into three general categories. First, and most important, is a need to increase priority for field application of ergonomics methods and technologies to agricultural practice. Funding for this work has been declining in favor of epidemiological and educational approaches, which have not demonstrated the preventive impact of field application studies.

Second, work on technology needed to make significant engineering improvements to high risk jobs. The example demonstrated here of the adaptation of an existing powered platform to the specific needs of fresh pear harvest provides a good demonstration. This is work that is beyond the financial resources of either the involved growers or of the small machine production companies who could only look forward to small numbers of sales even if the pear machine were widely adopted. The problem of lack of funding for technology adaptation is further demonstrated by the work on alternative ladder designs reported here. It has been made abundantly clear to us by cooperating ladder manufacturers that they will not undertake major ladder redesign without clear scientific evidence supporting such changes due to their concerns for worsening a currently perceived “stable” liability situation. This work will likely not go forward without increased public funding. Finally, the problem of highly repetitive hand cutting and a clear lack of applicable alternative cutting technologies persists. There must be more integrated work between engineering development research and field application work on high priority problems for prevention improvements across commodities in agriculture. The notion prevailing in some quarters, that all necessary fundamental technological needs have already been developed, needing only minor adaptation is absolutely false. This is especially so, in terms of the agricultural industry.

Third is the need to make prevention of musculoskeletal disorders the highest priority in farm safety. There is no question but that MSDs are by far the most prevalent and costly disabling injury in the industry. However, most organizations supporting this work do not appear to recognize either this fact or the fact that the hazards involved can be readily addressed. Instead, prevention priorities continue to focus on pesticides or other issues with more apparent political appeal.

REFERENCES

Meyers, J, Miles, J, Faucett, J, Fathallah, F, Janowitz, I, Smith, R, Weber, E. (2005) Smaller Loads Reduce Risk of Back Injury During Wine Grape Harvest. California Agriculture 59(4):25-31.

Davis, K.G., and Marras, W.S., (2000), Assessment of the Relationship Between Box Weight and Trunk Kinematics: Does A Reduction in Box Weight Necessarily Correspond to a Decrease in Spinal Loading, Human Factors, 42(2), 195-208.

Baugher, T., Schupp, J., Lesser, K., Harsh, R.M., Seavert, C., Lewis, K., Auvi, T. (2009). Mobile platforms increase orchard management efficiency and profitability. International Society for Horticultural Science Acta Horticulturae 824: International Symposium On Application Of Precision Agriculture For Fruits And Vegetables.

Hignett, S., McAtamney, L. Rapid entire body assessment (REBA); Applied Ergonomics. 31:201-205, 2000.

Faucett, J., Meyers, J., Tejeda, D., Janowitz, I., Miles, J., Kabashima, J. An instrument to measure musculoskeletal symptoms among immigrant Hispanic Farmworkers: Validation in the nursery industry. Journal of Agricultural Safety & Health, 7(3): 185-198, 2001.