Physical Demands and Low−Back Injury Risk Among Children and Adolescents Working on Farms

W. G. Allread, J. R. Wilkins III, T. R. Waters, W. S. Marras

ABSTRACT. *Little information currently exists regarding the risk of low−back disorders among youth who perform physically demanding farm activities. Thus, a field study was conducted in which children and adolescents who engage in farm work were recruited, fitted with a lumbar motion monitoring system, and then observed performing their usual chores. The lumbar motion monitor was used to record the trunk movements required while youth were performing routine manual material handling tasks on a farm. Workplace factors and motions from both males and females were recorded on over 40 farm tasks, such as feeding animals, lifting bales of hay and straw, and other miscellaneous farm chores. Although the sample size and number of observations in this study were small, the results showed that the magnitude of several work−related factors, such as weight and horizontal moment arm, and trunk motions for many farm activities were equal to or greater than those associated with high injury risk jobs previously assessed in industrial workplaces. In this study, we quantified the physical demands of tasks performed by children and adolescents on farms. In addition, the specific farm chores more likely to load the spines of youth and thereby contribute to musculoskeletal injury were identified.*

Keywords. *Farming, Manual material handling, Musculoskeletal disorders, Spine loading, Youth.*

More than 1.2 million youth (i.e., persons less than 20 years of age) reside on farms in the U.S. (Dacquel and Dahmann, 1993), and many of them engage in farm work that is potentially harmful to their musculoskeletal systems. Mines et al. (1997) reported that 8% of farm workers are under age 17; these children and adolescents perform a wide range of jobs having quite diverse physical demands. Chores such as the manual handling of hay bales, the lifting and carrying of water and feed buckets, and the repetitive use of hand tools (e.g., shovels, rakes) may increase the risk of developing one or more musculoskeletal disorders (MSDs). Unfortunately, little research has been conducted in this area, despite the fact that farm youth may be especially vulnerable to the physical demands of these types of activities.

Farm workers take part in a wide variety of physical tasks. These involve forceful exertions, stooping, static and awkward postures, and continual bending and twisting at the waist, which occur when handling heavy objects (Meyers et al., 1997). Youth on farms

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participate in many of these work activities. Marlenga et al. (2001) surveyed over 1,100 youth from nearly 500 farms in North America, which resulted in the collection of data on nearly 2,400 farm tasks. Those tasks performed by 10% or more of the children were: caring for large animals (31.0%); caring for small animals (26.5%); cleaning animal enclosures, such as stalls, pens, and corrals (16.0%); loading, unloading, and stacking hay (13.0%); and driving a tractor with a trailed implement (12.2%).

Many of these farm−related activities involve significant manual materials handling and exposure to factors found to be related to the development of MSDs and low−back disorders (LBDs). These factors include heavy physical work, static work postures, frequent bending and twisting, lifting and forceful movements, repetitive work, vibration, temperature extremes (Andersson, 1981; Keyserling et al., 1991), and the dynamic movements of the trunk during manual work (Marras et al., 1993). Adults in focus groups comprised of farm families believed that the lifting of materials and the use of pitch forks and shovels were most responsible for injuries to their children (Bartels et al., 2000). Many of the youth in that study also reported that muscle strains (in their extremities, shoulders, backs, or necks) occurred on a daily basis.

There are several reasons why children and adolescents are more likely than adults to become injured when working on farms. They may use equipment designed for adult−sized individuals; they may lack the needed physical and emotional maturity; they may more easily fatigue; they often have less work experience or use poor judgment; and they often desire to be treated as adults (Miller and Kaufman, 1998). In addition, it may be speculated that children and adolescents develop MSDs from doing farm work because of physiological and biomechanical issues. It has been reported that 15% to 20% of height is gained between the ages of 10 and 20 years (Marks and Cohen, 1978). During this growth spurt in adolescence, bone growth precedes and stimulates muscle lengthening. This resulting imbalance in the musculoskeletal system produces tightening of the muscles and tendons that surround the growth (Kidd et al., 2000) and can result in pain, overuse, or damage to the tendon−bone attachment. These findings suggest that special attention must be given to the types of farm activities performed by children and adolescents to reduce their risk of developing MSDs.

There is little information that describes the physical demands and musculoskeletal risks of youth who engage in farm work. Thus, the goal of this study was to document the types of agriculture−related work activities that are performed by children and adolescents, specifically those where there are risks for work−related low−back disorders (LBDs) for children and adolescents who work on farms.

Methods

Study Approach

This was a cross−sectional surveillance study of the trunk motions and work factors associated with agriculture−related activities performed by youth on farms in the Midwestern U.S. The study was approved by both The Ohio State University and NIOSH human subjects review boards. The approach first involved contacting farm families who would permit their children to be observed and monitored. While on the farms, work tasks were evaluated by an expert ergonomist to identify those tasks that potentially posed a risk of musculoskeletal injury to these children. Discussions with youth, parents, and employers supported our belief that the range of tasks identified for observation was representative of the daily tasks performed by youth in a typical day. Tasks selected by the ergonomists were identified and measured, including weights and lifting frequencies of the tasks and, when possible, trunk motions and risk of low−back disorder were quantitatively assessed. These data then were compared with workplace information, trunk motion data, and injury risks previously published in the literature for manual materials handling work found in industrial settings. This provided a relative assessment of the risks of LBDs associated with these farm tasks, specifically those involving children and adolescents.

Subjects

Young males and females who lived and/or worked on family farms were recruited. Data were collected on 15 individuals (8 males and 7 females). All subjects lived in central Ohio. Demographic information, for all children, and by gender, is presented in table 1. On average, males and females were not statistically different in age, height, or weight (at the 0.05 level). This is likely due to the large range in ages of these children, particularly for males (i.e., 10 to 18 years). Additionally, all males were right−handed, as were five of the seven females. Participation was voluntary, and youth with a history of previous back disorders were excluded from the study.

Tasks

This research focused on the tasks performed by farm youth (as reported by Marlenga et al., 2001) that may pose a risk of work−related LBDs. Thus, data were collected primarily on tasks involving materials handling (of animal feed, water, hay bales, tools, rocks, etc.) and work related to cleaning and moving objects. For repetitive tasks, observations generally lasted for at least 30 minutes or longer.

Data were gathered on a wide variety of tasks. Feeding activities involved a diverse range of animals (i.e., calves, chickens, cows, ducks, goats, horses, pigs, rabbits, and sheep), and the youth handled many different yet quantitatively comparable materials. This resulted in tasks that could be defined both broadly (e.g., “dump feed and water,” “lift bale”) or more specifically (e.g., “dump feed bag,” “lift hay bale”). A total of 41 detailed tasks were identified, which then were grouped into eight broad task categories (see table 2). For the sake of brevity, most of the data presented in this article reflect values that were determined for the broader task categories rather than the individual tasks. These task categories were: “lift feed and water” using bags and buckets (an example of which is shown in fig. 1); “carry feed and water,” typically in buckets (fig. 2); “dump feed and water,” primarily from bags and buckets (fig. 3); “lift bale,” comprised of alfalfa, grass, hay, or straw (fig. 4); “scoop food products,” such as feed or milk (fig. 5); “shovel” either manure or silage (fig. 6); “spread bedding” composed of hay or sawdust (fig. 7); and “miscellaneous,” which involved such tasks as moving feed wagons, picking up rocks, handling wheelbarrows, and connecting trailer hitches.

Variables

Although there was a focus on manual lifting tasks, there were no restrictions placed on the types of material handling tasks observed and monitored, and every effort was made to collect data on a diverse range of activities. The variables collected or computed for these activities are listed and described in table 3. They were grouped into three

Table 1. Subject demographic data.

	All Subjects (*n* = 15)		Males (*n* = 8)		Females (*n* = 7)	
Factor	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range
Age (years)	13.5 (2.4)	10.0−18.0	14.1 (3.0)	10.0−18.0	12.9 (1.5)	11.0−15.0
Height (cm)	156.9 (17.3)	121.9−190.5	161.3 (18.7)	134.6−190.5	151.8 (15.2)	121.9−164.5
Weight (kg)	59.3 (22.8)	28.6−97.5	59.8 (24.0)	28.6−97.5	58.7 (23.3)	29.5−90.7

Table 2. List of the 41 detailed farm tasks and the broadly defined task categories into which they were grouped.

Detailed Task	Task Category
Lift feed bag	Lift feed and water
Lift feed bucket	
Lift feed pail	
Lift water bucket	
Lift water pail	
Carry feed bucket	Carry feed and water
Carry water bucket	
Dump feed bag	Dump feed and water
Dump feed bucket	
Dump feed pail	
Dump water bucket	
Dump water trough	
Lift alfalfa bale	Lift bale
Lift grass bale	
Lift hay bale	
Lift straw bale	
Scoop feed	Scoop food products
Scoop powdered milk	
Shovel manure	Shovel
Shovel silage	
Spread hay	Spread bedding
Spread sawdust	
Change water bottle	Miscellaneous
Climb fence w/feed	
Coil hose	
Connect trailer hitch	
Dump wheelbarrow	
Fill feed bucket	
Fill/carry feed bucket	
Lift hay flakes	
Lift milk bottle	
Lift milk crate	
Move feed wagon	
Open mixer lid	
Pick up animal	
Pick up rocks	
Pull wheelbarrow	
Push wheelbarrow	
Rake stalls	
Sweep floor	
Use water hose	

categories: work factors pertaining to the physical characteristics of the work itself (e.g., weights of objects handled, distances from the body at which they were handled, vertical locations from the ground); kinematics of the trunk (positions, velocities, and accelerations in the lateral, sagittal, and transverse planes); and assessments of injury risk to the low back.

Figure 1. Example of a “lift feed and water” task.

Figure 2. Example of a “carry feed and water” task.

Figure 3. Example of a "dump feed and water" task.

Figure 4. Example of a "lift bale" task.

Figure 5. Example of a “scoop food products” task.

Figure 6. Example of a “shovel” task.

Figure 7. Example of a “spread bedding” task.

Table 3. List and description of the study variables.

Variable	Units	Description
Work factors		
Load weight	N	Weight of the object handled
Maximum moment arm	cm	Maximum horizontal distance from lumbosacral joint to load
Moment	Nm	External load moment generated about the lumbosacral joint
Vertical load height − origin	cm	Vertical location of the load at the beginning of the lift
Vertical load height − dest.	cm	Vertical location of the load at the end of the lift
Coupling	−−	Quality of hand−to−object interaction (qualitative measure)
Trunk kinematics − Lateral plane		
Left bend	°	Maximum position moved laterally to the left of center
Right bend	°	Maximum position moved laterally to the right of center
Range of motion	°	Range of lateral movement
Average velocity	°/sec	Average lateral velocity moved
Maximum velocity	°/sec	Maximum lateral velocity moved
Acceleration	$°/sec^2$	Maximum lateral acceleration moved
Trunk kinematics − Sagittal plane		
Extension position	°	Maximum upright position moved
Flexion position	°	Maximum forward position moved
Range of motion	°/sec	Range of sagittal movement
Average velocity	°/sec	Average sagittal velocity moved
Maximum velocity	$°/sec^2$	Maximum sagittal velocity moved
Acceleration	°	Maximum sagittal acceleration moved
Trunk kinematics − Transverse plane		
CCW position	°	Maximum counter−clockwise position moved
CW position	°	Maximum clockwise position moved
Range of motion	°	Range of twisting movement
Average velocity	°/sec	Average twisting velocity moved
Maximum velocity	°/sec	Maximum twisting velocity moved
Acceleration	$°/sec^2$	Maximum twisting acceleration moved
LBD risk assessment		
Lift rate	%	Risk value for the lift rate factor
Maximum moment	%	Risk value for the maximum moment factor
Maximum lateral velocity	%	Risk value for the maximum lateral velocity factor
Maximum sagittal flexion	%	Risk value for the maximum sagittal flexion factor
Average twisting velocity	%	Risk value for the average twisting velocity factor
Task risk	%	Overall risk value for the task

The low−back disorder (LBD) risk model (Marras et al., 1993) used here was developed from workplace and lumbar motion data gathered on adult employees in a wide variety of industrial manufacturing facilities. Over 400 jobs were monitored in these facilities and involved repetitive, manual materials handling. The numbers of LBDs associated with these jobs (taken from company medical records) were also obtained. Variables used as possible inputs into the risk model included workplace, trunk kinematic, and employee personal variables. Statistical analyses found that there were five factors (of over 100 considered) that 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); and the maximum lateral velocity, the maximum sagittal flexion, and the average twisting velocity produced by the spine during the job. This risk model was validated in a separate study (Marras et al., 2000).

The risk values generated for an activity using these five factors (on a scale from 0% to 100%) represent the probability that the task observed is similar to the characteristics of those high−injury jobs previously studied. As shown in figure 8, there is some overlap among the distributions of risk values computed for the low− and high−injury groups of jobs. However, fewer than 2% of the low−injury jobs observed produced risk values of 60% or greater (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. Marras et al. (2000) suggested that 71% to 100% be used to define high−risk jobs. However, he has since indicated that this may be too restrictive of a criterion and that a value of 61% to 100% may be more reflective of high−risk working conditions required of individuals (personal communication), because this range still provides excellent discrimination from materials handling jobs having no low−back injuries.

Equipment

Measurements of work factor variables were quantified using a heavy−duty scale, a Chatillon push−pull gauge, and a tape measure.

Kinematics of the trunk were recorded using a Lumbar Motion Monitor (LMM) system. The LMM is shown in figure 9, in relation to a spine model. It is a tri−axial electrogoniometer that is essentially an exoskeleton of the spine. The LMM measures the instantaneous position of the spine in three−dimensional space. It was attached to individuals 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 has been reported elsewhere (Marras et al., 1992).

Customized software was used to collect the LMM data, as well as to calculate the instantaneous position, velocity, and acceleration of subjects' lumbar spines as the farm tasks were being performed. This software also was used to compute LBD task risk, that is, the probability that the activities monitored were similar to jobs producing high numbers of LBDs in industrial production facilities (Marras and Kim, 1993).

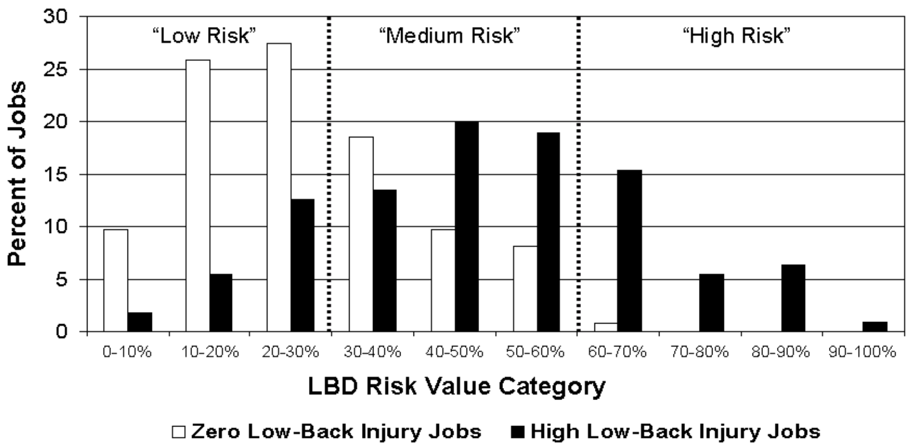

Figure 8. Distribution of LBD risk values for low− and high−injury industrial jobs.

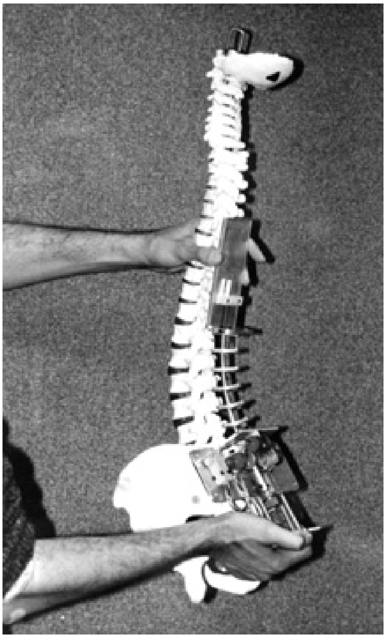

Figure 9. The Lumbar Motion Monitor (LMM).

Subject Recruitment and Data Collection Procedures

The first step in data gathering involved identifying volunteers for the study. The aim was to recruit individuals age 18 and younger who engaged in physically demanding farm work. Databases of those who participated in past research studies were the first to be contacted (Wilkins, 2002). Other sources of potential volunteers came from 4−H Extension agents in various counties around central Ohio and area high school and middle school agriculture departments.

When contacting family−run farms, investigators first stated their name, affiliation, and reason for the call, and then asked to speak to a parent, according to a prepared telephone script. The parents were briefed on the study objectives and data collection procedures. They were asked whether or not their children performed any of the activities of interest for this study, or any other physically demanding tasks. If they did, more−detailed information was gathered on these tasks, and the parents were asked if they would consent to having their child participate in the study. If so, an appointment time was made for data collection. The recruitment procedure was the same when contacting commercial farms, except that the farm owner/manager was first contacted and asked whether or not youths were employed at the facility.

Upon arriving at the site, investigators briefly reviewed the aims of the study with the participants and answered any questions posed. The youth and their parent/guardian/employer gave their written consent. Then, these individuals were asked to describe the work tasks that would be performed. This information was recorded on a data collection form, as were subject demographics.

The LMM then was shown and its operation explained to the volunteers. They next were fitted with the appropriately sized monitor. Six of the 15 children observed were too small to wear even the smallest sized LMM, as these were designed for use with an adult population. Typically, those standing less than 152 cm (60 in) tall could not wear the monitor.

Data collection was begun after waiting for several minutes for the child to adjust to wearing the LMM. During this time, the team of two to three investigators gathered the trunk kinematic data and measured the load weights, horizontal moment arms during load lifting, vertical origin and destination heights of the lifted loads, and other pertinent work factor information. In cases where the LMM was not worn by the child, only the task and work factor variables were measured. To the extent feasible, observations were made while the youth performed their routine work activities. In some cases, however, it was necessary to have the youth repeat the activity or simulate the activity in order to obtain a high−quality data sample.

After sufficient data were collected, the monitoring equipment was removed, and the youth was given a T−shirt and ball cap as compensation for participation.

Statistical Analysis

All subject, task, and work factor data were entered into the customized software used for LMM data collection and linked to the corresponding trunk kinematic and LBD risk information. These data then were analyzed using the Statistical Analysis System (SAS Institute, Inc., Cary, N.C.). Descriptive statistics (i.e., means and standard deviations) were computed for all dependent variables, combined across each of the eight general task categories. LBD task risk was computed for each of the 41 detailed tasks using the Marras and Kim (1993) five−variable model.

Results

In total, the 15 youth monitored for this study performed 41 separate tasks, comprising 362 materials handling observations. LMM data were collected on 36 (88%) of these tasks and 314 (87%) of the observations.

Farm Task Descriptive Data

Descriptive statistics (i.e., means and standard deviations) were computed across multiple observations for each of the eight broadly defined farm tasks. Data for the work factor variables and for the lateral, sagittal, and transverse trunk motions produced are shown in tables 4 and 5, respectively. Twenty−two of the 41 tasks were similar enough that they could be placed into one of seven specific categories (table 2). The remaining 19 tasks were placed into the miscellaneous category, even though the physical characteristics were quite diverse.

Across the descriptive data for the work factor variables (shown in table 4), bales were the highest−weight objects handled and produced the greatest external moment about the spine. The tasks related to lifting and dumping of feed and water also involved high load weights and moments about the spine, although these values were considerably lower than those produced during the lifting of bales. Also as shown in table 4, many of the products handled were placed at or near floor/ground level, as evidenced by the low average vertical heights at lift origin.

The data presented in table 5 show that no single farming task was responsible for the highest lateral, sagittal, or transverse trunk motions recorded. Two tasks (“lift bale” and “spread bedding”), however, did produce the highest maximum velocities and maximum accelerations for all three planes. The “lift bale” task produced the highest average lateral range of motion, velocity, and acceleration, and it was responsible for the highest sagittal velocity and acceleration means of the task groupings. However, the highest mean sagittal flexion occurred during “dump feed and water” tasks, and “lift feed and water”

Table 4. Descriptive data of workplace factors for the eight categories of generally defined farm tasks. Data shown are means (standard deviations).

	Variable						
Broadly Defined Task	No. Obs.	No. Subj.	Load Weight (N)	Maximum Moment Arm (cm)	Moment about Spine (Nm)	Vertical Load Height at Origin (cm)	Vertical Load Height at Destination (cm)
Lift feed and water	29	5	130.9 (95.1)	46.9 (14.6)	55.1 (39.7)	97.4 (37.9)	99.1 (41.9)
Carry feed and water	36	9	83.0 (54.3)	38.1 (15.3)	33.5 (30.3)	39.8 (11.9)	62.4 (40.8)
Dump feed and water	17	6	126.8 (83.8)	39.1 (24.2)	58.1 (62.1)	42.2 (29.6)	41.6 (26.3)
Lift bale	22	3	186.5 (33.8)	48.6 (8.1)	90.9 (25.1)	114.3 (0.0)	114.3 (0.0)
Scoop food products	60	8	55.0 (36.1)	36.4 (11.4)	19.9 (13.0)	27.0 (7.3)	104.7 (54.3)
Shovel	52	3	32.9 (19.8)	37.9 (4.8)	12.6 (7.9)	63.5 (0.0)	152.4 (0.0)
Spread bedding	39	3	65.1 (25.7)	49.9 (8.7)	31.2 (11.8)	15.2 (0.0)	81.3 (0.0)
Miscellaneous	93	13	94.7 (72.7)	40.8 (10.5)	40.4 (31.8)	38.8 (29.2)	75.0 (43.9)
Average			83.8 (68.4)	41.3 (12.5)	35.3 (33.2)	46.5 (33.2)	79.2 (45.8)

and “spread bedding” tasks produced the highest mean sagittal range of motion. The highest transverse motions occurred during the “spread bedding task; this task generated the greatest mean transverse range of motion, velocity, and acceleration.

Comparisons Between Farm and Industrial Work

An assessment of the physical demands required of farm work is possible by comparing the data in tables 4 and 5 with the workplace and trunk kinematic data previously collected in industrial settings. This information (from Marras and Kim, 1993), showing descriptive statistics for the low− and high−risk job categories, is presented in table 6. Across all farm task observations, the average load weight handled was 83.8 N, with the moment averaging over 35 Nm. This load weight is nearly identical to the average weight handled by industrial workers in high−injury jobs (84.7 N), although the generated average moment about the spine for the farm tasks was closer in magnitude to that produced in low−injury industrial jobs (23.6 Nm) compared to jobs with high injury rates (73.7 Nm). This may be due to the shorter arm reach capabilities and/or reduced strength of smaller youth compared to adults in industry. Average vertical lift locations were lower in the farm sample, both at the origin and destination of the lifts, compared to those same variables measured in industry.

The trunk kinematic data for many of the farm tasks were comparable in magnitude to the low−risk group of industrial jobs. In fact, trunk ranges of motion, velocities, and acceleration, averaged across the eight farm tasks (table 5) were similar to those found in industry for low−risk work (table 6). However, some farm work produced trunk motions more like high−risk industrial jobs. For example, on average, lifting bales and spreading bedding generated both lateral and transverse velocities that were comparable to the magnitudes of high−risk industrial jobs. Further, several farm tasks (i.e., dumping feed and water, spreading bedding, and the miscellaneous farm work) produced sagittal flexion values that were equal to or greater than the average high−risk job in industry.

Low−Back Disorder Risk for Farm Work

The computed probabilities of high−risk group membership for LBDs for the eight task categories (shown in table 7) produced large average values on one or more of the five risk model variables for most of the farm tasks. The lifting of bales produced the largest average maximum moment value (94%), although the dumping of feed and water generated an average maximum moment of nearly 77%. Lifting bales also produced the

Table 5. Descriptive data of trunk kinematic factors for the seven categories of generally defined farm tasks. Data shown are means (standard deviations).

	Lateral Plane					
Broadly Defined Task	Maximum Left Position (°)	Maximum Right Position (°)	Maximum Range of Motion (°)	Average Velocity (°/sec)	Maximum Velocity (°/sec)	Maximum Acceleration (°/sec^2)
Lift feed and water	−11.6 (6.0)	6.3 (5.8)	17.9 (7.4)	7.8 (3.6)	36.5 (15.5)	278.6 (139.0)
Carry feed and water	−9.3 (5.0)	8.8 (6.3)	18.2 (7.3)	9.2 (3.6)	38.3 (12.7)	274.1 (85.0)
Dump feed and water	−9.6 (10.8)	9.6 (5.3)	19.2 (10.5)	4.6 (2.3)	27.6 (14.2)	159.8 (95.9)
Lift bale	−14.0 (4.9)	7.0 (4.9)	21.0 (6.1)	14.2 (5.1)	49.5 (15.9)	380.9 (147.4)
Scoop food products	−7.5 (3.8)	2.2 (5.2)	9.7 (6.8)	6.3 (3.8)	19.8 (11.0)	136.3 (76.8)
Shovel	−7.4 (7.4)	7.9 (6.3)	15.3 (5.9)	8.8 (3.7)	27.7 (14.6)	188.9 (138.9)
Spread bedding	−13.9 (5.3)	5.7 (5.6)	19.6 (5.7)	12.3 (4.7)	42.5 (12.8)	303.9 (93.7)
Miscellaneous	−7.7 (5.3)	4.9 (5.7)	12.6 (6.9)	7.2 (3.6)	28.7 (15.2)	218.7 (135.2)
Average	−9.3 (6.2)	5.8 (6.0)	15.2 (7.6)	8.6 (4.5)	31.8 (16.2)	230.9 (136.2)

	Sagittal Plane					
Broadly Defined Task	Maximum Extension (°)	Maximum Flexion (°)	Maximum Range of Motion (°)	Average Velocity (°/sec)	Maximum Velocity (°/sec)	Maximum Acceleration (°/sec^2)
Lift feed and water	−12.3 (11.0)	14.5 (18.4)	26.7 (17.3)	6.1 (3.2)	37.3 (22.0)	207.4 (110.5)
Carry feed and water	−6.9 (6.6)	15.7 (11.4)	22.6 (15.3)	6.2 (2.8)	32.4 (18.2)	191.1 (82.7)
Dump feed and water	3.3 (23.0)	24.0 (10.4)	20.7 (15.9)	3.5 (2.8)	29.2 (23.6)	154.9 (120.5)
Lift bale	−8.8 (3.5)	13.6 (11.5)	22.3 (9.7)	10.6 (3.3)	38.7 (13.0)	271.9 (79.2)
Scoop food products	−0.6 (12.3)	11.0 (12.8)	11.6 (11.7)	5.1 (3.0)	19.4 (12.3)	120.2 (56.2)
Shovel	−4.4 (6.1)	8.8 (7.0)	13.2 (6.7)	7.4 (3.7)	21.2 (8.6)	132.1 (69.0)
Spread bedding	−9.0 (2.5)	17.9 (11.7)	26.9 (10.7)	9.7 (4.7)	37.2 (12.2)	238.8 (88.1)
Miscellaneous	2.0 (14.8)	18.5 (13.9)	16.5 (11.4)	6.3 (3.3)	27.9 (17.4)	162.6 (85.5)
Average	−3.6 (12.0)	14.8 (13.0)	18.4 (12.9)	6.9 (3.9)	28.6 (16.7)	174.1 (93.5)

	Transverse Plane					
Broadly Defined Task	Maximum CCW Position (°)	Maximum CW Position (°)	Maximum Range of Motion (°)	Average Velocity (°/sec)	Maximum Velocity (°/sec)	Maximum Acceleration (°/sec^2)
Lift feed and water	−3.7 (7.7)	11.1 (5.4)	14.8 (9.6)	5.5 (4.0)	33.2 (17.0)	228.8 (104.4)
Carry feed and water	−6.0 (4.8)	5.9 (7.5)	11.9 (9.6)	4.3 (3.0)	27.1 (17.0)	189.5 (102.1)
Dump feed and water	−6.9 (3.2)	5.3 (8.1)	12.1 (7.5)	2.0 (0.9)	28.5 (20.6)	172.0 (136.6)
Lift bale	−8.5 (6.1)	9.1 (6.2)	17.6 (8.9)	9.4 (4.1)	43.4 (16.9)	323.8 (120.4)
Scoop food products	−2.9 (5.6)	4.1 (4.2)	7.1 (3.6)	4.7 (2.6)	18.6 (9.6)	129.8 (57.9)
Shovel	−8.9 (4.2)	2.0 (4.3)	10.9 (6.0)	6.2 (3.0)	25.7 (16.3)	172.5 (111.7)
Spread bedding	−9.9 (6.2)	9.1 (4.1)	19.0 (6.5)	10.5 (5.8)	50.7 (27.8)	346.7 (211.8)
Miscellaneous	−5.9 (7.8)	5.0 (4.4)	10.9 (7.6)	5.4 (4.3)	27.3 (18.0)	188.4 (125.1)
Average	−6.4 (6.7)	5.8 (5.7)	12.2 (8.0)	6.1 (4.4)	30.2 (20.3)	208.5 (142.3)

highest maximum lateral velocity of all task groups, followed by shoveling (at 72%). Although dumping feed and water generated the largest amount of maximum sagittal flexion (93%), carrying feed and water, lifting bales, scooping food products, and spreading bedding tasks all produced sagittal flexion values of 74% or more. Shoveling generated the greatest average twisting velocity (87%), followed by lifting bales and spreading bedding (both with twisting velocities over 71%). Finally, the grouping of similar tasks that produced the highest average LBD task risk was bale lifting, at 65%.

Table 6. Descriptive data of workplace and trunk motion factors for low− and high−risk groups, from industrial jobs (Marras and Kim, 1993). Data shown are means (standard deviations).

Variable	Units	Low−Risk Group	High−Risk Group
Work factors			
Load weight	N	29.3 (48.9)	84.7 (79.4)
Maximum moment arm	cm	61.0 (14.0)	66.0 (12.0)
Moment	Nm	23.6 (38.6)	73.7 (60.7)
Vertical load height − origin	cm	105.0 (27.0)	100.0 (21.0)
Vertical load height − dest.	cm	115.0 (26.0)	104.0 (22.0)
Trunk kinematics − Lateral plane			
Left bend	°	−2.5 (5.5)	−1.5 (6.0)
Right bend	°	13.2 (6.3)	15.6 (7.6)
Range of motion	°	21.6 (10.3)	24.4 (9.8)
Average velocity	°/sec	7.2 (3.2)	10.3 (4.5)
Maximum velocity	°/sec	35.5 (12.9)	46.4 (19.1)
Acceleration	$°/sec^2$	229.3 (90.9)	301.4 (166.7)
Trunk kinematics − Sagittal plane			
Extension position	°	−10.2 (10.6)	−8.3 (9.1)
Flexion position	°	10.4 (16.0)	17.9 (16.6)
Range of motion	°	23.8 (14.2)	31.5 (15.7)
Average velocity	°/sec	6.6 (4.3)	11.7 (8.1)
Maximum velocity	°/sec	38.7 (26.5)	55.0 (38.2)
Acceleration	$°/sec^2$	226.0 (173.9)	316.7 (224.6)
Trunk kinematics − Transverse plane			
CCW position	°	−1.9 (5.4)	1.2 (9.1)
CW position	°	10.8 (6.1)	14.0 (8.7)
Range of motion	°	17.1 (8.1)	20.7 (10.6)
Average velocity	°/sec	5.4 (3.2)	8.7 (6.6)
Maximum velocity	°/sec	38.0 (17.5)	46.4 (25.6)
Acceleration	$°/sec^2$	146.7 (44.2)	304.6 (175.3)

Note in table 7 that the lift rate risk percentage for all tasks was assumed to be low for this analysis (1% for all tasks). This assumption was based on the fact that the farm work performed by youth in this study was not as repetitive as the industrial jobs used for comparison purposes and that the work was not performed on a full time basis. This assumption may likely result in an underestimate of the risk of LBDs for farm youth who perform manual material handling jobs at higher frequencies and for longer durations during intensive work periods, where the task frequency and work duration may approach that observed for adults in repetitive industrial jobs.

Discussion

The data collected for this study represent a significant first step in documenting the low−back injury risks of children and adolescents who perform manual tasks on farms. We recognize that the findings reported in this study are based on a limited sample size and that the number of observations was small, but we believe that the findings are representative of what would have been found had a larger population of workers been observed performing the same tasks. Therefore, we caution against drawing specific conclusions about the risk of low−back disorders for youth performing these jobs until larger sample sizes and more observations are reported. We have, for the first time, been able to quantitatively describe farm tasks to which youth are exposed and have assessed

Table 7. Descriptive data for LBD task risk variables across the eight categories of generally defined farm tasks. Data shown are means (standard deviations).

	Variable					
Broadly Defined Task	Lift Rate (%)	Maximum Moment (%)	Maximum Lateral Velocity (%)	Maximum Sagittal Flexion (%)	Average Twisting Velocity (%)	Task Risk (%)
Lift feed and water	1.0 (0.0)	57.9 (39.9)	65.4 (31.5)	64.9 (41.2)	55.5 (41.4)	48.8 (20.1)
Carry feed and water	1.0 (0.0)	53.0 (43.2)	64.2 (17.9)	79.5 (38.6)	47.3 (29.3)	49.0 (19.7)
Dump feed and water	1.0 (0.0)	76.8 (42.5)	42.3 (23.9)	92.8 (10.5)	3.5 (2.9)	43.3 (12.6)
Lift bale	1.0 (0.0)	93.5 (7.0)	83.8 (18.9)	75.3 (34.8)	71.2 (25.4)	65.0 (10.1)
Scoop food products	1.0 (0.0)	13.0 (15.3)	55.0 (17.5)	73.8 (48.5)	49.0 (39.0)	38.4 (12.4)
Shovel	1.0 (0.0)	5.3 (7.5)	72.0 (24.0)	56.3 (44.8)	87.3 (11.0)	44.4 (5.2)
Spread bedding	1.0 (0.0)	22.3 (21.8)	60.0 (25.4)	87.8 (19.2)	76.0 (26.2)	49.4 (10.3)
Miscellaneous	1.0 (0.0)	47.8 (39.5)	48.5 (23.1)	60.1 (40.3)	50.4 (36.7)	41.5 (16.3)

the LBD risk of these tasks. Over 40 manual materials handling farming tasks were observed and monitored, which covered a broad range of chores typically required of farm youth.

The information contained in this study further expands on the knowledge of injury risks to children and adolescents working on farms, in that objective and quantitative data were gathered on the physical nature of these tasks. Specifically, measures of load weights lifted, their location when handled, and, uniquely, the three−dimensional spine motion characteristics required during these activities, serve to better evaluate the work that is required of these individuals.

One surprising finding was that the average weight manipulated by the farm youth in this study was higher than the average weight of materials handled by adults in industrial settings. In fact, Marras and Kim (1993) found that object weight was one of the workplace and trunk kinematic factors that, by itself, best differentiated between high− and low−injury producing jobs. There are several possible reasons for this finding. First, farmers may have no choice but to purchase goods such as feed in containers commonly weighing as much as 222.5 N (50 pounds). Second, many items (e.g., bales) are produced in standard sizes, and thus their handling is cumbersome. Third, not all farm families may be educated about the risk of low−back disorders associated with lifting high−weight objects.

There were particular farming activities that posed a high level of LBD task risk. These detailed activities were: lifting water buckets; lifting hay, straw, and alfalfa bales; lifting feed bags; filling/carrying feed buckets; and filling feed buckets. Of the 36 tasks for which LMM data could be collected, these seven produced the highest level of risk (over 60%) using a well−documented LBD risk assessment tool (table 8). Further, the risk values associated with these particular farm tasks are comparable to industrial jobs where there have been high rates of LBDs for adults, who, unlike children and adolescents, have fully developed musculoskeletal systems. Of the tasks listed in table 8, only five would be classified as low risk (i.e., under 30%) when using the LMM risk assessment tool as a comparison. The remaining 24 tasks had risk values between 30% and 60%, indicating that (as evidenced by fig. 8), these activities likely fall somewhere between those believed to be either high or low risk.

It is suspected that the injury potential among children and adolescents is higher than among adults when exposed to similar workplace physical demands. One reason is the reduced physical strength capacity of children as opposed to adults. For example, Imrhan and Loo (1989) found that handgrip strength of male and female children (age 5 to

Table 8. Means (standard deviations) for each detailed farm task, ranked by percentage.

Category	Detailed Task	Task Risk (%)[a]
Risk = 60%+	Lift water bucket	72.0 (0.0)
	Lift hay bale	71.3 (11.0)
	Lift feed bag	69.3 (10.5)
	Fill/carry feed bucket	68.4 (18.6)
	Fill feed bucket	68.0 (0.0)
	Lift straw bale	66.0 (0.0)
	Lift alfalfa bale	64.0 (0.0)
Risk = 30% to 59%	Carry water bucket	56.4 (5.3)
	Lift grass bale	55.0 (0.0)
	Lift milk crate	55.0 (0.0)
	Spread hay	54.6 (8.1)
	Lift feed bucket	53.0 (1.7)
	Lift milk bottle	51.0 (0.0)
	Pick up rocks	51.0 (0.0)
	Dump feed bucket	50.0 (0.0)
	Dump feed bag	49.3 (0.6)
	Pull wheelbarrow	49.0 (0.0)
	Push wheelbarrow	47.0 (0.0)
	Scoop feed	46.4 (11.1)
	Lift hay flakes	46.0 (0.0)
	Shovel manure	45.9 (3.5)
	Lift feed pail	44.0 (7.9)
	Connect trailer hitch	43.0 (0.0)
	Spread sawdust	42.0 (0.0)
	Use water hose	41.0 (0.0)
	Rake stalls	40.4 (7.8)
	Dump wheelbarrow	40.0 (0.0)
	Shovel silage	40.0 (0.0)
	Carry feed bucket	39.6 (23.1)
	Move feed wagon	33.0 (0.0)
	Open mixer lid	31.0 (0.0)
Risk = 0% to 29%	Scoop powdered milk	28.0 (0.0)
	Coil hose	26.0 (0.0)
	Dump water trough	24.0 (0.0)
	Lift water pail	16.0 (0.0)
	Sweep floor	10.0 (0.0)

[a] Standard deviations equaling zero indicate that risk was assessed from data on a single youth.

12 years) was 31% and 41%, respectively, of their adult counterparts (age 18 to 40). Aside from the incomplete physiological development previously mentioned, the youth in this study were smaller in stature and weighed less than a typical industrial population (Marras and Kim, 1993). Thus, the handled loads observed here were a greater percentage of these individuals' body masses compared to what occurs in industry.

The use of the LMM and its associated LBD risk model appears to be relevant for the farm work studied here. It should be noted that this model may over− or under−estimate the risk of LBD for three reasons. First, since the risk model was developed from industrial jobs performed full−time, it may not apply equally to jobs that are performed part−time or seasonally. Second, this risk model was based on an adult population of workers. The factors associated with higher injury risk among youth may be different, but we know of no existing data for risk to children and adolescents in this context. Third, as mentioned previously, we assumed that the farm activities documented here (such as feeding livestock) were not performed continuously throughout the day and that they were performed infrequently, compared to industrial jobs. Because of this, we assumed the lifting rate to be low, resulting in low lifting rate risk values (1%) for the frequency component of the risk model for all of the observed farm tasks. As mentioned previously, this assumption may result in an underestimate of the risk of LBDs, since some workers may work at higher frequencies and for longer durations, such as those seen in typical industrial jobs.

It should be noted that there are other assessment techniques that can be used to document the physical demands of farm work, and low−back injury risk in particular. These include use of psychophysics to determine limits for lifting, lowering, pushing, pulling, and carrying (Snook and Ciriello, 1991) and manual lifting guidelines set forth by the National Institute for Occupational Safety and Health (Waters et al., 1993). However, Norman and McGill (1999) reported the findings of several studies showing that static models can greatly underestimate the spinal loads of dynamic tasks. Thus, the LMM was used in this analysis because it can realistically capture the dynamic motion components required of many farm tasks.

This study has found that several tasks required of children and adolescents on farms expose them to physical demands and trunk motions similar to those performed in industrial jobs that have historically created high LBD rates in adults. Future research should verify these findings by repeating the study with larger sample sizes. Nevertheless, these results identify the high−risk tasks that should be the primary focus in any intervention or training efforts aimed at reducing the MSD potential in farm youth.

Conclusion

These results represent a significant first step in documenting the low−back injury risks of children and adolescents who perform manual work in farming environments. This study has quantitatively described farm tasks to which youth are exposed and has assessed the LBD risk of these tasks. This information further expands on the knowledge of injury risks to children and adolescents working on farms. An unexpected finding was that the average weight manipulated by the farm youth studied here was higher than the average weight of materials handled by adults in industrial settings.

This study also identified the particular farming activities that posed the highest level of LBD task risk among children and adolescents, using a model developed for adults working in industrial environments. The injury potential among these younger individuals likely is higher than among adults when exposed to similar workplace physical demands.

Future research should verify the findings of this study by repeating it with a larger sample. However, these results identify the tasks that should be the primary focus in any intervention or training efforts aimed at reducing the MSD potential in farm youth.

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