HHS Public Access
Author manuscript
*Hum Factors*. Author manuscript; available in PMC 2016 November 09.

Published in final edited form as:
*Hum Factors*. 2016 August ; 58(5): 758–776. doi:10.1177/0018720816631902.

# Development and Evaluation of Ergonomic Interventions for Bucket Handling on Farms

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## Abstract

**Objective—**The aim of this study was to introduce and evaluate two interventions, Ergo Bucket Carrier (EBC) and Easy Lift (EL), for youths (and adults) to handle water/feed buckets on farms.

**Background—**The physical activities of both adult and youth farm workers contribute to the development of low-back disorders (LBDs). Many of the activities youths perform on farms are associated with increased LBD risk, particularly, the handling of water and feed buckets.

**Methods—**Seventeen adult and youth participants (10 males and seven females) participated in this study. To assess the risk of LBDs, the participants were instrumented with a three-dimensional spinal electrogoniometer while lifting, carrying, and dumping water buckets using traditional method and the two interventions.

**Results—**For both the adult and youth groups, the results showed that the two interventions significantly decrease the magnitudes of LBD risk in many of the tasks evaluated. Overall, the use of the EBC resulted in a 41% reduction in the level of LBD risk for the carrying task, and a reduction of 69% for the dumping task. Using the EL, on the other hand, is especially effective for lifting tasks (55% reduction in LBD risk). Results of the subjective response were consistent with the objective evaluations.

**Conclusion—**This study demonstrated the potential for ergonomic interventions in reducing LBD risk during the common farming task of bucket handling.

**Application—**Potential application of this study includes the introduction of the EBC and EL in family farms to reduce the LBD risk among youth and adult farmers.

### Keywords

family farm; intervention; youth; low back disorders; bucket

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## INTRODUCTION

The literature documents high incidence of low back disorders (LBDs) in the agricultural industry (Fathallah, 2010; Fathallah, Miller, & Miles, 2008; Guo et al., 1995; Park, Sprince, Whitten, Burmeister, & Zwerling, 2001; Walker-Bone & Palmer, 2002; Xiang, Stallones, & Keefe, 1999). A national survey in the U.S. shows that, for males, farming is the occupation with the fifth highest risk of inducing low back pain (Guo et al., 1995). It has been suggested that the preponderance of the morbidity is related to farm workers' working conditions, such as stooped working postures and awkward postures during lifting, carrying, and moving loads (Meyers et al., 1997). Such hazards, however, affect both adult and youth workers. Estimates show that each year in the United States, more than 2 million youths under the age of 20 are exposed to such agricultural hazards (Myers & Hendricks, 2001). These youths perform many farm-related activities involving significant manual handling of materials and are exposed to factors found to be related to the development of musculoskeletal disorders (MSDs) and LBDs (Allread, Wilkins, Waters, & Marras, 2004). For instance, emptying a bag of swine feed into a feeder, spreading straw, and shoveling silage into a feed bunk are all reported as causes of serious back injuries (Bartels, Niederman, & Waters, 2000).

It might be useful to first define terms commonly used in reference to workers based on their age. The term "legal adult" or "age of majority" (as opposed to "biological adult" where a child "becomes of age") is the threshold of adulthood as declared by law (Wikipedia, 2015). This age varies based on geographical regions (or countries) and may have several age-based restrictions (e.g., in the US, 18 is the age of majority, whereas, voting and drinking age is 21). In most circumstances, "adult" is usually in reference to the age of majority, or one of its exception, and not the biological adult age. According to the National Institutes of Health (NIH), the term "child" is an individual under the age of 21, where the definition spans the period from birth to the age where most children are dependent on their parents (NIH, 2015). Therefore, when the term "children" is used in the context of agricultural labor, the implication is that the parents oversee the welfare and legal circumstances related to this working yet "dependent" population. "Youths" and "adolescents" are usually used interchangeably, and according to the World Health Organization (WHO), refer to the period of transition from childhood to adulthood, commonly between the ages of 10 and 19 (WHO, 2015). Hence, in this paper, as in most of the related literature, the terms children, youths and adolescents will be used interchangeably, and will refer to the age range of 10–17, unless otherwise specified; whereas, the term "adult" will refer to the age of 18 and above.

Regardless of the hazardous nature of farm-related activities, in agriculture, age does not limit participation and children may do the work of an adult (Huneke, Von Essen, & Grisso, 1998). Youths 13 to 15 years old are usually expected to do pretty much what adults can do (Bartels et al., 2000). Additionally, the youth-involved farm-related activities are highly correspondent to geographical regions and commodity types (B. Marlenga, W. Pickett, & R. L. Berg, 2001a). The same study indicates that, in the U.S., Midwestern youths are primarily assigned to animal care (73.4%) and farm maintenance jobs (20.9%), compared to Western youths, whose tasks are mainly crop management (55.1%). Every year in the U.S., approximately 126,000 hired youth farm workers aged 14–17 years of age are employed in crop agriculture (DOL, 2000). These hired youth farm workers, especially the ones who work on non-family owned farms, are generally involved in harvesting/picking tasks (Bonato et al., 2003). Studies have documented harvesting tasks as being associated with potential LBD risk factors (Chapman et al., 2003; Conlan, Miles, & Steinke, 1995; Fulmer, Punnett, Slingerland, & Earle-Richardson, 2002) and back pain reports (Osorio et al., 1998). In addition, Allread and colleagues (2004) have investigated the magnitude of LBD risk that youth are exposed to while performing tasks that are routinely performed by Midwestern farm youths. They have quantitatively measured the trunk kinematics of these youth workers as well as workplace factors while the workers are performing 41 manual materials handling (MMH) tasks and found that the associated LBD risks of some tasks were comparable to that of industrial jobs with high LBD risks. Out of the 41 evaluated tasks, seven tasks (lift water bucket, lift hay bale, lift feed bag, fill/carry feed bucket, fill feed bucket, lift straw bale, lift alfalfa bale) are placed in the high LBD risk category, corresponding to the LBD risks found in industrial jobs, and 24 tasks are placed in the middle risk category.

Work-related injuries among youth workers in agricultural settings are a serious problem. The estimates of annual farm-related non-fatal injuries range from 1,700 to 1,800 per hundred thousand child farm residents (Rivara, 1997; Stueland, Lee, Nordstrom, Layde, & Wittman, 1996). Youths holding farm jobs simultaneously with non-farm jobs have a significantly higher proportion of injuries, of which sprain and strain are some of the most common types (Munshi, Parker, Bannerman-Thompson, & Merchant, 2002). In addition, muscle aches and strains of the back, shoulder, and other joints, are described as everyday occurrences among youths working on farms (Bartels et al., 2000). A study focusing on youth workers in Wisconsin fresh markets also revealed that over half of the youth workers reported experiencing low back discomfort, while 25% reported disabling discomfort (Chapman et al., 2003).

Intervention studies with the specific aim of reducing LBD risk factors associated with tasks performed by working farm youths have been somehow limited in the literature, with few notable exceptions (Allread & Waters, 2007; Kotowski, Davis, & Waters, 2009a, 2009b). Hence, the purpose of this study is to introduce and evaluate two interventions for bucket handling on farms. The two interventions and their development are firstly presented, followed by two evaluation phases; “Phase 1” is an intervention evaluation with adult volunteers, and “Phase 2” consisted of a confirmatory evaluation with youth volunteers from a local high school. The evaluation approach focused on the effectiveness of these two interventions in reducing LBD risk during the lifting, carrying, and dumping of water buckets. Subjective responses were also obtained during the two testing phases.

# METHODS

## Intervention Development

The job of handling water/feed buckets entails three main tasks: 1) lifting the bucket, 2) carrying the bucket to the destination and 3) dumping the content of the bucket at the destination (see Figure 1 for an example of these tasks). This job is commonly performed by youths on farms (Allread et al., 2004), where they transport water or feed from a source, such as water pump or a barn, to animal feeding containers. The objective of this phase of the study was to develop tools that are expected to reduce LBD related risk factors for youths performing manual handling of water/feed buckets. The design approach was to develop two tools; one to simultaneously address the carrying and dumping tasks, and another to address the lifting task.

In setting the tools design criteria, the research team relied on existing agricultural, biomechanical and ergonomic literature and guidelines, and consulted with colleagues and designers who are themselves farmers and grew up and worked on farms during their youth, and were familiar with the requirements and conditions surrounding bucket handling on farms.

Kepner-Tregoe (KT) decision analysis was performed to select the design of the major components for each task: the lifting aid, the carrying device, and the dumping mechanism (Voland, 2004). Constraints ("musts") and criteria ("wants") used in the analysis are described.

The constraints (musts) applied during the design process were:

- Operation of the design will require only one person- feasibility requirement.
- Operation of the design will require trunk postures that are less than those observed in the current manual handling method- reduce LBD risk (Marras et al., 1993).
- Operation of the design will require weight/force that is less than that observed in the current manual handling method- reduce LBD risk (Marras et al., 1993).
- The design can be used in outdoor conditions, e.g., dirt roads and grass fields, which are similar to farm environments.
- The design must be compatible with a conventional 5-gallon bucket.

The criteria (wants) applied during the process of design selections were:

- Complexity of the design is minimized. Complicated mechanisms, e.g., electrical powered motor and mechanical gear box, are likely to increase the cost of the design and require high maintenance.
- The design does not introduce additional musculoskeletal disorders risks at other joints besides the lower back (e.g., shoulder, arms, wrists, etc.).
- Cost of the design is minimized. Expensive tools will unlikely be used by farm families.

Based on the brainstormed design ideas, prototypes were built for testing purposes. Prototype testing results were then applied in the KT analysis for design comparisons and selection. The analysis results are presented in the following section for each of the three tasks.

**Carrying—**A wheeled design was chosen for the carrying method. The main decision was the number of wheels employed in the design. The type and size of the wheels were determined based on other criteria and are discussed below. Three options– two-wheel, three-wheel, and four-wheel– were evaluated and compared using the KT analysis.

Two-wheel design- In order to use a two-wheel design, the user has to bear partial weight of the handled object (e.g., wheel barrel). This design approach is used extensively on farms.

Three-wheel design- A three wheel design can support the full weight of object handled. Also, it allows the user to control the cart by maneuvering the pushing handles (see the built prototype in Figure 2). However, during field testing, this prototype design tended to commonly tip over on dirt roads.

Four-wheel design- This design can also support the full weight of the handled object. Additional handles are required at the rear side of the cart, since the rear wheels prevent the user from reaching the handles in the front (Figure 3). In addition, the design exhibited greater stability on dirt roads than the three-wheel design. The results of the KT Analysis are shown in Table 1. A four-wheel design met all the design constraints and was pursued for in the final design.

**Dumping—**Three dumping mechanisms (Type A, B, and C) were analyzed and compared using KT analysis. Table 2 summarized the analysis results. Type A- While the bucket is hanging in a frame that has a pivot point fixed to the carrier, users can dump by tilting the frame. The activation force is greatly reduced because of the difference in the acting moment arms (distance from the point of force application to the pivot of interest) (Figure 4). The moment arm (MA2) for the activation force ($F_{act}$) is adjusted to be three times the moment arm (MA1) associated with bucket weight ($F_{load}$), with MA1 equals to approximately the radius of a five-gallon bucket (7 in.). The location of the pivot point at half of the bucket height also reduces the amount of weight the users handle (Figure 5).

Type B- An air cylinder aided tilting mechanism that utilizes an air actuator to reduce the force required for the dumping process. An electric-powered compressor is required as the source of compressed air. Type C- Rails on both sides of the bucket with wheels mounted on its sides were considered. Dumping is completed by sliding the bucket down along the rails. Comparing the three mechanism types, Type A was selected as the option fulfilling all the desired design constraints and most of the design criteria (Table 2).

**Lifting—**The basic design for the lifting aid, a rod with a handle on one side and a hook at the other, allows the users to reach the handle of the bucket without bending down. However, the selection decision depended on the lifting mechanism, for which three types of mechanisms were compared (Two-handed, Spring-aided, and Air-Actuator-Aided). Table 3 shows the KT analysis results for this comparison. Based on these results, the two-handed operation was selected over the other two mechanisms.

**Design Specifications and Modifications—**Based on all the KT analyses presented above for each task, a carrier with four wheels was deemed best for the carrying task; a tilting mechanism which users operate at the same position as they push the cart was best for the dumping task; and a two-handed tool was best for the lifting task. For carrying and dumping tasks, an intervention, namely Ergonomic Bucket Carrier (EBC), was developed. For the lifting tasks, another intervention, called Easy Lift (EL), was constructed. The dimensions of the prototypes of the EBC and EL were based on the anthropometric data of youths between ages 12.5 and 17.5 (Snyder et al., 1977) and environmental factors associated with dumping/carrying/lifting of water/feed buckets (Allread et al., 2004). The dimensions of several parts of the EBC, including the height of the pushing handle and the height of the bucket stand, were made adjustable to match the users' anthropometrics and needs.

**Ergo Bucket Carrier (EBC)—**The final design of the EBC is shown in Figures 6 and 7. To use the device, the user first loads the bucket to the EBC, pushes the device to the destination, and then activates the dumping device by pushing a handle (Figure 7). The wheels were selected based on commercial availability, outdoor road conditions, and price. Pneumatic wheels that are less than 15 inches in diameter were selected to meet outdoor road conditions and to provide close contact with the destined container. The wheels selected for the front-end were fixed, pneumatic wheels with a 14 inch diameter; whereas, for the rear-end they were swivel, pneumatic wheels with a 10 inch diameter. Minor changes were made to the original designs to improve usability and performance. For example, the position of the handle for activating the dumping mechanism was changed from vertical (Figure 2) to horizontal so that the users could activate the dumping mechanism at the same position as they were in to push the EBC, which would facilitate the efficiency of the process (Figure 7). The length of the handle remained unchanged and so did the moment arms and related forces. In addition, the positions of the cart handles were altered with an outward angle so that users' wrists could remain in neutral position (Figure 7).

**Easy Lift (EL)—**The final design of the EL is shown in Figure 8. A power grip design is used on the grip handle. The power grip was an angled handle that kept the users' wrist in a neutral position so that the user can utilize her/his maximum power grip's strength (Figure 8) (Chaffin, Andersson, & Martin, 2006). The spinal loads associated with the use of EL are also expected to be less compared to manual lifting of the bucket due to the anticipated reduction in forward flexion (or bending) and spinal moment arms (distances between the load and the base of the lumbar spine).

During lifting and carrying, the user hooks the EL's U-shaped hook to the bucket's handle to lift and carry the bucket (Figures 9 and 10). For dumping, the user sets the bucket on the floor, rotates the EL to hook a long screw to the bottom of the bucket, and uses the bucket's handle and EL to lift and dump the bucket into the container (Figure 11)

## Intervention Evaluations

The purpose of this part of the study is to evaluate the efficacy of the newly developed bucket handling interventions (the EBC and EL) in reducing the risk of LBDs when compared to the manual handling of 5-gallon buckets. This intervention evaluation comprised of two phases: "Phase 1" was an intervention evaluation with adult volunteers, and "Phase 2" consisted of a confirmatory evaluation with youth volunteers from a local high school.

## Participants

**Phase 1:** Nine adult participants, including six males and three females, participated in this study. Average (std. dev.; range): age was 23.2 years (2.4; 20–26); height was 170.9 cm (9.7; 160–188); and weight 66.7 Kg (12.1; 52.3–90.9). Participants were identified as healthy individuals without back pain or injuries that pertained to the subjects' common physical activities (e.g. lifting, bending, and twisting). All participants signed an Institutional Review Board (IRB) approved informed consent form, and were given a t-shirt as a token of appreciation for their participation.

**Phase 2:** Eight youth participants (four males and four females) participated in a follow up evaluation. Average (std. dev.; range): age was 16.2 years (0.46; 16–17); height was 170.4 cm (13.5; 154–188); and weight 61.4 Kg (14.3). Participants were identified through a local high school biotechnology class for juniors and seniors and were healthy and without back pain or injuries that pertained to the participant's common physical activities (e.g. lifting, bending, and twisting). Since all participants were under 18 years, parental assent was obtained, and the participants signed an IRB approved informed consent form. Again, all participants were given a t-shirt as a token of appreciation for volunteering for the study.

## Experimental Setup

**Phase 1:** A standard path on grass that is approximately 15 feet in length was set for the subjects to follow. A grassy path was chosen to reflect some of the conditions commonly faced on family farms. The subjects started the tasks at one end of the grassy path, while three utility tubs of different heights (7, 17, and 27 in) were placed at the other end of the path. Three water levels corresponding to different weights (10, 25, and 40 lb) were marked on the inner face of a 5-gallon bucket. These weights corresponded to the 25$^{th}$, 50$^{th}$, and 75$^{th}$ percentiles of bucket weights observed on Midwestern farms (Allread et al., 2004).

The Lumbar Motion Monitor (LMM) (Chattecx Corp, Hixon, TN) was used to collect the kinematics of the spine, and the LBD risk model described by Marras et al. (1993) was used to evaluate the LBD risk of each condition. Briefly, the LMM is an exoskeleton electrogoniometer worn using a harness system (Figure 7), and provides three-dimensional angular kinematic information (angular position, velocity and acceleration in the sagittal, frontal or lateral, and transverse or twisting planes) of the lumbar spine during a given task (Marras et al., 1993). The LBD risk model identified five key risk factors; three kinematic risk factors (maximum sagittal flexion angle, maximum lateral angular velocity, and average twisting angular velocity), and two workplace risk factors (lift rate in lifts per hour, and moment in N.m.- load weight in Newtons; N, times distance from the base of the lumbar spine to the center of the load handled or "moment arm" in meters; m). The LBD risk model takes the values of these five risk factors and provides a risk value (in percentage), which reflects the probability of "high risk group membership" as described by Marras et al. (1993). It is anticipated that this approach will be appropriate to assess LBD risk among youths since it was shown that variability in the risk was stemming mainly from the jobs (or tasks) rather than from the individuals performing the jobs (Allread, Marras, & Burr, 2000). The approach has been successfully implemented to assess LBD risk among youths performing various tasks on farms, as well as evaluating intervention effectiveness for certain farm tasks (Allread & Waters, 2007; Allread et al., 2004).

**Phase 2:** This phase was similar to Phase 1; however, the weight of the bucket and the final height were fixed at 25 lb and 27 inches, respectively. Again, this phase was performed by 16–17 years old high school students, who handled water buckets using the three methods on grassy path.

## Experimental Design

**Phase 1:** The experiment was a 3×3×3 within-subject design. The independent variables and their levels were: method of carrying/dumping (Manual, EL and EBC), object weight (10 lb, 25 lb, and 40 lb), and destination height (7 in, 17 in, and 27 in). Each combination of the three independent variables (3×3×3 =27 treatments) was randomly assigned to the subjects. The dependent variables were low back disorder risk (in %) and subjective preference ranking.

**Phase 2:** The experiment for this phase was a 3×3 within-subject design. The independent variables and their levels were: method of carrying/dumping (Manual, EL and EBC), and task (lifting, carrying, and dumping). Each combination of the two independent variables (3×3 = 9 treatments) was randomly assigned to the participants. Again, the dependent variables were low back disorder risk (in %) and subjective preference ranking.

## Experimental Procedure and Data Collection

**Phase 1 and 2:** Prior to the experiment, each participant was provided with a letter from the Office of Human Research Protection and a copy of Experimental Subjects Bill of Rights. An informed consent form was then signed by and collected from each participant (and parental assent obtained ahead of time for those under 18 years- Phase 2). Anthropometric and demographic information were then collected. The research team members reiterated the details about the purpose and procedures of the experiment to the participants and answered any of their questions. The positions of EBC and EL were adjusted according to the subjects' anthropometrics. For the EBC, the handle was placed to correspond to the participant's elbow height, and for the EL, the handle was adjusted with respect to knuckle height to assure that it will clear the ground by at least 2 inches. The subjects were allowed to use the tools before the start of the experiment so that they become familiar with the different bucket handling methods.

The research team members assisted each participant in wearing the harnesses for the attachment of the LMM. The calibrated LMM was then attached to the harnesses as described in the literature (Marras, Allread, & Ried, 1999). The continuous trunk kinematics were collected at 60 Hz by the LMM software using a wireless transmitter/receiver system connected to and stored on a laptop computer.

After setting up all the equipment, the subjects performed the trials (27 trials for Phase 1 and 9 trials for Phase 2) in random order, as assigned by the researcher (randomization order was determined using a random number generator in Microsoft Excel). Each trial started with lifting of a bucket, which was filled with water, from the ground at one end of the standard path, followed by carrying of the bucket through the path, and finally ended with dumping the water into a designated container at the other end of the path. The participants were asked to handle one bucket for each trial. Video and photographs were taken during the experiment for documentation purposes.

In addition to the trunk kinematics measured by the LMM in real time, moment arms for the lifting, carrying, and dumping of buckets were collected by a dedicated researcher using a tape measure. The moment arms are needed to calculate the "moment" risk factor in the LMM risk model. The moments were calculated based on the handled weights and their associated moment arms with respect to the lumbar spine location at the fifth lumbar/first sacral joint (L5/S1) (Marras et al., 1999). Moment arms for each participant were measured during the experiment from the center of the L5/S1 to the force exertion point, which was the hands. Except for the carrying and dumping with the EBC, the forces associated with the tasks were equal to the handled mass (m) multiplied by the acceleration of gravity (g) with their directions pointing vertically downward. The forces required for the carrying and dumping using the EBC were measured with a digital push/pull force gauge (Chatillon DFS-500, AMETEK, Largo, FL). In this study, the lift rate used in the LMM risk model was assumed to be 1 (lift/hour) based on the conservative assumption that young farm workers usually lift infrequently throughout the day (Allread et al., 2004).

Subjective preferences regarding the handling methods were taken after completion of all trials. For each task (lifting, carrying and dumping), each participant gave a rating score (from 1 to 3; 1= least preferred, 2= average preference, or 3= most preferred) of each of the handling methods (Manual, EBC, and EL). Participants were provided with a form to record their rating on, which asked the following: "Please rate the tools, (3: The most preferred, 2: Average, 1: The least preferred), according to your preference in each of the following bucket handling methods." Hence, the participants gave a total of 9 ratings representing the three tasks and three handling methods combinations. Participants were given privacy to record their responses.

### Data Analysis

**Phase 1 and 2:** Data were analyzed by using the LBD risk model (Marras, Allread, Burr, & Fathallah, 2000; Marras et al., 1993). As described earlier, the risk model considers two workplace risk factors (lift rate and moment) and three motion risk factors (maximum sagittal flexion, maximum lateral velocity, and average twisting velocity) to generate a LBD risk value (in %) for a given condition. LBD risks were calculated for each of the 27/9 (Phase 1/Phase 2) conditions.

Repeated measures Analysis of Variance (ANOVA) tests were performed on the LBD risk data to test for the significance of factor effects (*alpha* of 0.05 was used in this analysis). If significant factor effects were observed in the ANOVA, Bonfferoni *post hoc* adjusted tests (*alpha* divided by the number of comparisons) were performed to identify the source of the significant differences. All statistical analyses were performed using Statistica 6.0 (StatSoft, Inc, Tulsa, OK).

To summarize the two phases and guide in the evaluation of the efficacy of the interventions, data from both groups (adults and youths) were combined and descriptive statistics of the LBD risk and its main risk factors were also presented.

# RESULTS

## LBD Risk

**Phase 1—**The ANOVA results revealed a significant main effect of lifting method ($p < 0.05$). In addition, the results of the *post-hoc* comparison for the LBD risks associated with different lifting methods suggested that the LBD risk for EL was significantly less than that for the other two lifting methods (Figure 12).

The results for carrying tasks indicated that the EBC was associated with a significantly lower LBD risk than the other two carrying methods (Figure 13).

The interaction between dumping method and object weight was found to be significant ($p < 0.05$). Figure 14 shows the results of ANOVA for the dumping tasks, in which the EBC was associated with a significantly lower LBD risk than the other two carrying methods, with the exception of the condition of low object weight (10 lbs).

**Phase 2—**The results of LBD risk for Phase 2 (youths) showed similar results to those obtained in Phase 1 (young adults). Figure 15 summarizes the ANOVA results *post hoc* analysis for the two independent variables considered in this phase (method and task). As expected, there was a significant method by task interaction ($p < 0.05$). The *post hoc* analysis revealed that for the lifting task, the EL exhibited the lowest LBD risk and was significantly lower than both the Manual and EBC conditions; whereas, for both the carrying and dumping task, the EL and EBC had significantly lower LBD risk than the manual method (Figure 15).

## Risk Factors Contributing to the LBD Risk-Combined Groups

Since the LBD risk results for the two groups were comparable; data from both groups were combined across all weights and heights to summarize the findings of the study. Also, to identify the contribution of each of the five risk factors described by Marras et al. (1993), descriptive statistics on four of these factors (maximum sagittal position, maximum lateral velocity, average twisting velocity, and maximum moment- Lift Rate was assumed constant across all conditions), as well as the overall LBD risk are presented in Table 4. Furthermore, to assess the individual contribution of each risk factor into the overall LBD risk, values for each risk factors (Table 4) were converted to relative LBD risk (in percent) using the LBD risk model scales described in the LMM risk model studies (Marras et al., 2000; Marras et al., 1993) (Figure 16). Note that when assessing the overall LBD risk for the job of handling water/feed bucket (all three sub-tasks combined), one would consider the highest value reached by each of the five LBD risk factors in all three tasks. For instance, for the case of the EBC, the overall LBD risk for that “job” was around 52%- maximum sagittal flexion, 99%, and maximum lateral velocity, 60%, were observed during the lifting task; the maximum average twisting velocity, 75%, was observed during the carrying task; and maximum moment, 28%, was observed during the lifting task (Figure 16). Similarly, the overall LBD risk for the EL and Manual jobs were around 50% and 58%, respectively.

### Subjective Assessment

Table 5 shows the results of the subjective responses from both young adults and youths. The results revealed a clear preference for the interventions. For the lifting task, the EL was preferred over the Manual and EBC methods. For both the carrying and dumping tasks, the EBC was preferred by most of the participants. It is also interesting to see that the manual handling condition was consistently the least preferred method for all three tasks.

## DISCUSSION

It is well-documented that youths commonly work on farms (Aherin & Todd, 1989; Browning, Westneat, & Szeluga, 2001; Freeman, Whitman, & Tormoehlen, 1998; Hawk, Donham, & Gay, 1994; B. Marlenga, W. Pickett, & R. L. Berg, 2001b; Barbara Marlenga, William Pickett, & Richard L. Berg, 2001; Park et al., 2003). In the United States, the Fair Labor Standards Act protects youths working in agriculture by providing minimum age standards and hours that youth may work and identifies hazardous jobs that are prohibited for youth under the age of 16 years (US Department of Labor, 2007). However, family farms are exempted from these child labor laws, as well as from occupational safety regulations (US Department of Labor, 2006), thus allowing parents to decide when their children are ready to begin a farm job and what extent they will be involved in farm work. Starting at very young ages and continues into their early adulthood, farm youth perform various kinds of physically demanding tasks to help out their families by sharing the burdens. Research among youths working on farms has revealed the demanding and laborious nature of farm work and the risks associated with various farm jobs (Allread et al., 2004; Brison et al., 2006; Marlenga et al., 2010; Wright, Marlenga, & Lee, 2013). Furthermore, it was shown that many of these jobs, particularly the handling of water/feed bucket, could be associated with trunk kinematics and spinal loads that are potentially harmful to youth workers (Allread et al., 2004).

Because of the lax child labor laws on family farms discussed earlier, lack of appropriate tools, and unrecognized risk of injury by parents and youth, interventions to eliminate or reduce the risk factors to youth workers are needed. This study introduced two newly developed interventions with the objective of reducing the risk of LBD to youth farm workers who are commonly assigned the job of handling 5-gallon water or feed buckets on family farms. The EL was developed to address LBD risk during the lifting task; whereas, the EBC was developed to address LBD risk during the carrying and dumping tasks.

### Intervention for Lifting Task

In general, the EL was shown as an effective tool in reducing LBD risk, especially during lifting, which is supported by both objective and subjective evidence. When compared to manual lifting, overall, the EL reduced the LBD risk by 55% (from 49% to 22% LDB risk; Table 4). This is a sizeable decrease of practical and biomechanical significance. When considering the LBD risk using the approach outlined by Marras and colleagues, it is desirable to maintain the LBD risk at or below 30%. The <=30% LBD risk level corresponds to the classification of industrial jobs as only "low risk" of LBDs (jobs with no historical record of back-related incidents or reports), with no jobs classified as "high risk" (jobs with more than 12 incidents per 200,000 man-hour) at that level (Marras et al., 2000; Marras et al., 1993). In other words, if a job has a LBD risk of 30% or less, it is expected that the combined kinematic and workplace risk factors to reflect those observed among "low risk" jobs, and hence, the likelihood of having LBDs in that job is greatly reduced. Looking closer at the source of reduction in the LBD risk when using the EL, it is apparent that the EL significantly reduced the maximum sagittal flexion angle when compared to the manual lifting (from 67.0 degrees to 13.7 degrees; a close to 80% reduction in sagittal flexion), as well as sizeable reduction in the maximum moment (about 21% reduction), along with small reductions in both lateral and twisting velocities (Table 4). The subjective ratings also demonstrated the preference and effectiveness of the tool.

For the EBC, overall, the LBD risk for the manual and EBC lifting conditions were more or less comparable, with the EBC slightly higher than the manual lifting condition (54.5% versus 49.6%; an 8% increase). The main source of the difference came from the maximum lateral velocity risk factor (46.9 degrees/s versus 36.4 degrees/s; a 22% increase). This might be due to the way subjects placed the bucket on the EBC, where side-loading is expected. A better access to the EBC bucket holding area should be considered to reduce lateral motion. As expected, the evidence from the subjective measurement agrees that the EBC lifting condition was similar to common manual lifting, since the lifting using the EBC is a manual lift.

### Intervention for Carrying Task

The use of the EBC was not only the most preferred carrying method, but also resulted in the least LBD risk among the three carrying conditions. The LBD risk for the EBC carrying condition was 22.2%, which was about 50% less than the manual carrying condition (44.2 % LBD risk), and is below the desired 30% LBD risk level presented by Marras et al. (2000). The main source of this substantial reduction in the risk is from the maximum moment (a 44% decrease), and from both the lateral and twisting velocities (about 13% and 25% decrease, respectively) (Table 4). Given these sizeable reductions in individual risk factors and the overall LBD risk, the EBC intervention is expected to greatly reduce the amount of spinal loads during carrying. Combining these sizeable objective findings with the favorable subjective preference, makes the EBC intervention as an effective method for controlling LBDs during carrying.

For the EL intervention, the overall LBD risk was statistically comparable to the Manual condition during carrying. However, the EL was preferred by both participant groups over the Manual condition. This may be due to the cushioned and angled grip handle on the EL, which might have been perceived as more comfortable than the smaller tubular plastic handle on the bucket.

## Intervention for Dumping Task

For the dumping task, when compared to the Manual condition, the EBC significantly reduced the LBD risk for both adults and youths (a 69% reduction), and was also the most preferred method by both groups. The overall LBD risk was lowest among all conditions for the combined group, about 11%, which is markedly under the desired 30% LBD risk level. As expected, the EBC substantially reduced the maximum sagittal flexion angle, as well as the maximum lateral velocity and maximum moment risk factors (Table 4). These significant reductions in the amount of force (and moment) required for dumping, as well as the reduction in the kinematic variables, are expected to lead to substantial decrease in spinal loading during dumping. This confirms that EBC could be an effective means for controlling LBD risk during dumping.

The use of the EL was the second most preferred dumping method (Table 5), and had the second lowest overall LBD risk (19%) after the EBC when compared to the Manual condition (a 46% reduction in LBD risk). The ability of the EL to maintain the LBD risk substantially below the recommended 30% level, makes it a successful simple tool for a dumping task.

## General Discussion

The results of this study showed that the developed interventions could be effective in reducing the overall LBD risk for the bucket handling job; however, the tools were different in their effectiveness in risk reduction among the three tasks. The overall LBD risk for the Manual job was reduced from 58% to around 52% for the EBC and 50% for the EL. This seemingly modest reduction is due to the fact that the overall LBD risk for the “job” is based on the maximum risk factors values observed among all three sub tasks. An approach that incorporates the advantages of each of the two introduced interventions would yield more substantial reduction in the overall LBD risk. Therefore, it is recommended that for lifting the bucket (including when lifting it into the EBC), the EL should be used; whereas, the EBC should be used during the carrying and dumping tasks. This combined approach is expected to provide maximum reduction in the overall LBD risk, since it capitalizes on the strength of each tool in reducing the risk factors within the sub tasks (sagittal flexion during lifting in the case of the El, and almost all the risk factors during carrying and dumping for the EBC). This approach is expected to be especially effective if the job requires the bucket to be carried over long distances (e.g., more than 20 feet). In cases where the carrying distance is short (e.g., only few feet), simply using the EL should provide an effective means for reducing the risk of LBD during bucket handling.

The results of the manual handling of buckets during this study agree with the findings reported by Allread et al. (2004), who showed the LBD risk for youth handling buckets ranged between 29 and 70% depending on the task and material handled (e.g., lifting a feed bucket versus dumping of water bucket). That study highlighted the need to develop interventions to address jobs that place youth on farms at increased risk of LBDs, including bucket handling. The proper deployment of the two interventions introduced in this current study is expected to provide sizeable LBD risk abatement for youth who commonly handle buckets on farms.

### Limitations and Future Work

Although the study showed the potential benefits of the EBC and EL in bucket handling tasks, the results produced relatively conservative intervention evaluations because of the limitations inherent in the design of the experiment, including the age and limited working experience of the subjects. The study included only 16 and 17 years old high school students and younger adult college students who were not experienced bucket handlers working on farms. This may limit the implications of the study results; however, it is also important to note that the participants were neither experienced with the use of the newly introduced interventions; therefore, the relative comparison among the methods should hold. The study focused on the risk of LBD during handling of buckets and did not consider the effects of manual handling or the two interventions on other joints of the body such as the hands/wrist or shoulders. However, the design criteria for the interventions attempted to consider the effects of these tools on the wrists and shoulder by properly designing the handles and adjusting the devices in accordance to the user's anthropometry. Further study should confirm whether these new tools may create new risks to other joints of the body, beyond of what is expected during manual handling. Furthermore, this study focused primarily on the physical risk factors contribution to LBD risk during handling of buckets. Factors such as physical immaturity, growth, and psychosocial factors among youth users might be possible sources of variations in injury risks and patterns. Lastly, improvements and redesign of the EBC and EL (e.g., ease of adjustability) are needed so that they may become available to the general public and bring the expected benefits to their users.

## CONCLUSION

The purpose of this study was to introduce and evaluate two newly developed interventions (the EBC and EL) in their effectiveness in reducing LBD risk associated with bucket handling tasks. The results showed that the developed interventions significantly reduced LBD risks when compared to manual handling of buckets, especially the EBC for carrying and dumping of water buckets, and the EL for lifting the buckets. An approach that incorporates the EL for lifting and the EBC for carrying and dumping is expected to result in the lowest LBD risk during bucket handling on farms, especially when carrying buckets over long distances.

## Acknowledgments

The authors would like to thank Drs. Bruce Hartsough, John Miles, and Mir Shafii for their invaluable contributions to this study, and the late Brandon Miller for assisting in Phase 2 data collection. Partial funding for this project was provided through NIOSH contract #211-2003-M-02374.

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**KEY POINTS**

- Two interventions were developed to help reduce low back disorders (LBDs) among youth who handle water/feed buckets on family farms.
- The two interventions, the Ergonomic Bucket Carrier (EBS) and the Easy Lift (EL), were evaluated among two groups consisting of adults and youths.
- Objective and subjective measures collected from both groups consistently showed that, when compared to manual bucket handling, the EBC and EL provided significant and marked reductions in LBD risk.
- An approach that incorporates EL for lifting and EBC for carrying and dumping is expected to result in the lowest LBD risk during bucket handling.

**Figure 1.**
Example of manual handling of water bucket. From left to right: lift, carry, and dump.

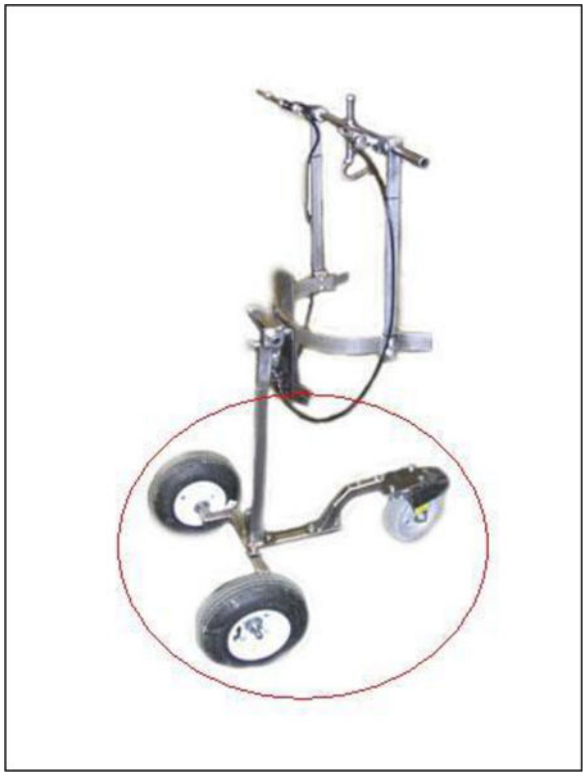

**Figure 2.**
Three-wheel prototype design

**Figure 3.**
Four-wheel prototype design

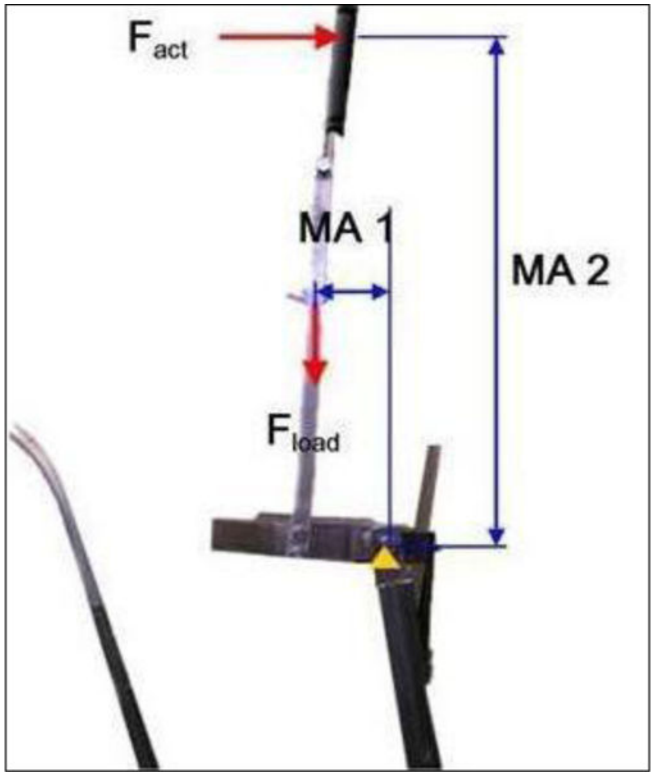


**Figure 4.**

Dumping mechanism (Type A); showing the acting moment arms (MA) when the bucket is upright.

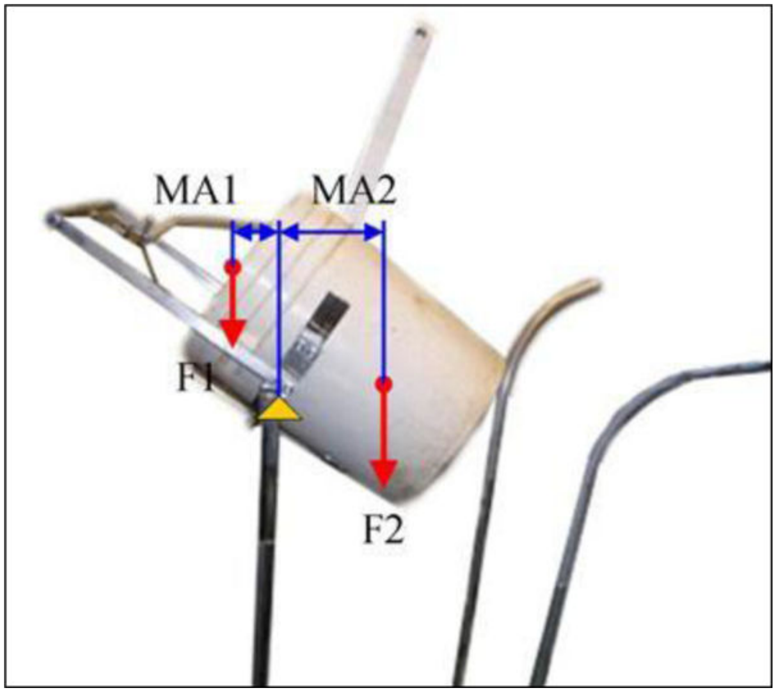


**Figure 5.**
Dumping mechanism (Type A); showing moment arms during when the bucket is tilted.

**Figure 6.**
Ergo Bucket Carrier (EBC).

**Figure 7.**
A participant performs a dumping task using the EBC.

**Figure 8.**
The Easy Lift (EL)

(a) (b) (c)

**Figure 9.**
Typical procedure for Lifting with the EL. The person starts by hooking the EL on the bucket (a and b), followed by initiating the lift and completing the lift and preparing to carry the bucket (c).

**Figure 10.**
A participant performs a carrying task using the EL.

**Figure 11.**
Dumping the bucket using the EL.

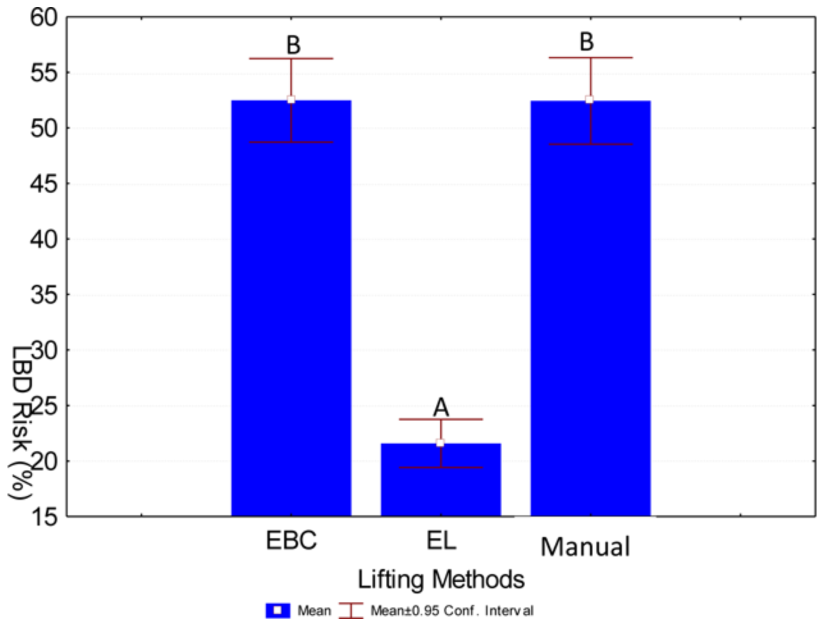


**Figure 12.**
LBD Risk during Lifting (Method Main Effect). Conditions with different letters are significant ($P < 0.05$).

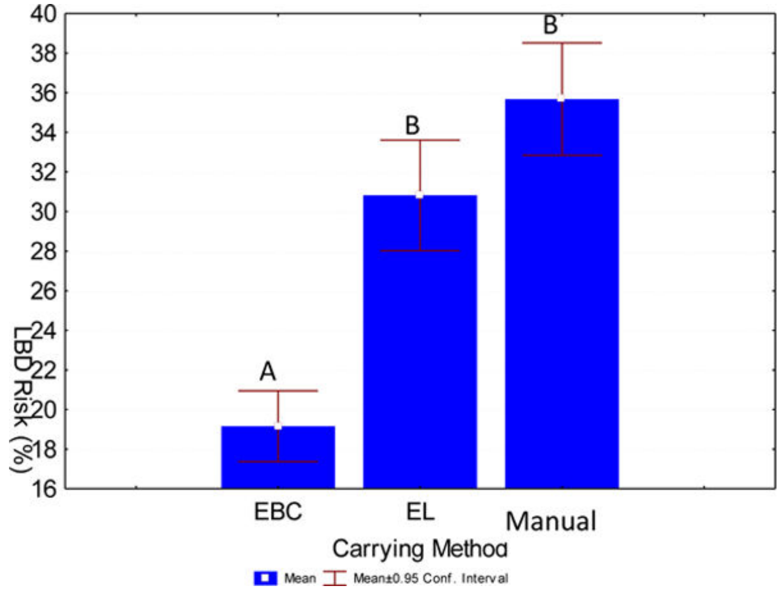


**Figure 13.**
Mean LBD Risks during Carrying (Method Main Effect). Conditions with different letters are significant ($P < 0.05$).

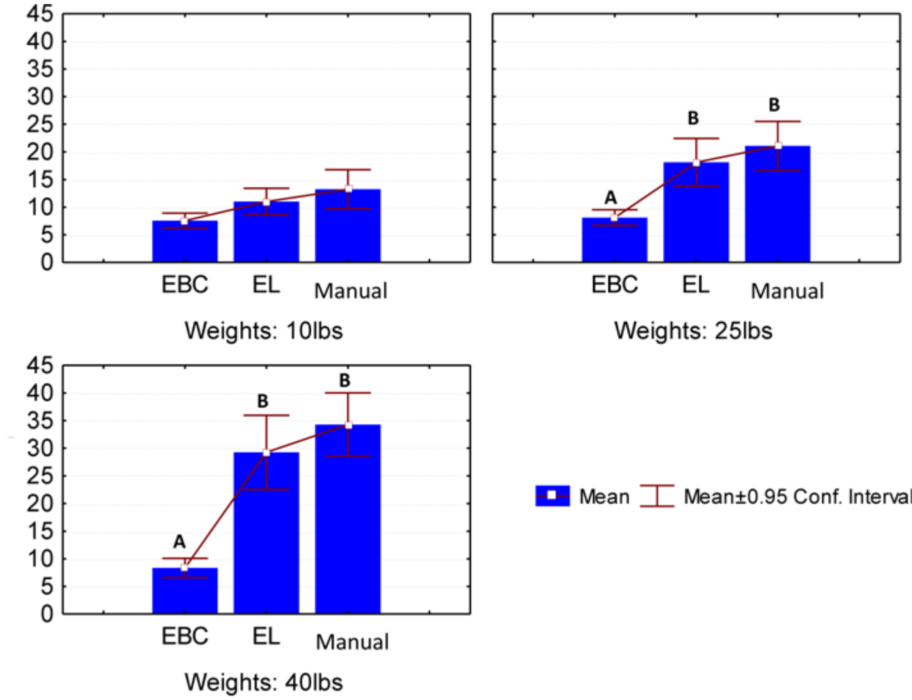


**Figure 14.**
Mean LBD Risks during Dumping (Interaction between Object Weight and Dumping Method). Conditions with different letters are significant (P < 0.05).

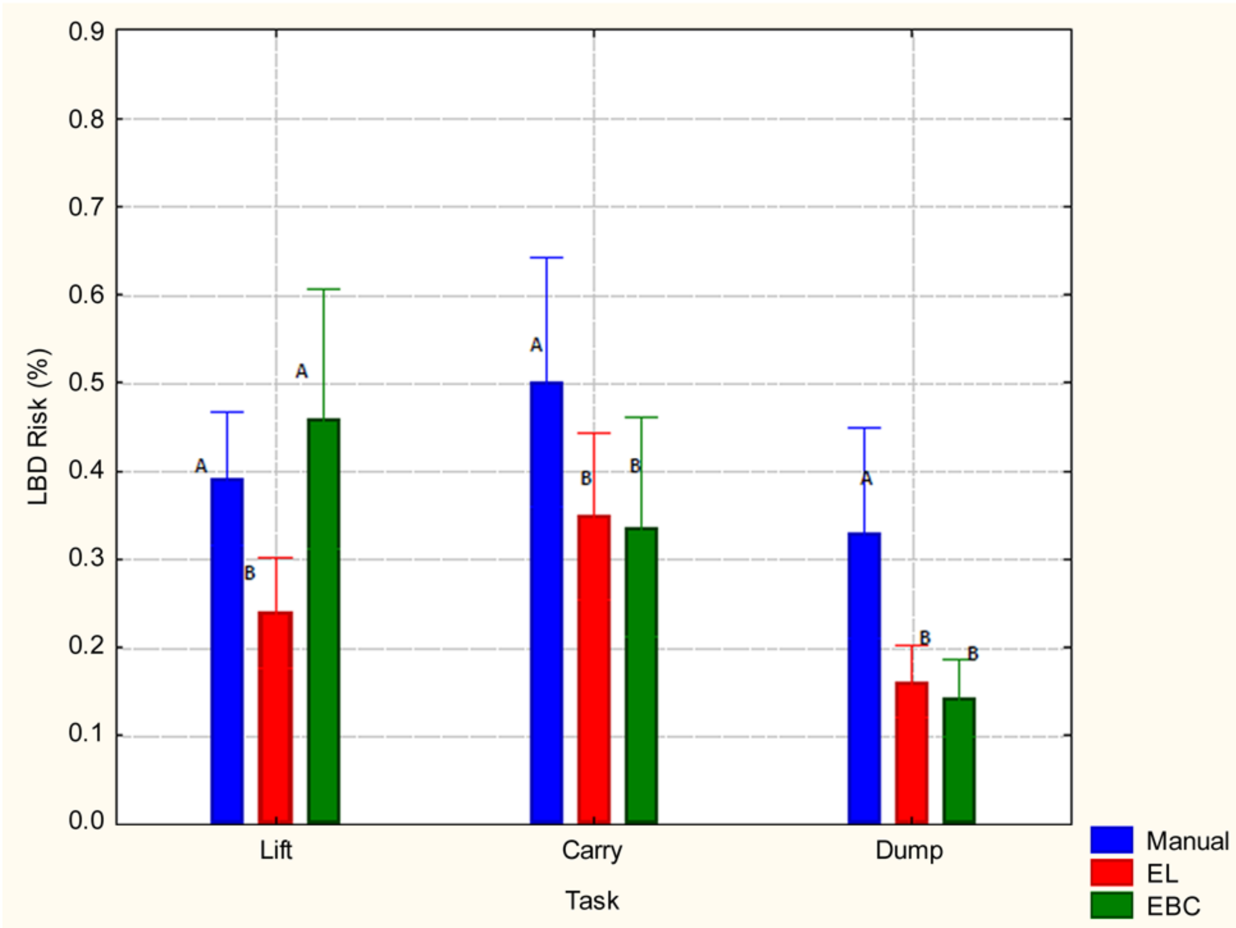


**Figure 15.**
LBD risk for each handling method (Manual, EL, and EBC) and task (Lift, Carry, and Dump) during Phase 2 (youths). Conditions with different letters are significant (only comparisons within a task were performed; $P < 0.05$)

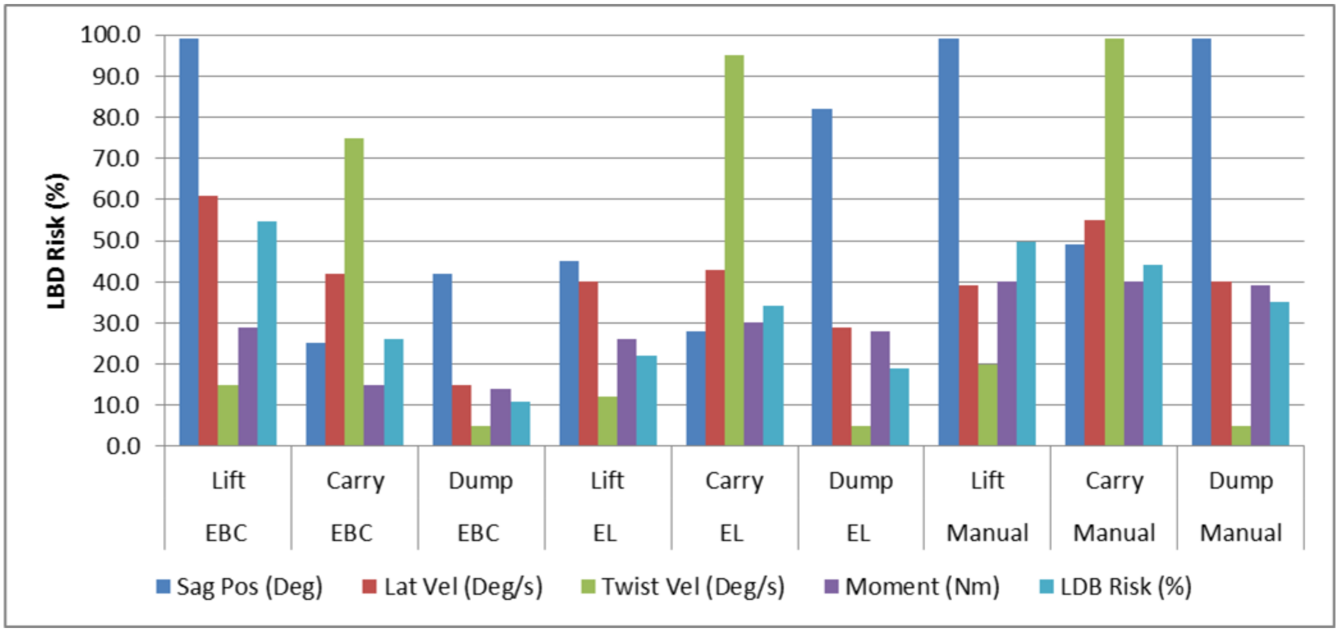


**Figure 16.**

Relative LBD risk (in %) for each of the risk factors along with the overall LBD risk (in %) for each of the method/task combination. Data shown are from the two combined groups (youths and adults).

Sag Pos: Maximum Sagittal Position; Lat Vel: Maximum Lateral Velocity; Twist Vel: Average Twisting Velocity (Marras et al., 1993).

**Table 1**

KT analysis for selection of carrying methods.

| | Carrying Method | | |
|---|---|---|---|
| **Constraints** | **Two-wheel** | **Three-wheel** | **Four-wheel** |
| **Requires one person** | Y | Y | **Y** |
| **Maintains trunk neutral postures** | Y | Y | **Y** |
| **Requires reduced force input**[a] | **N** | Y | **Y** |
| **Fits outdoor condition**[b] | Y | **N** | **Y** |
| **Fits 5-gallon bucket** | Y | Y | **Y** |

**Table 2**

KT Analysis for selecting the dumping mechanism.

| | Dumping Mechanism | | |
|---|---|---|---|
| **Constraints** | **Type A** | **Type B** | **Type C** |
| **Requires one person** | Y | Y | Y |
| **Maintains trunk neutral postures** | Y | Y | Y |
| **Requires reduced force input**[a] | Y | Y | Y |
| **Fits outdoor condition**[b] | Y | Y | Y |
| **Fits 5-gallon bucket** | Y | Y | Y |
| **Criteria** | | | |
| **Minimum Complexity** | 9 | 8 | 5 |
| **Introduces No New Risk** | 9 | 9 | 9 |
| **Minimum Cost** | 9 | 1 | 6 |
| **Final Score** | **27** | 18 | 20 |

## Table 3

KT Analysis for selecting the lifting aid mechanism.

| | Lifting Mechanism | | |
|---|---|---|---|
| **Constraints** | **Two-Hand** | **Spring** | **Air-Actuator** |
| **Requires one person** | Y | Y | Y |
| **Maintains trunk neutral postures** | Y | Y | Y |
| **Requires reduced force input[a]** | Y | Y | Y |
| **Fits outdoor condition[b]** | Y | Y | Y |
| **Fits 5-gallon bucket** | Y | Y | Y |
| **Criteria** | | | |
| **Min. Complexity** | 9 | 6 | 6 |
| **Introduce No New Risk** | 9 | 9 | 9 |
| **Min. Cost** | 9 | 6 | 3 |
| **Total** | **27** | 21 | 18 |

## Table 4

Average (standard deviation) of the four main risk factors along with the overall LBD risk are presented for each method/task combination. Data shown are from the two combined groups (youths and adults).

| Method/Task | Max Sagittal Flexion (degrees) | Maximum Lateral Velocity (Degrees/s) | Average Twisting Velocity (Degrees/s) | Maximum Moment (N.m.) | LBD Risk (%) |
|---|---|---|---|---|---|
| EBC/Lift | 68.6 (15.7) | 46.9 (21.2) | 4.3 (1.4) | 28.9 (7.1) | 54.5 (19.6) |
| EBC/Carry | 10.1 (10.1) | 38.1 (8.2) | 10.6 (5.3)) | 19.3 (16.5) | 26.2 (12.8) |
| EBC/Dump | 13.2 (10.5) | 21.5 (7.5) | 1.8 (0.9) | 18.9 (16.9) | 10.9 (5.0) |
| El/Lift | 13.7 (10.7) | 37.1 (8.7) | 4.1 (1.4) | 26.9 (6.7) | 22.2 (6.4) |
| EL/Carry | 10.9 (11.9) | 39.4 (8.3) | 12.5 (5.3) | 30.0 (3.7) | 34.1 (8.5) |
| EL/Dump | 20.6 (8.3) | 29.8 (9.6) | 1.8 (0.8) | 27.8 (5.8) | 19.0 (9.1) |
| Manual/Lift | 67.0 (15.7) | 36.4 (20.5) | 5.3 (2.0) | 34.4 (8.6) | 49.6 (18.4) |
| Manual/Carry | 13.9 (10.8) | 43.7 (9.7) | 14.1 (7.0) | 34.8 (8.2) | 44.2 (14.7) |
| Manual/Dump | 44.2 (21.5) | 36.9 (14.2) | 1.7 (1.1) | 33.8 (9.2) | 35.1 (14.4) |

**Table 5**

Subjective response for each task within each handling method for adults, youths, and a combined group. Values are sums of total response from all subjects within each group over the maximum possible score.

| | Task | | |
|---|---|---|---|
| **Method** | **Lifting** | **Carrying** | **Dumping** |
| **Manual** | | | |
| *Adults* | 14/27 | 10/27 | 15/27 |
| *Youths* | 10/24 | 12/24 | 9/24 |
| *Combined* | *24/51* | *22/51* | *24/51* |
| **EBC** | | | |
| *Adults* | 14/27 | **27/27** | **25/27** |
| *Youths* | 11/24 | **23/24** | **21/24** |
| *Combined* | 25/51 | **50/51** | **46/51** |
| **EL** | | | |
| *Adults* | **26/27** | 17/27 | 14/27 |
| *Youths* | **23/24** | 18/24 | 11/24 |
| *Combined* | **49/51** | 35/51 | 25/51 |

Note: One point is given for the least preferred, two for average, and three for the most preferred. Bold conditions indicate the most preferred conditions and italic conditions the least preferred.