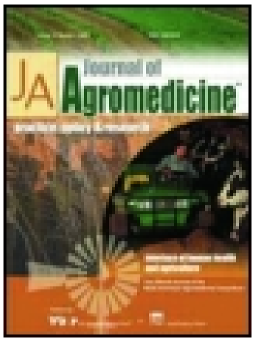

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*ASHCA/NIOSH CONFERENCE: PANEL PRESENTATION*

# Ergonomic Risks and Musculoskeletal Disorders in Production Agriculture: Recommendations for Effective Research to Practice

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**ABSTRACT.** Musculoskeletal disorders (MSDs) are increasingly recognized as a significant hazard of agricultural occupation. In agricultural jobs with significant physical labor, MSDs are typically the most frequently reported injury. Although not as lethal as tractor roll-overs, MSDs can result in disability, lost work time, and increased production costs. MSDs increase production costs as a result of worker absence, medical and insurance costs, decreased work capacity, and loss of employees to turnover and competition from other less physically demanding industries. This paper will provide an overview of what is currently known about MSDs in agriculture, including high-risk commodities, tasks and work practices, and the related regulatory factors and workers' compensation costs. As agricultural production practices evolve, the types of MSDs also change, as do ergonomic risk factors. One example is the previous higher rates of knee and hip arthritis identified in farmers in stanchion dairies evolving into upper extremity tendonitis, arthritis, and carpal tunnel syndrome now found in milking technicians in dairy milking parlors. This paper summarizes the presentation, "Musculoskeletal Disorders in Labor-Intensive Operations," at the Agricultural Safety and Health Council of America/ National Institute for Occupational Safety and Health conference, "Be Safe, Be Profitable: Protecting Workers in Agriculture," January 27–28, 2010, Dallas/Fort Worth, Texas. The primary focus of the paper is to address current research on ergonomic solutions for MSDs in agriculture. These include improved tools, carts or equipment, as well as work practices. One of the key challenges in this area pertains to measurement, due to the fact that musculoskeletal strain is a chronic condition that can come and go, with self-reported pain as its only indicator. Alternative measurement methods will be discussed. Finally, the implementation of research into practice is reviewed, with an emphasis on best practices that have been demonstrated to be effective in the agricultural setting, based on worker acceptance and comfort, improved productivity, and decreased MSDs. The paper will provide an overview for agricultural stakeholders as to the current science and practice of ergonomics in agriculture.

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## INTRODUCTION

Ergonomic hazards and the associated musculoskeletal disorders (MSDs) have become an increasingly recognized issue of concern in agricultural production. The US Department of Health and Human Services Healthy People 2010 Goal 20.3 is to reduce the rate of lost time injury and illnesses due to overexertion or repetitive motion.[1] In addition, the National Institute for Occupational Safety and Health (NIOSH) has identified MSDs as a priority area, and it specifically recommends reducing the incidence and prevalence of MSDs associated with work practices and production agriculture.[2]

Agriculture in the United States is typically divided into two broad segments: animal production and crop production.[3] Each segment has specific types of ergonomic risks and may be at risk for specific types of musculoskeletal disorders. Each segment of production agriculture can further be divided into smaller units; such as livestock, dairy, and poultry in animal production and field crops production requiring intensive hand work such as small vegetables, fruit, wine production, and tree bearing fruit. The work practices specific to each commodity must be fully understood to adequately assess potential ergonomic hazards. As producers and commodity groups recognize the cost of ergonomic hazards, including (i) employee turnover, (ii) potential workers' compensation costs secondary to medical costs, and (iii) escalating premiums from higher insurance modification rates, more attention will be paid to improving the ergonomic forces of the work environment. This paper is not designed to be a major review of the epidemiology of the prevalence of MSDs but rather to give an overview of the scope of MSDs in agriculture and then focus upon the state of current research-to-practice interventions. The reader is referred to a recent thorough review by Davis and Kotowski for more detail.[3] The emphasis will be on which interventions have been effective and how can the agricultural commodity groups and academia collaborate on designing and implementing further programs to effectively reduce ergonomic hazards in production agriculture.

## PREVALENCE OF MUSCULOSKELETAL DISORDERS IN AGRICULTURE

The true prevalence of MSDs in production agriculture is unknown for a number of reasons. First, the majority of farm and ranch operations have fewer than 11 employees, and thus are not required to report injuries to the Occupational Safety and Health Administration (OSHA). Workers' Compensation coverage of agriculture also varies markedly from state-to-state, which makes accurate reporting difficult. In addition, many workers (such as adolescents and youth, migrant workers) have precarious employment and are unwilling to report MSDs for fear of job loss. As a result, the 2008 Bureau of Labor Statistics (BLS) reported prevalence of nonfatal occupational injury and illness rates in agriculture, forestry, and fishing (AgFF) of 5.3 per 100 workers is likely to be significantly lower than the true rate. Even with these factors, the AgFF rate is higher than construction (4.7/100 workers), manufacturing (5.0/100 workers), and goods producing industries (4.1/100 workers).[4] MSDs are not separated out in separate reports from other nonfatal occupational injuries and illnesses In 2008, MSDs accounted for 29% for all injuries and illnesses resulting in days away from work across all industries and by inference this likely applies to agricultural production also.[5] An encouraging trend identified in BLS national data across industry in general is the gradual decrease in MSDs over the last decade, potentially from increased awareness and ergonomic interventions.[4] Based upon National Agricultural Workers' Survey (NAWS) 1999 data, the percentage of musculoskeletal pain or discomfort increases from 11% during the first year of farm work to 19% by the 10th year and was highest in those working in multiple crop categories.[6] Included are references providing examples of a number of surveys and pilot studies that have reported variable rates of MSDs affecting neck, shoulders, wrists, and back in all sectors of commodity production.[7–9] As these numbers vary regionally and by commodity, the readers are directed to the specific references and the review by Davis and Kotowski.[3]

## *ESSENTIAL FACTORS OF MUSCULOSKELETAL DISORDERS IN AGRICULTURE*

A useful definition of MSDs is provided by the Washington Bureau of Labor and Industries: *non-traumatic disorders of the soft tissues of the musculoskeletal system that can be aggravated by work activities such as repetitive motions, awkward postures, use of vibrating tools or equipment, or by manual handling of heavy awkward loads*.[10] Primary ergonomic risk factors include excess force, repetition, awkward posture, and vibration. Cold ambient temperatures and pressure points are secondary ergonomic risk factors. NIOSH considers the combination of force and repetition to be the strongest factor in developing MSDs.[11] A major consideration in preventing MSDs is adequate time for the affected body part to recover from physical forces and equipment that is not adequately designed to lessen the impact of force, awkward work postures, and pressure points. Body parts most commonly affected are the neck and back, shoulders, wrists, hips, and knees. Stooped work is considered to be a major contributing factor to low back disorders and a major ergonomic hazard throughout agriculture, particularly fruit, vegetable, and horticultural commodities.[12] Unique features of agriculture work practices associated with ergonomic hazards and MSDs include uncomfortable positions due to the natural positioning of crops in the field, variability of the physical characteristics of perishable and living product impacting the tools required in cultivation, harvest, and collection of biological product, and variable weather and extremes of temperature.[6]

## *MEDICAL ISSUES IN MUSCULOSKELETAL DISORDERS IN AGRICULTURE*

Common clinical diagnoses include low back pain, herniated lumbar discs, rotator cuff tendonitis and tears, wrist tendonitis, carpal tunnel syndrome, hip and knee arthritis.[12] The types of MSDs arising from agricultural practices have changed as technology and production practices have evolved. There is evidence that the previous hip and knee osteoarthritis that was increased in older owner/operators in smaller dairy operations is being replaced by shoulder, hand, and arm MSDs in modern milking parlors.[13,14] These clinical entities include overuse pain conditions, tendonitis, and carpal tunnel syndrome. Appropriate treatment modalities are often unavailable in rural agricultural regions, and medical providers knowledgeable about return to work management and/or access to occupational medicine clinics may not be available. The accepted general industry model promoted by workers' compensation carriers and supported by a large body of medical research is transitional work programs protecting the affected body part while preventing unnecessary physical deconditioning and prolonged medical recovery. Small-scale agricultural producers may not have the availability of transitional work for workers with musculoskeletal disorders who need a graduated return to full duty as part of the rehabilitation treatment program. An important component of an effective transitional work program is functional job descriptions addressing the ergonomic risk factors and the ability to assess the physical factors of the work practices involved in safe return to work. These are also not typically available in the agricultural workplace. See Table 1 for a listing of agricultural commodities and associated ergonomic risk factors and MSDs.

## *REGULATORY RESPONSES TO ERGONOMIC HAZARDS IN AGRICULTURE*

A national ergonomic standard does not exist. A rule was promulgated by United States

TABLE 1. Commodities and Associated Ergonomic Hazards and MSDs

| Commodity | Ergonomic hazard | MSDs | Reference |
|---|---|---|---|
| Dairy | a) Cleaning<br>b) Pre-stripping and frequent grasping<br>c) Attach milking machine<br>d) Manually cleaning animal stalls | a,b,c,d) Hand-wrist tendonitis<br>a,b,c) Carpal tunnel syndrome<br>Pronator syndrome | Stal[61]<br>Stal [62]<br>Stal[63]<br>Nonnenmann[64]<br>Pinzke[65] |
| Dairy | a) Kneeling, squatting<br>b) Tractor driving | Hip and knee arthritis | Gomez[8]<br>Thelin[66]<br>Toren[67] |
| Grape hand harvest | a) Carry full tubs<br>b) Sustained awkward postures<br>c) Repetitive grasping of pruning shears cutting grapes from vines<br>d) Pruning with arms raised and flexed above shoulder | a,b) Low back pain<br>c) Hand disorder<br>d) Shoulder MSDs | Duraj[32]<br>Meyers[68]<br>Meyers[69]<br>Roquelaure[70] |
| Orange harvest | Carrying bags while picking fruit on ladders | Low back pain | Meyers[69] |
| Apple harvest | a) Repetitive reaching and packing<br>b) Bearing heavy apple bags | Back, neck, and shoulder strain | Earle-Richardson[71]<br>Fulmer [72] |
| Crop harvest | a) Pruning, plant propagation, weeding<br>b) Repetitive contact stress on hand | Hand and wrist disorders | Meyers[68]<br>Janowitz[73]<br>Wakula[74] |
| Fruit harvesters | a) Reaching up over shoulder to pick<br>b) Carrying loaded harvest bags<br>c) Carrying ladders from tree to tree | Shoulder MSDs | Duraj[31]<br>Fulmer[72] |

Occupational Safety and Health Administration (OSHA) but rescinded using the Congressional Review Act of 1996 and will not be brought back as federal OSHA standard.[15] A voluntary approach utilizing ergonomic guidelines and consultation is the approach utilized by OSHA at the present time. The industry-specific guidelines that have been developed include both poultry and meatpacking.[16] For those states that do not have a state OSHA ergonomic standard, the Federal (FED/OSHA) guarantees that workplaces be free of recognized hazards and use the General Duty Clause as a catch-all for serious types of violations, including ergonomics, if they (FED/OSHA) cannot cite under existing special orders.[15] Those states with state occupational safety and health programs may develop their own ergonomic standards or programs. California and Washington examples of state ergonomic approaches are described below.

In California, Labor Code 6400(a) gives California Occupational Safety and Health Administration (Cal/OSHA) the authority to ensure that employers provide a safe and healthy workplace for all their workers. California is the only state with an active and enforceable Ergonomics Standard (§5110). Although the state of Washington promulgated an ergonomics rule, the electorate voted to repeal the rule in 2005 with a provision that the state is prohibited from enacting another ergonomics rule unless required by federal authorities. Both California and Washington have regulations requiring employers to develop injury prevention programs. Washington's rule, called an Accident Prevention Program (WAC-296-800-140), has been in effect since 2009, whereas California's regulation, called an Injury and Illness Prevention Program (§3203), has been in effect since 1991. California's regulation requires that all public and private California employers "*establish, implement, and maintain an effective Injury and Illness Prevention (IIPP)*."[17] The program must be in writing and must include the elements of responsibility, compliance, communication, hazard identification/assessment and correction, training, accident investigation, and recordkeeping. A copy of the IIPP must be maintained at each workplace, including temporary worksites. Failure to have an IIPP continues to be the number 1 cited violation by Cal/OSHA.

The Cal/OSHA Ergonomics Standard became effective on July 3, 1997, and affects all employers doing business in California, and applies to a job, process, or operation where repetitive motion injuries (RMIs) have occurred to one or more employees under certain conditions during a revolving 12 month period.[18] When the standard is triggered, the employer must design a program to minimize RMIs to include worksite evaluation, exposure control, and training. The impact that this legislation has had is not entirely clear. A number of factors have combined since 2004 to significantly change the length of harvest season, worker demographics and experience levels and perhaps most importantly the increased reliance on Farm Labor Contractors (FLCs) who, for a fee, provide crews for activities such as harvesting, pruning, weeding. FLCs comprise a large percentage, up to 70% according to some sources, of the agriculture labor force in California. FLCs must be registered with the US Department of Labor and licensed by the California Department of Industrial Relations. The FLC is required to carry all the insurances and must abide by all safety regulations.

In addition to California's unique safety and health regulations, the state has also worked to assist agricultural producers in dealing with rising workers' compensation rates, rising medical costs for injured workers, labor concerns, and water shortages and restrictions. For example, in 2004 California passed legislation reforming workers' compensation in an attempt at reining in annually escalating workers' compensation rates. Although this reduced costs for a time, the effect was short-lived, since overall health care costs have risen dramatically. To illustrate this, the average cost of a permanent disability back injury claim across all industries in 2002 was $55,570. In 2004, the average cost dropped to $45,963, but then by 2006, the average cost had risen to $49,283. For a permanent disability carpal tunnel syndrome/repetitive motion claim, the average cost in 2002 was $42,152, dropping to $37,598 in 2004 and rising again to $39,709 in 2006.[14]

## *DEVELOPMENT AND USE OF MSD PREVENTION INTERVENTIONS IN AGRICULTURE*

### *Intervention Development and Improvement*

Although most agricultural workplaces are not regulated with respect to ergonomic hazards, employers have participated in and supported the development of ergonomic interventions on a number of occasions. Typically, the need for an ergonomic intervention arises from the observation of a high frequency of musculoskeletal conditions associated with a particular commodity or work task,[12,19] although there are some examples in the literature of a more general ergonomic workplace "check-up."[20] If the ergonomic hazards (e.g., force, repetition, awkward postures, contact stress, cold ambient temperature, and vibration[21]) are determined to be amenable to intervention, the next step is to consider what type of intervention will be most appropriate.

The occupational health and safety hierarchy uses a three-tier approach for implementing workplace safety interventions listed in descending order or prioritization: engineering controls to reduce hazards, work practice changes to reduce exposure, and the use of personal protective equipment.[11] However, in the context of agricultural ergonomics, we propose a more specific, four-tier framework, shown in Table 2. The agricultural workplace is unique in that the built environment is minimal. Much of agricultural work is done outside rather than in indoor, mechanized workstations. Agricultural workers often have choices about the tools they use (they may even bring their own). As shown in Table 2, ergonomic interventions in farming can be divided along two dimensions: materials versus practices, and farm level versus individual level interventions. This creates four general categories of ergonomic interventions.

This framework can be a useful tool for agricultural employers. Once the determination is made as to whether interventions will be made at the farm level or at the level of the individual worker, and also whether the focus will be materials or behaviors, the range of existing interventions to consider is significantly narrowed.

TABLE 2. Dimensions of Ergonomic Intervention Characteristics in Agriculture

| | Materials | Practices |
|---|---|---|
| Farm level | 1. Farm-level changes in structures, machines, or common equipment.<br>Example: modified handle attachment and lever arm for beef calf weighing station<br>Most costly, easiest adoption | 2. Farm-level changes, work processes and procedures, equipment.<br>Example: a mandated 5-minute rest break every hour of stoop labor with berries and nursery work<br>Moderate cost and adoption |
| Individual worker level | 3. Individual level changes, tools and small equipment.<br>Example: modified wheelbarrows for youth (adjustable handles, added push-bar and three wheels)<br>Modest cost, variable adoption | 4. Individual worker behavior.<br>Example: body mechanics training (especiallylifting) for fruit packing house workers<br>Least costly, most difficult adoption |



Generally speaking, farm level interventions and those that focus on materials rather than practices are preferable in agriculture because they typically require less individual motivation to change and new skill acquisition. On the other hand, cost is frequently an obstacle to farm level changes. Thus, farm level, material-based interventions (Table 2, box 1) are most desirable, and individual worker behavior interventions (Table 2, box 4) are the least desirable. In the migrant and seasonal farm worker setting, quadrant 4 is particularly problematic, since these workers are often face severe economic pressure, making individual experimentation with new practices unacceptably risky.

The most effective intervention is to engineer or "design out" the hazard by physically modifying materials, methods, tools, or machinery. In a tree budding operation, where no acceptable tools or technologies are found to help alleviate either postures or the repetitiveness of a task, modifying standard rest breaks was found to improve workers' symptoms reports and had a modest impact on productivity.[22] Anecdotal evidence indicates that limiting risk factors through administrative controls of training, stretching programs, and job rotation tend to have short-term gains. To ensure these efforts are sustainable requires a shift in safety culture and a positive attitude by frontline supervisors. In the prevention of back injuries, proper lift training has always been the first line of defense because it is quick, inexpensive, and can be conducted in any environment. According to the literature, training alone is ineffective in back injury prevention.[23,24] It has a short-term effect and as injuries continue, the worker is blamed for not lifting properly and more training is prescribed. The major value of an education program is to increase employee awareness about back injury risk factors and to provide some ergonomic analysis and solution generation skills.

Agricultural workers often play the primary role in identification and refinement of ergonomic interventions in agriculture.[25–29] Although the researcher can provide a range of ideas across the categories above, it is the workers themselves who are intimately familiar with work processes and who can best assess possible efficacy and feasibility. Managers and employers can also play an important role at this stage, since they are in a position to assess the likely costs, logistical considerations and productivity impacts of any proposed intervention. The "ergonomic work-team," representing workers and managers, and using a consensus building approach, is widely used.[28,29]

In California, where an ergonomic standard was in place, researchers at the Agricultural Ergonomics Research Center (AERC) at University of California Davis undertook a multi-commodity, multi-intervention development program, with support from private industry and NIOSH. The goal was to establish several demonstration projects that could serves as models for innovation across California and nationally. Among the interventions developed were detachable handles to lift and carry potted plants in a wholesale nursery,[30] smaller tubs[31] and powered pruners in the wine grape industry, and the mechanized dumping of tubs[32] in the wine grape industry. These and other designs from this first wave of intervention designs have been featured in NIOSH's "Simple Solutions."[28]

### Tested Ergonomic Interventions in Agriculture

In Tables 3 to 6, all ergonomic interventions in agriculture that the authors could identify that have been formally evaluated (published journal articles or published reports) are presented. Each of the four quadrants from Table 2 is contained in a separate table.

## INTERVENTION EVALUATION

One critically important step in reducing musculoskeletal disorders in agriculture is rigorously evaluating the effectiveness of new interventions. It is not enough to know that workers and employers like a new tool or process; it must be shown that regular use will decrease musculoskeletal disorders to justify the investment of resources in development and distribution. This is much more difficult than it may seem. First, the vast majority of musculoskeletal injuries in agriculture are musculoskeletal strain, a disorder that has no simple diagnostic test associated with it. Second, many of the testing technologies used in other industries require a controlled environment, not present on the farm, for accurate measurement. In the discussion that follows, researchers' work to overcome these obstacles will be presented.

### Intervention Evaluation Efficacy Research

Once an intervention has been developed to the satisfaction of the ergonomics team, the next step is efficacy research. Efficacy studies simply answer the question of whether an intervention has the *ability* to reduce hazardous ergonomic exposures in a *controlled setting*. This setting is most commonly one in which the adoption of the intervention is 100%, and the measurement instrumentation is well supported. This is particularly important in agricultural research, since the work environment is so varied. If the intervention fails in this environment, no further study is warranted. These types of studies are logistically far simpler than a large-scale field study.

The purpose of these measurement instruments is not to document the presence or absence of injury, but rather to look for a measurable reduction in the extent of ergonomic stresses or hazards is observed. For example, if EMG demonstrates reduced muscle exertion while carrying a load in combination with a new tool, we can infer that the body is reacting to less stress placed on it by the load.

Looking at Tables 3 through 6, 16 of the 28 intervention evaluations were either entirely or partly efficacy studies, taking place in a laboratory or simulated work environment. This is the most common type of ergonomic evaluation currently in agriculture, due to the newness of field, and also the substantial difficulties associated with larger field studies. The most common outcome is the presence or extent of some kind of ergonomic hazard, such as awkward posture, weight borne, vibration, or velocity of movement. Among the 16 studies, most used some type of randomization, simulated actual work activities, and objective criteria for evaluation. Six of these compared among several tools or interventions without designating a "control" or "usual equipment/practice" condition. Among the remaining 10, 8 concluded that the intervention was totally or largely effective while three were determined to have mixed or inconclusive results.[19,30,33–38,49] Variants of the laboratory studies involve videotaping agricultural workers in the field and carrying out the hazard analysis in the laboratory.[37,38]

### Intervention Effectiveness Research (Studying Interventions in the Field Setting)

Once an intervention has succeeded in efficacy testing, a field trial typically follows. Then the intervention is placed in the actual farm environment and evaluated. In addition to measuring

TABLE 3. Farm-Level Changes, Structures, Machines, Large Equipment

| Commodity | Intervention | Population, design, sample size | Main outcomes | Results and conclusions |
|---|---|---|---|---|
| Beef calves | Handle attachment and lever arm interventions[33] | Five male and 2 female volunteers, mean age 23; and 2 farmers. Ergonomic Lab NC State University Lab.Laboratory and field studies | Laboratory study: muscle activities quantified for major lower back and knee muscle groups during performance of the lifting task. Field study: Farmers opinion of use | Handle attachment design is less cumbersome to move and use than the lever arm design, lab and field study reveal lever arm design provides highest reduction in muscle activity and joint loading. Either intervention should decrease risk to low back and shoulders when performing this task. |
| Cattle | Rugged cart and proper orienting of feed bags and modified feed bin[34] | 7 male and 7 female youth, ages 12–18, residents of central Ohio who regularly perform handling and scooping farm tasks. Simulated lab evaluation design | A lumbar motion monitor device was used to quantify trunk movement and determine injury risk level | The cart significantly reduced low-back injury risk by nearly 10%; The modified feed bin did not significantly reduce low-back injury risk. Regardless of the method scooping feed from the top of the bin reduced lower back disorder risk by 50%. |
| Ground crops | Four back support devices for stoop labor[35] | 9 subjects (4 males and 5 females) UC Davis college students. 2 by 3 (device $\times$ weight (0, 10, and 20 lbs)) within-subject design, with: no device and four device levels | Percentage of maximum EMG for lower back calves and arms | All four devices reduced trunk muscle activities to varying degrees. Two devices generated increased activities in the knee flexor muscle. |
| Ground crops | Lying prone workstations (2)and one upright sitting workstation[36] | Dutch harvest workers (unspecified sample size) reported every hour while doing planting or weeding using on one of four methods | Self-reported level of discomfort for all relevant parts of the body, as compared with walking | Prone interventions relived back and upper legs, but caused armpit and head discomfort. Although upright sitting caused discomfort in lower back and buttocks, it was preferred in parcels with little weed. |
| Sheep shearing | Sheep manipulator[37] | 5 male shearers were filmed using three video cameras at University of Western Australia Robotic Sheep Shearing facility | EMG activity and 3D kinematic data for 7 segments of shearing action. L5/S1 compressive and shear forces | Manipulator allowed shearers to maintain a more upright posture (mean trunk angle >65 degrees), which decreased the compressive (max. <1350 N) and shear forces at L5/S1 (max. <260 N). |
| Sheep shearing | Commercial trunk harness[38] | 12 male New Zealand sheep shearers (machine) to evaluate the effect on shoulders using a commercial trunk harness | Shoulder postures and cumulative shoulder moments. Flexion, abduction, and adduction shoulder movements | Decrease in % of time spent in shoulder flexion greater than 90 degrees and the time spent in shoulder abduction greater than 45 degrees. Reduced cumulative net joint flexion abduction, and adduction. |

| | | | | |
|---|---|---|---|---|
| Unspecified | Optimal tractor driver seat dimensions[39] | 5 experienced tractor drivers Analytic Hierarchy Process (AHP) (comparison methodology) | Evaluation of three seats by 5 tractor operators with respect to given criteria | Operators' preference of 3 different seats. Ergonomic criteria. |
| Unspecified | Design of tractor operator enclosures[40] | 100 volunteer (88 male and 12 female), of which 94 were agricultural workers ages 18 to 79 years from W Virginia | Body size and shape information registered using a 3D full-body scanner. A principal component analysis identified 15 human body models for assessing tractor-cab accommodation | Coordinates of 34 body landmarks and the semi-axis-length for each landmark location were developed for tractor control component placement. The vertical clearance (90 cm) for agriculture tractor enclosure in the current SAE International J2194 standard appeared too short. |
| Unspecified | Modified wheel-barrows for youth[41] | Experimental design 10 girls and 10 boys ages 11 to 18 years from local 4H programs, in simulated-field study design | Used lumbar motion monitor to capture trunk posture and motion while youth performed simulated task. Assessed rates of perceived exertion and comfort of use | Reduction in sagittal trunk flexion and velocity with all 3 alterations.Little impact on lower back disorder risk levels, increase in perceived risk and exertion with alteration |
| Wine grapes | Five commonly used wine grape trellis systems[42] | 10 male and 1 female volunteers with 2 yrs vineyard pruning experience. One-way within subject experimental design with 5 levels (trellis systems) | Subjects performed a simulated pruning task as wrist and trunk postures were gathered using electrogoniometers | Significant postural differences among the trellis systems. The VSP was the optimal system in terms of decreasing relative MSD risk. |
| Wine grapes | Grape conveyor system (ground level up to transport trailer)[31] | Qualitative implementation and observation; number of California workers and farms not specified | Implementation and observation only | No apparent difficulties; productivity levels same or higher, higher quality product; worker and management interest in system. 2002 Update: Reduced worker lifting but increased time spent in poor posture. |

TABLE 4. Farm-Level Changes, Work Processes and Procedures

| Commodity | Intervention | Population, design, sample size | Main outcomes | Results and conclusions |
|---|---|---|---|---|
| Berries, nursery | Mandated 5 minute rest break every hour[22] | 2 trials, 1 compared workers ($n$ = 66) randomly assigned strawberry workers to E or Control; 2 used a cross-over design with 16 pairs. | Self-reported symptoms, including severity of symptoms | Less severity of self-reported symptoms among subjects in experimental conditions. Some intervention vs. control ordering effects on productivity need to be explored further. |
| Meat packing | Rest breaks[43] | 28 men employed in a local meatpacking plant over a period of 4 weeks | Perceived discomfort relationship between the discomfort perceived on the job and musculoskeletal capability was investigated. | Results indicated that active microbreaks significantly reduced the level of discomfort perceived by employees during the course of the working day. The subjective ratings of perceived discomfort correlated significantly with anthropometric, strength and background information ($R^2$ = .66). |

TABLE 5. Individual-Level Changes, Tools, and Small Equipment

| Commodity | Intervention | Population, design, sample size | Main outcomes | Results and conclusions |
|---|---|---|---|---|
| Blueberry | Modified blueberry rake[44] | 29 rakers tried intervention and control equipment in the field | Productivity, acceptability picking force used, self-reported pain | Significantly increased productivity, acceptability. Significantly reduced picking force used, self-reported pain. |
| Fruit trees | Pneumatic shears[45] | German fruit tree pruners, $N = 15$. measurements with manual, pneumatic and pruning saw | Heart rate and energy transformation | Pneumatic shears require less physical work than with pruning saw. |
| Fruit trees | 9 varieties of pruning shears[46] | Mechanical laboratory test using wooden dowels of different sizes, and force meter | Force required to cut dowels of different sizes | Two of the four most efficient were also the least expensive. |
| Nursery | Hand grip tool[30] | | Self-reported pain; use of self-treatment; productivity; worker/supervisor acceptance | Reduction in self-reported pain, self-treatment of symptoms. |
| Orchard Fruit | Support belt for fruit picking bucket or bag[19,26] | Lab study: 10 university students; randomized condition within-subject trial. Field trial: 96 apple harvest workers randomized intervention-placebo within-subject trial ("placebo" belt did not attach to the picking bucket) | Lab: EMG muscle recruitment changes (15 muscles) indicative of stress placed on the back, neck, and shoulder. Field: harvest worker reported musculoskeletal pain, 1-day muscle fatigue, intervention acceptability, productivity effects | Lab: muscle recruitment significantly reduced in 11/15 muscles with intervention belt. Field: fewer reports of worker pain symptoms when using intervention, too sparse for statistical analysis. Muscle fatigue tests inconclusive, high level of worker acceptance; no intervention-placebo productivity differences, both significantly higher than usual equipment. Results support the effectiveness of the belt in reducing back, neck, and shoulder strain. |
| Ground crops | Harness bucket system and dual-bucket system[47] | 8 males North Carolina university students and community volunteers, (mean age 29) | Muscle activation levels under different postures/loads (effect of knee and back angle) | Harness-based system and dual bucket system; prototypes showed mixed results for ergonomic impact and impact on productivity. |
| Ground crops | Weeding tools[49] | 9 subjects (7 male, 2 female) | Lower back MSD risk factors, inflammatory response, sagittal positions, and trunk velocities. Monitored trunk kinematics while workers performed four weeding tasks using different tools | Worker's sagittal position with hoe weeding was not significantly different from the short-handled tool. Workers weeding with hoe displayed highest trunk velocities. Automated weeding tool showed significantly reduced biomechanical risk factors. Productivity results not promising. |

(*Continued*)

TABLE 5. (*Continued*)

| Commodity | Intervention | Population, design, sample size | Main outcomes | Results and conclusions |
|---|---|---|---|---|
| Animal | Ergo Bucket Carrier (EBC) and Easy Lift (EL)[48] | Farm youth, 6 males, 3 females | LBD risk measured with 3D spinal electrogoniometer while handling water buckets using 3 handling methods | Both interventions reduce magnitude of LBD risk; EBC effectively reduce LBD risk for carrying and dumping tasks and EL for lifting tasks. |
| Sugarcane | manual sugarcane cutting tools[50] | *N* = 3 no prior cutting experience South Africa and Guyana | Strength prediction modeling, body stress levels in the cutting motion.Cutting postures of three subjects were contrasted, their extreme postures were identified | Cutlass required less cutting force than the machete because of the slicing cut provided by the curved blade edge of the cutlass. However, the biomechanical analysis indicated that the bent blade of the machete required less flexion of the back and therefore was likely to cause less back fatigue and injury. |
| Unspecified | Stool height for the squatting worker[51] | 40 male and female Korean college students and 10 female farmers age 32–69. Lab and field evaluation design | Subject comfort rating method as well as pair-wise ranking test was applied under conditions of different working positions. | Comparable results were found from both evaluation measures. Strongly recommended to use proper height of stools with corresponding working position. |
| Unspecified | Modified shovels for youth[52] | 10 girls and 10 boys ages 11–18 years, from local 4-H programs Simulated-field study design Objective and subjective evaluations | Used lumbar motion monitor to capture trunk posture and motion while youth performed simulated task. Assessed rates of perceived exertion and comfort of use | Add-on handles decreased sagittal flexion but increased twisting when compared to reg. shovels—ratings worse for add-on shovels. Appears to be trade-off between sagittal and non sagittal motion—minimal impact on risk of low back injury. Further research needed to determine consequences of trade-off. |
| Wheat | 9 varieties of wheat sickle[53] | Analysis of ergonomic features on 9 sickles on 6 Indian farmers. Field and laboratory measurement | Body angle, heart rate, work performance | Optimal sickle design specifications identified. |
| Wine grapes | Smaller tubs[32] | 116 California vineyard workers. Pre-post survey without control | OSHA log injuries, pain, musculoskeletal symptoms; productivity | Reduction in reported pain and musculoskeletal symptoms. No change in reported injuries; slight reduction in productivity. |

TABLE 6. Individual-Level Changes, Work Processes and Procedures

| Commodity | Intervention | Population, design, sample size | Main outcomes | Results and conclusions |
|---|---|---|---|---|
| Blueberry | Raking slower at the beginning of the season[54] | Cross sectional study on Maine raker strain symptoms, $N = 134$. Association between self-reported slower raking at the beginning of the season | Self-reported pain | Raking more slowly did not reduce pain. |
| Fruit packing house work | Proper body mechanics particularly with respect to lifting[25] | 178 workers from 3 fruit packing-houses in Eastern WA, ages 18–50 years. 95% Spanish speaking and 76% female | Written pre-test post test, immediately after, and again two weeks after; observation of lifting technique immediately after training $n = 178$ written test, $n = 15$ performance observation Knowledge gain and performance of correct body mechanics during lifting | Culturally appropriate body mechanics education is an effective intervention for increasing knowledge and promoting correct lifting techniques. |

physical effects on workers, researchers also need to assess worker acceptance of the intervention and its effect on productivity.

At first glance it might seem that the optimal endpoint for evaluation would be lost work time injury. However, determining when a worker has a definitive "case" of strain is problematic, since there is no simple diagnostic test for the condition. Moreover, given the fact that many workers will continue to work when they have muscle strain for economic reasons, this endpoint would significantly be underreported. It is not surprising that only two evaluation studies included lost work time injury as an endpoint. In the absence of such a diagnostic test, researchers have used self-reported pain and other symptoms, and intermediate indicators of strain (or likelihood of strain development) such as muscle fatigue, muscle exertion, and force production as study outcomes.

Although pain is the most commonly reported musculoskeletal strain symptom, its use in research is also problematic due to its subjectivity. Even when studies measure pain changes within the same subjects, field conditions and a number of other factors may influence reporting. Workers from different cultures may have varying understandings of terms like "pain," "discomfort," and "injury." Hard work, fatigue, and musculoskeletal discomfort are a way of life for both family farmers and migrant and seasonal workers. Viewing musculoskeletal disorders as an occupational illness represents a paradigm shift for many in agriculture, and can make hazard identification and intervention development difficult if participants do not have a clear concept of ergonomics. Also, migrant and seasonal workers may not report pain for fear of being given less desirable work tasks on the farm, or losing one's job. In the study by Miles and Steinke, the fact that there was a discrepancy between levels of self-reported pain and self-reported self-treatment for pain (the latter being more frequent) was a further indication of the underreporting of pain among migrant and seasonal farm workers.[56]

Ultimately, practical and logistical concerns often determine the choice of an endpoint. Lost work time strain injuries are much less common than musculoskeletal symptoms alone, thus this method requires large samples or long study periods. Field use of portable EMG is currently experimental, and requires a high degree of measurement expertise, and extensive pilot studies. Other field methods used in interventions in agriculture are: heart rate (as a measure of exertion),[45] observed body angles when working,[37,53] worker rating of exertion,[32,41] worker preference,[39] worker comfort rating,[36,41,43] and relative loss of muscle strength or range of motion over the work day.[19] As in the laboratory evaluation studies, these latter measures are meant to be indicators of exposure to ergonomic hazards, rather than evidence of ergonomic harm.

Among field trials, smaller pilot studies in agriculture involve implementing interventions in the agricultural setting and measuring a range of impacts: worker comfort, body postures and loads, worker and employer enthusiasm, ease of use or worker comments, and respiratory rate (as a measure of exertion). Among the 36 total evaluations assessed, 15 small field trials were identified. In some evaluations, multiple intervention variants were compared and further design changes were made during the research. This type of study is also important as a means of piloting future larger field studies.[47]

Lastly, nine larger or more formal ergonomic field trials were identified. These studies had at least 20 subjects, some had over 100.[25,26] In these evaluations, the goal was to determine the effect of intervention in the agricultural workplace when used as intended. Eight of these studies assessed musculoskeletal strain symptoms or self-reported pain.[19,22,25,31,32,43,44,54] Of these, five utilized random assignment and/or a control group. [19,22,31,32,49] Of these, three found significantly reduced musculoskeletal symptoms associated with intervention use,[22,31,44] whereas a fourth was equivocal due to an overall sparsity of reported symptoms.[19]

*Intervention acceptance*: Intervention acceptance is critically important to the success of any intervention so much so that it has developed into its own scientific discipline.[56,57] *Diffusion of Innovation Theory* argues that certain characteristics of the intervention itself affect the likelihood of a new innovation being adopted by any population.[58] Research suggests that perceived benefit, consistency with existing practices and values, and intervention simplicity are most strongly associated with intervention acceptance.[59] Among the 28 evaluations described above, 16 include some measure of acceptance or intention to adopt in the future.

*Productivity effects*: Similarly, an ergonomic intervention in agriculture cannot hope to be widely adopted unless it can be demonstrated to at least have a neutral effect on agricultural productivity. Ideally we would like to see an *increase* in productivity, making it that much easier to disseminate. In hand harvest agriculture, because worker wages are typically tied to individual worker productivity, it is a relatively simple matter to track productivity effects on an intervention. Among the 36 total evaluations reviewed 11 include some measure of productivity effects.

## *BEST PRACTICES*

Shortly after California's ergonomics standard became effective in 1997, the UC Davis AERC received funding for a 3-year project to demonstrate a set of "best practices" guidelines for implementing the Cal/OSHA ergonomics standard in agricultural workplaces and to help determine the efficacy of such programs (NIOSH Cooperative Agreement PHS RO1 OH14508.) Three farming operations, a tree nursery, and a fruit packing company participated in the project. The farming operations included cotton, strawberry, and tomato production. Among the findings of this study included:

1. *Responsive agricultural employers can and will make positive, "good faith" efforts at complying with both the language and the intent of the regulation.*
2. *There are no commercially available, "off-the-shelf" tools or technologies for most of the most serious ergonomics hazards found in these agricultural workplaces.*
3. *Responsive agricultural employers may need external consultation to develop compliance programs that are efficacious in reducing targeted ergonomics hazard exposures.*
4. *It is unclear that good faith compliance with the elements of the California regulation will result in significant reduction of the most serious ergonomics hazard exposures.*
5. *Agriculture's generally low profit margins inhibit capacity and enthusiasm for expensive or fundamental changes in technology or practice.*
6. *Active involvement of workers in improved prevention programs faces obstacles in agricultural workplaces.*

These six themes underscore some of the difficulties inherent in recommending best practices: interventions are difficult to evaluate, agriculture faces serious economic challenges, and solutions to ergonomic problems have to be customized to the commodity and sometimes even to the farm itself. Because the fundamental goal of ergonomics is to adapt the workplace to fit the worker, solutions by definition must be customized to the individual workplace. CDC-NIOSH had attempted to address this problem by presenting a range of simple interventions (13 in all), some of which are adaptable to a number of different commodities. This was meant to serve as a manual for farm managers to use in developing their own solution. It represented the current best practices from the standpoint of a summation of expertise at that time in engineering and agriculture applied to ergonomics.[28]

From a research point of view, the ultimate goal is to subject interventions to randomized controlled trials and identify those that stand out as substantially reducing injury. However, as the above discussion demonstrates, the challenges to obtaining this type of evaluation data have made progress in this area slow.

To summarize, we have included 28 of the 36 evaluation studies found in the evaluation literature, covering 10 different commodity groups that were most applicable to North American production agriculture. The vast majority were equipment and tool interventions rather than administrative or behavioral interventions. Roughly half of the evaluations were in laboratory or simulated fields, with the other half nearly evenly split between small field pilots and large field trials. Among all these evaluations a minority used randomization and control groups, and there was a great deal of variability in study designs. About half of the studies evaluated explored worker acceptance and a third considered productivity effects.

Based on the results of the evaluation trials, we can say tentatively that the strongest evidence exists for the effectiveness of the 5-minute rest break[22,43] and the ergonomic blueberry rake,[44] and nearly as strong evidence exists for the smaller harvest tub for wine grapes.[31] Among efficacy studies, six other interventions proved successful with strong designs: a device for calf weighing,[33] a weight transfer device for stoop labor,[35] a gripping device for small plant containers,[30] a feed transport cart and modified scooping practices,[32] a support belt for orchard harvest work,[19] and a bucket carrier cart and lifting device.[49]

More broadly, five ergonomic issues were addressed in a number of interventions, and therefore might have application to other agricultural settings. These are stooping, general overwork and fatigue, hand tools such as shovels and rakes, transfer of weight to more appropriate part of the body, and the ability to customize an intervention for different body sizes and shapes.

## *RECOMMENDATIONS FOR EFFECTIVE TRANSLATIONAL ERGONOMIC RESEARCH*

Although the body of research in intervention efficacy and effectiveness is growing, researchers are limited by the inherent difficulties of data collection in the agricultural environment and lack of one widely accepted evaluation methodology. Large-scale field trials that are designed to validate smaller efficacy evaluation methods are greatly needed. They would move the state of the science ahead, and make the development and testing of a wide range of interventions on the farm accessible to all. Standardization of and validation of laboratory methods, such as lumbar motion monitors, by larger field studies would be an important tool agriculture and aid in the development and implementation of effective technologies and work practices. Consensus on what level of evidence is sufficient to begin research to practice is also needed to set a practical evaluation standard. Thinking ahead about the availability of manufacturers to supply future needs in engineering modifications and devices based upon pilot studies is also a necessary component of effective research to practice.

Many interventions are commodity specific and it would make sense to have commodity groups leading research. Questions such as what are cost-effective methods for small as well as large operations need to be answered. A key to research to practice is having widely accepted evidence of “efficacy” of an intervention. Commodity groups, in collaboration with the NIOSH Agricultural Health and Safety Centers and US Department of Agriculture (USDA), can also aid in determining the parameters of producer acceptance of ergonomic interventions, including cost-effectiveness and measures of impact upon productivity that are critical in determining whether an intervention is accepted. This also includes effective assessment of costs of ergonomic risks and MSDs, such as workers’ compensation and impact of turnover and rural labor issues. As noted earlier in this paper, commodity groups have actively participated in field studies. An example of a proactive commodity-specific approach is the development of the Pork Production Safety System by the National Pork Board as collaboration with industry, health care providers, and academicians. This included safe lifting and manual material handling aids. Dissemination of commodity-specific results through sharing “success stories” with researchers and fellow producers, as well as suggestions for improvement on interventions that are flawed, will help shape effective research to practice and decrease occupational injuries and illnesses.

Agricultural workers are an important component in addressing ergonomic risk reduction and may have insight into solutions if included in the discussion. NIOSH researchers recommended a strategy of improving agricultural ergonomic research and dissemination of results that is still very relevant.[60] This included worker acceptance, cultural beliefs, educational level considerations, and form of the information delivered,

In order to determine success in decreasing the number of MSDs, improved surveillance for MSDs is necessary. Presently, estimates of MSDs are based upon scattered surveys. Workers' compensation data are a valuable tool in assessing the extent of cost of MSDs but there is no common pool of shared data. Improved communication and sharing of data between insurers and the Bureau of Labor would help obtain a more complete assessment of the impact of agricultural ergonomic risk factors.

## CONCLUSION

Ergonomic risks present in production agriculture and the resulting MSDs pose a physical and economic concern to both producers and workers. The goal of this paper was to identify key elements in existing ergonomic research that will lead to effective translational research. The approach by necessity is multifactorial, involving producers, workers, researchers, extension safety specialists, governmental agencies, and workers' compensation insurers. The authors' recommend ongoing efforts that will lead to effective field trials of ergonomic interventions combined with administrative practices to decrease MSDs and dissemination of results throughout the agricultural and academic communities.

## REFERENCES

1. Healthy People 2010. Centers for Disease Control. Available at: http://www.healthypeople.gov/document/HTML/Volume2/20OccSH.htm. Accessed September 10, 2009.

2. National Institute for Occupational Safety and Health. National Occupational Research Agenda National Agriculture Forestery and Fishing Agenda. Available at: http://www.cdc.gov/niosh/nora/comment/agendas/agforfish/pdfs/AgForFishDec2008.pdf. Accessed September 15, 2009.

3. Davis KG, Kotowski SE. Understanding the ergonomic risk for musculoskeletal disorders in the United States agricultural sector. *Am J Ind Med.* 2007;50:501–511.

4. United States Department of Labor Bureau of Labor Statistics. Available at: http://bls/gov/iif/oshsum.htm. Accessed January 15, 2010.

5. *NIOSH Worker Health Chartbook 2004*. Department of Human Health Services (NIOSH) 2004. Publication no. 2004-16. Available at: http://www.cdc.gov/niosh/docs/2004-146/ch3/ch3-1.asp.htm. Accessed April 18, 2010.

6. Kirkhorn SR, Earle-Richardson G. Repetitive motion injuries. In Lessenger JL, ed. *Agricultural Medicine: A Practical Guide*. New York: Springer; 2006:324–338.

7. Dillon C, Petersen M, Tanaka S. Self-reported hand and wrist arthritis and occupational data form the U.S. National Health Interview Survey-Occupational Health supplement. *Am J Ind Med*. 2002;42:318–327.

8. Gomez MI, Hwang S, Stark AD, May JJ, Hallman EM, Pantea CI. An analysis of self-reported joint pain among New York farmers. *J Agric Saf Health.* 2003;9:143–157.

9. Osorio A, Beckman J, Geiser C, Husting EL, Inai A, Summerill KF. California farm survey of occupational injuries and hazards. *J Agric Saf Health.* 1998;(Special Issue No. 1):99–108 .

10. Washington State Department of Health. Work-related musculoskeletal disorder. 2002. Available at: http://www.doh.wa.gov/HWS/doc/OH/OCC_WMD.doc. Accessed Aril 18, 2010.

11. NIOSH. *Elements of Ergonomics Programs: A Primer Based on Ergonomic Assessments of Musculoskeletal Disorders*. Washington, DC: DHHS (NIOSH); 1997. Publication no. 91-117. Available at: http://www.cdc.gov/niosh/docs/97-117/eprefer.html. Accessed 04/18/2010.

12. Fathallah FA, Miller BJ, Miles JA. Low back disorders in agriculture and the role of stooped work: scope, potential interventions, and research needs. *J Agric Safety Health.* 2008;14:221–245.

13. Kolstrup C, Stal M, Pinzke S, Lundqvist P. Ache, pain, and discomfort: the reward for working with many cows and sows? *J Agromed.* 2006;11:45–56.

14. Pinske S. Changes in working conditions and health among dairy farmers in southern Sweden. A 14-year follow-up. *Ann Agric Environ Med.* 2003;10:185–95.

15. OSHA. Effective ergonomics strategies for success. United States Department of Labor. Available at: http://www.osha.gov/SLTC/ergonomics/four-ronged_factsheet.html. Accessed February 16, 2010.

16. OSHA. Ergonomic guidelines. United States Department of Labor. Available at: http://www.osha.gov/SLTC/ergonomics/guidelines.html. Accessed February 16, 2010.

17. California Code of Regulations. Title 8 Subchapter 7, General Industry Safety Orders, Group 15, Occupational Noise, Article 106, Ergonomics Section 5110, Repetitive Motion Disorders. Injury and Illness Prevention Program. Subchapter 7. Available at: http://www.dir.ca.gov/title8/5110.html. Accessed February 19, 2010.

18. California Worker's Compensation Losses and Expenses. Worker's Compensation Insurance Rating Bureau of California. Available at: https://wcirbonline.org/wcirb/. Accessed January 10, 2010.

19. Earle-Richardson G, Jenkins PL, Strogatz D, Bell EM, Sorensen JA, May JJ. Orchard evaluation of ergonomically modified apple bucket. *J Agromed.* 2006;11:95–105.

20. Heikkonen J, Louhevaara V. Empowerment in farmers' occupational health services. *Ann Agric Environ Med.* 2003;10:45–52.

21. Lynch RM. Ergonomics. In: Breslow L, Goldstein B, Green LW, Keck CW, Last JM, McGinnis M, eds. *Encyclopedia of Public Health*. New York, NY: Macmillan Reference, USA; 2002. Available online at: http://www.encyclopedia.com/doc/1G2-3404000320.html. Accessed December 10, 2009.

22. Faucett J, Meyers J, Miles J, Janowitz I, Fathallah F. Rest break interventions in stoop labor tasks. *Appl Ergon.* 2007;38:219–226.

23. Daltroy LH, Iverson MD, Larson, MG, Lew R, Wright E, Ryan J, Zwerling C, Fossel AH, Liang MH. A controlled trial of an educational program to prevent back injuries. *N Engl J Med.* 1997;337:322–328.

24. Zwerling C, Daltroy LJ, Fine LH. Johnston JJ, Melius J, Silverstein BA Design and conduct of occupational injury intervention studies: a review of evaluation strategies. *Am J Ind Med.* 1997;32:164–179.

25. Holmes W, Lam P-Y, Elkind P, Pitts K. The effect of body mechanics education on the work performance of fruit warehouse workers. *Work.* 2008;31: 461–471.

26. Earle-Richardson G, Jenkins PL, Strogatz D, Bell EM, Sorensen JA, May JJ. Electromyographic assessment of apple bucket intervention designed to reduce back strain. *Ergonomics.* 2008;51:902–919.

27. May J, Hawkes L, Jones A, Burdick P, Ginley B, Santiago B, Rowland M. Evaluation of a community-based effort to reduce blueberry harvesting injury. *Am J Ind Med.* 2008;51:307–315.

28. Barron S, Estill CF, Steege A. Lalich N, eds. DHHS (NIOSH), *Simple Solutions: Ergonomics for Farmworkers*. 2001; Washington, DC: DHHS (NIOSH). Publication no. 2001–111.

29. Zalk DM. Grassroots ergonomics: initiating an ergonomics program utilizing participatory techniques. *Ann Occup Hyg.* 2001;45:283–289.

30. Janowitz I, Meyers JM, Faucett J, Tejeda DG, Miles JA, Duraj V, Kabashima JN. Reducing risk factors for the development of work-related musculoskeletal disorders in nursery work. Richmond, CA: UCSF Ergonomics Program; 1999. Available at: http://ag-ergo. ucdavis.edu/papers/nurseryij.htm. Accessed April 18, 2010.

31. Duraj V, Miles JA, Meyers JM, Faucett JA, Janowitz IL, Tarter ME, Tejeda DG, Smith RH, Weber EA. Harvesting aids for reducing ergonomics risk factors in wine grape hand harvesting. University of California Agricultural Ergonomics Research Center. American Society of Agricultural Engineers; 2000. Available online at: http://ag-ergo.ucdavis.edu/papers/2000AsaeVineInterven.pdf. Accessed on April 20, 2010.

32. Duraj V, Miles JA, Meyers JM. Machine handling of winegrape picking containers. 2001. Available at: http://ag-ergo.ucdavis.edu/papers/2001AsaeVineHarv.pdf. Accessed January 15, 2010.

33. Southard SA, Freeman JH. Ergonomic interventions for the reduction of back and shoulder biomechanical loading when weighing calves. *Int J Ind Ergon.* 2007; 37:103–110.

34. Allread WG, Waters TR. Interventions to reduce low-back injury risk among youth who perform feed handling and scooping tasks on farms. *J Agric Safety Health.* 2007;13:375–393.

35. Barrett AL, Fathallah FA. Evaluation of four weight transfer devices for reducing loads on the lower back during agricultural stoop labor. Presented at ASAE Annual International Meeting July–August 2001. Paper no. 1-8056. St. Joseph, MI: ASAE.

36. Roelofs PFFM., Bruinsma A. Ergonomic improvement of manual work near the ground in arable farming. Agrotechnology and Food Innovations, University of Wageningen; 2004. Available at: http://www.agri-ergonomics.eu/downloads/PDF/Summary/ground_level_LR.pdf. Accessed April 18, 2010.

37. Marshall RN, Burnett AF. A kinematic, kinetic and electromyographic comparison of stooped sheep shearing techniques and shearing with a sheep manipulator. *Appl Ergon.* 2004;35:137–145.

38. Gregory DE, Milosavljevic S, Pal P, Callaghan JP. An examination of shoulder kinematics and kinetics when using a commercial trunk harness while sheep shearing. *Appl Ergon.* 2008;39:29–35.

39. Srdjevic Z. Operators' participation in selecting the most ergonomic driver seat. *J Agric Saf Health.* 2005;11:347–352.

40. Hsiao H, Whitestone J, Bradtmiller B, Whisler R, Zwiener J, Lafferty C, Kau T-Y, Gross M. Anthropometric criteria for the design of tractor cabs and protection frames. *Ergonomics.* 2005;48:323–353.

41. Kotowski SK, Davis KG, Waters TR. Investigation of select ergonomic interventions for farm youth. Part 2: Wheelbarrows. *J Agromed.* 2009;14:44–57.

42. Kato AE, Fathallah FA, Miles JA, Meyers JM, Faucett J, Janowitz I, Garcia EG. Ergonomic evaluation of winegrape trellis systems pruning operation. *J Agric Saf Health.* 2006;12:17–28.

43. Genaidy AM, Delgado E, Bustos T. Active microbreak effects on musculoskeletal comfort ratings in meatpacking plants. *Ergonomics.* 1995;38:326–326.

44. May J, Hawkes L, Jones A, Burdick P, Ginley B, Santiago B, Rowland M. Evaluation of a community-based effort to reduce blueberry harvesting injury. *Am J Ind Med.* 2008;51:307–315.

45. Hermes H, Schulz D, Burzik A, Knuth H. Results of examination on the physiology of effort on fruit tree pruning by means of pneumatic pruning shears, *Z Gesamte Hyg.* 1986;32:670–672.

46. Parish RL. Operating force requirements for manual pruning shears. *Appl Eng Agric.* 1998;14:349–352.

47. Mirka GM, Shin G, Shu Y, Zheng L, Jiang Z, Costello T, Harvesting ground-level crops: a biomechanical assessment and ergonomic intervention. Presented at ASAE Annual Meeting; Las Vegas, Nevada: July 2003. Paper number 038021.

48. Ramahi AA, Fathalla FA. Ergonomic evaluation of manual weeding practice and development of an ergonomic solution industrial ergonomics. In: *Human Factors and Ergonomic Society Annual Meeting Proceedings, Industrial Ergonomics*, 1421–1425;2006;Santa Monica, CA: Human Factors and Ergonomics Society.

49. Tang SC, Fathallah FA. Development and evaluation ergonomic interventions for bucket handling on farms. In: *Human Factors and Ergonomic Society Annual Meeting Proceedings, Industrial Ergonomics,* 1289–1293.

50. Clementson CL, Hansen AC. Pilot study of manual sugarcane harvesting using biomechanical analysis. *J Agric Saf Health.* 2008;14:309–319.

51. Jung HS, Jung HS. Evaluation of proper height for squatting stool. *Ergonomics.* 2008;51:671–690.

52. Kotowski SK, Davis KG, Waters TR. Investigation of select ergonomic interventions for farm youth. Part 1: Shovels. *J Agromed.* 2009;14:33–43.

53. Dilbaghi M, Gandhi S, Bimla. Ergonomic evaluation of improved sickles in wheat harvesting. *Indian J Agric Eng.* 2008;45:7–11.

54. Estill CF, Tanaka S. Ergonomic considerations of manually harvesting Maine wild bluerries. *J Agric Saf Health.* 1998;4:43–57.

55. Miles TP, Flegal K, Harris T. Musculoskeletal disorders: time trends, comorbid conditions, self-assessed health status, and associated activity limitations. In: Van Nostrand JF, Furner SE, Suzman R, editors. Health data on older Americans: United States, 1992. National Center for Health Statistics. *Vital Health. Stat.* 1993;(27):275–288.

56. Miles JA, Steinke WE. Citrus workers resist ergonomic modifications to picking ladder. *J Agric Saf Health.* 1996;2:7–15.

57. Mayer T, Gatchel R, Betancur J, Bovasso E. Trunk muscle endurance measurement. Isometric contrasted to isokinetic testing in normal subjects. *Spine.* 1995;20:920–926.

58. Rogers EM. Lessons for guidelines from the diffusion of innovations. *Jt Comm J Qual Improv.* 1995;21: 24–28.

59. Greenhalgh T, Robert G, Bate P, Kyriakidou O, Macfarlane F, Peacock R. How to Spread Good Ideas: A systematic review of the literature on diffusion, dissemination and sustainability of innovations in health service delivery and organization. Report for the National Coordinating Centre for NHS Service Delivery and Organisation R. & D. London: NCCSDO; April 2004. Available at: http://www.sdo.nihr.ac.uk/files/project/38-final-report.pdf. Accessed April 18, 2010.

60. Estill CF, Baron S, Steege AL. Research and dissemination needs for ergonomics in agriculture. *Public Health Rep.* 2002;117:440–445.

61. Stal M, Hagert CG, Moritz U. Upper extremity nerve involvement in Swedish female machine milkers. *Am J Ind Med.* 1998;33:551–559.

62. Stal M, Pinzke S, Hansson GA, Kolstrup C. Highly repetitive work operations in a modern milking system: a case-study of wrist positions and movements in a rotary system. *Ann Agric Environ Med.* 2003;10:67–72.

63. Stal M, Englund JE. Gender difference in prevalence of upper extremity musculoskeletal symptoms among Swedish pig farmers. *J Agric Saf Health.* 2005;11:7–17.

64. Nonnenmann MW, Anton D, Gerr F, Merlino L, Donham K. Musculoskeletal symptoms of the neck and upper extremities among Iowa dairy farmers. *Am J Ind Med.* 2008;51:443–451.

65. Pinzke S, Stal M, Hansson GA. Physical workload on upper extremities in various operations during machine milking. *Ann Agric Environ Med.* 2001;8:63–70.

66. Thelin A Jansson B, Jacobsson B. Osteoarthritis of the hip-joint and farm work. *Am J Ind Med.* 2004;45:202–209.

67. Toren A, Oberg K Lembke B, Enlund K, Rask-Andersoen A. Tractor-driving hours and their relation to self-reported low-back and hip symptoms. *Appl Ergon.* 2002;33:139–146.

68. Meyers JM, Miles JA, Faucett J, Janowitz I, Tejeda DG, Kabashima JN. Ergonomics in agriculture: Workplace priority setting in the nursery industry. *AIHA J.* 1997;58:121–126.

69. Meyers JM, Miles JA, Faucett J, Janowitz I, Tejeda DG, Kabishima JN. High risk taks for musculoskeletal disorder in agricultural fieldwork. In: *Proceedings of the IEA 2000/HFES 2000 Congress*; San Diego, CA; July 30–August 4;2000.

70. Roquelaure Y, Dano C, Dulolier G, Fanello, Pennaeau-Fontbonne D. Biomechanical strains on the hand-wrist system during grapevine pruning. *Int Arch Occup Environ Health*. 2002;75:591–595.

71. Earle-Richardson G, Jenkins, PL, Slingerland DT, Mason C, Miles M, May JJ. Occupational injury and illness among migrant and seasonal farmworkers in New York State and Pennsylvania, 1997–1999: pilot study of a new surveillance method. *Am J Ind Med.* 2003;44:37–45.

72. Fulmer S, Punnett L, Slingerland D, Tucker A, Earle-Richardson G. Ergonomic exposures in apple harvesting: Preliminary observations. *Am J Ind Med.* 2002;(Suppl 2):3–9.

73. Janowitz I, Tejeda DG, Miles JA, Duraj V, Fathalla F, Meyers JM, Faucett J. Ergonomics interventions in the manual harvest of wine grapes. In: *Proceedings of the IEA 2000/HFES 2000 Congress*; San Diego, CA; 2000.

74. Wakula J, Landau K. Ergonomic analysis of grapevine pruning and wine harvesting to define work and hand tools design requirements. In: *Proceedings of the IEA 2000/HFES 2000 Congress*; San Diego, CA; 2000.