Interventions to Reduce Low-Back Injury Risk Among Youth Who Perform Feed Handling and Scooping Tasks on Farms

W. G. Allread, T. R. Waters

Abstract. *Children and adolescents who perform farm chores are exposed to cumulative trauma injury risks, particularly to the low back. For example, they may routinely handle heavy materials and need to adopt awkward postures during farm chores. Two potential interventions aimed at reducing low-back injury risk were examined in the laboratory: the use of a rugged cart and proper orienting of feed bags to ease feed transport; and the use of a modified feed bin, intended to allow easier access to product scooped from the bin at different levels. A lumbar motion monitor device was used to quantify trunk movement and determine injury risk level. Fourteen male and female youth who regularly perform these farm chores participated in the study. The cart significantly reduced low-back injury risk by nearly 10%, compared with manual feed bag lifting and carrying. The modified feed bin did not significantly reduce low-back injury risk, compared with traditional scooping. Regardless of the method used, however, scooping feed from the top of the bin reduced lower back disorder risk by 50% or more compared to the two lower levels. This study showed that relatively simple and low-cost solutions can be applied to farm environments to help protect the low backs of youth who perform farm chores.*

Keywords. *Farming, Feed handling, Feed scooping, Interventions, Musculoskeletal disorders, Spinal loading, Youth.*

In addition to the nearly 1.3 million children and adolescents (those under age 20) who live on U.S. farms (Dacquel and Dahmann, 1993), approximately 800,000 live with hired farm workers and may work with their parents on these jobs (Oliveira and Cox, 1989). Farm tasks performed by these youth typically involve animal care, crop management, tractor usage and the operation of other powered equipment, and maintenance (Marlenga et al., 2001). Midwestern farm youth were reported more likely to care for animals, such as handling and feeding.

A survey conducted by the USDA National Agricultural Statistics Service (NASS, 2004) found that there were nearly 23,000 agricultural-related injuries to youth who lived, worked, or visited a farm in 2001. Many types of injuries were reported, including lacerations, broken bones, abrasions, strains and sprains, contusions, punctures, and burns (NIOSH, 2001). In addition, the National Research Council (NRC, 1998) reported that parents usually underreport their children's involvement in the work force, especially

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Submitted for review in November 2006 as manuscript number JASH 6740; approved for publication by the Journal of Agricultural Safety and Health of ASABE in May 2007.

The findings and conclusions in this report are those of the author(s) and do not necessarily represent the views of the National Institute for Occupational Safety and Health.

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when their children are still in school. These facts underscore the need to improve safety and work methods when youth are doing farm chores.

There are several reasons why youth are more likely than adults to develop musculoskeletal injuries when performing farm work. One is that children often are working with items designed for individuals (adults) who are usually larger and stronger (Miller and Kaufman, 1998). A second reason involves the growth rates that adolescents experience. Marks and Cohen (1978) reported that 15% to 20% of one's height is gained between the ages of 10 and 20. During this time, bone growth precedes and stimulates muscle lengthening; this produces an imbalance in the musculoskeletal system and produces a tightening of the muscles and tendons that surround the growth (Kidd et al., 2000). The result can be pain, overuse, or damage to the tendon-bone attachment, and it can make adolescents more likely than adults to develop a musculoskeletal disorder, or MSD (NRC, 1998). Third, children may be asked to perform work for which they do not yet have the needed developmental skills. Murphy and Hackett (1997) advised that only when youth become young teenagers (13 to 16 years) should they have the responsibility to manually handle feed and to feed animals. However, this chore often is done by younger individuals.

Across the range of environments in which adolescents find work, a significant percentage experience activity-related back strains, which result in pain and lost time from the job (Parker et al., 1994). Youth working on farms suffer from severe injuries more often than those working in other settings (Runyan and Zakocs, 2000). More specifically, particular farm tasks often performed by youth present a high injury risk to the low back. Allread et al. (2004) quantified the physical work requirements and trunk motions of 41 farm tasks performed by youth. These were categorized into activities involving: lifting, carrying, and dumping animal feed and water; lifting various types of bales; scooping food products; shoveling; spreading bedding; and performing miscellaneous tasks. These researchers found that nearly 20% of the tasks monitored contained work factors that created a high risk of injury, while two-thirds of the tasks involved work that produced a moderate injury risk. Two tasks performed by youth that were identified as potentially high risk included handling feed bags and scooping feed from bins. These findings indicate that children and adolescents are exposed to many farm work activities that place them at some risk of low-back injury. These results suggest that improvements to these activities may considerably reduce the chances that back injuries will develop in this population.

The North American Guidelines for Children's Agricultural Tasks (Lee and Marlenga, 1999) recommended lifting guidelines for reducing MSDs. These guidelines advised that youth should not lift objects that are greater than 10% to 15% of their body weight, nor should they carry these loads farther than 9.1 to 13.7 m. Using these criteria, a 60 kg child should not lift an object weighing more than 9 kg. However, Allread et al. (2004) reported that farm youth often handle items considerably heavier than this guideline suggests. In a review of agricultural safety and health data by Hard et al. (2002), the authors concluded that comprehensive approaches are needed to further analyze the problem of traumatic agricultural injuries and their risk factors for injury.

The purpose of this article is to report the findings from a laboratory study designed to evaluate the effectiveness of two new ergonomic interventions for youth to handle feed bags and scoop feed from bins.

Methods

Study Approach

Children and adolescents between the ages of 12 and 18 were studied in a laboratory setting while simulating two common farm-related tasks: handling bags of feed; and scooping feed from bulk storage bins. These tasks were selected because they have been shown to produce significant levels of low-back disorder (LBD) risk (Allread et al., 2004) and because feasible and low-cost interventions may be able to reduce this risk. Two different designs for performing each task were studied. One involved doing the work as was often observed on farms, and the second was based on a task redesign (i.e., using a cart to reduce feed bag lifting and carrying, and scooping from a new, ergonomically designed feed bin).

The hypothesis tested was that the proposed task interventions would significantly reduce trunk kinematics, subsequent low-back injury risk, and ratings of perceived exertion, compared with typical methods used to handle and scoop feed. Statistical tests were used to determine if these two interventions produced significant differences.

Subjects

The investigators recruited male and female youth who were experienced in performing the study tasks. During the screening process, any subject reporting a history of previous back injury was excluded from the study. A total of 14 individuals (7 of each gender) were tested. All subjects resided in the central Ohio area. Age and anthropometric information for all youth, by gender, is shown in table 1. The male and female groups did not differ statistically (at the $\alpha = 0.05$ level) in age, height, or weight, but a 6 cm difference in height and 2 kg difference in weight may be meaningful biomechanically.

Tasks

All subjects performed two farm tasks that were simulated in a laboratory. Their design was based on observations and measurements of youth doing actual tasks as part of their normal farm chores (Allread et al., 2004). The first task (fig. 1) required the lifting and carrying of feed bags, usually from a storage area. The second task (fig. 2) involved scooping feed from a bulk storage bin. The laboratory simulations required subjects to use "typical" work methods to perform the tasks, as well as to perform them using different methods that better incorporated ergonomics principles. These alternative task designs were chosen in an effort to significantly lower loading on the body (particularly to the low back) and subsequent injury risk. The aim of this study was to develop simple and low-cost interventions that would have a large, positive impact.

Equipment

For the feed handling task, bags weighing 11.3 kg and 22.7 kg were used. These represented weights commonly lifted by youth on farms (Allread et al., 2004). The cart built for the new, ergonomically designed tasks (fig. 3) included three rails, designed for both cart handling and to allow upright positioning of the bags. (On farms, bags often are laid flat and at ground level.) Rubberized wheels were used on this cart so that it could

Table 1. Subject age and anthropometric data.

Factor	All Subjects (n = 14) Mean (SD)	All Subjects (n = 14) Range	Males (n = 7) Mean (SD)	Males (n = 7) Range	Females (n = 7) Mean (SD)	Females (n = 7) Range
Age (years)	15.1 (1.9)	12.0-18.0	14.6 (2.4)	12.0-18.0	15.6 (1.3)	14.0-18.0
Height (cm)	167.4 (10.8)	149.9-182.9	170.5 (13.6)	149.9-182.9	164.2 (6.8)	156.2-170.2
Weight (kg)	56.9 (7.7)	40.7-65.8	58.0 (8.8)	40.7-65.8	55.9 (7.0)	45.4-62.6

Figure 1. Example of a feed handling task performed on a farm.

Figure 2. Example of a feed scooping task performed on a farm.

Figure 3. Wheeled cart used to transport feed bags.

move more easily over rough surfaces, such as those frequently found in farm environments.

The scooping tasks were performed from plastic bins. They were marked at three different vertical levels (22.9, 45.7, and 68.6 cm from the ground; fig. 4) to ensure that the material was refilled to the same level. For the typical scooping task, no bin modifications were made. However, for the ergonomically designed scooping task, the bin was angled 30° from vertical (fig. 5a). This was intended to allow easier access to feed materials. The bin also included a drop-down flap (fig. 5b), whose purpose was to provide easier retrieval of feed near the bottom of the bin. A commercially available galvanized scoop (fig. 6) was used for all conditions.

Figure 4. Bins used for scooping feed during the typical task conditions.

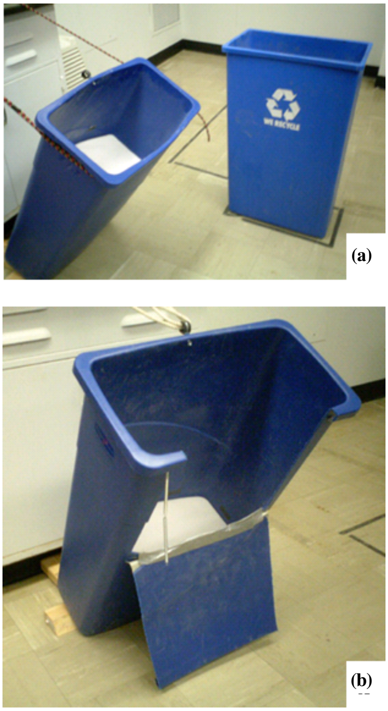

Figure 5. Bins used for scooping feed during the proposed task conditions (a) were angled and (b) included a flap to provide easier access to lower levels.

Figure 6. Galvanized scoop used for all feed scooping tasks.

Figure 7. The Lumbar Motion Monitor (LMM).

A Lumbar Motion Monitor (LMM) was used to measure subject trunk kinematics. It is shown in figure 7. The LMM is a tri-axial electrogoniometer (essentially an exoskeleton of the spine) that measures the instantaneous position of the spine in three-dimensional space. It was placed on subjects using shoulder and pelvic harnesses. Signals from the LMM were transmitted using digital telemetry and recorded on a laptop computer. The design and measurement accuracy of the LMM were reported by Marras et al. (1992).

Customized software captured the LMM data and calculated the instantaneous position, velocity, and acceleration of subjects' lumbar spines during the simulated work. It also computed LBD task risk, i.e., the probability that the activities monitored were similar to jobs found to produce high numbers of LBDs in industrial production facilities.

The LBD risk model (Marras et al., 1993) used for this study was developed from workplace and lumbar motion data collected on adults in over 400 manual materials handling jobs across diverse industrial manufacturing facilities. The numbers of LBDs linked to these jobs (taken from company medical records) also were obtained. Variables used as possible inputs into the risk model included workplace, trunk kinematic, and employee personal variables. Statistical analyses determined that five of these variables (from over 100 considered) best distinguished the "high-risk" group (jobs having twelve or more LBDs per 100 full-time employees per year) from the "low-risk" group (jobs having zero LBDs and no job turnover). These five factors were: the job's hourly lift rate, the maximum external moment generated about the spine (the product of the load weight and the distance it is held from the lumbosacral joint), the maximum spinal lateral velocity, the maximum spinal sagittal flexion, and the average spinal twisting velocity produced during the job. This risk model was validated by Marras et al. (2000).

The risk values generated for a task using these five factors (on a scale from 0% to 100%) represent the probability that the task observed is similar to high-injury jobs previously studied. There was some overlap found among the risk values computed for these low- and high-injury job groups. However, fewer than 2% of the low-injury jobs produced risk values greater than 60% (compared with over one-quarter of the high-injury jobs). In contrast, 80% of low-injury jobs had risk values of 30% or less, while 80% of high-injury jobs had risk values above 30%. Thus, risk values of 0% to 30%, 31% to 60%, and 61% to 100% could be used as general benchmarks to distinguish between jobs likely having low, medium, and high injury rates to the low back, respectively, for youth and adolescents. Although Marras has previously suggested that 71% to 100% be used to define high-risk jobs (Marras et al., 2000), he has indicated that a value of 61% to 100% may be more reflective of high-risk conditions (personal communication).

For this study, estimates of lifting frequency (i.e., the lift rate factor in the risk model) were based on data from Allread et al. (2004). Thus, across all LBD risk computations, this risk level factor was set at 1%. Feed handling and scooping tasks, as well as other farm chores performed by youth, are much less repetitive than the industrial jobs used for comparison purposes. In addition, unlike industrial work, these farm tasks are not performed on a full-time basis. However, this fact simply represents one end of the continuum across materials handling tasks. Note that this assumption may underestimate the risk of LBDs for farm youth who perform manual material handling tasks at higher frequencies and for longer durations during intensive work periods, where the lifting frequencies and work durations may indeed approach that observed for adults in repetitive, industrial jobs.

Borg's (1994) ratings of perceived physical exertion (RPE) were used to allow subjects to evaluate their physical effort for the study tasks. The whole-body scale (with a range of 6 to 20) was used, as was the body part scale (range: 0 to 11), for the low back, shoulders, and hands/wrists. This resulted in four RPE values for each test condition.

Variables

The two simulated farm tasks had unique independent variables. For the feed handling task, there were two bag weight levels (11.3 kg and 22.7 kg) and two transport methods (typical and proposed). Within each method, there were two tasks. The typical approach involved (1) lifting a bag from near floor level and (2) carrying it to a destination table. The proposed method required (1) pushing a cart of three bags to a destination table and then (2) lifting each bag to this table. For the scooping task, there were three scooping levels (bin material at 22.9 cm, 45.7 cm, or 68.6 cm from the floor) and two transfer methods (typical and proposed).

Table 2. List and description of the dependent variables.

Variable	Units	Description
Work area		
Moment arm-origin	cm	Maximum horizontal distance from lumbosacral joint to load (beginning of exertion)
Moment arm-destination	cm	Maximum horizontal distance from lumbosacral joint to load (end of exertion)
Moment-origin	Nm	Maximum moment about the lumbosacral joint (beginning of exertion)
Moment-destination	Nm	Maximum moment about the lumbosacral joint (end of exertion)
Trunk kinematics		
Lateral plane		
Left bend	deg	Maximum position moved laterally to the left of center
Right bend	deg	Maximum position moved laterally to the right of center
Range of motion	deg	Range of lateral movement
Average velocity	deg/s	Average lateral velocity moved
Maximum velocity	deg/s	Maximum lateral velocity moved
Acceleration	deg/s^2	Maximum lateral acceleration moved
Sagittal plane		
Extension position	deg	Maximum upright position moved
Flexion position	deg	Maximum forward position moved
Range of motion	deg	Range of sagittal movement
Average velocity	deg/s	Average sagittal velocity moved
Maximum velocity	deg/s	Maximum sagittal velocity moved
Acceleration	deg/s^2	Maximum sagittal acceleration moved
Transverse plane		
CCW position	deg	Maximum counter-clockwise position moved
CW position	deg	Maximum clockwise position moved
Range of motion	deg	Range of twisting movement
Average velocity	deg/s	Average twisting velocity moved
Maximum velocity	deg/s	Maximum twisting velocity moved
Acceleration	deg/s^2	Maximum twisting acceleration moved
LBD risk assessment		
Task risk	%	Risk value for a specific activity
Job risk	%	Overall risk value for related activities
Rating of perceived exertion		
Whole body	--	Subjective rating, using Borg scale (range: 6-20)
Low back	--	Subjective rating, using Borg scale (range: 0-10)
Shoulders	--	Subjective rating, using Borg scale (range: 0-10)
Hands and wrists	--	Subjective rating, using Borg scale (range: 0-10)

The dependent variables are summarized in table 2, categorized into four groups. Four work area measures reflected the distance from and moment about the spine when the task was performed, both at its onset and its termination. Trunk kinematics involved the positions, velocities, and accelerations of the spine as it moved in three-dimensional space, i.e., in the lateral (side-bending), sagittal (forward-bending), and transverse (twisting) planes. Two LBD risk assessments were calculated, one for each separate condition, and one for the “job” (e.g., transporting feed bags with the typical method, using the “proposed method” for scooping feed across all height levels). Finally, four different ratings of perceived exertion were measured for each condition (whole body, low back, shoulders, and hand/wrists).

Subject Recruitment and Data Collection Procedures

The first step in data gathering was to solicit volunteers. The aim was to recruit individuals ages 12 to 18 who engaged in physically demanding farm work and who regularly handled feed bags and scooped feed. Employees in 4-H Extension offices across several counties in central Ohio were contacted and briefed on the study. If it was agreed that the study would be of interest to members, they were sent a project summary with general criteria for subject recruitment. The 4-H officers then forwarded this summary to their members (either through an email announcement, newsletter, or at a meeting), which included the investigators' contact information.

When a potential subject or his/her parent contacted the investigators, they were read a prepared script that reiterated the study and its participation requirements. It also was confirmed that the child regularly performed the activities of interest for this study and had no back injury history or other ailments that would put them at risk for injury. If not, the caller was informed that the criteria were not met. If the criteria were met and consent was given, a time was set for data collection.

When the participant and a parent/guardian arrived at the study site, the investigator reviewed the aims of the project, the tasks to be performed, and the equipment to be used in data collection. Any questions about the procedure were answered. Parents provided written, informed consent for subjects less than 18 years of age. Subjects 14 to 17 years of age also signed consent forms in addition to their parents, and those under 14 provided verbal consent. Subject demographics then were recorded, and the subject was fitted with the appropriately sized LMM.

The order in which farm tasks were studied (feed handling or scooping) was randomly selected, and the specific conditions within that task were performed in a random order. Subjects were allowed to practice the task before data collection began.

The typical feed handling task is shown in figure 8. Three feed bags were stacked on top of one another from floor level (fig. 8a). Subjects lifted each bag individually and carried it a distance of 3.0 m (fig. 8b) to a table, whose height was 76.2 cm from the floor.

Figure 8. The typical feed handling task, which required subjects to (a) lift each bag and (b) carry it to a designated location.

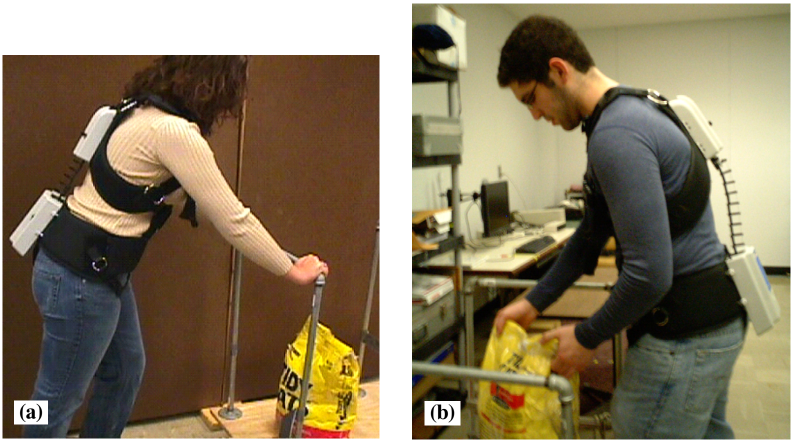

Figure 9. The proposed feed handling task, in which subjects (a) pushed the bags on a wheeled cart and then (b) lifted them to a designated location.

Figure 9 depicts the proposed feed handling method. Feed bags initially were placed on a wheeled cart. Subjects first pushed the cart containing three bags a distance of 3.0 m (fig. 9a). The measured force to push the cart containing three 11.3 kg bags was 3.6 kg, and it required 5.9 kg to push three 22.7 kg bags. These bags then were lifted onto the same table used in the typical task design (fig. 9b).

Figure 10 shows feed scooping using a typical farm chore scenario. Subjects removed feed from each of the three different bin levels and dumped it in an empty bin 0.8 m to the right of the feed bin. The same scoop was used for all conditions. Each subject was asked to scoop an amount of feed they felt comfortable with and to handle a similar amount during each trial. The average (SD) scoop/feed weight was 2.1 (0.6) kg, and eight of the 14 subjects handled 2.3 kg during each scooping task.

The same scooping procedure was used for the proposed scenario and modified equipment (fig. 11). Subjects were instructed to scoop from this bin in whatever manner

Figure 10. The typical feed scooping task, from the (a) top, (b) middle, and (c) bottom locations of the bin.

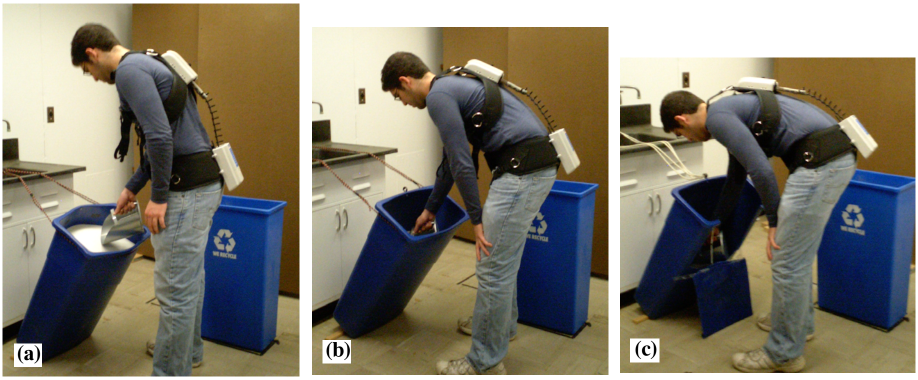

Figure 11. The proposed feed scooping task, from the (a) top, (b) middle, and (c) bottom bin locations.

they preferred. No other instruction was given so as not to influence technique, trunk motions, or exertion ratings.

Three cycles of each task were gathered. Following each set, subjects were asked to rate their level of perceived whole-body exertion as well as their exertion specifically to the low back, shoulders, and hands/wrists using posted Borg scales. Throughout the study, subjects were given ample rest time between exertions and water to drink.

After data from all conditions were gathered, the monitoring equipment was removed, and subjects were each given $50 for participation in the study.

Statistical Analysis

All subject, task, and work factor data were entered into the customized software used for LMM data collection, linking it with its corresponding trunk kinematic inputs. The same software was used to calculate LBD task and job risk values for each of the conditions, averaged across the 14 subjects. These data then were analyzed using Statistica (Release 4.5, 1993). Descriptive statistics (i.e., means and standard deviations) were computed for all dependent variables, across the various study conditions. Paired t-tests and analysis of variance techniques, at the $\alpha = 0.05$ significance level, were used to compare the typical task methods with those proposed for improvement. Post-hoc comparisons were made using Tukey's HSD test.

Results

Across both farm task simulations, each subject performed 42 exertions, not including practice trials. Results for the feed handling and feed scooping activities are discussed separately.

Feed Handling

The descriptive statistics for this task are presented in table 3 for the work factor variables, trunk kinematics, task LBD risk, and perceptions of exertion. Across all conditions, boldface type indicates values that are significantly higher at the $\alpha = 0.05$ level. The major findings presented in table 3 show that:

- Lifting bags from the ergonomic cart produced significantly higher moments (by about 6% to 10%). However, transporting bags using the cart (pushing bags rather than carrying them) resulted in a highly significant drop in moment, by at least 65%.

Table 3. Descriptive data of dependent measures for the feed handling activity. Data shown are means (standard deviations).[a]

Dependent Measure	Units	Lifting: 11.3 kg Bag, From floor	Lifting: 11.3 kg Bag, From cart	Lifting: 22.7 kg Bag, From floor	Lifting: 22.7 kg Bag, From cart	Transporting: 11.3 kg Bag, Hand carry	Transporting: 11.3 kg Bag, Push cart	Transporting: 22.7 kg Bag, Hand carry	Transporting: 22.7 kg Bag, Push cart
Work factors									
Moment arm-origin	cm	36.1 (5.9)	**39.6 (4.6)**	36.1 (4.8)	38.1 (5.9)	36.8 (4.3)	**40.5 (5.8)**	35.2 (4.4)	**40.6 (5.3)**
Moment arm-destination	cm	36.1 (5.9)	38.5 (4.7)	36.1 (4.8)	39.2 (5.8)	36.8 (4.3)	39.5 (6.4)	35.2 (4.4)	**40.6 (5.3)**
Moment-origin	Nm	40.2 (6.6)	**44.0 (5.2)**	80.3 (10.7)	84.7 (13.1)	**41.0 (4.8)**	14.4 (2.1)	**78.3 (9.9)**	23.5 (3.1)
Moment-destination	Nm	40.2 (6.6)	42.8 (5.2)	80.3 (10.7)	**87.2 (12.9)**	**41.0 (4.8)**	14.1 (2.3)	**78.3 (9.9)**	23.5 (3.1)
Trunk kinematics – Lateral plane									
Left bend	deg	–4.9 (3.7)	**–7.4 (3.2)**	–5.3 (4.4)	**–7.8 (2.9)**	**–7.3 (3.6)**	–5.4 (2.3)	–8.3 (5.9)	–6.6 (2.2)
Right bend	deg	–0.3 (3.2)	**1.6 (3.1)**	1.0 (4.4)	**3.8 (5.2)**	1.7 (3.6)	1.9 (1.4)	1.2 (5.9)	2.1 (1.5)
Range of motion	deg	4.7 (2.5)	**9.0 (2.7)**	6.3 (2.9)	**11.5 (4.7)**	**9.0 (2.8)**	7.3 (1.9)	9.5 (3.5)	8.6 (2.1)
Average velocity	deg/s	6.0 (2.1)	6.1 (1.8)	6.5 (2.8)	7.2 (2.1)	**7.3 (2.4)**	5.6 (1.3)	6.8 (2.3)	6.1 (1.3)
Maximum velocity	deg/s	15.8 (6.7)	19.8 (7.3)	20.5 (9.0)	23.6 (9.0)	**23.1 (7.3)**	18.7 (3.9)	22.4 (6.5)	21.4 (4.1)
Acceleration	deg/s^2	126.6 (53.2)	141.8 (40.7)	162.7 (58.5)	167.5 (66.3)	**186.1 (62.4)**	140.0 (24.4)	174.2 (49.2)	152.2 (25.5)
Trunk kinematics – Sagittal plane									
Extension position	deg	5.5 (9.3)	**–11.7 (7.8)**	0.5 (10.6)	**–14.5 (7.9)**	–17.1 (5.1)	–16.2 (5.9)	–17.8 (6.5)	–15.9 (5.6)
Flexion position	deg	**37.3 (8.4)**	16.3 (13.2)	**36.8 (9.7)**	16.8 (16.3)	–7.7 (6.5)	–7.8 (5.3)	–3.4 (7.9)	**–7.4 (4.5)**
Range of motion	deg	31.8 (5.8)	28.0 (9.3)	36.3 (11.5)	31.3 (13.0)	9.4 (2.3)	8.4 (2.8)	**14.5 (6.0)**	8.5 (2.9)
Average velocity	deg/s	**34.3 (6.9)**	12.7 (3.7)	**27.9 (8.7)**	13.2 (4.2)	6.2 (1.7)	5.3 (1.5)	**8.1 (2.4)**	5.5 (1.2)
Maximum velocity	deg/s	**62.6 (11.1)**	39.9 (15.1)	**59.2 (17.9)**	42.0 (14.6)	19.2 (5.2)	19.2 (7.2)	**27.8 (8.9)**	20.4 (5.2)
Acceleration	deg/s^2	**476.1 (97.6)**	221.1 (53.5)	**377.5 (86.6)**	248.2 (120.1)	144.1 (48.8)	147.1 (50.5)	**205.6 (82.8)**	156.8 (47.1)
Maximum velocity	deg/s	14.6 (8.5)	**24.1 (9.6)**	24.4 (21.1)	37.9 (23.2)	**27.9 (10.5)**	21.3 (7.6)	33.5 (17.1)	28.1 (12.3)
Acceleration	deg/s^2	123.2 (70.3)	**160.3 (70.0)**	191.6 (117.2)	263.7 (155.6)	**196.6 (77.1)**	151.5 (60.0)	231.1 (102.0)	193.4 (87.9)

(cont'd)

- There was a trade-off in trunk motions between the two lifting approaches. While the typical method generated more sagittal plane movement, taking bags from the cart (using the ergonomic approach) generally created higher lateral and twisting motions.

Table 3 (cont'd). Descriptive data of dependent measures for the feed-handling activity. Data shown are means (standard deviations).[a]

		Lifting				Transporting			
		11.3 kg Bag		22.7 kg Bag		11.3 kg Bag		22.7 kg Bag	
Dependent Measure	Units	From floor	From cart	From floor	From cart	Hand carry	Push cart	Hand carry	Push cart
Trunk kinematics – Transverse plane									
CCW position	deg	−1.3 (3.1)	**−6.2 (5.0)**	−4.2 (7.4)	−9.1 (7.7)	−7.7 (4.9)	−5.4 (3.1)	−11.3 (9.3)	−7.5 (4.4)
CW position	deg	2.5 (3.6)	4.2 (4.6)	3.0 (4.0)	6.4 (7.8)	4.9 (5.0)	2.6 (3.9)	3.8 (6.2)	2.9 (3.2)
Range of motion	deg	3.9 (3.0)	**10.4 (4.5)**	7.2 (6.8)	**15.5 (10.1)**	**12.6 (6.8)**	7.9 (3.0)	15.1 (11.1)	10.4 (4.9)
Average velocity	deg/s	5.1 (2.7)	6.8 (3.4)	6.4 (4.5)	8.9 (6.1)	**8.4 (4.3)**	5.6 (3.0)	8.1 (5.2)	7.1 (4.0)
LBD risk assessment									
Task risk	%	0.38 (0.09)	0.34 (0.10)	0.51 (0.11)	0.47 (0.12)	**0.25 (0.09)**	0.11 (0.06)	**0.36 (0.10)**	0.16 (0.07)
Perceived exertion									
Whole body	--	10.6 (2.2)	9.6 (2.3)	13.7 (1.9)	12.6 (2.1)	**9.5 (2.3)**	7.3 (1.3)	**12.2 (1.9)**	8.1 (1.8)
Low back	--	2.4 (1.4)	1.9 (1.7)	4.9 (2.2)	4.1 (2.4)	**1.5 (0.9)**	0.6 (0.7)	**3.7 (1.6)**	1.2 (1.1)
Shoulders	--	2.2 (1.6)	1.8 (1.3)	4.3 (1.4)	3.8 (1.8)	**1.8 (1.1)**	0.9 (0.8)	**4.1 (1.8)**	1.4 (1.2)
Hands and wrists	--	2.0 (1.2)	1.8 (1.8)	4.5 (2.0)	4.1 (1.5)	**1.7 (1.1)**	0.9 (0.9)	**3.6 (1.7)**	1.2 (0.8)

- Nearly all significantly greater trunk motions during bag transport involved carrying. That is, cart pushing resulted in fewer spinal movements.
- LBD risk for the feed bag lifting tasks did not differ between the typical and proposed approaches. However, carrying bags produced LBD risk more than double that required for cart pushing, regardless of bag weight. These effects were statistically significant.
- Subjects perceived that more physical exertion was required during bag carrying than cart pushing, for both bag weights.

Feed Scooping

Descriptive information for the scooping tasks is shown in table 4. As with bag handling, scooping produced trade-offs, primarily in terms of trunk kinematics. Of particular note:

- Only when scooping was performed from the bottom of the bin were there significant work factor differences between the two task methods. These were on the order of 5% to 10% and were greater using the ergonomically designed method.
- The proposed scooping method actually resulted in significantly greater motions in the sagittal plane but less motion in the transverse plane. There were few differences between the two task designs in the lateral plane of trunk movement.
- No significant differences in LBD risk or perceived exertion ratings were found between the two task designs, regardless of scooping level.

Table 4. Descriptive data of dependent measures for the feed-scooping activity. Data shown are means (standard deviations).[a]

Dependent Measure	Units	Scooping from Bottom of Bin: Typical method	Scooping from Bottom of Bin: Proposed method	Scooping from Middle of Bin: Typical method	Scooping from Middle of Bin: Proposed method	Scooping from Top of Bin: Typical method	Scooping from Top of Bin: Proposed method
Work factors							
Moment arm-origin	cm	38.1 (5.4)	**42.1 (4.7)**	37.6 (4.4)	37.6 (4.9)	34.5 (5.0)	35.0 (3.9)
Moment arm-destination	cm	37.6 (5.7)	39.9 (5.3)	38.6 (4.7)	40.6 (6.3)	37.0 (6.7)	38.6 (6.2)
Moment-origin	Nm	7.9 (2.3)	**8.7 (2.4)**	7.8 (2.3)	7.8 (2.2)	7.2 (2.2)	7.4 (2.6)
Moment-destination	Nm	7.8 (2.4)	**8.2 (2.2)**	8.0 (2.3)	8.4 (2.5)	7.7 (2.4)	8.1 (2.7)
Trunk kinematics – Lateral plane							
Left bend	deg	**–7.1 (3.0)**	–5.4 (3.7)	–5.7 (3.3)	–5.3 (3.8)	–5.7 (3.0)	–4.7 (3.3)
Right bend	deg	6.8 (5.8)	5.8 (3.9)	6.2 (4.7)	5.4 (5.0)	3.9 (3.1)	**5.5 (3.8)**
Range of motion	deg	**13.9 (5.8)**	11.2 (4.4)	11.9 (5.4)	10.7 (5.2)	9.6 (3.8)	10.2 (4.0)
Average velocity	deg/s	6.4 (2.4)	5.8 (1.4)	6.2 (2.7)	5.6 (2.1)	5.4 (1.7)	5.8 (2.6)
Maximum velocity	deg/s	21.7 (6.5)	21.5 (7.2)	20.2 (8.1)	19.7 (7.3)	17.7 (4.3)	18.0 (6.8)
Acceleration	deg/s^2	116.2 (31.8)	117.3 (29.5)	119.4 (53.8)	107.3 (33.3)	101.3 (15.0)	100.5 (39.5)
Trunk kinematics – Sagittal plane							
Extension position	deg	–9.4 (6.4)	–8.7 (6.2)	–9.3 (6.0)	–8.9 (6.5)	–10.9 (6.3)	–10.6 (6.6)
Flexion position	deg	29.1 (10.0)	**32.1 (9.1)**	17.3 (13.6)	**22.6 (10.4)**	0.2 (9.4)	**5.4 (11.5)**
Range of motion	deg	38.6 (9.9)	40.8 (8.3)	26.6 (11.1)	**31.5 (9.0)**	11.1 (5.7)	**16.0 (6.7)**
Average velocity	deg/s	12.8 (4.2)	13.3 (3.6)	9.7 (5.1)	**11.6 (4.9)**	5.5 (3.8)	**6.6 (3.6)**
Maximum velocity	deg/s	43.5 (13.9)	**48.6 (12.8)**	31.9 (14.1)	**38.2 (12.1)**	19.4 (8.4)	**23.1 (10.1)**
Acceleration	deg/s^2	179.4 (59.0)	182.1 (67.9)	162.3 (67.6)	162.4 (57.1)	116.1 (40.9)	112.2 (42.5)

(cont'd)

Job LBD Risk

Two of the primary benefits of the LBD risk model of Marras et al. (1993) are that: (1) it combines the workplace and trunk motion variables found to best distinguish between high and low injury rate jobs, and (2) it determines the effect on risk of multiple tasks that comprise a job. This is relevant to the current study, since feed handling involves multiple tasks (e.g., both lifting and moving bags), and working postures vary as feed levels change due to scooping from the bins.

Table 4 (cont'd). Descriptive data of dependent measures for the feed-scooping activity. Data shown are means (standard deviations).[a]

Dependent Measure	Units	Scooping from Bottom of Bin: Typical method	Scooping from Bottom of Bin: Proposed method	Scooping from Middle of Bin: Typical method	Scooping from Middle of Bin: Proposed method	Scooping from Top of Bin: Typical method	Scooping from Top of Bin: Proposed method
Trunk kinematics – Transverse plane							
CCW position	deg	**–6.5 (4.2)**	–5.0 (3.7)	**–7.1 (4.0)**	–5.2 (3.7)	**–6.2 (3.4)**	–4.7 (3.1)
CW position	deg	3.9 (3.4)	2.8 (3.5)	3.7 (3.2)	2.5 (2.7)	3.1 (4.2)	2.8 (3.3)
Range of motion	deg	**10.4 (3.3)**	7.8 (2.5)	**10.8 (3.9)**	7.7 (2.5)	**9.3 (3.8)**	7.6 (2.8)
Average velocity	deg/s	5.0 (1.7)	4.5 (2.0)	**5.3 (2.3)**	4.1 (1.8)	**4.8 (2.3)**	4.1 (2.2)
Maximum velocity	deg/s	21.4 (5.6)	20.3 (7.5)	21.3 (5.9)	18.8 (4.8)	**21.8 (7.8)**	16.5 (6.3)
Acceleration	deg/s^2	136.1 (42.1)	134.5 (53.9)	131.2 (35.6)	124.9 (39.1)	134.1 (44.3)	109.5 (41.0)
LBD risk assessment							
Task risk	%	0.30 (0.07)	0.29 (0.06)	0.24 (0.11)	0.25 (0.09)	0.12 (0.09)	0.13 (0.11)
Perceived exertion							
Whole body	--	8.8 (2.2)	8.5 (2.1)	8.1 (1.5)	8.0 (1.8)	7.4 (1.4)	7.4 (1.0)
Low back	--	1.5 (1.1)	1.6 (0.9)	1.0 (0.8)	1.0 (0.8)	0.6 (0.6)	0.5 (0.5)
Shoulders	--	1.3 (0.8)	1.4 (0.8)	1.3 (0.7)	1.1 (0.6)	0.9 (0.7)	0.7 (0.4)
Hands and wrists	--	1.6 (1.1)	1.7 (1.1)	1.5 (1.2)	1.8 (1.5)	1.3 (1.3)	1.3 (1.2)

[a] **Boldface** values within each set of columns are statistically significant at the $\alpha = 0.05$ level.

Thus, LBD risk was calculated for the job of handling feed bags. These data are graphically illustrated in figure 12. The typical work method produced an LBD risk value that, on average, was significantly greater than that of the proposed work method for both bag weight levels. This combined assessment (using information from both the lifting and transporting tasks) indicates that low-back injury risk levels could be reduced by nearly 10% through the use of a cart to handle bags. This result supports the hypothesis that the proposed method can have a positive impact on reducing LBD risk.

The same procedure was used to determine LBD risk for the feed scooping job across the three bin levels studied. The result is shown in figure 13. No significant differences in LBD risk were found between the typical and proposed methods, either overall or within any of the scooping levels. This finding does not support the hypothesis that the proposed method would result in lower values for the dependent measures and, subsequently, lower LBD risk.

One interesting finding shown in figure 13 is the dramatic difference in LBD risk across the three scooping levels, regardless of method. Analysis of variance techniques found that, for the typical method, each scooping level was statistically different from the others. With the proposed design, LBD risk during scooping from the top of the bin was significantly lower than that at either the middle or bottom levels. Regardless of the

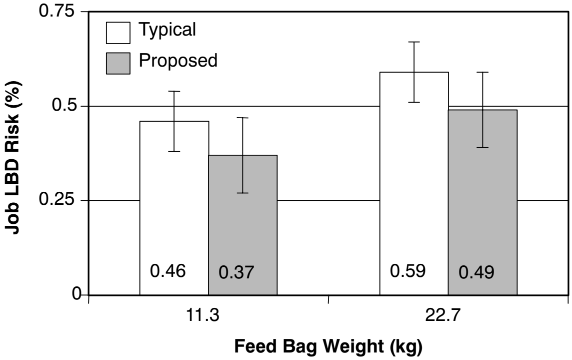

Figure 12. LBD risk values for the typical and proposed feed handling jobs, across both bag weights studied.

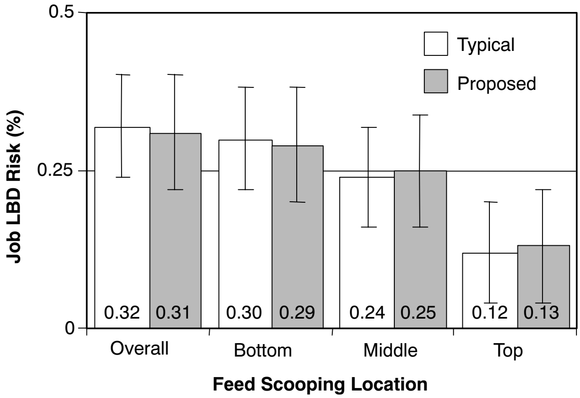

Figure 13. LBD risk values for the typical and proposed feed scooping jobs, both overall and for each scooping level studied.

method used, scooping feed from the top reduced risk by 50% or more compared with either bottom or middle scooping.

Discussion

This study measured the potential impact of two particular interventions aimed to reduce low-back injury risk among youth who feed animals. The hypothesis that these modifications would significantly reduce risk was partially supported. Overall, the feed bag handling intervention reduced LBD risk by roughly 10% across varying feed bag weights. Although the feed scooping intervention was not found to be an improvement over the approach typically used on farms, an additional task modification of raising the bin while lowering the drop-down flap might provide greater improvement. This will be discussed later in this section.

Several notable outcomes can be derived from the feed bag handling portion of this study. First, significant reductions in trunk motions, particularly in the sagittal plane, can be derived by storing bags upright, and on a wheeled cart. This may allow some youth to assume a better, and less-risky, posture during bag lifting. Second, the experimental design may have produced an underestimate of LBD risk. Here, lifting feed bags using a “typical” approach produced risk values averaging 59% for the heavier bag (fig. 12). However, Allread et al. (2004) found average LBD risk for this task to be 69.3% across all bag handling tasks measured in the field. This may be because subjects were provided unobstructed access to the bags (fig. 8a), which could seldom be the case in a farm setting. Third, transporting feed bags using a cart clearly reduced LBD risk compared with carrying them. This was due to the lower forces exerted during cart pushing and the reduction in spine motions across all planes. Fourth, the cart’s design (fig. 3) may be able to be improved. Spine lateral and transverse motions actually were higher when lifting bags from the cart, compared with unobstructed bag lifting from the floor. As figure 9b illustrates, the cart’s rail, or the orientation of the cart relative to the table, may have been responsible for these increases. A cart with lower bag support rails, or the increased training of subjects (who initially were unfamiliar with the cart) may have produced lower LBD risk values for this task.

The fact that the proposed scooping intervention did not reduce LBD risk was surprising. Similar ergonomic designs, where materials to be retrieved from bins are angled towards the user, are commonly found in industry, and many types of bin lift and tilt systems are commercially available. Common also in industry are storage containers with fold-down flaps like the one designed into the proposed bin (fig. 5b), whose intent is to provide easier access to materials. Because feed bin storage systems on farms vary widely (e.g., purchased bins and tubs, homemade containers), choosing a different-sized bin may have changed our results.

In retrospect, it is likely that if we had provided a bin lifting device to raise the vertical height of the bin during the scooping task, in addition to the fold-down flap, we could have shown a significant improvement over the original task design. This is because the vertical height of the material would have remained at approximately the same optimal vertical height level (equivalent to the top level), thereby decreasing the sagittal flexion required for the task and maintaining a reduced LBD risk assessment, as shown in figure 13. Giving subjects more training as to the merits of these design features may have produced different results; however, the investigators did not want to influence how subjects interacted with this equipment.

Perhaps the most important finding from the scooping portion of this study was the large decrease in LBD risk seen when scooping occurred from the top of the bin (figs. 10a and 11a). Risk values were half of those calculated when scooping was performed from the middle of the bin, just 23 cm lower. This clearly shows how work height impacts low-back movements and, ultimately, injury risk.

One limitation of this study was that the proposed work methods were simulated in a laboratory. These results may change if the tasks were performed in actual farm settings. This relates particularly to cart pushing, where floor surfaces in barns and sheds are often uneven. Testing cart pushing in an outdoor environment likely would require a cart with different wheels than those used here. In addition, a risk model developed from industrial manual materials handling was applied to farm work. This may have over- or underestimated the LBD risk in this study, since the model was based on industrial jobs performed full-time, not on farm jobs that are performed part-time or seasonally. Thus, the frequency component input into the model was 1%. This assumption may underestimate LBD risk, because some farm youth may perform these tasks at higher frequencies and for longer durations, such as those seen in many industrial jobs. The study also was limited by the need to utilize laboratory simulations with good floor surfaces, compared with less than optimal floor surfaces at the worksite. In addition, the small sample size could have influenced the study. Finally, because we did not investigate the effect of the intervention on spinal loading prediction, per se, it may be difficult to truly understand any trade-offs between the off-plane and sagittal motion.

Conclusion

This study has shown that relatively simple and low-cost changes made to commonly performed farm tasks can reduce injury risk to the low back. These results also show the importance of providing training and education to children and adolescents, so they can understand how work methods differing from their typical approach can be beneficial.

A further conclusion from this study is that interventions based on ergonomic and biomechanical principles found to be successful in other work environments must be carefully applied to farm tasks. Given the diverse ways in which feed handling and scooping are performed on farms, a "one size fits all" strategy may not be the most ideal approach to implementing work method changes. Educating youth and their parents on the activities that place them more at risk of a musculoskeletal disorder may enable more appropriate integration of these concepts into their unique farm environments.

Because this study focused on just two tasks often performed by children and adolescents on farms, further research should be conducted whose aim is to address these other activities. Together, this knowledge can greatly reduce the factors that impact youth injuries.

Acknowledgements

This research was made possible by a contract from the National Institute for Occupational Safety and Health. The authors are grateful to Dr. Carolyn M. Sommerich and Dr. William S. Marras for use of their laboratory spaces.

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