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Upper Extremity and Lower Back Moments During Carrying Tasks in Farm Children

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Farm youth commonly perform animal care tasks such as feeding and watering. The purpose of this study was to determine the effects of age, bucket size, loading symmetry, and amount of load on upper body moments during carrying tasks. Fifty-four male and female participants in four age groups (8–10 years, 12–14 years, 15–17 years, and adults, 20–26 years) participated in the study. Conditions included combinations of large or small bucket sizes, unilateral or bilateral loading, and load levels of 10% or 20% of body weight (BW). During bucket carrying, elbow flexion, shoulder flexion, shoulder abduction, shoulder external rotation, L5/S1 extension, L5/S1 lateral bending, and L5/S1 axial rotation moments were estimated using video data. The 8–10 year-old group did not display higher proportional joint moments as compared with adults. Decreasing the load from 20% BW to 10% BW significantly decreased maximum normalized elbow flexion, shoulder flexion, shoulder abduction, shoulder external rotation, L5/S1 lateral bending, and L5/S1 axial rotation moments. Carrying the load bilaterally instead of unilaterally also significantly reduced these six maximum normalized joint moments. In addition, modifying the carrying task by using smaller one-gallon buckets produced significant reductions in maximum L5/S1 lateral bending moments.

Keywords: Biomechanics, ergonomics, injury, inverse dynamics, posture

Injuries to farm children are unique because of the types of tasks involved, the developmental issues regarding the etiology of the injury, and the potentially severe consequences of the injury. Operation of tractors and field equipment or having direct contact with livestock are considered complex and hazardous tasks for children to undertake. Therefore, parents often involve their children in agriculture by assigning them farm maintenance and livestock feeding because they are deemed to be safer activities (Marlenga et al., 2001). However, carrying tasks may require children to move or lift loads that are proportionally large, heavy, and often unilaterally loaded. No data are currently available to help parents gauge the risks associated with these tasks or to identify appropriate carrying limits based on the age of their children.

In the United States, agriculture was the industry division with the highest death rate in 2005 (National Safety Council, 2007), and 22,648 children/adolescents were injured on farms in 2001 (USDA, 2004). Because children and adolescents residing on farms are not restricted under the guidelines set by the Occupational Safety and Health Administration, their potential risk for injury may be underestimated. Fatal and nonfatal reports in children and adolescents have typically focused on injuries associated with product-related, accidental, and traumatic injuries (Cogbill et al., 1985; Rivara, 1985; Bancej & Arbuckle, 2000; Gerberich et al., 2001). While a decline of fatal injuries has been documented, it is unknown the extent that nonfatal injuries result in disability and loss of productive work capability (Reed & Claunch, 2000).

One study that addressed nonfatal injuries included musculoskeletal disorders (MSDs), which frequently included sprains and strains of the upper limbs, lower limbs, and back (Pickett et al., 1995). Musculoskeletal disorders may be less often reported as a farm injury owing to the "injury" classification requiring a visit to a doctor or emergency room. Farm youth have described frequent musculoskeletal pain in the upper and lower extremities, trunk, neck, and shoulders, although youth

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typically do not treat or report an injury of this type (Bartels et al., 2000). This same study reported that farm youth perceive that MSDs are more frequent and that they pose a greater long-term risk than adults realize.

In terms of injury mechanisms, there is a lack of research evidence about which tasks pose the greatest risk to farm youth. Farm youth commonly perform animal care tasks such as feeding, watering, and cleaning stalls (Marlenga et al., 2001). Previous field research has identified that the magnitude of weight manipulated by farm youth tends to be higher than the magnitude of weight manipulated by adults in industrial settings (Allread et al., 2004). In addition, younger individuals may be less efficient when performing weight-bearing movement (Rowland, 2005), which may lead to more rapid fatigue and a greater injury risk. Many adolescents report working long hours on the farm or working multiple jobs (farm and nonfarm), which may also contribute to fatigue (Munshi et al., 2002; Parker et al., 2002).

Morrissey and Liou (1988) found that the maximum weight that individuals were willing to carry was reduced with wider containers, which may indicate increased difficulty carrying 5-gallon (18.9 L) buckets as compared with 1-gallon (3.8 L) buckets. There is also evidence that unilateral lifting increases asymmetrical loading in the lower back. When comparing one-handed to two-handed lifting, Allread et al. (1996) predicted an increased risk of suffering a lower back disorder with one-handed lifting, and Marras and Davis (1998) found increased spinal lateral shear with one-handed lifting. In addition, Granata and Wilson (2001) reported reduced spinal stability for lifting postures that involve trunk twisting (axial rotation) and Fowler et al. (2006) observed increased spinal flexion and lateral bending when carrying an asymmetric load. Moment generation requirements for lifting may provide insight into muscle activity and injury risk. Seroussi and Pope (1987) found a strong correlation between frontal plane moments and erector spinae electromyographic activity, and Marras et al. (2000) used sagittal plane moments as an input into their lower back disorder risk model.

There may be a variety of options for how a bucket carrying task could be modified to reduce the moment requirements on the upper body: lowering the amount of weight in the buckets, using smaller buckets, and bilateral carrying of the buckets. First, the amount of weight carried could be based on a percentage of body weight to partially account for differences in body size. Second, young children could carry smaller diameter buckets to partially account for having arms of shorter length than adults and reduce shoulder abduction moments. Third, the amount of weight carried could be split between buckets in each hand rather than a single bucket to increase loading symmetry and reduce lateral bending moments of the lower back.

The purpose of this study was to determine the effects of age, bucket size, and loading symmetry on upper body moments during carrying tasks. Two of the hypotheses were based on differences between carrying conditions. Because carrying smaller buckets allows a person to bear the load closer to their body, it was hypothesized that shoulder abduction moments would be lower when using 1-gallon buckets as compared with 5-gallon buckets. Since carrying buckets bilaterally provides a balance of moments in the frontal plane, it was also hypothesized that L5/S1 lateral bending moments would be lower when carrying the same amount of weight bilaterally as compared with unilaterally. A third hypothesis was formed by considering the physical size differences between age groups. Taking into account that the bucket diameters would be proportionally larger as compared with arm length in young children, it was hypothesized that shoulder abduction and L5/S1 lateral bending moments would be proportionally highest in the 8–10 year-old group as compared with adults. The outcomes of the study may provide initial guidelines to assist parents to identify lifting and carrying limits appropriate for the age of children and adolescents.

Methods

Fifty-four male and female participants in four age groups (8–10 years, 12–14 years, 15–17 years, and adults, 20–26 years) participated in this study. As a sample of convenience representative of farm youth, children were recruited from local 4-H chapters, which are youth organizations sponsored by the United States Department of Agriculture. Informed consent was obtained from all participants in accordance with Iowa State University Institutional Review Board guidelines concerning human subjects. Parental permission was obtained for minors participating in the study, and dominant handedness was recorded. The sex distributions and average participant age, height, and body mass in each age group are presented in Table 1.

Two bucket sizes were compared: large, 5 gallon (18.9 L) and small, 1 gallon (3.8 L). The 5-gallon buckets were 36.8 cm high and 30.0 cm in diameter, whereas the 1-gallon buckets were 19.5 cm high and 16.7 cm in diameter. The buckets were filled with a total of either 10% body weight (BW) or 20% BW using sealed bags of lead shot to test the effects of carried load. Load symmetry was tested by carrying one bucket in the dominant hand (unilateral) or carrying an equally loaded bucket in each hand (bilateral). During bilateral carrying the total carried weight was split between the two buckets. The six carrying conditions were as follows: (a) unilateral large 20% BW, (b) unilateral large 10% BW, (c) unilateral small 20% BW, (d) unilateral small 10% BW, (e) bilateral small 20% BW, and (f) bilateral small 10% BW. Three repetitions of each bucket carrying condition were performed for a total of eighteen trials per participant. The order of the conditions was balanced across subjects to reduce biasing effects of learning and fatigue. Research participants also walked carrying empty buckets, but results of these trials will not be presented. Bilateral

Table 1 Participant Characteristics: Average Values Plus/Minus 1 Standard Deviation Are Reported for Age, Height, and Mass

Age Group	Sex (M:F)	Age (year)	Height (m)	Mass (kg)
8–10	9:4	8.8 ± 1.0	1.38 ± 0.09	35.1 ± 9.4
12–14	9:6	12.6 ± 0.9	1.56 ± 0.06	52.7 ± 12.1
15–17	5:7	15.6 ± 1.0	1.76 ± 0.04	67.0 ± 7.6
Adult	5:9	22.8 ± 1.8	1.72 ± 0.09	67.3 ± 10.6

large bucket carrying conditions were not performed because of fatigue considerations, particularly with the youngest children.

While carrying the bucket(s), participants walked 6 m and kinematic data were collected using an eight-camera system (Peak Motus, Centennial, CO). Research participants were instructed to walk at a comfortable pace while looking straight ahead. The kinematic data were collected at 120 Hz and filtered at a 6-Hz cutoff frequency with a fourth-order, low-pass, zero phase-shift Butterworth filter. On the upper body, reflective markers were placed on the third metacarpals, midwrists, midforearms, lateral humeral epicondyles, medial humeral epicondyles, midtriceps, and acromions. Additional markers were placed on the suprasternale, on the lower back at the L5/S1 intervertebral level, and on the greater trochanters. Markers were placed on the bottom outer edge of the bucket(s) to measure accelerations of the carried load caused by bucket swinging. The full marker set was captured during a static posture, and then the medial humeral epicondyle markers were removed so they did not interfere with movement during bucket carrying. Medial humeral epicondyle markers were recreated using the lateral humeral epicondyle, midtriceps, and shoulder markers during the dynamic trials.

Kinematics were analyzed for the middle 2 m of the bucket carrying, which allowed for the capture of one full stride. Wrist joint centers were set at the midwrist markers, since multiple markers surrounding the wrist joint were often too close to be resolved in pilot studies, particularly in the youngest children. Elbow joint centers were calculated as the midpoint between the tracked lateral and recreated medial humeral epicondyle markers. Shoulder joint centers were located using the acromion markers and the elbow joint centers according to de Leva's adjustments (1996b). The L5/S1 joint center was located by the position of the L5/S1 marker in the vertical and medial/lateral directions. In the anterior/posterior direction, the L5/S1 joint center was calculated at 68% from the L5/S1 marker to the midpoint of the greater trochanter markers as adapted from de Looze et al. (1992). Similar to the wrist, it was assumed that the hand segment mass centers were aligned with the third metacarpal markers owing to difficulties associated with tracking multiple hand markers. The forearm and upper arm segment mass centers were calculated as a percentage of segment length (de Leva, 1996a). A combined head/torso segment mass center was calculated as a weighted average of the combined segment masses and overall combined segment length.

An upper body inverse dynamic model was used to calculate elbow, shoulder, and L5/S1 joint moments. Joint rotations were calculated as three successive rotations (flexion/extension, abduction/adduction, and internal/external rotation) at the elbow, shoulder, and L5/S1 joints. Segment masses were estimated as a percentage of body weight and segment moments of inertia were scaled using segment masses and lengths (de Leva, 1996a). Hand contact forces were calculated by summing the known bucket weight acting vertically downward with the known bucket mass multiplied by the measured bucket acceleration in the anterior/posterior, medial lateral, and vertical directions. The applied moment between the bucket and the hand was assumed to be zero. Joint forces and moments were calculated successively from the wrists to elbows to shoulders to L5/S1 using Newton–Euler equations.

With the capture of one full stride length and small upper body ranges of motion, maximum joint moments were used as a measure of highest loading during carrying. Elbow joint moments were transformed to the upper arm coordinate system, whereas shoulder and L5/S1 joint moments were transformed to the torso coordinate system. Wrist joint moments will not be presented as a result of an inability to accurately track the joint center with a single marker. The dependent variables were maximum joint moments for elbow flexion, shoulder flexion, shoulder abduction, shoulder external rotation, L5/S1 extension, L5/S1 lateral bending, and L5/S1 axial rotation. To aid in comparisons involving research participants with a wide range of ages and body sizes, maximum joint moments were scaled by body mass. To avoid the inclusion of noisy data, trials with marker discontinuities resulting in high angular acceleration (>100 rad/s^2) were eliminated from the analysis. This angular acceleration threshold corresponds to eliminating trials that resulted in rotational movement frequencies above ~16 Hz. For each research participant, maximum joint moments were then averaged across remaining trials for the six carrying conditions.

Multivariate ANOVA (SPSS, Chicago, IL) was used to test the effects of age group, carrying condition, and their interaction on the maximum normalized joint moments. The significance level was set to $p < .05$ with a Bonferroni correction of seven (number of dependent variables). When significant main effects were found, post hoc tests of multiple comparisons were also made at a significance level of $p < .05$ with a Bonferroni correction of seven. The effects of age on maximum joint moments were compared between the four age groups (six possible comparisons). To test the effects of carried weight, two comparisons were possible: unilateral large 20% BW vs. unilateral large 10% BW and unilateral small 20% BW vs. unilateral small 10% BW. Two possible comparisons tested the effects of loading symmetry: unilateral small 20% BW vs. bilateral small 20% BW and unilateral small 10% BW vs. bilateral small 10% BW. Finally, two possible comparisons tested the effects of bucket size: unilateral large 20% BW vs. unilateral small 20% BW and unilateral large 10% BW vs. unilateral small 10% BW.

Results

Maximum joint moments (normalized to body mass) were significantly dependent upon age group ($p < .01$) and carrying condition ($p < .01$). In contrast, the interaction between age group and carrying condition was not significant ($p = .92$).

Effects of Age Group

Maximum shoulder abduction moments were significantly higher for adults as compared with the 8–10 year ($p < .01$) and 15–17 year ($p = .04$) age groups (Figure 1). In addition, maximum L5/S1 lateral bending moments were significantly higher for the 12–14 year ($p < .01$), 15–17 year ($p < .01$), and adults ($p < .01$) as compared with the 8–10 year age group. Differences in maximum elbow flexion, shoulder flexion, shoulder external rotation, L5/S1 extension, and L5/S1 axial rotation moments between age groups were not statistically significant ($p = .22$ and higher for all comparisons).

Effects of Weight Carried

Maximum elbow flexion ($p = .02$), shoulder flexion ($p < .01$), shoulder abduction ($p < .01$), shoulder external rotation ($p < .01$), L5/S1 lateral bending ($p < .01$), and L5/S1 axial rotation ($p < .01$) moments were significantly higher when carrying a unilateral large 20% BW bucket as compared with a unilateral large 10% BW bucket (Figure 2). Maximum elbow flexion ($p = .01$), shoulder flexion ($p < .01$), shoulder abduction ($p < .01$), shoulder external rotation ($p < .01$), L5/S1 lateral bending ($p < .01$), and L5/S1 axial rotation ($p = .01$) moments were also significantly higher when carrying a unilateral small 20% BW bucket as compared with a unilateral small 10% BW bucket. Differences in maximum L5/S1 extension moments as a function of the amount of weight carried were not statistically significant ($p = .27$ and higher).

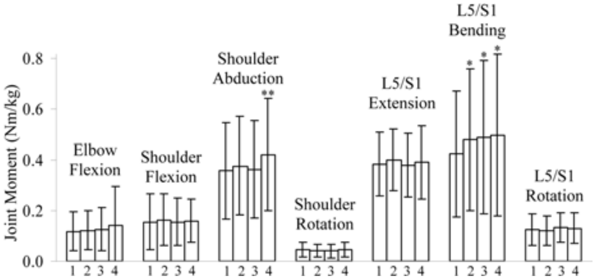

Figure 1 — Maximum joint moments as a function of age group. Joint moments were scaled by body mass and are reported as averages across conditions with standard deviations. Age groups: (1) 8–10 years old, (2) 12–14 years old, (3) 15–17 years old, (4) adult. Age significance: *significantly greater than the 8–10 age group, **significantly greater than the 8–10 and 15–17 age groups.

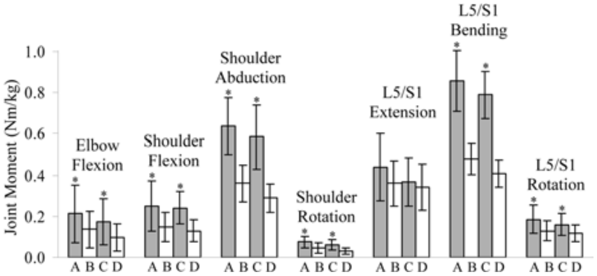

Figure 2 — Maximum joint moments as a function of amount of weight carried. Joint moments were scaled by body mass and are reported as averages across age groups with standard deviations. Shaded columns indicate 20% BW carrying conditions, and unshaded columns indicate 10% BW conditions. Carrying conditions: (A) unilateral large 20% BW, (B) unilateral large 10% BW, (C) unilateral small 20% BW, (D) unilateral small 10% BW. Weight significance: *20% BW significantly greater than 10% BW.

Effects of Loading Symmetry

Maximum elbow flexion ($p < .01$), shoulder flexion ($p < .01$), shoulder abduction ($p < .01$), shoulder external rotation ($p < .01$), L5/S1 lateral bending ($p < .01$), and L5/S1 axial rotation ($p < .01$) moments were significantly

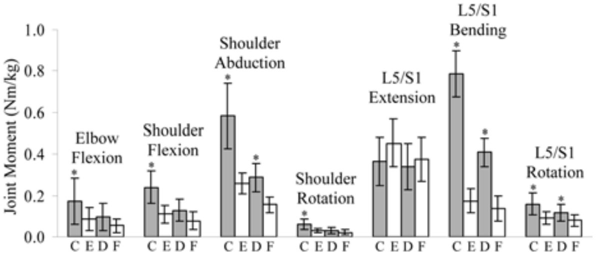

Figure 3 — Maximum joint moments as a function of unilateral versus bilateral carrying. Joint moments were scaled by body mass and are reported as averages across age groups with standard deviations. Shaded columns indicate unilateral carrying conditions, and unshaded columns indicate bilateral carrying conditions. Carrying conditions: (C) unilateral small 20% BW, (E) bilateral small 20% BW, (D) unilateral small 10% BW, (F) bilateral small 10% BW. Unilateral significance: *Unilateral significantly greater than bilateral.

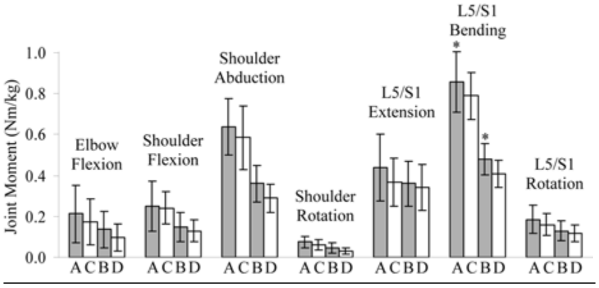

Figure 4 — Maximum joint moments as a function of bucket size. Joint moments were scaled by body mass and are reported as averages across age groups with standard deviations. Shaded columns indicate large (5-gallon) buckets, and unshaded columns indicate small (1-gallon) buckets. Carrying conditions: (A) unilateral large 20% BW, (C) unilateral small 20% BW, (B) unilateral large 10% BW, (D) unilateral small 10% BW. Size significance: *large greater than small bucket.

higher when carrying a unilateral small 20% BW bucket as compared with bilateral small 20% BW buckets (Figure 3). In addition, maximum shoulder abduction ($p < .01$), L5/S1 lateral bending ($p < .01$), and L5/S1 axial rotation ($p = .05$) moments were significantly higher when carrying a unilateral small 10% BW bucket as compared with bilateral small 10% BW buckets. However, differences in maximum elbow flexion, shoulder flexion, and shoulder external rotation due to unilateral versus bilateral carrying were not statistically significant with the 10% BW load ($p = .24$ and higher). Maximum L5/S1 extension moments were not dependent upon unilateral versus bilateral carrying at either the 10% or 20% BW load ($p = .09$ and higher).

Effects of Bucket Size

Maximum lateral bending moments were significantly greater when carrying the large bucket unilaterally as compared with carrying the small bucket unilaterally at both the 10% BW ($p = .04$) and 20% BW ($p = .04$) loads (Figure 4). Maximum elbow flexion, shoulder flexion, shoulder abduction, shoulder external rotation, L5/S1 extension, and L5/S1 axial rotation moments were not dependent upon bucket size ($p = .12$ and higher).

Discussion

Our first hypothesis was that maximum normalized shoulder abduction moments would be lower when carrying small (1 gallon) buckets as compared with large (5 gallon) buckets. This hypothesis was not supported because shoulder abduction moments were not significantly dependent upon bucket size (Figure 4). Although a larger bucket would move the center of the carried load further away from the body, the research participants could have adjusted their posture to avoid increased shoulder abduction moments. One way that this could be achieved is through increased lateral bending of the trunk, which would reduce the moment arm between the carried load and the shoulder joint. The fact that L5/S1 lateral bending moments were significantly higher when carrying the large bucket would appear to support this explanation.

Our second hypothesis was that maximum normalized L5/S1 lateral bending moments would be lower when carrying the load bilaterally as compared with unilaterally. This hypothesis was supported since L5/S1 lateral bending moments were significantly higher with unilateral bucket carrying than with bilateral carrying (Figure 3). This is of interest because Seroussi and Pope (1987) found increased erector spinae electromyographic activity when testing frontal plane moments up to 26 N·m. In comparison, the maximum L5/S1 lateral bending moments averaged 22.7 N·m when carrying a unilateral 10% BW bucket and 43.7 N·m when carrying a unilateral 20% BW bucket in this study. Other studies have demonstrated spinal kinematic and kinetic differences with asymmetric loading at levels between 10% and 20% BW. Marras and Davis (1998) found increased spinal lateral shearing forces with one-handed lifting at an average of 17% BW, and Fowler et al. (2006) found increased lateral bending with asymmetric load carrying at 17.5% BW.

Our third hypothesis was that maximum normalized shoulder abduction and L5/S1 lateral bending moments would be proportionally higher in the 8–10 year-old group as compared with adults. This hypothesis was not supported and in fact, the opposite results were observed. Maximum shoulder abduction and L5/S1 lateral bending moments were significantly higher in adults than in 8–10 year olds (Figure 1). Higher shoulder abduction and L5/S1 lateral bending moments were predicted in 8–10 year olds on the premise that the loaded buckets would introduce a larger moment arm as a percentage of body size. While surprising initially, the kinetic results indicate that the 8–10 year olds were able to compensate for their smaller anthropometry through altered posture and technique. One possible explanation for the lower shoulder abduction and lateral bending moments may be that the 8–10 year olds held the buckets very close (or even touching their legs) while carrying the heavier loads, whereas the adults carried the buckets away from their body.

Even though 8–10 year olds appeared to be able to compensate for unilateral lifting, it should be stressed that carried loads were set as a proportion of body weight. Therefore, 8–10 year olds were carrying an average of 52% absolute load that the adults were carrying (Table 1). The amount of weight carried did have a distinct effect on the upper extremity and lower back moments. When increasing carried load from 10% to 20% BW, maximum normalized elbow flexion, shoulder flexion, shoulder abduction, shoulder external rotation, L5/S1 lateral bending, and L5/S1 axial rotation moments all significantly increased (Figure 2). The average amount carried in this study by 12–14 year olds (52 N at 10% BW and 103 N at 20% BW) and older age groups was comparable to loads measured in the field.

Allread et al. (2004) reported the average load for carrying feed and water to be 83 N and estimated a 49% risk of lower back disorders. As a validation of this prediction model, Marras et al. (2000) found a significant correlation between reduction of lower back disorder risk rate and actual incidence rates.

One limitation of this study is that a sample of convenience was used for research participants. Using the CDC growth charts, the participants in this study tended to be taller (+4% 8–10 years, ~0% 12–14 years, +5% 15–17 years) and heavier (+9% 8–10 years, +15% 12–14 years, +18% 15–17 years) than fiftieth percentile children (CDC, 2000). The three age groups of children did have distinct body sizes, as the average height and mass were separated from each other by over one standard deviation (Table 1). However, the 15–17 year olds had an average height and mass that was similar to adults. Differing rates of maturity for females and males may make it appropriate to set different age groupings by sex, but further studies with additional participants are needed before such divisions can be made. A second limitation was combining the torso and head segments in the inverse dynamic model. Although the research participants were instructed to look straight ahead, any flexion/extension or lateral bending at the neck would introduce errors into the L5/S1 joint moment calculations. A further limitation of a controlled laboratory study is that a smooth, level walking surface and a solid carrying load was analyzed. For example, it is a reasonable assumption that balance would be more severely tested with rough outdoor terrain carrying buckets of water.

Several general conclusions can be drawn from this study. The higher loads carried (20% BW) in this study appear comparable to load levels associated with increased risk of lower back disorders found in previous studies. If it is practical in a field setting to carry lower amounts of weight (10% BW), then six of the seven maximum upper extremity/low back moments were significantly reduced. However, there was no evidence that carrying guidelines as a percentage of body weight should be lower for the 8–10 year-old group. In addition, if it is feasible to split a load for bilateral carrying, then six of seven maximum joint moments were significantly reduced. Modifying the carrying task by using 1-gallon buckets also produced significant reductions in maximum L5/S1 lateral bending moments.

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