Commercially Available Friction-Reducing Patient-Transfer Devices Reduce Biomechanical Stresses on Caregivers' Upper Extremities and Low Back

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Objective: The aim of this study was to evaluate the efficacy of commercially available friction-reducing patient-transfer devices in reducing biomechanical stresses on caregivers and patients.

Background: Caregivers suffer from high prevalence of work-related musculoskeletal disorders, which is associated with manual patient handling. However, there is not enough information available on the efficacy of various friction-reducing devices in reducing biomechanical stresses in the upper extremities and low back.

Method: During patient-transfer tasks performed by 20 caregivers, we measured hand force; shoulder and trunk posture; shoulder moment; muscle activity in the flexor digitorum superficialis, extensor digitorum communis, biceps, triceps, trapezius, and erector spinae; and usability ratings from four devices: a draw sheet, a repositioning sheet, a slide board, and an air-assisted device. In addition, triaxial head acceleration of mock patients was measured to evaluate patients' head acceleration.

Results: The slide board and air-assisted device significantly reduced hand force ($p < .001$), shoulder flexion ($p < .001$), shoulder moment ($p < .001$), muscle activities of caregivers ($p < .004$), and patients' head acceleration ($p < .023$) compared with the draw sheet. However, no significant differences in biomechanical measures were found between the repositioning and draw sheets. The air-assisted device consistently showed the lowest biomechanical stresses and was most preferred by participants.

Conclusion: Reduction in caregivers' biomechanical stresses and mock patients' head acceleration indicates that a slide board and an air-assisted device can be effective engineering controls to reduce risk of injury.

Application: The study results can provide a recommendation for engineering controls to reduce biomechanical stresses for both caregivers and patients.

Keywords: air-assisted device, friction-reducing device, head acceleration, musculoskeletal disorders, patient handling

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INTRODUCTION

Professional caregivers are at high risk of work-related musculoskeletal disorders (WMSDs) (Bureau of Labor Statistics, 2016; Davis & Kotowski, 2015). Health care sectors deal with one of the highest injury rates (4.2 per 100 full-time workers) in the United States (Bureau of Labor Statistics, 2016) and high prevalence (43% to 66%) of musculoskeletal pain in the low back and upper extremities among nursing personnel (Cheung, Gillen, Faucett, & Krause, 2006; Davis & Kotowski, 2015; Mbaisi, Ng'ang'a, Wanzala, & Omolo, 2013; Yassi & Lockhart, 2013). The estimated economic burdens of WMSDs are over 2 million lost workdays and US$13.1 billion (Bureau of Labor Statistics, 2016).

Manual patient handling is one of the most significant challenges in the health care industry (Davis & Kotowski, 2015; Marras, Davis, Kirking, & Bertsche, 1999) because of various WMSD-related physical risk factors, including forceful exertion (e.g., handling overweight and obese patients) and awkward postures (e.g., deep bending and twisting) during patient-handling tasks (Nagavarapu, Lavender, & Marras, 2016; Wiggermann, 2015; Zhou & Wiggermann, 2017). Common manual patient-handling tasks include lifting, repositioning, and transferring a patient from a bed to another location (another bed, wheelchair, bathtub, or toilet). Previous studies found that these manual patient-handling tasks substantially increased caregivers' physical stress and discomfort, especially in their upper extremities and low-back regions (Drew, Kozey, & Moreside, 2015; Garg, Owen, Beller, & Banaag, 1991; Marras et al., 1999; Skotte & Fallentin, 2008).

To reduce these physical stresses during manual patient handling, various engineering controls, such as friction-reducing slide sheets, slide boards, and air-assisted transfer devices, have been developed and evaluated (Bartnik & Rice, 2013; Drew et al., 2015; Pellino, Owen, Knapp, & Noack, 2006; Skotte & Fallentin, 2008; Weiner, Kalichman, Ribak, & Alperovitch-Najenson, 2017). These studies demonstrated that these engineering controls further reduced hand forces and perceived exertion of caregivers compared with conventional cotton draw sheets. However, there is still a lack of studies that evaluate biomechanical benefits (e.g., hand force, muscle loading [electromyography; EMG], and joint moment on the upper extremities and low back) of the air-assisted devices in comparison with other friction-reducing devices.

In addition, manual patient-handling tasks can also adversely affect the safety and comfort of the patients being handled. A previous study showed that high head acceleration increased uneasy feeling among elder patients during manual patient transfer, and nonexpert caregivers increased head acceleration significantly compared with expert caregivers (Liao, Yoshikawa, Goto, & Hamada, 2015). Given the potential effects of head acceleration on patients' safety and comfort during patient transfer, it is important to characterize and compare patients' head acceleration between different transfer devices during patient-transfer activities.

Therefore, the primary study objective was to determine whether there were any differences in hand pull force, shoulder and trunk postures, shoulder moments, muscle activities in the upper extremities and low back, patients' head acceleration, and subjective usability ratings among four patient-transfer devices during standardized patient-transfer tasks.

METHOD

Participants

In a repeated-measures design, 20 professional caregivers ($M \pm SD$: age, 24.7 ± 4.3 years; height, 165.8 ± 8.6 cm; body mass, 72.7 ± 21.6 kg; body mass index [BMI], 26.2 ± 6.0 kg/m^2; caregiving experience, 3.6 ± 3.1 years) were recruited via e-mail solicitation and printed flyers. The gender distribution (18 females and two males) was to reflect a realistic caregiving workforce in the United States (U.S. Census Bureau, 2013). Inclusion criteria were (a) a minimum of 6 months' professional caregiving experience, (b) no limitation in physical activity, (c) no current (past 7 days) musculoskeletal pain in the upper extremities and low-back regions, and (d) no current WMSDs or cardiovascular diseases.

Since at least two caregivers are recommended to perform patient-transfer tasks (Weiner et al., 2017), one caregiver assistant was recruited and trained to provide consistent support to all 20 participants throughout the entire study period (Figure 1).

Two healthy males with comparable body dimensions (age, 23 and 26 years; height, 174 and 176 cm; body mass, 71 and 73 kg) were recruited to serve as mock patients for the entire study. They were instructed to cross arms and provide no assistance to caregivers during a transfer, to simulate the immobility of bedridden patients (Figure 1). This study was approved by the university's institutional review board, and each participant gave his or her informed consent before the participation.

Standardized Patient-Transfer Tasks

Standardized patient-transfer tasks included (a) lateral transfer (pulling and pushing a mock patient between two hospital stretchers (Prime Series and IsoFlex SE Support Surface; Stryker, Portage, MI) and (b) repositioning (sliding a patient up on a stretcher) (Figure 2). All the tasks were repeated in a random order on all four patient-transfer devices: 3 tasks × 4 devices × 2 repetitions = 24 trials. Prior to actual trials, all the participants received a brief training on how to transfer and reposition a mock patient using all four patient-transfer devices based on Occupational Safety and Health Administration (OSHA) guidelines (OSHA, 2009) and transfer device manufacturers' recommendations. The height of both surfaces was initially set to the knuckle height of the participant (Nagavarapu et al., 2016). The surface the patient was slid from was set slightly higher than the surface the patient moved toward. The right hands of all the caregivers were always positioned toward the head of the mock patient. Then, participants were allowed to practice patient-transfer and repositioning tasks with each device until they felt comfortable with the tasks and devices.

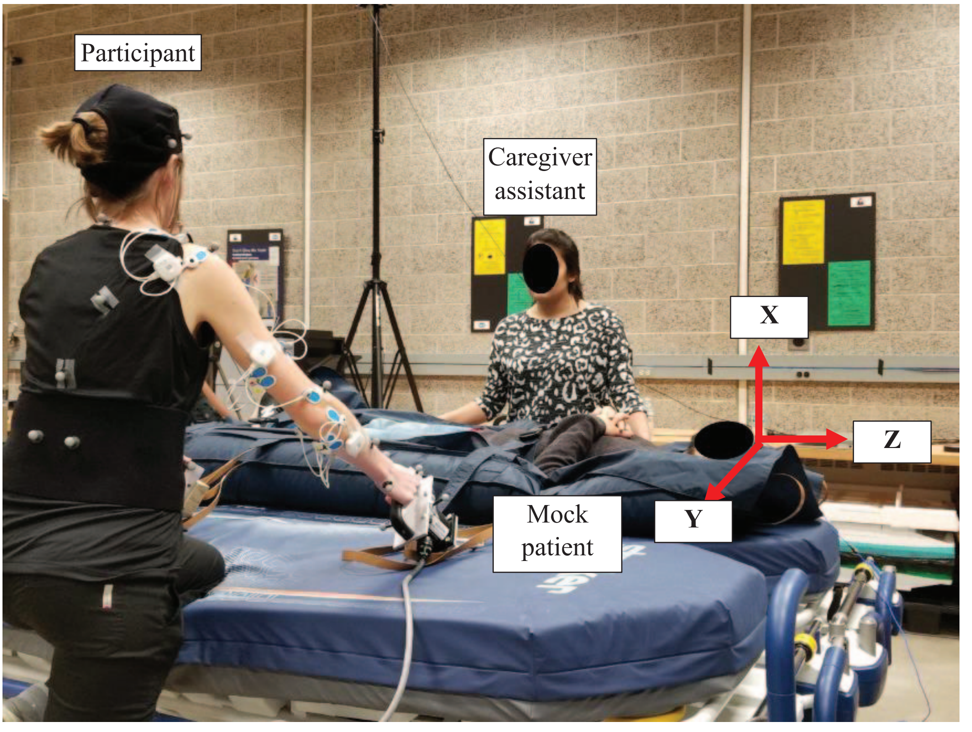

Figure 1. Experimental setup with a participant, caregiver assistant, and mock patient. The basicentric axes of a recumbent human body (mock patient) are also shown.

Figure 2. Standardized patient-transfer tasks.

Apparatus

Four patient-transfer devices. The four patient-transfer devices tested in this study were (a) draw sheet (Patient Bath Blanket; Linteum Textile Supply, Little Ferry, NJ), (b) two-in-one friction-reducing repositioning sheet and sling (Comfort Glide Sling; Medline, Northfield, IL), (c) slide board (Pro-Slide; Pro-Lite, Ivyland, PA), and (d) air-assisted device (PPS Glide; PPS, Eugene, OR) (Figure 3). Use of a draw sheet is a conventional practice in patient transfers, so it was considered as a control condition.

Three-dimensional hand pull force. Three-dimensional hand pull force (tension) was collected at 1000 Hz from the right hand using a 6-degrees-of-freedom load cell (PY6; Bertec, Columbus, OH) during a lateral pulling task. The absolute mean measurement error of this load cell (hysteresis and linearity) was less than 0.2% over a 0-to-5,000 N range. The handle was

Figure 3. Four patient-transfer devices tested in this study: (a) draw sheet, (b) friction-reducing repositioning sheet, (c) slide board, and (d) air-assisted device.

mounted on the load cell (diameter = 7.2 cm), and the other side of the load cell was clamped to each transfer device. The distance from the load cell to the handle was 25 cm and was consistently applied to each transfer device.

Kinematic data (shoulder and trunk posture, shoulder net moment). Kinematic data of the upper body were collected at 100 Hz using an eight-camera optical motion capture system (Flex 13; Optitrack, Natural Point, OR). Twenty-seven reflective markers (14-mm diameter) were placed bilaterally on the head, upper arm, lower arm, hand, trunk, and pelvis based on the Plug-In-Gait upper-body marker set (Winter, 2009). A minimum of three noncollinear body landmarks were used on each segment to create a segment coordinate system. An additional three reflective markers were placed on the load cell to estimate locations and force vectors. Raw kinematic data were filtered by a digital zero-phase fourth-order Butterworth filter with a cut-off frequency of 6 Hz (Motive 2.0; Optitrack, Natural Point, OR).

The right shoulder's three-dimensional net moment was computed by inverse dynamics using biomechanics analysis software (Visual3D; C-Motion Inc., Germantown, MD). The segment length was scaled based on the motion capture data, and the segment mass was estimated as a percentage of individual's body mass (Dempster, 1955). Flexion and abduction angles of the right shoulder were calculated using instantaneous orientations of the anatomical axes in the right upper arm and the trunk. Shoulder moment was calculated using three-dimensional hand pull force, shoulder posture data, upper-extremity segment mass, and inertia. Trunk flexion angle was computed using the rotation matrix between the anatomical coordinate system of the trunk and pelvis.

Muscle activity (EMG). EMG data were collected at 1000 Hz using a wireless data logger (WBA; Mega Electronics, Kupio, Finland) and Ag/AgCl surface electrodes from seven muscles: flexor digitorum superficialis (FDS), extensor digitorum communis (EDC), biceps, triceps, trapezius (TRAP), and left and right erector spinae (ES). Skin preparation and electrode placements were conducted per the European Recommendation for Surface Electromyography (Hermens et al., 1999). For ES, the surface electrodes were placed 4 cm apart from midline of the spine at L3 level (Mirka & Marras, 1993). Raw EMG data were band-pass filtered (10–350 Hz), rectified, and averaged using a 125-ms moving window (MegaWin; Mega Electronics, Kupio, Finland). Processed EMG data were normalized by either maximum voluntary contractions (MVCs) or submaximal reference voluntary contractions (RVCs). Then, the normalized EMG data were summarized by 90th (peak) percentile values based on amplitude probability density function (APDF) (Jonsson, 1982).

MVCs were collected from FDS, EDC, biceps, triceps, and TRAP (Harms-Ringdahl, Ekholm, Schüldt, Linder, & Ericson, 1996; Mogk & Keir, 2003) at the end of experimental session. To avoid potential back injuries, submaximal RVCs were collected from ES during 30° forward bending (Soderberg & Knutson, 2000). Each contraction lasted 3 s and three MVCs/RVCs were collected. A 2-min break was provided between exertions to minimize possible residual fatigue (Soderberg & Knutson, 2000). The highest 95th percentile value of root mean squares among three MVCs/RVCs was used to normalize EMG data (Odell, Barr, Goldberg, Chung, & Rempel, 2007).

Patient head acceleration. Head acceleration of the mock patients was measured at 2400 Hz using a four-channel data recorder (Model DA-20; Rion Co., Tokyo, Japan) and a triaxial accelerometer (Model 356B40; PCB Piezotronics, Depew, NY) rigidly coupled to each patient's head using a securely fastened headband. The accelerometer was placed according to ISO 2631-1 whole-body vibration standards (x, back to chest; y, right to left; z, feet to head) shown in Figure 1. Raw acceleration data were filtered by a Channel Frequency Class 180 low-pass filter based on the SAE J211 convention (Post, Clark, Robertson, Hoshizaki, & Gilchrist, 2017). Filtered acceleration data were summarized as peak (90th percentile) root mean squares.

Usability questionnaire. A usability questionnaire was developed based on a usability survey used in previous studies to evaluate patient-transfer devices during transfers between a bed and a wheelchair (Sun et al., 2015, 2018). The questionnaire consisted of six questions (ease of use, effort to use, safety, patient's falling concern, appearance of device, and adoption of device at work) measured on a 7-point Likert scale (1 = *strong negative* to 7 = *strong positive*). In addition, the questionnaire included open-ended questions so that participants could rate their preference rankings and describe reasons for their rankings.

Statistical Analysis

The dependent variables included hand pull force, shoulder flexion and abduction angles, truck flexion angle, shoulder moments, muscle activity in seven muscles, head acceleration, and subjective usability ratings. Prior to statistical data analyses, normality of each dependent variable was tested using Shapiro-Wilks W tests in SPSS (Version 24; IBM Corporation, Armonk, NY). For normally distributed data, including shoulder flexion and abduction angles, one-way repeated-measures ANOVA was conducted to identify any differences in shoulder flexion and abduction among the four patient-transfer devices using SPSS. Due to non-normality, trunk flexion angle, muscle activities of all muscles, and head accelerations were transformed by either log or Johnson transformations and then analyzed using one-way repeated-measures ANOVA. Because hand pull force, shoulder moments, and usability ratings were still non-normal even after transformation, nonparametric tests (Friedman tests) were used to analyze those data in SPSS.

Any statistical significance was followed up with a Tukey HSD post hoc test or Wilcoxon signed-rank test to determine which transfer device showed lower biomechanical stresses. Statistical significance was determined as $p < .05$. The Cohen's d effect sizes were calculated to examine the differences in the aforementioned measures between friction-reducing devices relative to the cotton draw sheet (Liao et al., 2015).

RESULTS

Three-Dimensional Hand Pull Force

Hand pull force was substantially (up to 67%) lower using the air-assisted device as compared with the draw sheet (Cohen's d = –3.80; see Table 1 and Appendix Table A1). Hand pull force on the draw and repositioning sheets was higher than on the slide board (ps < .001) and air-assisted device ($p < .001$); however, no differences were observed between the draw and repositioning sheets (Cohen's d = –0.23; see Table 1 and Appendix Table A1).

TABLE 1: Mean Peak Right Hand Pull Force, Posture, and Shoulder Moment for Four Transfer Devices During Lateral Pulling, Lateral Pushing, and Sliding-Up Tasks

		Transfer Device				
Measure (Unit)	Task	Draw Sheet	Repositioning Sheet	Slide Board	Air-assisted Device	*p*
Peak right hand pull force (N)	Lateral pulling	128.7^{A} (3.8)	122.7^{A} (4.5)	103.9^{B} (5.4)	42.3^{C} (3.4)	<.001
Peak shoulder flexion (°)	Lateral pulling	59.4^{A} (2.0)	49.0^{B} (2.6)	47.0^{B} (2.4)	35.3^{C} (2.9)	<.001
	Lateral pushing	92.1^{A} (2.8)	88.0^{AB} (2.5)	87.2^{AB} (2.4)	80.7^{B} (2.8)	<.001
	Sliding up	31.2^{A} (1.8)	27.2^{A} (1.7)	26.4^{A} (1.7)	9.5^{B} (2.2)	<.001
Peak shoulder abduction (°)	Lateral pulling	2.1^{A} (1.4)	7.2^{B} (1.3)	4.3^{AB} (1.4)	15.1^{C} (1.3)	<.001
	Lateral pushing	8.9^{A} (1.1)	8.7^{A} (1.0)	8.8^{A} (1.1)	12.4^{A} (1.0)	.007
	Sliding up	9.4^{A} (1.4)	8.9^{A} (1.4)	11.0^{A} (1.2)	19.4^{B} (1.2)	<.001
Peak trunk flexion (°)	Lateral pulling	29.3^{A} (1.3)	24.8^{AB} (1.8)	21.3^{B} (1.3)	14.8^{C} (1.9)	.121
	Lateral pushing	53.8^{A} (1.3)	51.7^{A} (1.3)	50.8^{A} (1.2)	41.8^{B} (1.4)	.487
	Sliding up	19.1^{A} (0.9)	18.0^{A} (0.9)	17.1^{A} (0.9)	8.7^{B} (0.8)	<.001
Peak shoulder flexion moment (Nm)	Lateral pulling	33.4^{A} (2.6)	28.8^{B} (2.6)	27.8^{B} (2.52)	11.1^{C} (0.9)	<.001
Peak shoulder abduction moment (Nm)	Lateral pulling	5.0^{A} (1.1)	6.4^{A} (1.0)	4.4^{A} (0.7)	0.3^{B} (0.4)	0.001
Peak shoulder net moment (Nm)	Lateral pulling	41.2^{A} (2.2)	35.9^{B} (1.9)	30.5^{B} (2.3)	14.4^{C} (1.0)	<.001

Note. Standard errors shown in parentheses. Superscript letters (A, B, and C) denote significant differences from pairwise comparisons among transfer devices based on a Tukey HSD post hoc test or Wilcoxon signed-rank test.

Kinematic Data (Shoulder and Trunk Posture, Shoulder Moment)

The results showed that shoulder flexion ($ps < .001$) and abduction ($ps < .007$) were significantly different across transfer devices in all three tasks, whereas the transfer devices did not affect trunk flexion angles during lateral pulling and pushing tasks ($ps > .121$).

Shoulder flexion using the air-assisted device was significantly lower relative to the draw sheet during all three tasks: lateral pulling ($p < .001$; Cohen's $d = –1.55$), pushing ($p = .013$; Cohen's $d = –0.65$), and sliding up ($p < .001$; Cohen's $d = –1.71$) (see Table 1 and Appendix Table A1). Shoulder flexion using the draw sheet was higher relative to the three other devices during the lateral pulling task; however, there were no significant differences in shoulder flexion among the draw sheet, repositioning sheet, and slide board during lateral pushing ($ps >$

.563) and sliding-up tasks (*p*s > .283) (Table 1). In contrast, shoulder abduction using the air-assisted device was higher relative to the three other devices during lateral pulling (*p*s < .001) and sliding-up tasks (*p*s < .001) (Table 1). No substantial differences in shoulder abduction were found among the draw sheet, repositioning sheet, and slide board during lateral pushing (*p*s > .998) and sliding-up tasks (*p*s > .800).

Shoulder moments (flexion, abduction, and net) during the lateral pull task showed significant difference across the four patient-transfer devices (*p*s < .001). Shoulder moments using the air-assisted device was significantly lower relative to the draw sheet (*p*s < .001; Cohen's *d* = –2.45 to 0.92), whereas the draw sheet required higher shoulder net and sagittal moments than other devices (*p*s < .001) (Table 1 and Appendix Table A1).

Muscle Activity (EMG)

Muscle activity in all seven muscles was lower using the air-assisted device relative to the draw sheet (Cohen's *d* = –1.97 to –0.32) (Table 2 and Appendix Table A2). The draw and repositioning sheets tended to have higher muscle activity in all the muscle groups as compared with the slide board and air-assisted device, with different degrees of statistical significance.

Patient Head Acceleration

For lateral pulling and pushing tasks, patient head acceleration was lowest using the air-assisted device but highest using the draw sheet for *x*- and *z*-axes (Cohen's *d* = –1.35 to –0.67); however, these differences were relatively smaller for the *y*-axis (Cohen's *d* = –0.76 to –0.72) (Table 3 and Appendix Table A3). During the sliding-up task, the air-assisted device showed lower patient head acceleration than the other devices on *x*- and *z*-axes; however, no consistent trend was found on the *y*-axis (Table 3).

Usability Questionnaires

The results showed that the air-assisted device was preferred to the other devices, whereas the draw sheet received the lowest usability ratings (Table 4). Eighteen out of 20 participants (90%) chose the air-assisted device as the most preferable device, and 16 out of 20 participants (80%) gave the lowest ranking to the draw sheet. The effect sizes indicated that the air-assisted device showed a greater effect on improving usability (Cohen's *d* = 0.95 to 3.94) (Appendix Table A4).

DISCUSSION

This study evaluated the efficacy of four patient-transfer devices in reducing biomechanical stresses of caregivers and head acceleration of mock patients during standardized patient-handling tasks. Friction-reducing devices (the air-assisted device and slide board) showed significantly lower biomechanical stresses on the upper extremities and low back, and higher usability ratings, as compared with the conventional draw sheet. These findings were also supported by the relatively greater effect sizes for the air-assisted device as compared with the draw sheet.

For the lateral pulling task, hand pull force was significantly lower on the slide board (104 N) and air-assisted device (42 N) compared with the conventional draw sheet (129 N). These differences could be partially due to the lower coefficient of friction of the slide board (plastic) and the air-assisted mattress (air gap) compared with the draw sheet (Lloyd & Baptiste, 2006; Pellino et al., 2006). The air-assisted device reduces friction by circulating low-pressure, high-volume air through thousands of microperforations. However, hand pull force was not significantly different between the friction-reducing repositioning sheet (synthetic nylon) and the cotton draw sheet. This finding was supported by the limited effect size (|Cohen's *d*| = 0.23). A previous study also showed that a single layer of slide sheet was not effective in reducing hand force as compared with a draw sheet (Larson, Murtagh, & Rice, 2018).

Shoulder net moment was significantly lower using the slide board (31 Nm) and the air-assisted device (14 Nm) as compared with the draw sheet (41 Nm) during the lateral pulling task (|Cohen's *d*| > 0.75). Authors of a previous study evaluated females' shoulder strength capability using shoulder pull moment, which ranged from 24 to 55 Nm (Chow & Dickerson, 2016).

TABLE 2: Mean Muscle Activity in Flexor Digitorum Superficialis (FDS), Extensor Digitorum Communis (EDC), Biceps, Triceps, Trapezius (TRAP), and Left and Right Erector Spinae (ES) for Four Transfer Devices During Lateral Pulling, Lateral Pushing, and Sliding-Up Tasks

		Transfer Device				
Muscle (Unit)	Task	Draw Sheet	Repositioning Sheet	Slide Board	Air-assisted Device	*p*
FDS (%MVC)	Lateral pulling	30.8^{A} (2.7)	31.2^{A} (3.4)	25.3^{AB} (2.8)	19.3^{B} (2.6)	<.001
	Lateral pushing	40.9^{A} (3.8)	45.4^{A} (3.8)	39.1^{A} (4.8)	32.9^{A} (3.0)	.004
	Sliding up	30.7^{A} (2.0)	34.7^{A} (2.6)	29.1^{A} (2.5)	15.7^{B} (2.3)	<.001
EDC (%MVC)	Lateral pulling	72.6^{A} (9.4)	69.6^{A} (7.2)	63.5^{AB} (6.8)	49.6^{B} (5.5)	<.001
	Lateral pushing	69.4^{A} (6.8)	64.1^{A} (7.2)	66.8^{A} (8.4)	54.7^{A} (4.8)	.198
	Sliding up	77.2^{A} (8.6)	86.9^{A} (10.7)	72.8^{AB} (8.6)	49.3^{B} (6.4)	<.001
Biceps (%MVC)	Lateral pulling	25.7^{A} (2.4)	25.1^{A} (2.3)	19.3^{A} (1.8)	13.6^{B} (1.6)	<.001
	Lateral pushing	41.4^{A} (3.4)	41.5^{A} (3.7)	32.9^{A} (2.8)	18.8^{B} (1.9)	<.001
	Sliding up	22.6^{A} (2.1)	27.8^{A} (2.9)	18.9^{A} (2.0)	13.4^{B} (1.5)	<.001
Triceps (%MVC)	Lateral pulling	26.6^{A} (3.2)	21.0^{AB} (2.3)	17.0^{B} (2.1)	14.3^{B} (1.6)	<.001
	Lateral pushing	27.9^{A} (2.6)	26.7^{AB} (2.9)	22.0^{AB} (2.3)	19.2^{B} (2.4)	<.001
	Sliding up	21.3^{A} (1.8)	25.7^{A} (2.6)	18.5^{AB} (2.0)	13.4^{B} (1.8)	<.001
TRAP (%MVC)	Lateral pulling	84.7^{A} (8.5)	65.7^{AB} (5.3)	56.8^{B} (5.9)	49.3^{B} (5.1)	<.001
	Lateral pushing	72.2^{A} (6.8)	77.7^{A} (7.4)	59.8^{A} (5.8)	31.3^{B} (3.0)	<.001
	Sliding up	74.9^{AB} (5.2)	84.5^{A} (6.2)	59.0^{B} (4.3)	39.3^{C} (4.6)	<.001
Left ES (%RVC)	Lateral pulling	121.7^{AB} (6.2)	150.5^{A} (9.8)	116.8^{B} (6.9)	83.6^{C} (4.4)	<.001
	Lateral pushing	177.4^{A} (12.4)	183.9^{A} (12.2)	170.4^{A} (10.9)	107.8^{B} (7.5)	<.001
	Sliding up	112.0^{A} (6.2)	118.8^{A} (6.7)	102.2^{A} (6.0)	51.5^{B} (3.0)	<.001
Right ES (%RVC)	Lateral pulling	160.8^{A} (8.9)	174.5^{A} (11.8)	139.3^{A} (8.8)	93.3^{B} (8.8)	<.001
	Lateral pushing	205.9^{A} (13.8)	224.0^{A} (10.4)	193.6^{A} (13.7)	125.6^{B} (10.1)	<.001
	Sliding up	218.9^{A} (13.2)	213.3^{AB} (15.6)	157.1^{B} (13.7)	97.7^{C} (9.9)	<.001

Note. Standard errors shown in parentheses. Superscript letters (A, B, and C) denote significant differences from pairwise comparisons among transfer devices based on a Tukey HSD post hoc test or Wilcoxon signed-rank test. MVC = maximum voluntary contraction; RVC = reference voluntary contraction.

TABLE 3: Mean Patient Head Acceleration for Four Transfer Devices During Lateral Pulling, Lateral Pushing, and Sliding-Up Tasks

		Transfer Device				
Axis (Unit)	Task	Draw Sheet	Repositioning Sheet	Slide Board	Air-Assisted Device	p
x (m/s^2)	Lateral pulling	129.5^{A} (21.2)	41.8^{B} (4.1)	72.0^{B} (14.0)	28.8^{C} (1.6)	<.001
	Lateral pushing	82.7^{A} (15.3)	42.6^{B} (8.2)	49.8^{B} (13.9)	36.6^{B} (6.7)	<.001
	Sliding up	39.9^{A} (2.3)	42.7^{A} (3.3)	45.3^{A} (3.2)	27.0^{B} (1.2)	<.001
y (m/s^2)	Lateral pulling	97.8^{A} (5.3)	83.9^{AB} (4.5)	79.3^{AB} (4.7)	75.3^{B} (5.3)	.002
	Lateral pushing	107.8^{A} (5.5)	80.2^{C} (4.1)	99.8^{AB} (6.6)	85.1^{BC} (4.6)	.013
	Sliding up	39.4^{AB} (2.0)	41.8^{AB} (2.1)	34.0^{B} (1.6)	47.5^{A} (3.4)	.023
z (m/s^2)	Lateral pulling	105.9^{A} (14.4)	60.3^{AB} (5.8)	59.3^{B} (7.0)	29.7^{C} (1.9)	<.001
	Lateral pushing	91.2^{A} (11.9)	48.6^{B} (2.3)	68.7^{B} (13.3)	32.9^{C} (2.4)	<.001
	Sliding up	65.3^{A} (3.8)	68.6^{A} (4.0)	66.7^{A} (3.3)	46.8^{B} (2.9)	<.001

Note. Standard errors shown in parentheses. Superscript letters (A, B, and C) denote significant differences from pairwise comparisons among transfer devices based on a Tukey HSD post hoc test or Wilcoxon signed-rank test. x = back to chest; y = right to left; z = feet to head.

Risk of WMSDs in the shoulder region increases if shoulder moment exceeds this strength capability (Chaffin, 1975; Kahn & Monod, 1989). In this study, the air-assisted device was the only device with shoulder moment below the strength capability (Chow & Dickerson, 2016). Given lower shoulder moment, the air-assisted device may have potential to reduce risk for WMSDs in the shoulder region.

Shoulder flexion was significantly lower using the air-assisted device as compared with the other devices, especially during lateral pulling and sliding-up tasks (|Cohen's d| > 1.55). According to a review study by Putz-Anderson et al. (1997), shoulder flexion angles exceeding 60° could be associated with WMSDs in the shoulder region due to increased muscle activity and shoulder impingement. In this study, all transfer devices showed shoulder flexion less than 60° during lateral pulling and sliding-up tasks, whereas lateral pushing tasks caused shoulder flexion greater than 60° of all transfer devices. This finding indicates that the lateral pushing task could still pose risk of WMSDs in the shoulder area regardless of different friction-reducing devices.

For the shoulder abduction angle, the air-assisted device showed the greatest angles (12° to 19°) in all three tasks. Once the air-assisted device was fully inflated, the surface height was increased up to 27 cm. This increased surface height may have caused greater shoulder abduction with the air-assisted device compared with other devices. However, the air-assisted device showed the lowest shoulder abduction moment during the lateral pulling task. This lower shoulder moment could be related to the lower acceleration of the arm movement while using an air-assisted device compared with other devices, evidenced by lower patient head acceleration. In

TABLE 4: Mean Usability Ratings for Four Transfer Devices

Question	Draw Sheet	Repositioning Sheet	Slide Board	Air-Assisted Device	*p*
1. How easy was it to use this transfer device? (1 = *very difficult* to 7 = *very easy*)	3.2^{A} (0.3)	4.8^{B} (0.3)	5.8^{C} (0.2)	7.0^{D} (0.1)	<.001
2. How much effort did it take to use this transfer device? (1 = *very much effort* to 7 = *little effort*)	2.5^{A} (0.3)	3.5^{A} (0.3)	5.2^{B} (0.3)	6.7^{C} (0.1)	<.001
3. How safe was it to use this transfer device? (1 = *very unsafe* to 7 = *very safe*)	4.6^{A} (0.3)	5.6^{B} (0.3)	5.2^{B} (0.3)	5.9^{B} (0.3)	.013
4. Were you concerned that the patient may fall while using this transfer device? (1 = *highly concerned* to 7 = *not at all concerned*)	5.3^{A} (0.4)	6.0^{B} (0.3)	4.9^{A} (0.4)	5.5^{AB} (0.4)	.133
5. Did you like the appearance of the transfer device? (1 = *strongly dislike* to 7 = *strongly like*)	3.5^{A} (0.3)	5.1^{B} (0.3)	4.2^{B} (0.5)	6.5^{C} (0.2)	<.001
6. Would you like to use this transfer device at your work? (1 = *not at all* to 7 = *really want it*)	3.2^{A} (0.4)	4.9^{B} (0.3)	4.7^{B} (0.4)	6.6^{C} (0.2)	<.001

Note. Standard errors shown in parentheses. Superscript letters (A, B, and C) denote significant differences from pairwise comparisons among transfer devices based on a Tukey HSD post hoc test or Wilcoxon signed-rank test.

addition, the increased moment due to shoulder abduction may have been washed out by accompanied flexion of the elbow and wrist, as seen in previous papers (Marras et al., 2000; Picchiotti et al., 2019).

The air-assisted device showed significant reduction in trunk flexion compared with the draw sheet in all three tasks (|Cohen's d| > 1.39). This trend mirrored muscle activity in the ES, which was lowest using the air-assisted device during all tasks. However, trunk flexion did not differ between the cotton draw sheet and repositioning sheet, especially in the sliding-up task (|Cohen's d| = 0.18). A previous study showed that trunk flexion during patient transfer was mainly driven by handle height (MacKinnon & Vaughan, 2005). Limited differences in trunk flexion between the devices can be explained by the fact that the bed height was set at knuckle height of a participant to minimize the spinal loading, as suggested by a previous study (Nagavarapu et al., 2016). This result is consistent with a previous study showing that lateral patient-handling tasks required little deviation of trunk extension or rotation when caregivers followed patient-handling guidelines (Drew et al., 2015).

The air-assisted device showed significantly lower muscle activity in all muscle groups compared with the draw sheet in all three tasks (|Cohen's d| > 0.32). The lower muscle activity using the air-assisted device is in line with lower hand pull force, shoulder net moment, and shoulder flexion. Substantially high muscle activities in EDC (up to 87%MVC) and TRAP (up to 85%MVC) with the draw and repositioning sheets can be explained by significant arm elevation (shoulder flexion up to 92°) and hand pull force (up to 129 N). Given lower muscle activity in all muscle groups, the air-assisted device may be an effective engineering intervention to reduce risk for WMSDs of both upper extremities and low back.

X-axis (back-to-chest) head acceleration was lower using all three friction-reducing devices compared with the draw sheet in lateral pulling and pushing tasks. Especially, the air-assisted device was most effective in reducing head acceleration (|Cohen's *d*| > 0.48). The 10-g (98-m/s^2) linear acceleration threshold is commonly used to assess head impact in sports players, including football players (Crisco et al., 2010; Reynolds et al., 2016). When using the draw sheet, patient head acceleration in all three axes exceeded the 10-g (98-m/s^2) threshold during lateral pulling and pushing tasks. Such high head acceleration using the draw sheet could increase brain impact and torque and muscular loading in the neck and therefore increase risk of headache, dizziness, and even minor brain or neck injuries, especially in critically ill patients (Hinz, Menzel, Bluethner, & Seidel, 2010; Liao et al., 2015). Given lower head acceleration, the air-assisted device could be advantageous to reduce risk of head acceleration and associated discomfort and injuries among patients.

Shoulder and trunk flexion angles were 39° (45%) and 27° (55%) lower during lateral pulling as compared with lateral pushing. These differences are in line with ES muscle activity, which was 36% lower during lateral pulling as compared with lateral pushing. Lateral pushing required a combination of lifting and pushing exertions and a substantial amount of flexion of the shoulder and trunk to transfer a patient toward a stretcher. This result is similar to previous findings among emergency medical services workers showing that pulling by both caregivers from one side showed a significant reduction in low-back stress (Lavender et al., 2007).

Usability ratings showed that the air-assisted device was most preferred, whereas the draw sheet was least preferred. These self-reported results are well supported by the objective biomechanical data, including hand pull force, shoulder flexion, shoulder net moment, and muscle activity. A previous study also reported the associations between hand force and caregivers' usability scores (Sun et al., 2018).

There are a few limitations in this study. First, relatively light mock patients (body mass = 71 to 73 kg) were tested. Given the large portion of overweight (64%) and obese populations (30%) in the United States (McGinley & Bunke, 2008), our study results may underestimate true biomechanical stresses during patient-transfer activities. Therefore, evaluating caregivers' biomechanical stresses with overweight and obese patients will be merited. Furthermore, hand pull force was measured only for the right hand. To minimize potential unbalanced hand force between hands, we designed the bilateral pulling handles to balance the load between the hands and also controlled participants' hand positions on the pelvis and shoulder of a mock patient. The mock patient's head was always toward the right hand of participants. We believe this setup helped relatively evenly distribute the pull force between the hands. However, bilateral measurement of hand force will be merited in future studies.

In addition, the 25-cm offset between the hand and load cell might have altered the caregivers' postures as compared with typical practice. Nevertheless, our findings should still provide important implications, considering this study was comparative in nature. Last, activities required to apply each device underneath the patient prior to performing the patient transfer were not assessed in this study. A previous study showed that patient weight and bed height significantly affected caregivers' spinal loads during sling application and removal in bed (Nagavarapu et al., 2016). Therefore, it will be meaningful to address the usability and physical demands of caregivers while setting up friction-reducing devices under the patient in the future studies.

CONCLUSION

Among the four patient-transfer devices tested in this study, the slide board and air-assisted device were most effective in reducing hand pull force, shoulder flexion, shoulder net moment, and muscle activity in the upper extremities and low back. In addition, these devices reduced patient head acceleration during patient-transfer tasks. These results indicate that the slide board and air-assisted device can be effective engineering controls to not only reduce caregivers' WMSD-related risk but also improve patients' safety.

APPENDIX

TABLE A1: Effect Sizes (Cohen's *d*) and 95% Confidence Intervals of Peak Right Hand Pull Force, Posture, and Shoulder Moment for Four Transfer Devices During Lateral Pulling, Lateral Pushing, and Sliding-Up Tasks

Measure (Unit)	Task	Draw Sheet–Repositioning Sheet	Draw Sheet–Slide Board	Draw Sheet–Air-Assisted Device
Peak right hand pull force (N)	Lateral pulling	–0.23 [–0.67, 0.21]	–0.86 [–1.32, –0.39]	–3.80 [–4.49, –3.03]
Peak shoulder flexion (°)	Lateral pulling	–0.72 [–1.17, –0.26]	–0.91 [–1.37, –0.44]	–1.55 [–2.03, –1.03]
	Lateral pushing	–0.24 [–0.68, 0.21]	–0.29 [–0.73, 0.15]	–0.65 [–1.09, –0.19]
	Sliding up	–0.36 [–0.80, 0.09]	–0.44 [–0.89, 0.02]	–1.71 [–2.20, –1.18]
Peak shoulder abduction (°)	Lateral pulling	–0.60 [–1.04, –0.14]	–0.26 [–0.70, 0.19]	–1.54 [–2.02, –1.03]
	Lateral pushing	0.04 [–0.40, 0.48]	0.02 [–0.42, 0.46]	–0.51 [–0.95, –0.06]
	Sliding up	0.05 [–0.39, 0.50]	–0.21 [–0.66, 0.24]	–1.23 [–1.70, –0.74]
Peak trunk flexion (°)	Lateral pulling	–0.46 [–0.90, –0.01]	–0.98 [–1.44, –0.50]	–1.40 [–1.87, –0.90]
	Lateral pushing	–0.26 [–0.70, 0.18]	–0.37 [–0.81, 0.07]	–1.39 [–1.87, –0.89]
	Sliding up	–0.18 [–0.63, 0.26]	–0.34 [–0.79, 0.11]	–1.91 [–2.42, –1.36]
Peak shoulder flexion moment (Nm)	Lateral pulling	–0.28 [–0.73, 0.17]	–0.36 [–0.81, 0.10]	–1.87 [–2.38, –1.32]
Peak shoulder abduction moment (Nm)	Lateral pulling	0.22 [–0.23, 0.66]	–0.10 [–0.55, 0.34]	–0.92 [–1.38, –0.45]
Peak shoulder net moment (Nm)	Lateral pulling	–0.40 [–0.85, 0.05]	–0.75 [–1.20, –0.28]	–2.45 [–3.01, –1.85]

TABLE A2: Effect Sizes (Cohen's *d*) and 95% Confidence Intervals of Muscle Activity in Flexor Digitorum Superficialis (FDS), Extensor Digitorum Communis (EDC), Biceps, Triceps, Trapezius (TRAP), and Left and Right Erector Spinae (ES) for Four Transfer Devices During Lateral Pulling, Lateral Pushing, and Sliding-Up Tasks

Measure (Unit)	Task	Draw Sheet–Repositioning Sheet	Draw Sheet–Slide Board	Draw Sheet–Air-Assisted Device
FDS (%MVC)	Lateral pulling	0.00 [–0.44, 0.44]	–0.34 [–0.78, 0.10]	–0.73 [–1.17, –0.27]
	Lateral pushing	0.21 [–0.23, 0.65]	–0.04 [–0.47, 0.40]	–0.32 [–0.76, 0.12]
	Sliding up	0.34 [–0.10, 0.78]	–0.06 [–0.50, 0.38]	–1.04 [–1.49, –0.56]
EDC (%MVC)	Lateral pulling	–0.06 [–0.51, 0.39]	–0.18 [–0.63, 0.27]	–0.48 [–0.93, –0.02]
	Lateral pushing	–0.14 [–0.59, 0.31]	–0.06 [–0.51, 0.39]	–0.42 [–0.87, 0.04]
	Sliding up	0.17 [–0.29, 0.62]	–0.08 [–0.52, 0.38]	–0.60 [–1.05, –0.03]
Biceps (%MVC)	Lateral pulling	–0.07 [–0.50, 0.37]	–0.52 [–0.96, –0.07]	–0.94 [–1.39, –0.47]
	Lateral pushing	0.00 [–0.44, 0.44]	–0.46 [–0.90, –0.01]	–1.29 [–1.75, –0.79]
	Sliding up	0.30 [–0.14, 0.74]	–0.31 [–0.75, 0.13]	–0.84 [–1.28, –0.37]
Triceps (%MVC)	Lateral pulling	–0.35 [–0.79, 0.10]	–0.59 [–1.03, 0.14]	–0.82 [–1.27, –0.36]
	Lateral pushing	–0.11 [–0.55, 0.33]	–0.44 [–0.88, 0.01]	–0.62 [–1.07, –0.17]
	Sliding up	0.31 [–0.13, 0.75]	–0.23 [–0.67, 0.21]	–0.70 [–1.15, –0.24]
TRAP (%MVC)	Lateral pulling	–0.42 [–0.86, 0.02]	–0.60 [–1.05, –0.15]	–0.81 [–1.26, –0.35]
	Lateral pushing	0.13 [–0.31, 0.57]	–0.30 [–0.74, 0.14]	–1.23 [–1.70, –0.74]
	Sliding up	0.27 [–0.18, 0.70]	–0.53 [–0.97, –0.08]	–1.16 [–1.62, –0.67]
Left ES (%RVC)	Lateral pulling	0.54 [0.09, 0.98]	–0.05 [–0.49, 0.39]	–1.15 [–1.61, –0.67]
	Lateral pushing	0.09 [–0.35, 0.53]	–0.10 [–0.53, 0.34]	–1.08 [–1.54, –0.60]
	Sliding up	0.17 [–0.28, 0.60]	–0.25 [–0.69, 0.19]	–1.97 [–2.48, –1.42]
Right ES (%RVC)	Lateral pulling	0.21 [–0.23, 0.65]	–0.38 [–0.81, 0.07]	–1.21 [–1.67, –0.72]
	Lateral pushing	0.31 [–0.13, 0.75]	–0.07 [–0.51, 0.37]	–0.97 [–1.42, –0.50]
	Sliding up	–0.06 [–0.50, 0.38]	–0.73 [–1.17, –0.27]	–1.65 [–2.14, 1.13]

Note. MVC = maximum voluntary contraction; RVC = reference voluntary contraction.

TABLE A3: Effect Sizes (Cohen's *d*) and 95% Confidence Intervals of Patient Head Acceleration for Four Transfer Devices During Lateral Pulling, Lateral Pushing, and Sliding-Up Tasks

Measure (Unit)	Task	Draw Sheet–Repositioning Sheet	Draw Sheet–Slide Board	Draw Sheet–Air-Assisted Device
x (m/s^2)	Lateral pulling	–1.02 [–1.51, –0.51]	–0.56 [–1.04, –0.06]	–1.19 [–1.69, –0.67]
	Lateral pushing	–0.56 [–1.03, –0.08]	–0.38 [–0.86, 0.10]	–0.67 [–1.14, –0.18]
	Sliding up	0.16 [–0.31, 0.63]	0.33 [–0.15, 0.81]	–1.22 [–1.71, –0.69]
y (m/s^2)	Lateral pulling	–0.48 [–0.95, 0.00]	–0.64 [–1.12, –0.14]	–0.72 [–1.19, –0.23]
	Lateral pushing	–0.98 [–1.47, –0.47]	–0.23 [–0.71, 0.25]	–0.76 [–1.24, –0.27]
	Sliding up	0.19 [–0.28, 0.66]	–0.51 [–0.98, –0.02]	0.48 [0.00, 0.95]
z (m/s^2)	Lateral pulling	–0.75 [–1.23, –0.25]	–0.73 [–1.22, –0.22]	–1.35 [–1.86, –0.81]
	Lateral pushing	–0.86 [–1.34, –0.36]	–0.31 [–0.78, 0.17]	–1.18 [–1.68, –0.66]
	Sliding up	0.14 [–0.33, 0.61]	0.07 [–0.41, 0.54]	–0.93 [–1.42, –0.43]

TABLE A4: Effect Sizes (Cohen's *d*) and 95% Confidence Intervals of Usability Ratings for Four Transfer Devices

Question	Draw Sheet–Repositioning Sheet	Draw Sheet–Slide Board	Draw Sheet–Air-Assisted Device
1. How easy was it to use this transfer device? (1 = *very difficult* to 7 = *very easy*)	1.20 [0.51, 1.85]	2.14 [1.32, 2.87]	3.93 [2.81, 4.90]
2. How much effort did it take to use this transfer device? (1 = *very much effort* to 7 = *little effort*)	0.70 [0.05, 1.32]	1.86 [1.08, 2.56]	3.94 [2.81, 4.91]
3. How safe was it to use this transfer device? (1 = *very unsafe* to 7 = *very safe*)	0.73 [0.07, 1.35]	0.42 [–0.21, 1.04]	0.95 [0.28, 1.58]
4. Were you concerned that the patient may fall while using this transfer device? (1 = *highly concerned* to 7 = *not at all concerned*)	0.39 [–0.24, 1.01]	–0.22 [–0.84, 0.40]	0.09 [–0.53, 0.71]
5. Did you like the appearance of the transfer device? (1 = *strongly dislike* to 7 = *strongly like*)	1.16 [0.47, 1.81]	0.41 [–0.22, 1.03]	2.47 [1.60, 3.24]
6. Would you like to use this transfer device at your work? (1 = *not at all* to 7 = *really want it*)	1.11 [0.42, 1.75]	0.89 [0.22, 1.52]	2.52 [1.64, 3.29]

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KEY POINTS

- Given lower biomechanical stresses in caregivers' upper extremities and low back, the air-assisted device and slide board can be effective engineering controls to reduce injury risk among caregivers and patients.
- Friction-reducing devices (repositioning sheet, slide board, and air-assisted device) significantly reduced patients' head accelerations compared with a conventional draw sheet.
- The repositioning sheet did not significantly reduce biomechanical stresses in caregivers' upper extremities and low back compared with the conventional draw sheet.

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