

## Investigation of Select Ergonomic Interventions for Farm Youth. Part 2: Wheelbarrows

Susan E. Kotowski MS , Kermit G. Davis PhD & Thomas R. Waters PhD

To cite this article: Susan E. Kotowski MS , Kermit G. Davis PhD & Thomas R. Waters PhD (2009) Investigation of Select Ergonomic Interventions for Farm Youth. Part 2: Wheelbarrows, Journal of Agromedicine, 14:1, 44-57, DOI: [10.1080/10599240802612653](https://doi.org/10.1080/10599240802612653)

To link to this article: <https://doi.org/10.1080/10599240802612653>



Published online: 13 Feb 2009.



Submit your article to this journal [↗](#)



Article views: 173



Citing articles: 11 View citing articles [↗](#)

## Investigation of Select Ergonomic Interventions for Farm Youth. Part 2: Wheelbarrows

Susan E. Kotowski, MS  
Kermit G. Davis, PhD  
Thomas R. Waters, PhD

**ABSTRACT.** Previous research has provided evidence that farm youth performing farm chores may be at risk of developing a low back musculoskeletal injury. In order to reduce these risks, effective interventions for reducing the stressors that cause the injuries are needed. The objective of the current study was to investigate alternative wheelbarrow styles as an intervention for youth working to transfer material on the farm with respect to trunk motion and perceived exertion. A lumbar motion monitor was used to capture three-dimensional trunk kinematics while several wheelbarrow tasks (e.g., pushing, pushing over bump, and dumping) were performed by youth. Ratings of perceived exertion and comfort of use were also assessed. Results indicated a reduction in the sagittal trunk flexion and velocity was achieved by adding a push bar to the handles, in combination with three-wheels, or utilizing adjustable handles. However, these alterations had little impact in the predicted low back disorder risk levels. Additionally, the youths' perceptions of risk and exertion levels were greater for these alternative wheelbarrows than for the regular wheelbarrow. Therefore, the mismatch between perception and kinematic response will probably affect usage of the alternative wheelbarrows. While the results indicate that alternative wheelbarrow designs can reduce the awkward postures and motions during wheelbarrow tasks, further research into the effectiveness of these interventions, including spine loading and long long-term use, is necessary.

**KEYWORDS.** Farm youth, interventions, manual material handling, musculoskeletal disorders, wheelbarrow

### *INTRODUCTION*

Approximately 2 million youth currently work on farms in the United States,<sup>1</sup> and these youth are exposed to numerous biomechanical

stressors<sup>2</sup> while working on these farms. However, little research has focused on finding interventions to reduce the risks of back injuries and other musculoskeletal disorders in these youth. Previous research has found muscle

---

Susan E. Kotowski and Kermit G. Davis are affiliated with the Low Back Biomechanics and Workplace Stress Laboratory, University of Cincinnati, Department of Environmental Health, Cincinnati, Ohio, USA.

Thomas R. Waters is affiliated with the Division of Applied Research and Technology, National Institute for Occupational Safety and Health, Cincinnati, Ohio, USA.

This research was made possible by a contract from the National Institute for Occupational Safety and Health. The authors would also like to thank Matt Hammer, Chunhui He, Balaji Sharma, and Qiang Zheng for their assistance in data collection. The findings and conclusions in this paper are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health.

Address correspondence to: Kermit G. Davis, PhD, Director, Low Back Biomechanics and Workplace Stress Laboratory, University of Cincinnati, Department of Environmental Health, Cincinnati, OH, 45267-0056, USA (E-mail: kermit.davis@uc.edu).

strains and body discomfort to be prevalent in many farm youth.<sup>3,4</sup> The high physical demands associated with these tasks are not only detrimental to youth because of the pain and discomfort they cause in the short term, but also raise the risk potential that later in their adult life they will develop low back or other musculoskeletal disorders (MSDs).<sup>5-7</sup> Allread et al. reported that using a wheelbarrow on the farm poses a medium risk of low back disorders to farm youth.<sup>2</sup> These findings, along with previous documentation of the biomechanical stresses placed on youth performing farm tasks, illustrate the need for development and testing of interventions aimed at farm chores performed by youth.

To address this need, two studies were conducted to examine the effectiveness of low low-cost interventions in reducing adverse trunk motions and awkward postures during common farm tasks. In the first study,<sup>8</sup> add-on handles for shovels were found to produce trade-offs between sagittal and non-sagittal trunk motions, with reduction in sagittal flexion, but increases in twisting. The implication of these trade-offs is that add-on handles may not be an effective intervention for one of the farm tasks performed by farm youth.

The current paper presents the results of a study examining the effectiveness of alternative wheelbarrows in reducing adverse trunk motions and awkward postures for material transfer tasks on the farm. The objective of this study was to investigate the use of additional tires or adjustable handles on the wheelbarrow as potential interventions to reduce the biomechanical stress for youth. As with Part 1 that investigated intervention for shovels,<sup>8</sup> this study was focused on demonstrating the potential different designs of wheelbarrows to reduce awkward postures and fast motions during common material-transferring tasks.

## METHODS

### *Study Overview*

A repeated-measures, simulated-field study design was utilized to determine whether

wheelbarrow design, in the form of additional wheels or adjustable handles, could reduce the biomechanical stress placed on the youth during the transferring of farm material (grain, bedding, and waste products). The study was conducted on a flat grassy area outside the laboratory during dry conditions (e.g., not raining or snowing). Four different types of wheelbarrows were tested: regular, two-wheel, three-wheel, and adjustable handle. Data collection consisted of three-dimensional trunk kinematics recorded with a lumbar motion monitor, moment arm measurements, Borg's ratings of perceived exertion (RPE), and subjective ratings of comfort that was used for ranking of "least comfortable wheelbarrow to use" to "most comfortable to use." For detailed information about data collection methods and data processing, please refer to Kotowski et al.<sup>8</sup>

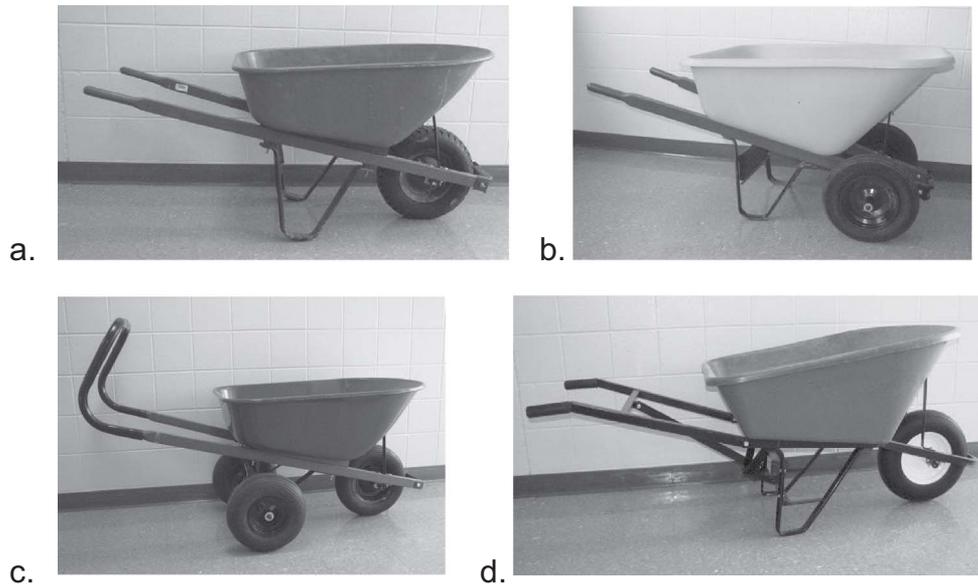
### *Subjects*

Twenty (10 girls, 10 boys) youth, ages 11 to 18 years old, who had experience working on farms were recruited from local 4-H programs. Demographic characteristics for the study population, such as age, weight, and height, are reported in Part 1.<sup>8</sup> All youth and/or their parents signed a consent and assent form approved by the University of Cincinnati Institutional Review Board and the NIOSH Human Subjects Review Board before participating in the study.

### *Wheelbarrow Designs*

Four different wheelbarrow designs were evaluated in the current study: (1) regular, (2) two-wheel, (3) three-wheel, and (4) adjustable handle (Figure 1). The regular design is a traditional wheelbarrow with one-wheel (17.8 cm diameter) and, a 0.17-cubic meter-m<sup>3</sup> bucket with, and non-adjustable handles. The two-wheel design has two-wheels on the front (20.2 cm diameter), a 0.23 cubic meter-m<sup>3</sup> bucket, and non-adjustable handles. The three-wheel design had two wheels at the back, along with one wheel on the front (all wheels had a 17.8 cm diameter). It has a 0.17 cubic meter-m<sup>3</sup> bucket with a continuous hand rail attached to the traditional style non-adjustable handles. Finally, the adjustable handle design is similar to the regular

FIGURE 1. Wheelbarrows tested: (a) regular, (b) two-wheel, (c) three-wheel, and (d) adjustable handle.



wheelbarrow (one wheel with diameter of 20.2 cm diameter), with the exception of the two handles having a 38-cm range of adjustment to adjust to the user's height. The bucket has the capacity of 0.17 cubic meter- $m^3$ . All wheels were pressurized to 30 psi prior to data collection.

### *Experimental Wheelbarrow Tasks*

Three separate tasks were performed using each of the wheelbarrows: (1) pushing, (2) pushing over a bump, and (3) dumping. Each task was repeated three times consecutively for each wheelbarrow at a self-selected speed, with each subject completing a condition in about the same amount of time. The order of the tasks was randomized and counterbalanced among the subjects. Subjects were allowed to adjust the height of the handle on the adjustable handle wheelbarrow for each task, with the setting then being recorded by one of the investigators. For each of the tasks, the wheelbarrow was filled with a mixture of sand (11.4 kg), shelled corn (11.4 kg), and straw (2.2 kg), for a total weight of 25 kg. This is a relatively light load in order to provide adequate human subject protection. There was only minimal difference in the force required to push/lift the different types

of wheelbarrows. All wheelbarrow tasks were performed on a grassy level area outdoors under good environmental conditions—moderate temperature and dry. Subjects were allowed to practice with all the wheelbarrows prior to data collection until they felt comfortable using the wheelbarrows.

### *Push*

During the pushing task, the youth picked up the wheelbarrow and pushed the wheelbarrow approximately 7.6 m over a grassy surface (Figure 2). Data collection was started after the subject had picked up the wheelbarrow and was stopped just before the subject put the wheelbarrow down on the ground.

### *Pushing Over a Bump*

During the pushing over a bump task, the farm youth picked up the wheelbarrow and pushed it approximately 3.0 m before going over a bump (height of 10.2 cm and width of 15.2 cm) and then continued pushing the wheelbarrow for approximately 3.0 m more (Figure 3). This task simulated pushing a wheelbarrow over a threshold or obstacle in a

FIGURE 2. A subject pushes the wheelbarrow with the adjustable handle.



FIGURE 3. A subject pushes the wheelbarrow with three wheels over a bump.



barn or field. Again, data collection was started after the subject had picked up the wheelbarrow and was stopped just before the subject put the wheelbarrow down on the ground.

#### *Dumping Material*

For the dumping task, the farm youth were asked to stand in an upright posture until data

FIGURE 4. A subject dumps the sand, corn, and straw mixture into the simulated stall using the wheelbarrow with two wheels.



collection started, pick-up the wheelbarrow and dump the contents into a simulated stall, and then place the wheelbarrow back on the ground and return to an upright posture in one smooth continuous motion (Figure 4), at which point data collection stopped. The method of lifting the handles and dumping the wheelbarrow was self-selected by the subjects.

#### *Dependent Variables*

The dependent variables included (1) peak three-dimensional trunk kinematics, as measured by the lumbar motion monitor, including position and velocity of the trunk in the sagittal, lateral, and transverse planes; (2) lumbar motion monitor low back disorder risk index; (3) Borg's RPE; and, (4) ranking order of the wheelbarrows based on perceived comfort of use (1 being easiest to use to 4 being hardest to use).

The lumbar motion monitor<sup>9</sup> measured instantaneous three-dimensional trunk kinematics (position, velocity, and acceleration) during the pushing, pushing over a bump, and dumping tasks. Several subjective ratings were also collected from the subjects. After using each type of wheelbarrow under each condition, subjects were asked to give a RPE (Borg's scale, 6 = very, very light to 20 = very, very hard).<sup>10</sup> The RPE assesses the whole whole-body

exertion level for a specific task. After subjects had used all four wheelbarrows (under a specific task: push, push over a bump, and dumping), they were also asked to place them in order of most comfortable to use to least comfortable to use (1 = least comfortable, 4 = most comfortable). Thus, for each condition (e.g., push, bump, and dump), each wheelbarrow would be comparably ranked to the other wheelbarrows (rank order). Thus, the subjective ratings included a perceived exertion level for each shovel and a relative comfort ranking. The RPE provides an estimate of the perceived effort level during each of the shovel conditions immediately after the condition was completed, while whereas the ranking of comfortable level of use provides a relative to each other. The perceptions of the farm youth are important information that provides some indication of the level of willingness in using the interventions.

In addition, the lumbar motion monitor kinematic data were processed using the lumbar motion monitor low back disorder risk model, which predicts “probability of membership in the high-risk low back disorder group.” Low back disorder risk is based on an index that incorporates five kinematic and workplace variables (maximum sagittal flexion position, lift rate, maximum external moment, maximum lateral velocity, and average twisting velocity), along with moment arm measurements and load weight through logistic regression methods.<sup>11,12</sup> A moment arm is defined as the perpendicular distance between an applied force vector and the point about which the moment is occurring, and the external moment is the product of the moment arm and the force. The lift rate was estimated as a very conservative value of eight wheelbarrow tasks per hour and was consistent for all wheelbarrow conditions. According to the lumbar motion monitor low back disorder risk model, a lift rate of eight wheelbarrow tasks per hour would be expected to have no impact on the low back disorder risk for any of the wheelbarrow tasks. The weight lifted for each wheelbarrow was estimated by attaching strap across the handles and connecting it to a force gauge. The wheelbarrow handles were then lifted by the force gauge and a reading was

obtained. Due to difficulty measuring the moment arm during the wheelbarrow task, it was decided that a single moment arm measurement would be obtained to compute the external moment (multiply weight by moment arm) for input into the low back disorder risk model for each wheelbarrow load. The single moment arm was obtained by averaging three moment arm measurements for each wheelbarrow prior to data analysis. The moment arm (e.g., horizontal distance between load and low back) was measured between the handles where the hands grasped the wheelbarrow handles and the low back (approximately the L5/S1 location) at the maximum distance during the task—when the wheelbarrow was being tipped upright to dump the contents. The external moment was then determined by multiplying the weight lifted by the moment arm for each wheelbarrow task.

### **Data Analysis**

Descriptive statistics (mean and standard deviations) were computed for the peak trunk kinematic (posture and velocity of the low back) variables as a function of wheelbarrow design. A repeated-repeated-measures split-plot analysis of variance (ANOVA) statistical analysis was performed on all dependent variables. For all significant independent variables, post-hoc analyses (Tukey multiple pairwise comparisons) were performed to determine the source of the significant effect(s) ( $p < 0.05$ ). The rank order variables were analyzed using a non-parametric analysis, Kruskal-Wallis rank sum. Separate analyses were done for the wheelbarrow tasks for the rank order of ease of use. SAS version 9.1 (SAS Institute, Inc., Carey, NC) was used for all statistical analyses. Since each task was repeated three times, the moment arm measurements from each trial were averaged prior to being analyzed.

## **RESULTS**

The ANOVA showed the main effect of wheelbarrow was significant ( $p < 0.05$ ) for several of the three-dimensional kinematic variables for each of the push, bump, and dump

TABLE 1. Summary of the p-values for the analysis of variance (ANOVA) Results for Each of the Peak Trunk Posture and Velocity-Dependent Variables (significant effects [ $p < 0.05$ ] are shaded) and Descriptive Statistics (average and standard deviations) for Wheelbarrow Main Effect for the Pushing of the Wheelbarrow Task (different alpha characters indicate significant differences at  $p < 0.05$ ) as a function of the pushing of the wheelbarrow task

	Sagittal flexion	Lateral flexion	Twist	Sagittal velocity	Lateral velocity	Twist velocity
ANOVA results*						
Wheelbarrow	.15	<b>.03</b>	<b>.049</b>	.23	<b>.02</b>	<b>.047</b>
Wheelbarrow by gender	.12	.47	.45	.16	.49	<b>.003</b>
Main effect of wheelbarrow type†						
Regular	16.89A (6.11)	7.14AB (2.49)	9.47A (2.91)	27.68A (7.80)	32.60A (10.61)	41.87A (13.24)
Two-wheel	18.46A (6.53)	6.72A (1.96)	10.74A (3.49)	30.24A (10.37)	35.20AB (9.73)	45.58A (11.95)
Three-wheel	18.64A (7.34)	8.06B (2.25)	10.99A (3.00)	30.59A (7.46)	36.52B (11.28)	44.70A (10.90)
Adjustable	15.77A (6.36)	7.59AB (2.79)	10.66A (3.22)	27.95A (8.41)	35.76AB (10.45)	41.43A (11.76)

\*Summary of the  $p$  values for the analysis of variance (ANOVA) for each of the peak trunk posture and velocity-dependent variables (significant effects [ $p < .05$ ] are in bold).

†Descriptive statistics (average and standard deviations) for wheelbarrow main effect (different alpha characters indicate significant differences at  $p < .05$ ).

tasks, indicating the wheelbarrow design impacted the way the youth moved. Only one variable (twist velocity) had a significant “wheelbarrow by gender” interaction, indicating gender had a significant influence on the effect of wheelbarrow. Tables 1 through 3 summarize the ANOVA results as well as provide the mean (standard deviations) for the four wheelbarrow designs for the kinematic variables as a function of task (pushing of wheelbarrow, pushing wheelbarrow over bump, and dumping of wheelbarrow). The following sections will discuss the significant results by task.

### **Trunk Kinematics (Posture and Velocity)**

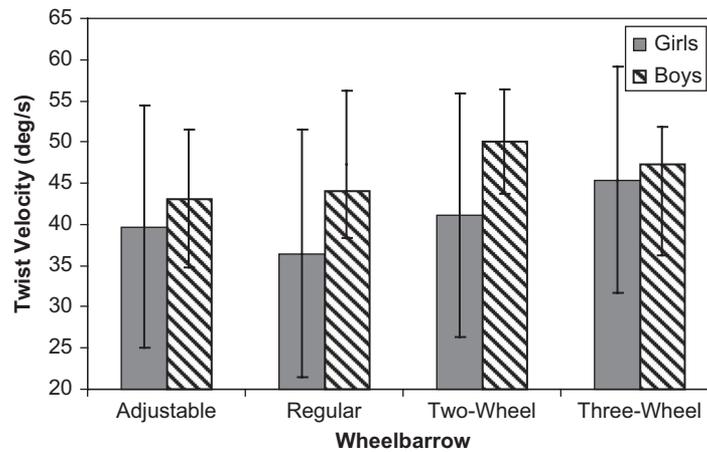
#### *Pushing the Wheelbarrow*

For the pushing task, non-sagittal motion (lateral flexion  $p = 0.02$  and twist  $p = 0.045$ ) was significantly impacted by the type of wheelbarrow used with no difference for sagittal flexion (see Table 1). In general, the regular wheelbarrow had slightly less lateral flexion and twist (by about  $2^\circ$ ) than the other wheelbarrow designs. Maximum lateral velocity and maximum twist velocity were also significant during the pushing task. There was only a small increase in trunk velocity for

lateral flexion and twisting (about  $3^\circ/s$  in both planes) for the three-wheel wheelbarrow and the two-wheel wheelbarrow as compared to the traditional or adjustable wheelbarrow. While these are relatively small differences in posture and velocity, they would represent a more non-neutral posture during the pushing conditions. One reason for small differences being identified as significant may be the highly repeatable nature of the task, which resulted in low variability in the outcome measures.

The impact of wheelbarrows on the trunk twist velocity (Figure 5) during the pushing tasks was influenced by the gender of the youth (e.g., interaction between gender and wheelbarrow was significant). The largest differences between the boys and girls occurred with the regular and two-wheel wheelbarrows. For the pushing tasks, the girls had the lowest twist velocities when pushing the regular wheelbarrow, whereas the three-wheel wheelbarrow was most beneficial for boys. In general, girls also reduced the external trunk moment by reducing the distance between the hands and back as compared to boys, with the largest differences occurring when pushing the three-wheel wheelbarrow.

FIGURE 5. Maximum twist velocity as a function of gender and wheelbarrow during pushing the wheelbarrow task.



### Pushing Wheelbarrow Over Bump

The ANOVA results indicated that maximum lateral flexion, maximum sagittal flexion, and maximum twist were all significant for one or more of the modified wheelbarrow types for the “bump” task (Table 2). The largest difference in trunk kinematics between the different wheelbarrows was for sagittal flexion, where

the adjustable and three-wheel wheelbarrows had the least amount of sagittal flexion (by more than 5°), as compared to the regular and two-wheel type wheelbarrows. There were only small differences between the wheelbarrows for lateral flexion and twist (about 2°).

Significant differences were also observed for some test conditions for maximum lateral velocity and maximum sagittal velocity of the

TABLE 2. ANOVA Results for Each of the Peak Trunk Posture and Velocity-Dependent Variables and Descriptive Statistics for Wheelbarrow Main Effect for the Pushing of the Wheelbarrow Over Bump Task Summary of the p-values for the analysis of variance (ANOVA) for each of the peak trunk posture and velocity dependent variables (significant effects [ $p < 0.05$ ] are shaded) and descriptive statistics (average and standard deviations) for wheelbarrow main effect (different alpha characters indicate significant differences at  $p < 0.05$ ) as a function of the pushing wheelbarrow over bump task

	Sagittal flexion	Lateral flexion	Twist	Sagittal velocity	Lateral velocity	Twist velocity
ANOVA results*						
Wheelbarrow	<b>.0003</b>	<b>.0007</b>	<b>.002</b>	<b>.004</b>	<b>.03</b>	.17
Wheelbarrow by Gender	.37	.96	.45	.53	.22	.34
Main effect of wheelbarrow type†						
Regular	27.10B (8.66)	6.74A (1.89)	9.36A (2.18)	42.61B (12.51)	33.54A (9.81)	42.31A (12.48)
Two-Wheel	25.64B (9.25)	6.68A (1.78)	9.81AB (2.32)	40.72B (11.20)	35.73AB (9.28)	46.09A (11.71)
Three-Wheel	20.36A (6.55)	8.20B (2.02)	11.18C (2.69)	38.53AB (5.88)	37.69B (9.27)	44.64A (12.13)
Adjustable	20.05A (6.58)	7.23AB (1.86)	10.70BC (3.28)	33.43A (8.88)	35.36AB (9.71)	42.92A (12.12)

\*Summary of the  $p$  values for the analysis of variance (ANOVA) for each of the peak trunk posture and velocity-dependent variables (significant effects [ $p < .05$ ] are in bold).

†Descriptive statistics (average and standard deviations) for wheelbarrow main effect (different alpha characters indicate significant differences at  $p < .05$ ).

trunk, similar to the results above for position. Maximum sagittal velocity was greatest for the regular wheelbarrow (about 43°/s), although not significantly different from the two-wheel and three-wheel wheelbarrows. The regular wheelbarrow did produce the lowest maximum lateral velocity (about 34°/s), although it did not significantly differ from the two-wheel and adjustable handle wheelbarrows. There was not a strong trend in lateral velocity between the different wheelbarrows during pushing over the bump. However, a strong effect was seen for sagittal velocity where the regular and two-wheel wheelbarrows had the highest velocities and the adjustable handle wheelbarrow had the lowest maximum sagittal velocity (e.g., a difference of approximately 8°/s). It appears that the use of adjustable handles was effective in reducing the sagittal trunk motion, with limited impact on the non-sagittal motion as compared to the regular wheelbarrow.

*Dumping of Wheelbarrow*

The ANOVA procedures for the dumping task revealed significant wheelbarrow effects on maximum lateral and sagittal flexion (Table 3). As with the other tasks, the largest differences

between wheelbarrows was for maximum sagittal flexion, where the most extreme positions were found for the regular and two-wheel wheelbarrows (about 43° for regular and two-wheel, 35° for the adjustable, and 30° for the three-wheel). Thus, the adjustable and three-wheel wheelbarrows were found to keep the youth more upright during the dumping of the wheelbarrows. Although there were some significant differences noted for lateral flexion and twist (<2°), these differences would not be considered to be of practical significance.

For the trunk velocities for the different wheelbarrows (Table 3), the regular and two-wheel wheelbarrows had the highest sagittal velocities (about 85°/s), while whereas the lowest was measured for the three-wheel wheelbarrow (about 60°/s). As with position, the lateral and twist velocities had some small significant effects but the differences were relatively minor as compared to sagittal velocity. One interesting result for twist velocity was the slight increase for the three-wheel wheelbarrow compared to the other three.

*Subjective Assessments*

In general, the rankings (rank order from 1 = least comfortable to 4 = most comfortable)

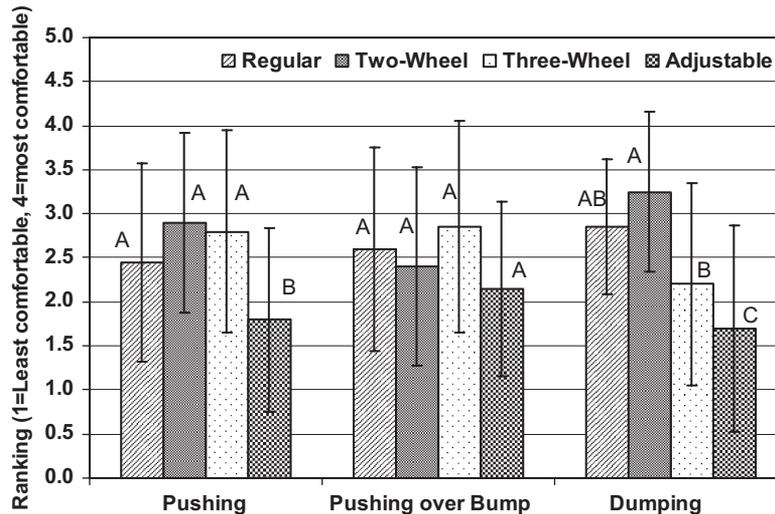
TABLE 3. ANOVA Results for Each of the Peak Trunk Posture and Velocity-Dependent Variables and Descriptive Statistics for Wheelbarrow Main Effect for the Dumping of Wheelbarrow Task  
 Summary of the p-values for the analysis of variance (ANOVA) for each of the peak trunk posture and velocity dependent variables (significant effects [p < 0.05] are shaded) and descriptive statistics (average and standard deviations) for wheelbarrow main effect (different alpha characters indicate significant differences at p < 0.05) as a function of the dumping of wheelbarrow task

	Sagittal flexion	Lateral flexion	Twist	Sagittal velocity	Lateral velocity	Twist velocity
ANOVA results*						
Wheelbarrow	<b>.0001</b>	<b>.02</b>	.052	<b>.0002</b>	<b>.048</b>	.02
Wheelbarrow by Gender	.15	.07	.98	.09	.52	.37
Main effect of wheelbarrow type†						
Regular	43.32A (9.77)	7.51A (2.55)	8.97A (2.59)	83.48A (32.14)	29.28A (9.65)	32.64A (8.18)
Two-Wheel	43.39A (11.38)	8.11AB (2.63)	9.01A (2.74)	84.25A (35.66)	32.40A (11.59)	33.75A (8.93)
Three-Wheel	29.31B (8.69)	7.69B (2.65)	8.98A (2.61)	58.29B (13.73)	28.40A (9.77)	38.94B (11.40)
Adjustable	34.95B (7.93)	8.95B (2.73)	10.10A (3.12)	70.23AB (19.94)	33.55A (10.12)	37.05AB (9.48)

\*Summary of the p values for the analysis of variance (ANOVA) for each of the peak trunk posture and velocity-dependent variables (significant effects [p < .05] are in bold).

†Descriptive statistics (average and standard deviations) for wheelbarrow main effect (different alpha characters indicate significant differences at p < .05).

FIGURE 6. Average ranking for comfort of use from 1- most comfortable to 4- least comfortable for the wheelbarrows with significant effects ( $p < 0.05$ ) for the pushing of wheelbarrow ( $p = 0.03$ ) and dumping of wheelbarrow ( $p = 0.0002$ ) tasks, but not pushing wheelbarrow over bump ( $p = 0.36$ ).



indicate a preference for the two-wheel wheelbarrow, but there was a lot of overlap between these rankings among the youth across all conditions (Figure 6). Based on the scores, it is apparent that there was not total agreement for all subjects on which wheelbarrow was the most or least comfortable since there were no perfect scores (4 or 1, respectively). Further, there was no significant difference between the wheelbarrows for the “ranking” variable during pushing the wheelbarrow over the bump, which reflects a lot of variation within the ratings of individual wheelbarrows. One trend was that the adjustable handle wheelbarrow was perceived the worst for all conditions.

Similar, but not identical, trends were found for the perceived exertion ratings, where the adjustable wheelbarrow was rated to have the highest exertion levels and the two-wheel wheelbarrow having the lowest exertion levels (Figure 7). Again, there was overlap with regard to the distributions about the means resulting in only the extreme cases being significantly different (e.g., adjustable versus two-wheel) for the pushing over bump and dumping of wheelbarrow tasks.

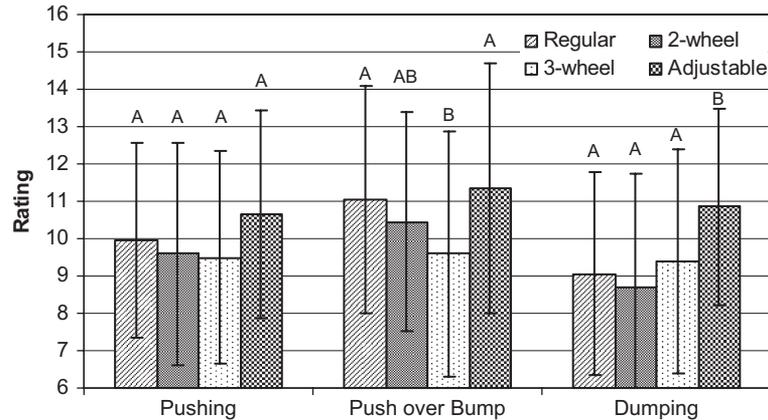
For both subjective ratings, gender had a limited effect on the perceptions of the different wheelbarrows for all the tasks, as seen by a

non-significant gender-wheelbarrow interaction effect.

#### ***Low Back Disorder Risk (Probability of High High-Risk Group Membership)***

For the low back disorder risk prediction, or ‘probability of high high-risk group inclusion,’ there were significant differences between the wheelbarrows for the dumping ( $p = 0.01$ ) and pushing ( $p = 0.02$ ) tasks, but not for the pushing over a bump task ( $p = 0.35$ ). The overall low back disorder risk index, along with the individual factors that contribute to the low back disorder risk index, are shown for each wheelbarrow under each of the conditions (pushing, pushing over bump, and dumping) are shown in Table 4. There were no significant “wheelbarrow by gender” interactions for any of the three tasks, indicating the effect of the wheelbarrows on low back disorder risk was independent of gender. For the pushing of wheelbarrow task, the predicted risk values ranged from 41% (regular wheelbarrow) to 45% (three-wheel wheelbarrow). For the pushing wheelbarrow over bump task, the four wheelbarrows did not differ from each other in terms of predicted risk (46% to 47%). For the dumping of wheelbarrow task, the regular and three-wheel wheelbarrows had

FIGURE 7. Average rating of perceived exertion (RPE) on a scale of 6 to 20 for the different wheelbarrows with significant ( $p < 0.05$ ) effects for the dumping of wheelbarrow ( $p = 0.0002$ ) and pushing wheelbarrow over bump tasks ( $p = 0.004$ ), but not significant for the pushing wheelbarrow task ( $p = 0.19$ ).



the lowest risk prediction (37%), which was significantly lower than the adjustable handle wheelbarrow (40%), but not different than the two-wheel wheelbarrow (39%). The pushing over a bump consistently had the highest predicted risk, followed by the pushing, and then the dumping tasks.

## DISCUSSION

Based on the wide usage of wheelbarrows on the farm by youth, the current study concentrated on evaluating different wheelbarrow designs to determine their effectiveness for reducing the low back stressors placed on farm youth. Wheelbarrow tasks commonly include pushing loads long distances, pushing the wheelbarrow over objects like thresholds, sticks, and holes, and dumping contents out of the wheelbarrow. The current study serves as a demonstration study where the concepts of three different designs of wheelbarrows were evaluated for their effectiveness in controlling awkward postures and fast motions in the low back.

In a previous study by Allread et al.,<sup>2</sup> tasks commonly performed by farm youth, such as pushing and dumping tasks, were found to have a 47% and 40%, respectively, risk of being included in a high high-probability group of developing a low back disorder. Based on these

assessments, these tasks would be considered to be of moderate risk (medium risk category) for low back disorders.<sup>11,12</sup> This level of risk prompted the need to determine whether inexpensive and novel interventions for wheelbarrows, in the form of additional wheels or adjustable handles, could potentially reduce the risk of a low back injury in farm youth performing pushing and dumping tasks. The results showed that both types of interventions impacted trunk postures and motions, as well as subjective exertion and comfort ratings.

Overall, the different designs significantly affected the trunk postures and motions in comparison to the regular, more traditional wheelbarrow. The wheelbarrow design had little impact on the trunk position and motion when solely pushing, but larger differences were noted when the tasks became more challenging and demanding (e.g., pushing over a bump or dumping the load). The only difference of consequence for the pushing task would be the increase of non-sagittal motion for the three-wheel wheelbarrow, which may have resulted from a different action mode (e.g., pushing completely versus lifting and pushing). For the other two conditions, a trade-off occurred, with more non-sagittal motion (e.g., lateral flexion and twist) but a significant reduction in sagittal motion for the alternative wheelbarrows as compared to the regular wheelbarrow. The

TABLE 4. Summary (Average and Standard Deviation) of the Probability of High-Risk Membership for Individual Factors and Overall Low Back Disorder (LBD) Risk for Each Wheelbarrow and Condition. Each column provides the probability value (values from 0 to 100) for the specific risk factor (peak sagittal flexion [sag flex], peak lateral velocity [lat vel], average [ave] twist velocity [vel], lift rate, and peak trunk moment [mom]) which are combined to obtain the overall LBD risk index (mean values with standard deviations in parentheses)

Wheelbarrow type	Lift Rate#	Pushing of wheelbarrow				Pushing wheelbarrow over bump				Dumping of wheelbarrow						
		Peak sag flex	Peak lat vel	Ave twist vel	Peak trunk mom	Peak sag flex	Peak lat vel	Ave twist vel	Peak trunk mom	Peak sag flex	Peak lat vel	Ave twist vel	Peak trunk mom			
Regular	0.02 (0.0)	59.8 (24.8)	33.7 (19.1)	84.4 (21.9)	22.6 (3.4)	40.5 (9.8)	87.4 (15.8)	35.4 (17.7)	83.0 (22.0)	22.6 (3.4)	46.0 (7.5)	98.0 (0.0)	27.7 (17.3)	32.4 (16.1)	32.4 (16.2)	36.5 (5.8)
Two-wheel	0.02 (0.0)	66.2 (24.9)	38.4 (17.5)	87.3 (17.6)	25.2 (3.6)	43.8 (10.2)	84.7 (17.9)	39.3 (16.7)	86.2 (17.3)	25.2 (3.6)	47.5 (8.7)	98.0 (0.0)	33.3 (8.9)	34.0 (21.7)	25.2 (3.6)	38.5 (7.6)
Three-wheel	0.02 (0.0)	66.3 (28.5)	40.8 (20.3)	89.3 (16.0)	25.4 (3.6)	44.8 (9.9)	74.9 (24.4)	42.9 (16.7)	89.2 (14.6)	25.4 (3.6)	46.9 (8.7)	91.0 (14.8)	26.2 (17.6)	41.0 (24.8)	25.4 (3.6)	37.1 (7.6)
Adjustable	0.02 (0.0)	55.0 (28.1)	39.3 (18.8)	87.1 (18.8)	9.4 (3.9)	42.6 (10.5)	73.2 (25.3)	38.7 (17.5)	85.1 (21.5)	29.4 (3.9)	45.7 (11.1)	97.7 (1.3)	35.4 (18.2)	36.4 (20.7)	29.4 (3.9)	40.2 (6.9)

Note. Each column provides the probability value (values from 0 to 100) for the specific risk factor (peak sagittal flexion [sag flex], peak lateral velocity [lat vel], average [ave] twist velocity [vel], lift rate, and peak trunk moment [mom]), which are combined to obtain the overall LBD risk index (mean values with standard deviations in parentheses).

#Lift rate was assumed to be 10 lifts/day for all conditions and wheelbarrow types which that would be considered extremely low risk.

adjustable handle and three-wheel wheelbarrow made the biggest difference during the pushing over the bump and dumping with respect to reduction of trunk velocity and more upright postures. These two wheelbarrows were effective in reducing the moment about the spine by reducing the trunk flexion. In all, based on the trunk postures and motions, the adjustable handle wheelbarrow and three-wheel wheelbarrow were effective in reducing the sagittal motions and extreme flexion postures during common wheelbarrow tasks, with only slight increases in off-plane motion.

However, a totally different trend was found for the subjective perceptions of the youth. It is interesting to note that the adjustable wheelbarrow was considered to be the most strenuous (e.g., highest exertion) and least preferred during all three of the conditions (pushing, pushing over a bump, and dumping). One potential explanation would be that the handles were adjusted by the individual youth and thus may not have been totally adjusted correctly. However, the kinematic data indicates that this probably was not the case, given the reduction in sagittal motion. Another interesting perception was the tendency of the two-wheel wheelbarrow as the best wheelbarrow, with the lowest perceived exertion during the dumping task. This may be due to the two wheels being in the front of the wheelbarrow, allowing a more stable dumping action. However, review of the findings for trunk postures suggests that the youth still bent forward significantly. The key to these perceptions is that a more strenuous and less safe perception may lead to the intervention not being adopted. Thus, the mismatch between the trunk kinematics and perceptions needs to be further understood to determine what may be driving these mismatches.

Another consideration about the subjective ratings of exertion and comfort of use is that these are the immediate feelings of the farm youth, which could have been affected by the lack of familiarity with the interventions. This may have been the reason for the worse ratings for the three intervention wheelbarrows. However, this has some potential ramifications for compliance of usage on the farm. There may be a necessary break in period where the farm

youth need to get familiar with all the benefits of an intervention before they will perceive its utility and get past the unfamiliarity issues.

Some additional insight into the importance of the different kinematic adaptations may be provided from the utilization of the lumbar motion monitor low back disorder risk model.<sup>11,12</sup> While this risk model has been developed for adult workers, it may provide a relatively good estimate for the risk associated with these complex tasks, given that multiple planes of motion were impacted by the wheelbarrow designs. Based on the risk predictions, there was no difference in the low back disorder risk estimates between the four wheelbarrows during the pushing over a bump task. For the pushing and dumping tasks, the regular wheelbarrow was found to have the lowest low back disorder risk, while whereas the three-wheel wheelbarrow and adjustable handle had the highest (45% and 40%, respectively). Overall, the “dumping” task had the lowest risk estimate, with the “pushing over a bump” having the highest. Thus, based on the low back disorder risk estimates, there was limited overall impact and these values remained at the levels found on farms by Allread and associates,<sup>2</sup> with risk values ranging from 47% for pushing tasks to 37% for dumping tasks (moderate risk). This indicates that while although the modified wheelbarrows showed some impact on trunk kinematics, the impact may not be large enough to reduce the risk of injury. On the other hand, the risk model may not have been sensitive enough to estimate the risk of these types of tasks since because there was only a significant reduction in sagittal flexion motion (only one of the five factors in the model).

The experimental results may represent a “best” case scenario given that the loads being moved were relatively light compared to those potentially incurred on the farm due to protection of the farm youth. As a result, how the farm youth performed the moving of the wheelbarrows could have changed and the low back disorder risk values may be under-estimated.

Although this study was conducted using subjects who had experience working on farms, and simulated farm tasks utilizing wheelbarrows, several other considerations must be taken into account when interpreting the results.

First, since because the study was cross-sectional in design, the subjects were only able to familiarize themselves with the intervention wheelbarrows at the start of the study, a potential disadvantage for the three alternative wheelbarrows since because all had prior experience using the regular wheelbarrow. This lack of familiarity with the intervention wheelbarrows may have affected not only how they handled the intervention wheelbarrows, but also their perception of them. A prospective study is necessary to determine if the results would change as the subjects adapt to the interventions over an extended period of time. Secondly, while trunk kinematic measurements provide insight into the impact of the interventions, a more comprehensive study involving muscle activity (via electromyography) used to estimate spinal loads is necessary to fully understand the effect of the interventions on the risk of developing a low back injury. The effect of the interventions on other body joints such as the shoulders should also be considered in future evaluations. The current study provides a first evaluation of the changes that occur when performing common wheelbarrow tasks. Future studies need to understand the load response on the soft tissues of the body that may occur from these changes.

While the focus of this study was on farm youth ages 11- to 18 years old, the results would likely be similar if adult farmers were tested since because the wheelbarrows are not specifically sized for youth. There is the potential that adult farmers would actually have more severe trunk kinematics as they would be taller in stature, which would require a greater degree of sagittal flexion to grasp the wheelbarrows. Size of the farm youth may also have impacted the results. While the sample size in the current study is too small to determine the influence of individual anthropometric characteristics, such as body height (stature) and body weight, it is important to remember that body size can have a significant impact in how an individual moves during physically demanding jobs such as moving wheelbarrows. The key is to use proper ergonomic principles—fit the job to the worker when deciding what wheelbarrow to use. The alternative wheelbarrows, particularly the adjustable wheelbarrow, may have a greater

impact on large individuals as compared to the regular wheelbarrow.

Other designs for the wheelbarrow could be more effective in changing how the farm youth perform the transferring of material. Another critical component that was not investigated in the current study was characteristics of the wheels. The air pressure level may play a dominant role in the pushing and maneuvering effort. For example, under-inflated wheels would lead to a higher pushing force on the wheelbarrow. In addition, the size of the wheel may also be critical in how the wheelbarrow responds during movement to uneven surfaces, obstacles (e.g., bumps), and environmental conditions (e.g., wet or icy surfaces).

## CONCLUSION

The results of this study give some indication that additional wheels or adjustable handles on wheelbarrows may not be the complete answer to reducing the risk of low back injuries in farm youth. While the intervention wheelbarrows, such as those with adjustable handles and three-wheels, reduced sagittal flexion, particularly for the dumping tasks, there were slight increases in the lateral and twisting motions. Overall, the results indicated a large reduction in the sagittal flexion position and velocity was achieved by adding a push bar on the handles in conjunction with three wheels or utilizing adjustable handles. However, these alterations showed little change in the predicted low back disorder risk levels. Further, the perceptions of these wheelbarrows, with respect to risk and exertion levels, were greater than the regular traditional wheelbarrow. Thus, there is a mismatch between perception and kinematic response, which would potentially influence the usage of these wheelbarrows. Further research is needed to identify the long-term impact of the different wheelbarrow interventions, as well as how these perceptions may be altered so that proper usage of effective wheelbarrows is broadly adopted. It is also suggested that future research investigate the biomechanical impact (e.g., muscle activity, spinal loading, and other joint loading) of these interventions. In conclusion, the addition of wheels and a push bar or adjustable

handles has some utility in reducing the postural demands on youth during common wheelbarrow tasks, but the true impact has yet to be fully evaluated.

## REFERENCES

1. Myers JR, Hendricks KJ. Injuries Among Youth On Farms in the United States, 1998. Cincinnati, OH: National Institute for Occupational Safety and Health. 2001; DHHS (NIOSH) publication 2001-154. Available at: <http://www.cdc.gov/niosh/childag/pdfs/2001154.pdf>. Accessed October 23, 2008.
2. Allread WG, Wilkins JR 3rd, Waters TR, Marras WS. Physical demands and low-back injury risk among children and adolescents working on farms. *J Agric Saf Health*. 2004 Nov;10(4):257-274.
3. Bartels S, Niederman B, Waters TR. Job hazards for musculoskeletal disorders for youth working on farms. *J Agric Saf Health*. 2000 Aug;6(3):191-201.
4. Chapman LJ, Newenhouse AC, Meyer RH, Karsh BT, Taveira AD, Miquelon MG. Musculoskeletal discomfort, injuries, and tasks accomplished by children and adolescents in Wisconsin fresh market vegetable production. *J Agric Saf Health*. 2003 May;9(2):91-105.
5. Walker-Bone K, Palmer KT. Musculoskeletal disorders in farmers and farm workers. *Occup Med (Lond)*. 2002 Dec;52(8):441-450.
6. Manninen P, Riihimäk H, Heliövaara M. Incidence and risk factors of low-back pain in middle-aged farmers. *Occup Med (Lond)*. 1995 Jun;45(3):141-146.
7. Axmacher B, Lindberg H. Coxarthrosis in farmers. *Clin Orthop Relat Res*. 1993 Feb;287:82-86.
8. Kotowski SE, Davis KG, Waters TR. Ergonomics interventions for farm youth. *Part 1: Shovels*. *J Agromedicine*. 2009;14(1): xx-xx, this issue.
9. Marras WS, Fathallah FA, Miller RJ, Davis SW, Mirka GA. Accuracy of a three-dimensional lumbar motion monitor for recording dynamic trunk motion characteristics. *Int J Ind Ergonomics* 1992;9:75-87.
10. Borg GA. Psychophysical bases of perceived exertion. *Med Sci Sports Exerc*. 1982;14(5):377-381.
11. Marras WS, Lavender SA, Leurgans SE, Rajulu SL, Allread WG, Fathallah FA, Ferguson SA. The role of dynamic three-dimensional trunk motion in occupationally-related low back disorders. The effects of workplace factors, trunk position, and trunk motion characteristics on risk of injury. *Spine* 1993 Apr;18(5):617-628.
12. Marras WS, Lavender SA, Leurgans SE, Fathallah FA, Ferguson SA, Allread WG, Rajulu SL. Biomechanical risk factors for occupationally related low back disorders. *Ergonomics* 1995 Feb;38(2):377-410.