HARVESTING AIDS FOR REDUCING ERGONOMICS RISK FACTORS IN WINE GRAPE HAND HARVESTING

by

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Summary:

Three wine grape harvesting aids for reducing ergonomics risk factors in hand harvest operations were designed and tested. These included a smaller picking tub with add-on grip enhancements, a lightweight frame to locate the picking tub 10 inches (25.4 cm) above the ground, and an alternative picking-knife handle. The smaller picking tubs were tested as the primary intervention in a two-season-long trial that included pre- and post-season health reviews comprised of first aid reports, OSHA 200 logs, and individual worker symptom surveys. Results and observations pertaining to the tubs indicate significant reduction in pain symptoms, minor change in productivity, general worker favor, and widespread adoption. Pilot trials of the tub stand and knife handles showed potential long-term adoptability and are encouraging further development work.

Background:

The California winegrape industry employs over 31,000 workers, many of whom perform labor intensive tasks. In northern California's Napa and Sonoma Counties, which account for nearly half of all winegrape acreage in the state, much of the harvest is still performed by hand because of hilly terrain and winemaker preferences. Hand harvest work is physically demanding and exposes a large workforce to high risk factors for musculoskeletal disorders (MSDs). This University of California ergonomics research project, with funding from the NIOSH Community Partners for Healthy Farming program, worked with winegrape vineyard farmers and farm workers to demonstrably reduce risk factors for identified MSDs.

A review of the health records for MSDs for a thirty month period among 194 workers of three cooperating vineyard companies showed that back injuries predominate and that "lifting during harvest" and "tractor/equipment" predominate reported causes (Meyers et al., 1998). Representing 435 lost workdays, there were 29 MSDs defined for 28 workers. While the sample of vineyards was not randomly selected and may not be fully generalized to the industry, a suggested rate of incidence of 80 per 1,000 workers is many times higher than 60 per 100,000 targeted by the US Public Health Service in Healthy People 2000 published in 1991.

Project cooperators participated fully in project decision making and provided full access to their OSHA200 logs, first aid reports, and workers. All cooperators have active injury and illness prevention programs. Provision of worker's compensation insurance benefits is required in California. Participating operations were all mid-size by industry standards and account for more than 200 permanent employees at the involved work sites (seasonal employees were not included as a means of minimizing subject loss over the course of the study). This industry is almost completely non-union in California, and there was no active union representation at any of the cooperator sites. The majority of workers in these operations are Spanish-speaking, from Mexico. They earn an average of about $8-10 per hour. Vineyard work is considered a comparatively good job by most California farm workers because it is relatively well paid and, at these sites, includes health benefits.

In order to identify job tasks involving high risk for exposure to ergonomics risk factors, a three-part strategy was implemented as follows:

1. cooperators' injury and first aid records were reviewed for reported MSDs and injuries determined to be likely MSDs in development;
2. all jobs were described and screened for ergonomics risk factors using a check sheet method used in previous studies (ANSI Z365); and,
3. workers and supervisors were asked to identify jobs deemed especially physically difficult or demanding.

This information, along with cooperators' estimates of worker exposure in terms of number of workers and duration of job task, was used to jointly select the hand harvest job for primary ergonomics intervention focus. The intervention turned out to be a smaller picking tub with improved grips. A tub stand and alternate picking knife handle were pilot tested only and did not affect workers participating in the season-long intervention trials.

The predominant picking tub currently in use throughout the industry is pictured in Figure 1. It is 24 inches in width, 16 inches in length, and 8 inches in depth. When full of grapes the tub weighed a season average of 57 pounds (25.5 kg) and could exceed 70 pounds (32 kg) depending on grape variety and tub loading. By contrast, the recommended weight limit for this kind of task, calculated using the Revised NIOSH Lifting Equation (Waters et al., 1993), is 16.8 pounds (7.6 kg). Another guideline (Mital et al., 1989) suggests a weight limit of 31 pounds (14 kg).

Figure 1: Worker holds partially full large tub.

The hand harvest job cycle lasts from 2 to 4 minutes. It generally consists of cutting grapes from the vine and dropping them into the tub, stooping to move the tub to the next position or to gather errant leaves and grapes, and carrying the filled tub to dump the cut grapes into trailer-mounted bins for transport. When cutting, the worker stands facing the vine, reaches in with the non-dominant hand, grasps a grape cluster, and cuts it free with a curved knife held in the dominant hand (Figure 2). The worker must constantly alter his/her body position, involving all joints of the body to see, reach, cut, and dispose of the grape clusters. Body position is different depending on the height and style of the trellis, the amount of leaves remaining on the vine, and worker height and personal preference (Figure 3).

As the worker moves along the vine to reach new clusters, he/she must either stoop to lift and place the tub in a new location or push it with a foot to slide it along with a sideways leg movement (Figure 4). Pushing the tub with a leg becomes too difficult and is avoided when the tub becomes one third to one half full. The worker may stoop or remain stooped to remove errant leaves or to gather grapes that missed the tub.

Figure 2: Worker prepares to cut grape cluster.

When the tub is full, the worker stoops to lift it, carries it to the tractor/trailer, and dumps the grapes into the bulk transport bin at a height of four to five feet (122 to 152 cm). Workers often carry the tubs overhead, which involves using a thigh to help accelerate the tub upward, changing the grip at mid-chest, and then combining arm, shoulder, back, and leg muscles in a coordinated thrust to propel the grapes to a particular area of the bulk bin (Figures 5 & 6). The same actions are usually required if the tub is carried at waist height and then lifted at the bulk bin.

Figure 3: Worker in stooped position while harvesting.

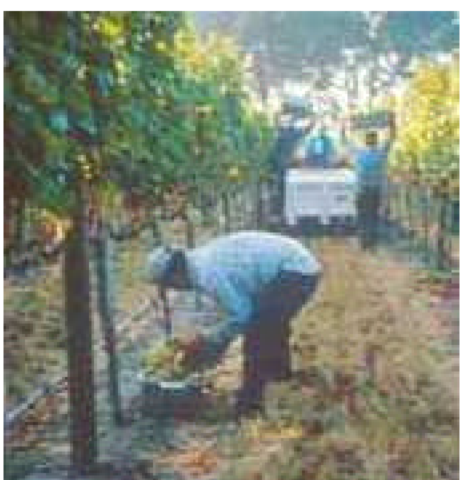

Figure 4: Worker is bent to remove leaves and move tub.

Figure 5: Worker empties full tub into 4-by-8 foot steel bulk bin.

The harvesting crew spreads out across at least three rows and works to fill the bulk bin being towed by a tractor in the middle row. Many of the crewmembers must somehow transport their full tubs of grapes into the middle row. Depending on trellis and other vineyard characteristics, a worker may have to bend under a vine, step over an irrigation line but under the vine, or carry the bin through foliage in order to reach the middle row. Frequently the workers in the adjacent rows dump their full tub by literally throwing themselves against the vine with their full tub held in outstretched arms above their head. The vine can be up to 7 feet (214 cm) high and is supported by a steel horizontal wire. An alternate way employed by various crews is to slide full tubs under the vine in exchange for another crew member's partial or empty tub. This means some workers have to lift a higher number of tubs per shift than do other workers.

Figure 6: Worker empties full tub into 4-by-4 foot 3-count plastic bulk bin transport. Bins, as shown here, are occasionally in headlands.

Ergonomics risk factors in the manual handling of cut grapes include:

- Highly repetitive gripping, using a knife to make 25-50 cuts per minute
- Sustained trunk flexion (forward bend) of 20-45° for about 30 seconds at a time while cutting
- Severe trunk flexion (forward bend) of up to 90° for several seconds several times during each cycle when stooping to move the tub, remove leaves, or gather grapes
- Manually lifting and carrying an average 20 tubs per hour, averaging 57 pounds (26kg) each
- Contact stresses on hands from knife handle and from tub handles
- High metabolic demands: Average working heart rate of 125 beats per minute, with average energy expenditure of 47.7% aerobic capacity.

Although the health survey did not uncover a significant MSD incidence related to the picking knives other than minor cuts, the fact of little evolution in knife technology presented an opportunity to at least confirm the acceptance of the existing tools. The two existing picking knife handle styles have been around for a long time. The round wooden style remaining has apparently remained unchanged for decades, and the popular plastic handle style is in wide use (Figure 7).

The round wooden handle style dates back perhaps 30 years, and the molded plastic style has been around for quite a while and is really the only alternative stocked in the local vineyard supply stores. The curved blade can be either serrated or smooth depending on worker preference. The smooth ones are easier to sharpen. The round wooden handle provides a symmetry that allows the worker to easily reposition the knife blade according to need. The plastic handle has a slip-resistant texture. Both knives include a hole at the handle end used to loop a leather string that goes around the workers wrist and serves several purposes. The string prevents knives from getting lost in bulk bin transport containers; the knife can be released without dropping when the worker needs both hands for a quick job; and the string can be used to harness additional pulling power.

Figure 7: Existing wooden handle (left) and plastic handle (right).

An interesting feature of the plastic handle is its asymmetric shape. It appears, but was not able to be confirmed in this study, that the contoured side of the handle should rest against the palm of a hand, but this orients the blade to the outside of the worker or away from the other hand. In theory this may serve as a safety feature to prevent cuts. However, in practice it was observed that the worker holds the handle the other way so that the blade is oriented to the inside or to the other hand, or the worker will hold it pointing straight away, depending on the grape variety and trellis design.

Methods:

The method utilized was the interactive approach often described within Land Grant University circles as the Cooperative Demonstration Method. This method has developed in practice over the decades since its emergence in the early part of the Twentieth Century. Fundamentally, it is predicated on the idea that individuals are more likely to attend to and eventually adopt practices which either they themselves or persons they identify as counterparts are engaged in trying in the context of their own business operation. While there are a variety of more detailed analyses of the process of practice adoption by individuals and communities (Rogers, 1983), the cooperative demonstration has remained central to most successful Extension practice.

The cooperative demonstration consists of enlisting community partners external to the research and education establishment and essentially conducting a field-based research trial directed by academic staff, but implemented by the cooperating partners themselves. The results are jointly evaluated and generally the entire community is invited to observe both the trial and its evaluation. Over decades of practice this approach has evinced two distinct advantages over most other methods of introducing practice change into communities which are not already motivated to seek the practice in question. First, because the trial is field-based and implemented by a practitioner instead of being laboratory-based, modifications on the initial theoretical approach are almost always made to fit the practice to the field operations context. This inevitably makes the resulting practice or technology model more successful in use. Practitioners add to both understanding and technology when given a chance. Second, this approach has proven immensely powerful in introducing and stimulating acceptance of new ideas and technologies in a wide variety of community types, especially where there was no pre-existing demand for or even interest in the specific technology involved.

This approach dictates the recruitment of partners who are capable of undertaking implementation of the trial envisioned and who are willing to act as full partners in the development, implementation and evaluation of the trial. In this case, both owner/operators and workers were identified as partners. Full partnership in this context means that the partners share authority and expertise throughout. While this approach is old, it is finding new application in occupational settings under the label of community-based action-oriented research (Sclove, Scammell, Holland, 1998). Once partners are recruited, trial development, implementation and evaluation proceed with shared decision-making throughout and preferably in a context open to community observation and review.

The methods demonstrated in this particular trial consist of methods for:

a) identifying ergonomics risk factors,
b) identifying MSDs and MSD symptoms among Hispanic farmworkers,
c) applying engineering principles to the development of mechanisms for reducing risk factor exposure, and
d) evaluating the efficacy of changes in practices and technology to reduce both risk factors and MSDs and their symptoms.

Ergonomic Methods

In order to identify job tasks involving high risk for exposure to ergonomics risk factors, a three-part strategy was implemented as follows:

a) cooperator's injury and first aid records were reviewed for reported MSDs and injuries determined to be likely MSDs in development;
b) all jobs were described and screened for ergonomics risk factors using a checksheet method used in previous studies (ANSI Z-365); and
c) workers and supervisors were asked to identify jobs deemed especially physically difficult or demanding.

Health Effects Methods

The assessment of occupational MSDs related to ergonomics intervention in the agricultural setting is difficult for several reasons. First, work-related MSDs sometimes take months or years to develop and it is unlikely that significant results would be shown in terms of reportable or diagnosable injuries given the duration of this study period. The oversupply of labor in this industry also provides a disincentive to report occupational injury to employers. Additionally, a class/cultural propensity to disregard physical discomfort, and when in discomfort to utilize self or home remedies in place of seeking help from organized community health care systems, made it unlikely that health records would provide an accurate picture of MSD incidence. To enhance our power to test differences in musculoskeletal outcomes we employed a musculoskeletal pain and symptoms survey developed and used in our prior studies. This is a Spanish questionnaire compatible with the cultural, linguistic, and educational characteristics of Mexican field workers who have immigrated to work in California (Faucett, et al.).

The interview uses previously tested measures of pain severity, location, and duration and includes items to assist with determining the work-relatedness of the symptoms. The FACES Scale, for example, initially validated for measuring pain among multicultural pediatric populations, was chosen by agricultural workers to evaluate their pain severity. Similarly, the body diagram used to indicate pain location is one commonly used by other NIOSH researchers investigating musculoskeletal discomfort and has been used before by Dr. Faucett, but the symptoms to be identified are those suggested by the agricultural worker population.

The Spanish translation of the interview has undergone extensive forward and backward translation to ensure the appropriateness of the vocabulary and syntax for agricultural workers from the population to be evaluated.

This questionnaire was administered to all cooperating permanent workers pre- and post-harvest in 1997 (pre-intervention) and 1998 and 1999 (post-intervention). Two post-intervention observations were conducted because 1998 was an El Nino year, and harvest yields could have been abnormal.

<u>Engineering Intervention Development Methods</u>

Once priority job tasks for intervention were agreed upon, design constraints for intervention development were developed. Among design constraints employed were the following:

1. Isolate problems that all parties agree are problems.
2. Look for opportunities to do things which will have a positive effect on allowable load as per the NIOSH Lifting Guideline (Waters, et al, 1993)
    a) improve coupling (grip)
    b) reduce moments (lift with load closer)
    c) improve posture (less bending and twisting)
    d) reduce lifting frequency
    e) reduce the amount of force required (change the size of a "load").
3. Concentrate on engineering interventions by providing tools and procedures that will automatically meet objectives above, without extensive training or behavior modification for workers.
4. Recognize fiscal constraints associated by vineyards with engineering changes; concern for large capital expenditures, preferred focus on inexpensive solutions with the potential for short pay back periods.
5. Consult with workers in the field on design and prototype development and testing.

In addition one other fundamental constraint was added. This was a commitment to avoid or minimize job displacement for vineyard workers involved in the selected tasks.

As development concepts were defined, they were shared with cooperating workers and managers for feedback. At each stage in the development process, prototypes and pilot versions were brought to the field for examination, assessment and feedback by cooperators. This highly interactive process resulted in important insights for engineering faculty and significantly improved project collaboration and eventual acceptance of the interventions proposed.

Productivity and Acceptability Methods

Innovations in equipment, process or practice are usually adopted because they have a demonstrated positive impact on productivity, an impact sufficient to offset their costs in both economic and social terms. The establishment of complete cost-benefit analysis with respect to occupational health and safety is a more complex matter involving the true costs of injury and illness (Oxenburgh, 1994). However, most employers give priority to the simpler question of an innovation's impact on crude productivity as it is normally calculated in their workplace. Most often this will involve observations of worker or process productivity before and after implementation of the innovation. In order to facilitate innovation adoption in the workplace, we are primarily concerned here with the productivity assessment of interventions as evaluated by workers and managers.

While surveys were planned to assess adoptability and acceptability intentions in some detail, these were ultimately set aside when it became clear that all cooperators had adopted the smaller picking tub on a permanent basis. Adoption in action is the strongest evidence of an intervention's appeal. This speaks directly to both worker and management acceptance and obviated use of planned attitude surveys.

Cooperator's adoption actions notwithstanding, productivity impact of both interventions was assessed. In the harvest intervention trial, this took the form of assessing tons of grapes picked by participating crews on a daily basis. Tonnage picked and delivered to the winery is a figure regularly measured by all cooperators. Because the crop yield was lighter in 1998 than it had been in 1997 due to the El Nino weather effect, it was decided to apply for a no-cost project period extension to allow for collection of yield data in 1999.

Interventions:

The health, risk factor, and operations information obtained from the cooperators or generated by the research team were used to jointly select the hand harvest job for targeted intervention work. It was clear that the hand harvest job involved a very high number of past injuries and of risk factors and symptoms for future injuries. Moreover, the hand harvest job applies to over 90% of the worker population during the typical 8-10 week harvest season usually including all of August and September. The intervention selected for full-scale trial was simply a smaller picking tub. A tub stand and alternate picking knife handle were explored and tested on a pilot basis only.

Though not described in this paper, work was also done in the area of pruning, which occurs from January through March, and in hoeing and weeding, which occurs from April through May for certain vineyards. However, for reasons including capital costs, only powered pruners were studied in a limited intervention trial. The tests concluded that powered pruners could be advantageous in certain situations.

Smaller Tub

Several smaller tubs were subjected to field trials with workers during the 1997 harvest. It quickly became clear that any smaller tub must have the same structural strength and rigidity as the larger tubs. Less rigid tubs tended to buckle under the weight strain making them very hard to carry without spilling grapes. A satisfactory commercially available tub was found which is, as carried by the worker, 2 inches shorter from front to back and 1 inch narrower from side to side than the existing tub. Comparative external dimensions are 25" by 16" by 8" for the existing (larger) tub and 24" by 14" by 8" for the intervention (smaller) tub. Figure 8 below shows both tubs for comparison.

Laboratory weight measurements of empty clean used tubs showed the larger tub 5.6-5.7 pounds (2.5-2.6 kg) the smaller tub at 3.5-3.8 pounds (1.6-1.7 kg). Field tare measurements of the tubs generated a slightly larger differential, nearing 3.0 pounds (1.4 kg). Weight differential is attributable to tub wear, possibly to minor differences in manufacturing lots, ever so slight differences between the molds of branded versus generic models, and potential accumulation of soil. Though the smaller tub has a 13% smaller volume than the larger tub, the smaller tub weighed a season average of 46 pounds (21 kg) or 19% less when full compared to the 57-pound (26 kg) measurement for the larger tub. This is attributable to the mounding effect.

Figure 8: Larger tub (left) and smaller tub with add-on grip enhancements (right).

Workers suggested improvement in the grip, or hand coupling, because of significant contact stress to the palm or fingers, depending on whether the tub is carried at waist level or above the head. Workers and engineers devised a simple improvement by fitting a piece of split 1/2" Schedule 40 PVC pipe to the edge of the grip, which greatly improved hand coupling and reduced contact stress to the hands (Figure 9). The 5-inch PVC pipe segments were slit lengthwise in a jig on a band saw.

Figure 9: PVC grip on smaller tub.

In addition to being lighter, the smaller tub has a smooth bottom making it easier to slide with the leg along the vine as the harvest worker moves. This is done from 3-5 times

per tub load (depending on variety), and places high shear forces on the back and knee. The smaller tub requires some 32% less sliding force, from 19 pounds (8.6 kg) to 13 pounds (5.9 kg) on level ground. The larger tub has two half-cylindrical cutouts in it base to facilitate stacking, whereas the smaller tub has nest-stack structural features molded into the walls of the tub.
The NIOSH Lifting Index for the hand harvest lift task considers factors including weight, location of center of gravity, and nature of the hand coupling. The smaller tub showed a reduction in index by 29%, from 3.4 to 2.4. Bringing the lifting index down that much from above to below 3.0 could be interpreted as significant considering the following. There is some debate that there are workers who can work safely at a job that has an index greater than 1.0. However, members of the 1991 NIOSH committee suggesting that certain workers could work at an index greater than 1.0 also agree that "many workers will be at elevated risk if the lifting index exceeds 3.0." (Waters, et al., 1993).

Tub Cart

Hand cart technology for movement of tubs along the vine was explored to reduce repetitive gripping and lifting or leg movements. A later prototype tub cart (Figure 9) utilizes light but large plastic wheels attached to a light aluminum frame capable of carrying full harvest tubs and surviving field conditions. The model shown in Figure 10 weighs 5.2 pounds (2.4 kg). Tub carts reduce the extent of forward bending and the magnitude of forces required for moving the tub along the vine. They also improve "targeting" of cut grapes into the tub because the tub is closer to the grapes and further within the worker's peripheral vision.

Figure 10: Latest model tub cart.

The shear number of these carts (and the capital cost) that would be required for full project intervention combined with an uncertain sense of potential worker adoption left this tool in continued test and development phase.

Alternate Knife Handle

Alternative picking knife handles were explored for worker comparison with the two main existing styles. The intervention development focus was towards the combination of precise positioning followed immediately by strong pulling action. Precision is obtained by a pinch grip of a small diameter object (up to 1/2 inch) between the thumb and one or more fingers. Strength or power is achieved by full hand action around a large diameter object (around 1-1/4 inches). Generally, the alternative handles included a smaller dimension near the blade for precision control, a comparable or larger dimension along the main body of the handle for power, and an improved main body contour for power but also for comfort by reducing contact stresses. The alternative handles were fabricated out of wood, using blades removed from existing-style knives. Figure 11 shows an assortment of the knives tested. Note that the knife at the far right is an existing wooden handle knife with some modified ends that were sanded down. The knife second from the far right is a commercially available alternative that attempts to address some of the contact stress concerns.

Figure 11: Assortment of alternative knife handles.

Intervention Trial Results:

The intervention selected for full-scale trial and thus full evaluation was the smaller picking tub. A tub cart and alternate picking knife handle were explored and tested on a pilot basis only.

Smaller Tub

The smaller picking tub was not used in the 1997 harvest to provide baseline data using each worker as their own control in a pre-post-intervention design. Smaller tubs were introduced and used exclusively by cooperating workers in 1998 and 1999 harvests. The design was a pre-post trial with each worker serving as his/her own control.

Preliminary results from the 1998 trial, when compared with the 1997, trial suggested that tub size change was having a significant positive effect. However, because of the El Nino weather phenomenon, there was concern that the crop was significantly lighter, which might have meant that workers weren’t taxed as hard as they had been in 1997 (a heavy harvest year). To ensure the validity of trial results, the second intervention trial in the 1999 season was undertaken.

Worker Participation and Demographics

Workers were given pain and symptom surveys at the beginning and end of each harvest, and change in pain and symptoms was recorded for each harvest. Table 1 lists the number of workers from season to season who participated in the smaller tub intervention trial. From Fall 1997 to Fall 1999, 263 workers participated in the study. In Fall 1997, 195 workers completed both the pre- and post-harvest surveys. In 1998, we were able to complete pre- and post-harvest interviews with 116 workers who had participated in Fall 1997. In Fall 1999, we were able to re-interview 66 workers who had participated in both the 1997 and 1998 harvest season interviews. Complete data were available for 115 workers at the end of 1998 and 64 workers at the end of 1999 (including pre- and post-harvest data for each preceding year).

Table 1

Sample sizes for vineyard surveys 1997-1999 (Napa & Sonoma Counties).

	Cumulative total number of workers	Total participating each survey	Participated in pre & post Fall 1997	Other workers interviewed
1997 Pre-harvest	-	216	216	-
1997 Post-harvest	216	195	195	-
1998 Pre-harvest	-	171	150	21
1998 Post-harvest	236	149	122	27
1999 Pre-harvest	-	145	106*	39
1999 Post-harvest	263	111	83**	28

* 84 subjects were in pre- and post-harvest interviews for all three years
** 66 subjects were in pre- and post-harvest interviews for all three years

Workers who completed all four interviews for 1997 and 1998 did not differ statistically from those who only completed the initial survey in 1997 interviews (n=100) in terms of the type, extent, or severity of their symptoms (Table 2). Neither did the frequency with which they treated their symptoms or their demographics (age, years in US, years in the winery business, years in the California winery business). Those who were interviewed in both years were significantly less educated, however, than those who were only interviewed in 1997 (completers: mean= 5.3 yrs., sd=3.3 yrs.; non-completers: mean=6.2 yrs., sd=3.3 yrs; t= 2.03; p<0.04) This statistic suggests that those workers who can improve their situation do so.

Table 2

1997 demographic statistics on 115 vineyard workers who completed pre- and post-harvest surveys for both 1997 and 1998 (Napa & Sonoma Counties). All figures in years.

	Mean	Median	Standard dev.	Minimum	Maximum
Age	36	35	9	20	62
Education	5	5	3	0	15
Years in US	13	12	7	.5	40
Yrs. in winery business	11	10	6	1	28
Yrs. at this winery	7	6	5	0	23

The workers completing surveys in all three years (two surveys per year) were similar to the prior 1998 cohort, in which they were included (Table 3). There were other workers who were interviewed more than once during the three-year period, but they did not participate in consecutive harvests or complete the harvest season each year.

Table 3

1997 demographic statistics for 64 workers who completed all six surveys 1997-1999 (Napa & Sonoma Counties). All figures in years.

	Mean	Median	Standard dev.	Minimum	Maximum
Age	34	35	9	20.	62
Education	6	5	3	0	15
Years in US	12	12	6	2	37
Yrs. in winery business	10	10	5	2	25
Yrs. at this winery	6	6	3	0	13

Health Effects

As expected there was no significant reduction in the incidence of reported or diagnosed (OSHA 200) MSDs during the study period given the relatively short study period (3 years), length of MSD development, the oversupply of labor and previously documented concerns about workers' job security in this industry (Villarejo, 1999). In 1997, five injuries were documented by post-harvest. In 1998, 6 injuries were documented by post-harvest.

By contrast to injury reports, symptom reporting was relatively frequent. Furthermore, aching was by far the most common musculoskeletal symptom experienced by workers (Table 5). In 1997, four workers reported sharp persistent pain before harvest, and one worker reported this type of pain after harvest. There were no reports of sharp pain in 1998. Before harvest in 1997, three workers reported numbness; before harvest in 1998, four workers reported numbness. After harvest for both 1997 and 1998, one worker reported numbness. Tables 4 and 5 show the characteristics of symptoms for workers who reported them in 1997 and 1998.

Table 4 shows numbers of workers reporting various musculoskeletal symptoms. Of 95 workers who began the 1997 harvest with no MSD symptoms, 66 (70%) developed symptoms over the course of the harvest. This is a statistically significant increase ($p<0.01$). By the end of harvest 1998 (using smaller tubs), of 90 workers reporting no symptoms at the beginning of harvest, only 26 (29%) reported symptoms post-harvest. Detailed statistical analysis comparing 1997 and 1998 differences in harvest pain score changes showed rejection of the null hypothesis with a Student-t value of such a large magnitude ($t = 6.310$) that robustness issues became moot ($p<.001$).

Table 4

Percentages of workers reporting musculoskeletal symptoms by body location (n=116, Napa & Sonoma Counties).

	Pre-Harvest 1997 % (n)	Post-Harvest 1997 % (n)	Pre-Harvest 1998 % (n)	Post-Harvest 1998 % (n)
Hand	1%(1)	0%(0)	2%(2)	2%(2)
Forearm	1%(1)	3%(3)	2%(2)	3%(3)
Elbow/upper arm	2%(2)	4%(5)	1%(1)	4%(5)
Neck/Shoulders	6%(7)	16%(18)	5%(6)	11%(13)
Back	7%(8)	46%(53)	13%(15)	23%(27)
Knee	2%(2)	21%(24)	5%(6)	10%(12)
Feet	2%(2)	5%(6)	1%(1)	4%(5)

Table 5

Characteristics of aching pain for vineyard workers reporting musculoskeletal symptoms (n=115 <115 is not a typo>, Napa & Sonoma Counties).

	Pre-Harvest 1997	Post-Harvest 1997	Pre-Harvest 1998	Post-Harvest 1998
	mean/median (sd)	mean/median (sd)	mean/median (sd)	mean/median (sd)
Symptom severity (range=5)	1.5/2.0 (1.3)	2.8/3.0 (0.8)	2.5/3.0 (1.3)	3.0/3.0 (0.8)
Extent of the body affected (range=33)	1.6/1.0 (1.6)	2.5/2.0 (1.6)	2.1/2.0 (1.4)	3.2/2.0 (3.0)
Number of symptomatic days out of the last 30	8.9/3.0 (11.2)	16.2/15.0 (5.5)	13.6/15.0 (10.9)	17.1/15.0 (8.4)
Number of symptomatic days out of the last 7	3.4/3.0 (3.5)	3.1/3.0 (2.7)	4.2/4.0 (3.3)	3.3/3.0 (2.8)
% reporting any musculoskeletal symptom (n)	18% (21)	70% (81)	22% (26)	33% (38)
% of sample reporting aching (n)	13% (15)	68% (79)	19% (22)	32% (37)
Composite symptom score	66.0/30.0 (99.0)	129.8/90.0 (122.2)	37.7/0.0 (105.4)	66.2/0.0 (165.9)

Because the harvest was lighter in 1998 than in 1997, MSD pain data were collected for the 1999 harvest as well. In this case, harvest volume was more normal and the null hypothesis was again rejected with high significance ($t=3.127$, $p<.002$). The response variate confidence interval suggests, with 95% confidence, that the average 1997 pain score was reduced more than fivefold (5.7005) in 1998. The comparable factor calculated from the year 1999 scores was a 1.78 fold improvement. Some of the reduction in observed pain score improvement in 1999 may have been due to subject loss across the 3 harvest years. In any case, the impact of using smaller tubs in significantly reducing MSD pain and symptoms is clearly demonstrated.

<u>Productivity and Adoptability</u>

Use of the smaller harvest picking tubs resulted in slightly decreased productivity as measured in pounds delivered to the gondola per shift. Use of small tubs averaged some 168 pounds fewer grapes delivered per 8-hour work shift. While the small tub contains an average of 8 pounds fewer grapes, it fills faster so workers make more trips per hour with it (about 3 more per hour). It is important to note here that while workers were making more trips per shift, their energy expenditure and MSD symptoms decreased over those recorded for large tub use. During the field trials, neither workers nor owner /operators noted any perceived productivity difference. This is likely due to the small percentage proportion of the decrease (2.5%). Also, field time is not the factor of highest concern to workers or management since payment is for tons delivered not hours worked.

Adoptability depends on several factors. Initially, we intended to predicate this assessment on how well the innovation met Rogers' (1983) predictive factors. The smaller tub does satisfy those factors. More importantly, all participating workers and all cooperating owner/operators have indicated a continued preference for the smaller tub and will continue its use. Finally, there is a temporary small cost disadvantage to adoption of the smaller tub ($12-14 vs. $8-12). This is due to volume of tubs sold. Tubs must be replaced on about a biannual basis and as more small tubs are sold, the cost advantage will shift to them. We believe that as these cooperators continue to demonstrate their preference, the use of the small tub will disseminate easily throughout the region.

<u>Tub Cart</u>

The tub cart described here (Figure 12), along with a couple other models, was tested at several field locations. The tub cart received positive feedback in favorable field conditions. On dry, relatively flat terrain, the cart performed well. It was clear that the workers did not need to bend nearly as far as when they were not using a cart, especially to move the tub and cart to the next immediate position along the vine. On damp ground, soiled tended to build up on the wheels making the cart heavier to handle when it needed to be lifted and moved some significant distance along the vine. On rough terrain or along vines with high berms, the cart would not necessarily tip over but would stick further out and interfere with the worker's legs. The location and height of the cart handles slightly reduced the worker's ability to bend at the knees to better reach the

Figure 12: Tub cart in use.

grapes. Another occasional drawback was that it could not fit directly under the vine and drip irrigation, which a capability that some workers like.

Further development work is focusing on a handle-less cart that employs some simple mechanism to easily connect/disconnect the tub from the cart. This will eliminate handle interference. The cart height will remain at its current setting, which appears to be a good compromise between reduced worker bending and tub/cart load stability on typical terrain.

The NIOSH Lifting Index for the smaller tub with cart is 2.2, a 35% reduction from the larger tub with no cart and a 8% reduction from the smaller tub with no cart. Workers who used or saw the tub cart are motivated to continue testing it. Now that the small-tub trial is complete, wider testing among the worker population will be possible.

Alternative Knife Handle

Of the series of alternative-handled knives provided for limited tests, the one pictured on the right in Figure 13 was the most popular. The preferred alternative and the two existing knife handles (only the plastic style is shown here) are sized similarly but not exactly. The similarity helps provide a recognized feel and handling, and the small differences are believed to provide improvements in pinch grip control and contact stress points. The alternative handle's thickness near the blade tapers down to less than 1/2" providing for a better pinch grip hold, compared to the greater than 5/8"-3/4" dimensions of the existing knife handles. Its general body curvature reduces contact stresses on the palm and also allows for a certain amount of handle rotation in the palm without greatly compromising the reduced contact stresses. The handle's shape improves the power grip hold, likely reducing the amount of finger squeezing required to affect the same ultimate pulling force. Four additional copies of this knife were made and distributed for short term testing. None of these additional knives have been returned, perhaps an indication of their acceptance by workers who are unwilling to give them up.

Figure 13: Existing knife (left) and alternative knife (right).

Discussion:

The health effects data are important results. They make it clear that relatively minor adjustments in tools and tasks can have important and significant impact in MSD risk factor reduction or prevention in agricultural field jobs.

The results reported here are also of research importance. There has been a lack of prospective intervention studies reported in the literature. Many of those studies that employ interventions in work settings suffer from alterations over the course of the trial. This study demonstrates that intervention trials may successfully be completed when all stakeholders are involved. In addition to field interventions we have also provided some field corroboration for the idea that a threshold for human spinal loading may occur at or around the 50-pound load.

Because of the chronic nature of MSDs it would be overly optimistic to expect to see large reductions in reported MSD incidence in such a short-term intervention effort. For that reason the approach to assessing MSD pain and symptomatology was the chosen. The instrument used is an individual survey, administered in Spanish by trained interviewers. This research team has used this instrument in other NIOSH-funded studies. As with any self-report survey method, there is potential for subjective bias on the part of the respondent and the interviewer. Still it is an approach that has demonstrated merit in its potential for capturing changes in subject-recognized symptom development and changes in MSD development short of full disorder presentation.

The MSD pain and symptom measure is particularly relevant for this group of Hispanic workers who do not recognize early discomfort as “symptoms” of a potentially impairing disorder and are reluctant to report injuries. Many of the non-symptomatic workers undertook symptom self-treatment. We believe that these workers do indeed feel work-related symptoms sufficiently to attempt self-management, but for cultural, educational or occupational reasons do not identify their sensations as symptoms of health disorders or report them as such. We know that these workers have a strong work ethic and are fearful of losing workdays or even their jobs. Additionally, focus group participants reported that unless painful symptoms are genuinely work disabling, it is unlike that they will be reported as painful (“dolor” in Spanish); more frequently such sensations will be reported as bothersome (“molestias”) and will be regarded as commonplace occurrences rather than treatable disorders. The survey takes account of these cultural variations. Whatever the impetus for the workers' self-treatment, this issue deserves further serious inquiry to investigate cultural differences in symptom perception and the association between self treatment and symptom prevalence and severity.

Conclusion:

Ergonomics and health effects methods were shown to successfully reduce risk factors and pain symptoms for mulculoskeletal disorders in hand harvest of wine grapes. The use of a smaller picking tub, weighing 46 pounds (21 kg) full versus 57 pounds (26 kg), reduced a composite post-harvest pain score five-fold for 115 workers between pre-intervention year 1997 and post-intervention year 1998. Because of a lighter harvest in 1998 than in 1997, believed to be an effect of the El Nino phenomenon, the intervention trial period was extended to include one more complete harvest season. 66 of the 115 workers remained in the study and registered a nearly two-fold decrease in composite post-harvest pain score over pre-intervention year 1997.

Worker and management adoption of the smaller picking tub was widespread even though there was a small reduction in worker productivity in a set time period. Because the workers are paid piece rate (based on tonnage per day), the decrease in productivity of 2.5% translates to about 1/4 an hour more of work. However, this is not a concern to anyone involved. Subjective reports of energy expenditure clearly indicated workers were less tired by day's end using the smaller tubs even though they had to work a little longer.

Pilot trials with a tub cart that elevates the picking tub by 25 cm showed reduction in bending, lifting, and forces. The cart was more successful in dryer and smoother terrain. These trials have encouraged further work to address device handle interference issues.

Pilot trails of alternative knife-handles showed worker acceptance of an improved grip for the combination pinch and power grip. The pinch grip is necessary for quick and precise knife placement, and the power grip is necessary for strength needed to jerk the knife through the stem of a grape cluster. Though the existing knives could not be identified as causing any reported injuries other than minor cuts to the non-dominant hand, workers clearly were interested in continued use of the alternative handle style.

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