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The impact of drywall handling tools on the low back

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ABSTRACT

Carpenters and other construction workers who install drywall have high rates of strains and sprains to the low back and shoulder. Drywall is heavy and awkward to handle resulting in increased risk of injury. The purpose of this study was to evaluate several low-cost coupling tools that have the potential to reduce awkward postures in drywall installers. Five coupling tools were evaluated using the Lumbar Motion Monitor that measures trunk kinematics and predicts probability of low back disorder group membership risk (LBD risk). Workers answered surveys about their comfort while using each tool. The results indicate that use of the 2-person manual lift and the J-handle provide the best reduction in awkward postures, motions, low back sagittal moment, and LBD risk. The two-person manual lift appears to be the safest method of lifting and moving drywall, though using the two-person J-handle also significantly reduces injury risk. Given that carpenters are skeptical about using equipment that can get in the way or get lost, a practical recommendation is promotion of two-person manual lifting. For single-person lifts, the Old Man tool is a viable option to decrease risk of MSDs.

1. Introduction

In 2005 strains and sprains caused 34.7% of all non-fatal construction injuries resulting in time away from work and drywallers ranked second among the construction trades for back injuries with time away from work (CPWR, 2008). Chiou and Pan found that lifting drywall was the most hazardous task leading to traumatic injuries in drywallers (Chiou et al., 1997). A study evaluating Washington State's worker's compensation claims over a seven-year period found that overexertion was the second most common mechanism for injury (at 28.1%) in drywall installers (Lipscomb et al., 2000). These injuries were mostly sprains and strains of the back and accounted for the greatest proportion of medical costs, permanent impairment, and paid lost days. A surveillance study of injuries to unionized residential drywall carpenters found that overexertion accounted for 18.2% of their injuries where 11.1% of injuries were due to handling drywall panels (Lipscomb et al., 2003). This is not surprising given that many commonly used sizes of drywall exceed the NIOSH recommendations for lifting (Waters et al., 1993). Carrying drywall has also been shown to exceed the NIOSH action limit of 3400 N for disc compression forces (Yuan et al., 2007). Further, lifting and moving drywall panels from staging areas to the work site requires awkward low back postures. Such awkward postures and overexertion from lifting heavy objects are known risk factors for low back injury (NIOSH, 1997). Indeed, Pan and Chiou (1999) found that four common techniques for lifting drywall all produced considerable biomechanical stress to the shoulders, trunk and hips.

Drywall sheets come in a wide variety of dimensions. Common dimensions are 1.22 m × 2.44 m × 1.3 cm (4′ × 8′ × 1/2″) to 1.22 m × 3.66 m × 1.3 cm (4′ × 12′ × 1/2″) panels, with fire code panels being thicker (1.6 cm). Weights can range from 24.9 kg to 54.4 kg (55–120 lbs) for each sheet depending on the size (NIOSH, 2006). Due to the size and weight of these panels, lifting and moving them places considerable stress on the low back. Researchers, using the Michigan Three-Dimensional Static Strength Prediction Program (3DSSPP), have demonstrated that L5/S1 and L4/L5 disc compression forces are high, ranging from 2917 N to 5287 N, during different lifting and carrying methods when manually handling either a 27.2 or 36.3 kg drywall panel (Pan and Chiou, 1999). This simulation was applied to a static model and did not take into consideration dynamic variables such as velocity or acceleration, which have been shown to increase low back stresses and injury risk in manufacturing jobs (Marras et al., 1993).

Drywall panels, because of their dimensions and nature, do not have natural handholds and are awkward to lift and carry. Drywall lifts, dollies and carts, when available, eliminate manual carrying and lifting of the drywall panels. However, use of these devices is

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limited on construction sites where there are many uneven surfaces, crowded conditions or obstructions such as cords, debris or building supplies. Pan and Chiou (1999) recommend the need to identify assistive devices and less stressful methods for lifting drywall. The purpose of this study was to evaluate the use of five low-cost coupling tools (Gorilla Gripper, Old Man Tool, J-handle, Troll and Stanley), by evaluating dynamic outcome measures that could promote better postures for carrying and handling drywall panels and potentially reduce low back stress.

2. Methods and materials

Five coupling tools were selected for evaluation because they differed biomechanically in their design and use for lifting and carrying drywall panels, they were affordable ($22–$49.99), and with the exception of the "Old Man" tool, available at local building supply stores or on-line. The "Old Man Tool" was custom designed by a carpenter. Carpenters lifting drywall with each of the tools are shown in Fig. 1 and the tools are described below.

The *J-handle Panel Carrier* comes in sets of two and requires two workers, one at each end of the drywall. For this study it was placed on the opposite side of the drywall from the worker's body, resting the top of the panel against his trunk. It is possible to use the J-handle on the same side of the body, which might make coupling with the tool easier, without reaching over the top of the panel. The *Gorilla Gripper®* clamps on to the top edge in the center of the drywall and has a handle that is gripped in the hand, keeping the shoulder in a neutral position while the elbow is fully flexed with the wrist at shoulder level. The *Telpro Inc. Troll Model 49* has dual 12.7 cm wheels with a "shoe" for the drywall to sit, and a metal loop handle. Like a dolly, it is placed next to the drywall near the center of the length; the worker lifts one corner of the drywall and places it in the "shoe." The worker can then maneuver or lift and carry the drywall over thresholds and obstacles, while on the Troll. The *Old Man* tool was named by carpenters on a construction site where it was used by an older experienced carpenter. Researchers bought metal materials locally, cut components, and had a tool welded by a machinist. The tool has a shaft, which was modified to be adjustable in length in order to fit workers of different heights (58.4–78.7 cm). It also has a handle that we covered with rubber for a more comfortable grip. The shaft of the original old man tool was crimped below the handle to allow a more natural contact between the fingers. The *Stanley Panel Carry* is plastic with a grip that is textured on one side. It fits under the drywall on the same side as the worker and must be balanced by placing the free hand on top of the drywall. The carpenter must bend down to place the Stanley Panel Carry under the drywall.

2.1. Study participants

The same population of carpenters participated in both the focus groups and the biomechanical analysis. Twelve carpenters and two carpenter apprentices participated in the focus group sessions as well as the biomechanical evaluation. Their carpentry experience ranged from 1 to 38 years with a mean of 16 years. All participants were male. Participant demographics are shown in Table 1.

2.2. Qualitative assessment

Two focus groups with carpenters were conducted to determine their opinions about the drywall coupling tools. Both sessions lasted one hour and were held the hour prior to the start of the workday. Participants completed a validated symptom survey asking about demographics and musculoskeletal symptoms (Rosecrance et al., 2002). Then five drywall-carrying tools were shown to the workers. Each tool was placed with a standard $1.22\text{ m} \times 2.44\text{ m} \times 1.6\text{ cm}$ ($4' \times 8' \times 5/8''$) sheet of drywall and carpenters were provided sufficient time to use each tool until they felt comfortable handling drywall with all tools. Since these tools do not require a high degree of technical skill to master it was felt that experienced carpenters could make valid assessments about the tools with limited use. For each tool, carpenters completed a tool use questionnaire that asked them to rate questions using a 5 point Likert scale (Table 2). After coupling tools were examined and tried a group discussion was conducted about tool efficacy, comfort and practicality. The Stanley tool was eliminated from further evaluation since it was similar to the Old Man tool but shorter, and it was ranked so poorly in the focus groups.

2.3. Biomechanical assessment

To measure lumbar kinematics (posture and motion) for carpenters during the handling of drywall with each tool, the Lumbar Motion Monitor (LMM), a portable tri-axial electrogoniometer developed at Ohio State University (Marras et al., 1993) was used. The LMM has been used in other studies to evaluate low back stresses in construction workers (Hess et al., 2004, 2008). The LMM slides between two harnesses, one strapped between the scapulae and one around the pelvis. The LMM records time and position data in the lumbar region, in three planes, at 60 Hz via an analog-to-digital converter and transmit the information via digital telemetry to a laptop computer.

A standard sheet of $1.22\text{ m} \times 2.44\text{ m} \times 1.6\text{ cm}$ ($4' \times 8' \times 5/8''$) drywall weighing on average 33.1 kg was used for all trials. All trials were video taped using a digital camcorder.

For the biomechanical assessment, the three single-person coupling tools (Gorilla Gripper, Troll, and Old Man) and one two-person coupling tool (the J-handle) were evaluated along with the controls: a single-person and a two-person manual carrying technique. For the manual technique workers carried the drywall with one arm under and one arm above the panel. The single-person and two-person manual techniques studied can be seen in Fig. 1.

All participants were evaluated at their job site prior to the beginning of their regular work shift. An additional carpenter, who was not evaluated, was recruited to participate in the two-person carrying trials. All participants signed a consent form approved by the University of Oregon Office for Protection of Human Subjects. Demographic and anthropometric data were self-reported. After the participant was outfitted with the LMM the single-person trials were collected followed by the two-person trials. For each of the four tools evaluated trials were repeated 5 times in a randomized order, blocked by the one- and two-person conditions. For each trial, the task of lifting, carrying and lowering were verbally prompted to the participant and the biomechanical data was marked to note the different activity. At the beginning of each trial, the participant had the tool in his hand. At the "lift" prompt, he attached the tool to the drywall panel and placed the drywall panel in a position to carry it. At the "carry" prompt, he walked forward with the drywall 4.6 m and at the "lower" prompt, he lowered the drywall to the ground and released the tool. These prompts were given appropriately to have the motions as fluid as possible, but gave time for the researchers to mark the tasks in the data files.

2.4. Data analysis

Qualitative data from the focus groups were summarized. The low back biomechanical data were analyzed using the Proc Mixed Statistical Analysis using SAS software. For each trial, the peak and mean values of the kinematic variables (three-dimensional positions, velocities, and accelerations), and static sagittal moment

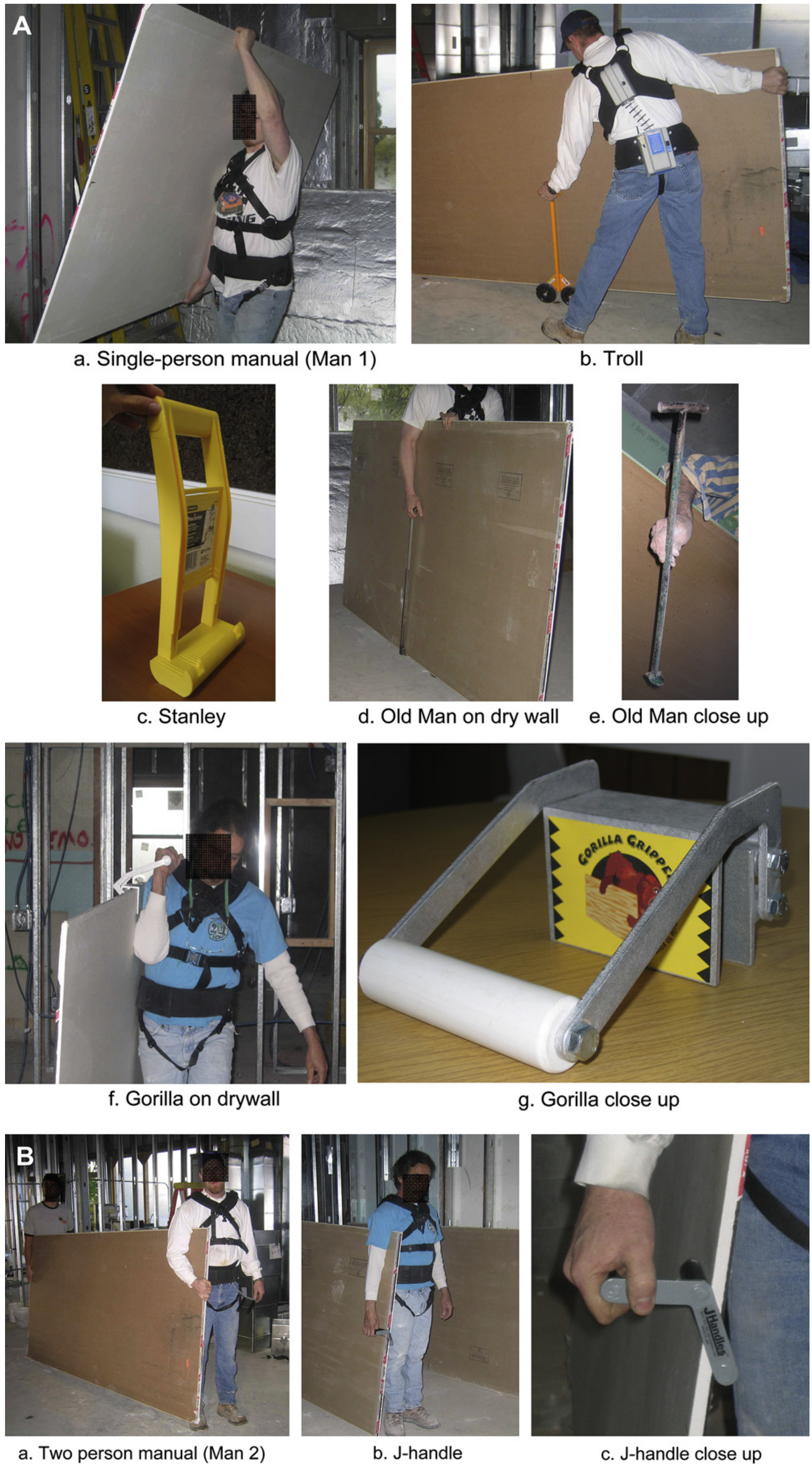

Fig. 1. A. Single-person drywall manual handling and use of tools. B. Two-person drywall manual handling and use of J-handle tool.

Table 1
Demographics of the 14 male construction workers who participated in the study.

	Mean	Std Dev	Range
Age (yrs)	36.93	12.20	19–55
Height (m)	1.77	0.05	1.70–1.82
Weight (kg)	84.99	14.54	65.8–113.4

were calculated. A repeated measures analysis of variance (ANOVA) was performed to identify whether the effect of the independent variable (type of coupling tool) was significant. The ANOVAs were blocked on task so that a comparison between the tools for each task was completed. For all significant ANOVA tests, follow-up Tukey HSD (Honestly Significant Difference) Tests, which account for the multiple comparisons, were conducted to identify the significant differences between the different handling methods.

3. Results

3.1. Focus group results

Only four of the fourteen carpenters surveyed indicated that they had used some type of tool to lift or carry panels. While it was not explicitly asked what tool they had used, informal responses indicated that workers used a mechanical panel lift as well as the Old Man tool. Eleven carpenters thought that a tool would make their job safer. In response to a symptom survey, thirteen carpenters reported having job-related aches, pains or discomfort to the neck, lower back, shoulders, wrist/hand, knees or feet, which suggests they are 'working hurt.' Only two carpenters indicated that these aches and pains had prevented them from doing a day work, while three reported that they had seen a physician in the last twelve months for their pain.

Table 2 shows survey responses for each tool. Based on the average scores, these carpenters liked the J-handle best. For ease of attachment the J-handle and Gorilla rated highest, probably because these tools did not require drywall to be lifted in order to attach the tool. The J-handle was the only tool to receive positive comments. When asked about discomfort in specific body parts using these tools, the shoulders rated highest for potential discomfort, especially for the Stanley and the Gorilla Gripper tools.

3.1.1. Carrying drywall manually

Carpenters reported they manually carry drywall both with two hands under as well as with one hand under and one hand on top of the sheet. They decided how to carry based on the situation; with shorter distances, when they need to maneuver more, or with 3.7 m sheets, two hands under the sheet works best. With two hands under, they rest the panel against their body. When they are going longer distances they carry panels with one hand under and one hand over the sheet, and rest the drywall against their shoulders and head.

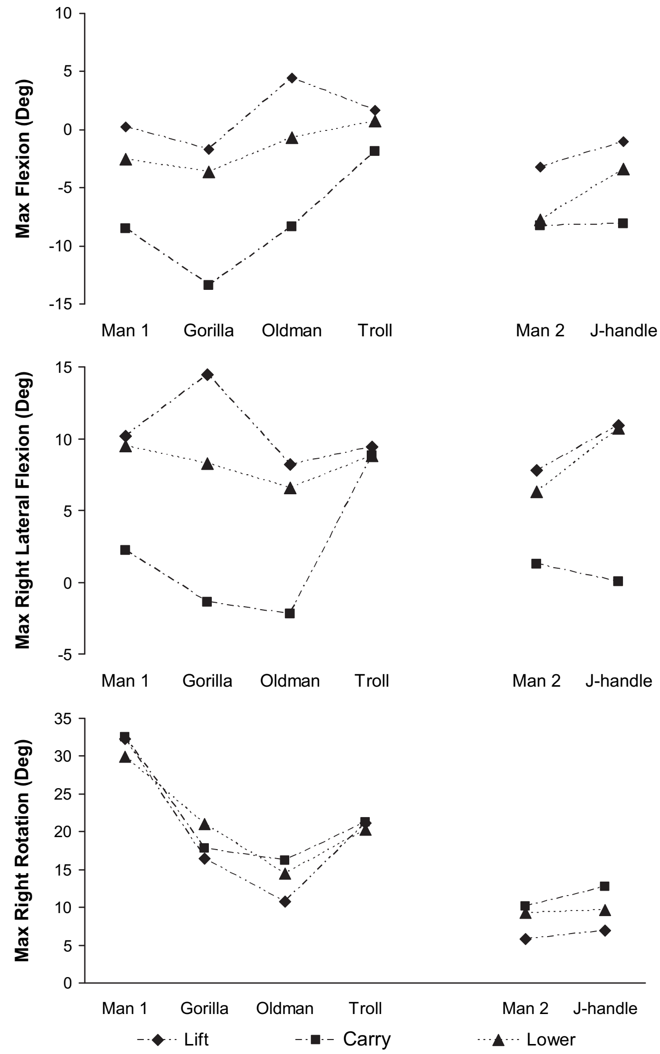

Fig. 2. Three-dimensional trunk postures for tools while performing drywall handling tasks. Data are discrete, connecting lines are for visual effect and are not meant to represent continuous data.

3.1.2. Tool liked best

The J-handle was liked the best overall. One group tried it with multiple sheets and with 12-foot lengths and thought it worked well. The Old Man tool was liked best for the single-person carry. Comments on the Troll included "OK" to "not practical." Some liked the Stanley Panel Carrier but did not like having to bend down to

Table 2
Mean responses to survey questions about tools. Average scores above 3 are in bold (1 = not easy/dislike and 5 = very easy/like).

n = 14	J-handle	Troll	Old Man	Gorilla	Stanley
How well do you like the tool?	**3.8**	2.7	**3.1**	2.5	2.1
How easy is the tool to attach?	**4.8**	2.5	**3.2**	**4.4**	2.0
How easy is lifting the drywall with this tool?	**4.1**	2.4	**3.7**	2.8	2.9
How easy is carrying drywall with this tool?	**3.7**	3.0	**3.5**	2.5	2.8
How easy is setting drywall down with this tool?	**4.2**	2.8	**3.3**	**3.9**	2.5
How comfortable is the grip?	**4.4**	2.7	**3.7**	**3.5**	2.9
How likely is this tool to make your job easier?	**3.1**	1.8	2.7	2.0	1.8
How durable is this tool?	**4.4**	**3.3**	**3.9**	**3.5**	2.9
How likely are you to buy this tool for yourself?	**3.1**	1.5	2.4	1.5	1.4
Average of all questions	**4.0**	2.5	**3.3**	3.0	2.4

Table 3
ANOVA results as identified by the Tukey's HSD (Honestly Significant Difference) Test and means (standard deviations) for selected variables. Appearance of the same letter (a–e) in a column indicates that means are not statistically different across tools.

	Sagittal flexion	Right lateral flexion	Right rotation	Sagittal flexion velocity	Lateral flexion velocity	Rotational velocity
Lifting						
p-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Least Sign. Diff	2.34	3.33	4.91	3.43	3.14	8.02
Man 1	$0.26^{b,c}$ (5.77)	10.14^{b} (3.02)	32.27^{a} (9.62)	38.87^{a} (11.01)	30.17^{a} (9.02)	74.80^{a} (27.11)
Gorilla	$-3.64^{b,c}$ (4.08)	$8.30^{a,b}$ (4.01)	$21.00^{b,c}$ (8.63)	18.68^{b} (5.70)	$16.80^{c,d}$ (5.80)	24.52^{c} (13.23)
Oldman	$-0.67^{a,b}$ (4.98)	6.58^{b} (4.27)	$14.45^{c,d}$ (7.45)	$20.99^{a,b}$ (7.44)	$17.17^{c,d}$ (6.53)	25.90^{c} (16.20)
Troll	$1.66^{a,b}$ (4.05)	9.40^{b} (6.23)	21.19^{b} (10.66)	22.96^{c} (7.53)	$24.65^{a,b,c}$ (6.58)	37.70^{b} (15.34)
Man 2	-3.21^{c} (4.77)	7.81^{b} (3.07)	5.79^{d} (6.00)	$25.91^{b,c}$ (12.97)	18.58^{c} (8.33)	18.55^{c} (9.32)
J-handle	$-1.04^{b,c}$ (5.50)	$10.92^{a,b}$ (4.55)	6.88^{d} (6.92)	23.07^{c} (11.61)	$25.37^{a,b}$ (10.94)	19.78^{c} (10.00)
Carrying						
p-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Least Sign. Diff	3.24	4.15	4.92	3.43	3.14	8.02
Man 1	-8.53^{b} (3.70)	2.24^{b} (3.04)	32.48^{a} (9.02)	15.33^{a} (5.94)	$12.11^{b,c}$ (4.81)	$37.26^{a,b}$ (12.80)
Gorilla	-13.40^{c} (3.37)	$-1.40^{c,d}$ (4.27)	$17.78^{b,c}$ (6.99)	$11.80^{a,b}$ (4.13)	$11.35^{b,c}$ (4.30)	39.11^{a} (15.14)
Oldman	-8.35^{b} (3.34)	-2.24^{d} (4.46)	$16.24^{c,d}$ (7.87)	9.81^{c} (2.75)	10.01^{c} (3.84)	$30.24^{b,c,d}$ (12.51)
Troll	-1.85^{a} (4.66)	8.82^{a} (4.99)	22.32^{b} (8.63)	$13.77^{a,b}$ (5.30)	16.24^{a} (7.66)	$33.27^{a,b,c}$ (15.04)
Man 2	-8.24^{b} (3.11)	$1.28^{c,b}$ (2.95)	10.10^{e} (6.07)	9.58^{c} (3.06)	$12.29^{b,c}$ (5.12)	23.56^{d} (10.80)
J-handle	-8.07^{b} (2.99)	$0.01^{c,b,d}$ (3.46)	$12.75^{d,e}$ (6.43)	$10.69^{b,c}$ (4.64)	$13.26^{a,b}$ (5.08)	$27.54^{c,d}$ (11.39)
Lowering						
p-value	<0.0001	0.01	<0.0001	<0.0001	<0.0001	<0.0001
Least Sign. Diff	4.18	4.00	5.98	5.71	6.07	10.73
Man 1	$-2.55^{a,b}$ (5.77)	$9.48^{a,b}$ (6.57)	29.90^{a} (9.57)	25.88^{a} (7.52)	$25.83^{a,b}$ (12.10)	57.12^{a} (22.64)
Gorilla	$-3.64^{b,c}$ (4.08)	$8.30^{a,b}$ (4.01)	$21.00^{b,c}$ (8.63)	18.68^{b} (5.70)	$16.80^{c,d}$ (5.80)	24.52^{c} (13.23)
Oldman	$-0.67^{a,b}$ (4.98)	6.58^{b} (4.27)	$14.45^{c,d}$ (7.45)	$20.99^{a,b}$ (7.44)	$17.17^{c,d}$ (6.53)	25.90^{c} (16.20)
Troll	0.76^{a} (5.15)	$8.79^{a,b}$ (4.20)	20.34^{b} (11.36)	$22.80^{a,b}$ (9.34)	26.94^{a} (8.48)	42.06^{b} (16.61)
Man 2	-7.73^{c} (3.81)	6.31^{b} (2.55)	9.24^{d} (6.67)	12.51^{c} (7.52)	13.06^{d} (6.09)	13.46^{d} (9.50)
J-handle	$-3.42^{a,b}$ (4.24)	10.75^{a} (3.54)	9.63^{d} (6.35)	18.61^{b} (8.69)	$19.86^{b,c}$ (6.95)	$19.14^{c,d}$ (11.92)

get under the panel to lift it and they made the derogatory comment that "it looks like it would be used by home builders." Comments on the Gorilla Grip included concern for the shoulder but, they liked the way it attached at the top of the sheet eliminating the need to lift the panel to attach the tool. Several carpenters commented that if they had to lift the drywall to attach a tool, "why not just lift it and carry it and not mess with a tool." They also suggested that tools need to be metal to be durable, and they need comfortable grips.

3.2. Biomechanical analysis results – low back

Analysis of variance results indicated a significant difference between the tools for each task (lifting, carrying, and lowering) for all dependent variables (including three-dimensional postures and velocities, static sagittal trunk moment, and LBD risk) at $p < 0.0001$ (Table 3). The differences between the tools as a function of each task are shown in Figs. 2 and 3 for three-dimensional trunk postures and velocities, respectively. In all, the differences between the tools were affected by the task being performed, as seen in these figures. Specific differences in the dependent variables between the tools will be discussed as a function of each task in the following sections.

3.2.1. Lifting

While there were several significant differences in flexion (forward bending) across tools, the postures remained relatively upright with less than 5° of flexion occurring (Table 3, Fig. 2). During lifting, the workers tended to lean more to the side (about 10°) with larger differences between the tools being observed. The Gorilla had significantly more right lateral flexion (side bending) than the majority of the other tools (with exception of the J-handle), approximately 5° more. The largest amount of trunk rotation (twisting) during lifting occurred for the single-person manual with more than 30° rotation (10° more than any tool). The Troll and Gorilla tools also had significant amounts of rotation (>15°) while the J-handle and two-person manual conditions produced the lowest amounts of right rotation (about 6°).

There were significant differences in trunk velocities across tools (Table 3). In all three-dimensions, the single-person manual had the highest trunk velocities indicating carpenters moved the fastest when lifting drywall as compare to the other tool conditions (about 5–10°/s in sagittal velocity, about 5°/s in lateral velocity, and about 30–50°/s in rotational velocity) (Fig. 3). For sagittal velocity, the Gorilla had the second greatest amount of motion but was not significantly different than the Old Man or two-person manual. All other tools had relatively the same amount of sagittal velocity (about 25°/s). For lateral velocity, the two-person manual had the lowest velocity (about 20°/s). There were three tiers of rotational velocity with velocities for the single-person manual (about 75°/s) fastest, followed by the Gorilla, Troll, and Old Man (between 30 and 42°/s), and finally the J-handle and two-person manual (at about 20°/s).

3.2.2. Carrying

Similar to lifting, flexion was limited when carrying with the carpenters remaining in an extended posture throughout. The Gorilla tool resulted in the greatest extension (backward bending) by 5° while the Troll had the least (remained upright). For most of the tools posture also remained neutral for right lateral flexion with the exception of the Troll that had about 8° of lateral flexion. The single-person manual condition had the greatest amount of trunk rotation, more than 30° while carrying. On the other hand, the J-handle and two-person manual conditions resulted in the most neutral rotational postures (about 10°). There was significant separation ($p < 0.05$) between the other tools but the magnitude was less than 5° of rotation.

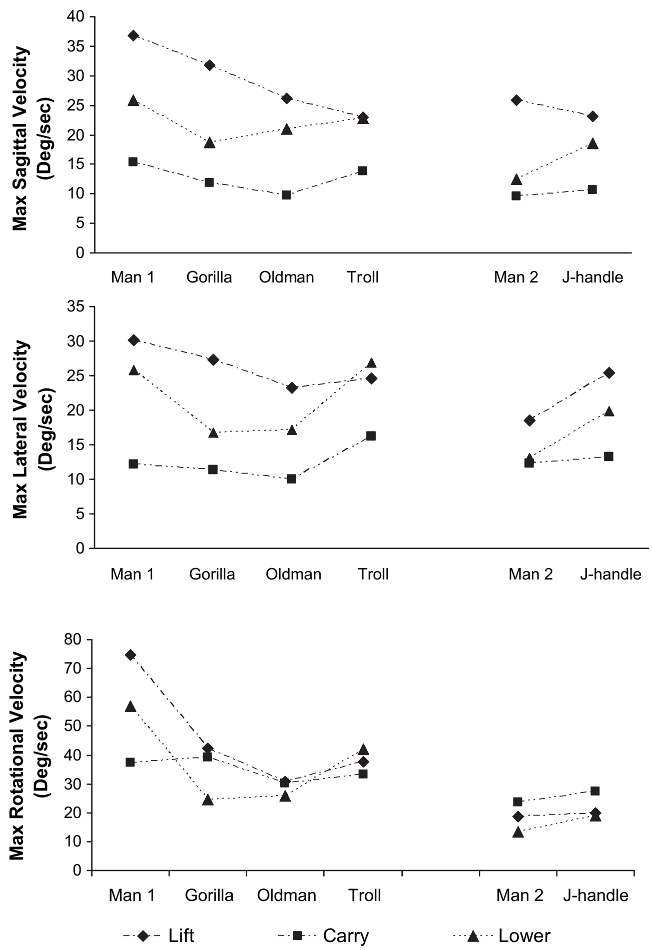

Fig. 3. Three-dimensional trunk velocities for tools while performing drywall handling tasks. Data are discrete, connecting lines are for visual effect and are not meant to represent continuous data.

Sagittal trunk velocities were relatively slow for all tools but the single-person manual had the highest levels (about 5°/s more than Gorilla, J-handle, Old Man, and two-person manual). The lateral velocities were highest for the Troll (about 16°/s) while all other tool conditions were approximately the same (10–12°/s). For rotational movements, the Gorilla produced the largest velocity (almost 40°/s) while the two-person manual had the slowest rotation (about 24°/s). The statistical overlap between the tools for rotational velocity was common where many of the tools were not statistically different significant from one another. For example, the Gorilla was not statistically different from single-person manual and Troll, while the two-person manual was not different from J-handle and Old Man.

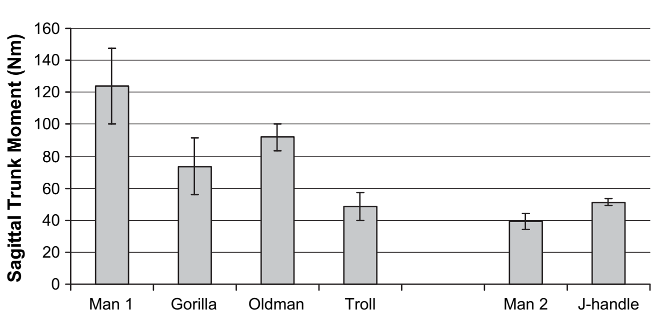

Fig. 4. Maximum static sagittal trunk moment for each tool when lifting drywall.

3.2.3. Lowering

Peak flexion for lowering was very similar to lifting where the subjects remained relatively neutral (less than 5° of flexion with the exception of two-person manual). While there were statistical differences in right lateral bending between the J-handle (greatest lateral bend) and Old Man and 2-person manual (lowest lateral bend), the differences were relatively small and the carpenters remained relatively neutral (6–8° of right lateral bend). For right rotation, there were basically three levels where single-person manual had the most rotation (about 30°), followed by Gorilla and Troll (at about 20°) and finally Old Man, J-handle, and two-person manual had the least (at between 9 and 14°).

The carpenters had the lowest sagittal velocity when lowering the drywall with two-person manual technique (about 12°/s). The sagittal velocities were greatest for the single-person manual technique (around 25°/s), although not significantly different from the Troll and Old Man (about 21°/s). Based on the statistical analyses, the Troll and the single-person manual techniques had the highest lateral velocities (slightly above 25°/s) while the two-person manual had the lowest (about 13°/s). All remaining tools (J-handle, Gorilla, and Old Man) produced lateral velocities around 17°/s. For rotational velocities during lowering, the single-person manual technique produced the highest values (above 55°/s), followed by Troll (at 42°/s) and Old Man and Gorilla (at 25°/s). The slowest rotational velocities occurred with the two-person manual condition (less than 15°/s).

3.2.4. Static sagittal moment

The single-person manual technique resulted in a significantly greater static sagittal moment when handling the drywall than any tool and over three times the moment as when using the two-person technique (Fig. 4). Basically, there were four levels of sagittal moments produced in handling the drywall: 1) worse case: single-person manual, 2) Old Man, 3) Gorilla, and best case: 4) J-handle, Troll, and two-person manual.

3.2.5. LBD risk

The probability of LBD group membership risk categorizes job risk as 'high' if the risk is greater than 60%, 'low' risk below 30%, and 'moderate' between 30% and 60% (Marras and Allread, 2006). The single-person manual transfer had the greatest probability of high risk group membership for all three handling tasks (44% for lifting, 38% for carrying, and 32% for lowering), placing workers in a moderate risk category, while all other methods of carrying drywall placed workers in the low risk category (Fig. 5). In general, the two-person manual technique resulted in the lowest risk probabilities (around 10%) for all handling tasks.

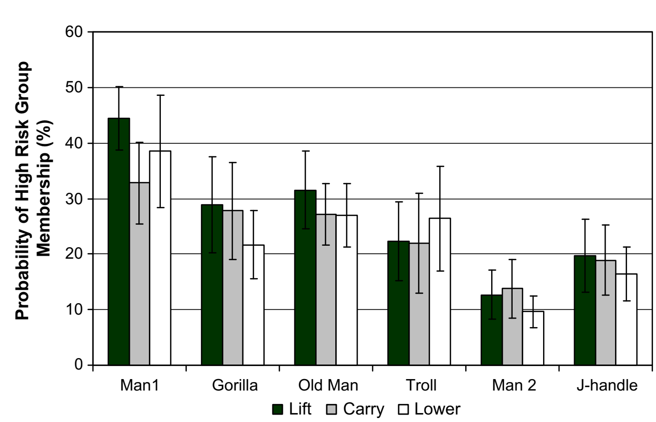

Fig. 5. Probability of low back disorder group membership risk (LBD Risk) for tools when handling drywall (means and standard deviations).

4. Discussion

4.1. Carpenter perceptions about handling methods

While carpenters rated the J-handle and Old Man tools as the best tools, they expressed reservations about using any tool due to the potential for them to negatively impact their productivity. All the coupling tools evaluated, while possessing qualities that spare the back, were perceived to require more time due to the time needed to find the tool and attach it to the drywall. Thus, the perceptions of the carpenters may limit the broad application of the tools. The main point is that if tools such as the J-handle and Old Man are going to be widely accepted on site, apparatus will need to be designed to keep the tools within reach (e.g. immediate vicinity). Moreover, the J-handle, which received the highest ratings, is only applicable with two-person lifts, a practice that is not usually followed when handling standard sized drywall. Carpenters also stated that these tools would mainly be useful for carrying and not for installing drywall. They believed that if a tool was only used for carrying, it would probably get in way when installing, and may require more lifting and lowering to add and remove the tool. They felt these limitations made the tools only useful for drywall stockers when a forklift cannot be used to put the panel close to the installation site. They also thought that these tools would be helpful when carrying panels long distances or when climbing stairs.

4.2. Effect of handling methods on the low back

While many of the differences noted in kinematic responses were very interesting, the question remains 'how does this relate to the risk of developing a low back injury?' Many of the measured variables were inputted into a logistic regression model developed by Marras et al. (1993) that predicted how well the measured tasks reflect motions measured in industrial jobs. The model utilizes five factors (maximum flexion, maximum medial-lateral velocity, average rotational velocity, lift rate, and static sagittal moment) in combination to predict the probability of being in a "high" risk group for low back disorders. Use of the LBD risk model allowed for the combination of kinematic variables to provide a more robust indicator of the overall effect of the multiple changes that occurred.

The LBD risk model indicated that the two-person manual lift was the least risky while the single-person manual lift was most risky (difference in the probability of 27%). The J-handle significantly reduced the risk values (reduction of 20% probability as compared to single-person). Some of this decrease in risk was due to the reduction in the low back moment associated with two carpenters sharing the work. The Troll, Gorilla and Old man tools also reduced the risk (reduction of 15%, 12% and 10% probability as compared to single-person, respectively).

The LBD risk model provides a surrogate estimate of the loading on the low back that occurs during these drywall handling tasks. The loads on the low back result from a complex relationship between the weight lifted, body postures and motions, and muscle activity response (Davis and Marras, 2000; Fathallah et al., 1998; Marras and Granata, 1995, 1997). In general, more awkward postures (e.g. more forward flexion, side bending, and/rotation), faster motions (e.g. higher velocities), and greater weights lifted (e.g. static trunk moments) will result in higher three-dimensional spine loads (Davis and Marras, 2000; Fathallah et al., 1998). The interaction between complex back motions (e.g. rotation and lateral bending) may result in damage to the lumbar facet joints and intervertebral discs over time (Shirazi-Adl, 1989, 1991).

These results demonstrated significant reductions in awkward, asymmetric postures, trunk moments, and velocities using several of the coupling tools and techniques (including J-handle, Old Man, Gorilla, and two-person lifting). Overall, the two-person techniques (two-person manual and J-handle) produced the most neutral postures, resulted in the slowest motions, and should be recommended across all worksites when handling and transferring drywall. These results indicate that working in teams may be more important than using tools. However, caution must be used with regard to recommending team lifting for drywall carrying. Marras et al. (1999) found that compression loads were significantly reduced with two-person lifts but, shear loads which were not evaluated in this study, increased when teams lifted asymmetrically. It was also noted that the trunk moments were not half the level of the single-person lifts due to these lifting asymmetries. This may have ramifications since handling drywall requires asymmetric positioning of the worker relative to the drywall. Lastly, lifting in pairs could present a different trip hazards from lifting alone, and requires communication between workers. Thus, while the current study supports the use of teams to handle drywall, workers need to be aware of the position of their body relative to the drywall (e.g. eliminate twisting and lateral bending and bend with knees) and communicate activities and trip hazards to each other.

4.3. Limitations

There are limitations associated with applying the LBD model to drywall handling. This model was developed utilizing highly repetitive industrial jobs, which may not accurately reflect the risk associated with handling drywall given the potential for drywall handling to be somewhat irregular. Moreover, the physical demands in the Marras database were significantly lower than those during drywall handling. However, the LBD risk model does provide an indication of the combined effect of the multiple kinematic and static moment changes that occur among the different lifting methods. Moreover, research has demonstrated that trunk velocity, and the interactions between awkward, asymmetric trunk postures and velocities are important factors contributing to low back injury (Marras and Mirka, 1989, 1990; Mirka and Marras, 1990).

Only one of the two carpenters carrying drywall was assessed during the two-person manual and the J-handle evaluations. It is possible that each individual does not contribute equally to the task and that important information was not captured. In addition, the two-person lifts were completed after the single-person lifts, which may have introduced slight bias. Further, the current investigation focused on the low back. Other body regions that would be of concern are the shoulder due to the stress on the joint during carrying of drywall, and possibly the wrist due to postures assumed when grasping the tools. Carpenters reports of shoulder discomfort may provide some evidence of this concern for the shoulder. Therefore, future studies of drywall handling tools should consider evaluation of the biomechanical stress to the shoulders and wrists. Finally, this study captured lifting, carrying and lowering drywall in a short simulation at a job site and not under actual work conditions. However, it was important to control the simulation in order to compare the tools objectively.

5. Conclusions

Based on the results as a whole both two-person techniques (two-person manual and J-handle) placed the carpenters in the most neutral back postures, produced the slowest motions, reduced the trunk moment, and LBD risk. However, these carpenters had the perception that the time to complete the handling task with the J-handle was longer than with manual handling because it takes time to find and attach the tool to the drywall. Presently, carpenters typically only use two-person lifts when drywall is longer and of heavier weight (extended sheets). The results also indicted that the other tools (Gorilla and Old Man) were successful in reducing awkward postures and motions in the low back as compared to the single-person manual but, they were not as effective as the two-person techniques. Thus, these results provide evidence that the two person techniques should be promoted on the work site. The two-person manual handling technique produced the best results with regard to acceptance by workers and for reducing low back stress. The J-handle could be effective in reducing the postural exposures to the back but, would need additional apparatus to keep it accessible to carpenters (e.g. attached to tool belt). For single-person lifts, the Old Man tool appeared to be a viable option for reducing risk of LBD that was well liked by carpenters.

Lastly, comments from the focus groups indicated that with proper staging drywall delivery could be fork lifted to the installation site, reducing the need for manual handling. When it must be moved, or carried up stairs manually then, use of these tools can reduce the risk of MSDs. Since two-person handing of drywall posed the least risk of injury, this practice should become part of a work practice change for carpenters and even written into union contracts much like masonry contracts that require two-person lifts when handling 12″ masonry block.

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