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Assessment of Muscle Activation of Caregivers Performing Dependent Transfers With a Novel Robotic-Assisted Transfer Device Compared With the Hoyer Advance

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Objective: The purpose of this study was to compare muscle activity in caregivers while using a novel robotic-assisted transfer device (Strong Arm) to a clinical standard of care (Hoyer Advance).

Design: A quasi-experimental design was used in which 20 caregivers (33 ± 15 yrs old) performed transfers with three surfaces (toilet, bench, and shower chair) with the Strong Arm and Hoyer Advance. Transfer completion time (seconds), peak percentage surface electromyography (EMG), and integrated EMG of the bilateral erector spinae, latissimus dorsi, pectoralis major and anterior deltoid were measured.

Results: Caregivers required less transfer time when transferring from wheelchair to surface using the Hoyer Advance ($P = 0.011$, $f = 0.39$). For the lower back, significantly lower peak percentage EMGs were found using Strong Arm in 50% and for the integrated EMG in 25% of the cases, with the remaining cases showing no significant differences. For the shoulder, significantly lower peak percentage EMG values were found using Strong Arm in 19% of transfers and lower integrated EMG was found in 25% of transfers when using the Hoyer Advance, with the remaining cases showing no significant differences.

Conclusion: Although back muscle activation during Strong Arm transfers is statistically, but not clinically, lower, additional features that couple with significantly lower muscle activation make it an alternative to the clinical standard for further research and possible clinical applicability.

Key Words: Moving and Lifting Patients, Back Injuries, Self-Help Devices, Wheelchairs

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What Is Known

- Transfer devices are popular remedies to reduce risk of caregiver injuries in the workplace. Although they reduce a significant amount of the muscle activation compared with a manual transfer, the Hoyer Advance does not completely eliminate overexertion, awkward biomechanical positioning, space constraints, and transfer distance that are required to complete an assistive transfer.

What Is New

- A novel robotic-assisted transfer device was evaluated, and this article builds off previous articles to develop assistive technology to relieve transfer-related injuries to both caregiver and wheelchair users and providing a more ergonomically friendly method to perform transfers.

Clinical guidelines and previous research suggest implementation of interventions and techniques to lower caregiver muscle activation as well as the load placed on the L5/S1 center of mass when lifting and transferring people with disabilities.[1–4] According to the National Institute of Occupational Safety and Health, a healthcare worker should lift no more than 35 lb.[2] Likewise, the International Observational Standards recommends lifting no more than 3400 N during a typical shift and 10 kg repetitively.[5] Despite these guidelines, it is estimated that 63.1% and 37.8% of caregivers develop worked-related back and shoulder pain, respectively, both reducing quality of life and work performance.[6–11] Previous research has shown that 43.4% of caregiver-related pain occurs because of transfer-related activities, including lifting (27.9%) or transferring (15.5%) a patient.[12] Transfer devices are popular remedies to reduce risk of caregiver injuries in the workplace.[13] For instance, a mechanical lift (the clinical standard of care) requires manual compression to lift and lower the mobility device user, who is secured to a sling and a harness, during a transfer.[13,14] Research shows that the use of this technology significantly lowers muscle activity compared with a manual transfer. However, it does not completely eliminate overexertion, awkward positioning, space constraints, and transfer distance that are required to complete an assistive transfer.[7,15–17]

The use of robotic-assisted transfer devices for caregiver-assisted transfers is a promising intervention to reduce healthcare-related strain.[18] For example, the Strong Arm (SA) (Fig. 1), a fully powered system, lifts and transfers mobility device users via sling with caregiver assistance, who directs

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Dr Cooper and Dr Grindle are coinventors and patent holders of Strong Arm and could therefore potentially benefit from the publication.

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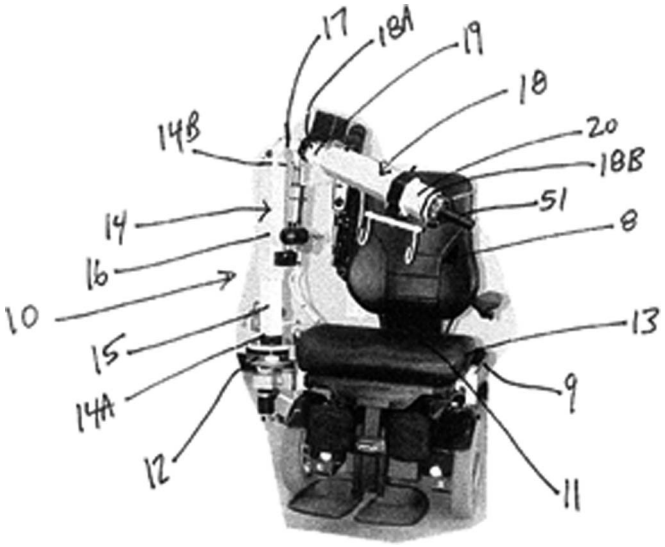

FIGURE 1. The SA design.

interaction with a joystick interface.[11,19] The joystick interface of the robotic arm provides 6 degrees of freedom, creating a more fluid transfer. Previous research confirmed the safety of the arm, perceived effort, as well as favorability from potential end users.[20]

Biomechanics outcomes have yet to confirm SA's ability to lower transfer-induced muscular demands. The purpose of this research study was to compare the muscle activation of caregivers performing dependent transfers using the SA and a standard mechanical floor lift (Hoyer Advance [HL][21]). It was hypothesized that there would be significantly lower peak and integrated muscle activity for the lower back (erector spinae and latissimus dorsi) and shoulder (pectoralis major and anterior deltoid) muscles when using the SA as compared with HL.

METHODS

Participants

This study was approved by the Veterans Affairs Pittsburgh Healthcare System Institutional Review Board. Based on data collected from previous research on the Personal Mobility and Manipulation Appliance technology,[22] an a priori power analysis conducted on G*Power showed that 20 participants were needed to confirm significant differences in the muscles of interest for device main effects. Participants were recruited from the Veterans Affairs Pittsburgh Healthcare System, the University of Pittsburgh School of Health and Rehabilitation Sciences, the University of Pittsburgh Medical Centre for Assistive Technology, and local research registries from the University of Pittsburgh Clinical Translational Science Institute, University of Pittsburgh Medical Centre, and the Human Engineering Research Laboratories. Caregivers were screened with the following inclusion criteria: (1) minimum age of 18 yrs, (2) more than 1 yr of experience in providing formal (e.g., paid or professional capacity) or informal (e.g., unpaid, family member or others) transfer assistance, (3) no history of pain or injury that could be aggravated during the study (participants with a history of pain were included on a case-by-case basis), and (4) not pregnant at the time of the study. Participants performed a 4-hr protocol at the Human Engineering Research Laboratories during one visit. Informed consent was signed before participants started the study protocol.

Study Protocol

Demographics

Investigators asked participants to complete a questionnaire for sociodemographic information, including age, height, weight, hand dominance, profession, years of transfer experience, and current employment setting. More information on the demographics and completed questionnaires can be found in Greenhalgh et al.[23]

Electromyography

Muscle activation was collected (sampled at 1500 Hz) using bipolar surface electrodes of a 16-channel electromyography (EMG) system (Noraxon Telemyo 2400 T). Eight electrodes were placed bilaterally on the erector spinae, latissimus dorsi, sternal portion of the pectoralis major, and anterior deltoid. Placement of the electrodes was in accordance to the placement standards of The SENIAM project[24,25] for EMG surface electrodes and was performed by the researcher with supervision of a clinical coordinator. The maximum voluntary contraction (MVC) of each muscle group was collected bilaterally over a period of 5 secs by manually applying an opposing force on the targeted muscle group to generate resistance. No verbal encouragement was given. Participants were prone to collect the erector spinae and latissimus dorsi muscle data, and supine for the pectoralis major and seated for the anterior deltoid. Data collection was verified after each trial and repeated after a rest period if necessary. The MVC could be seen as the maximum contraction that muscle could generate and was used to normalize the EMG data collected during the transfers.

Protocol

Before testing, participants were instructed on the usability of the two transfer devices (SA and HL) and practiced transferring a mannequin (75 kg)[26] to and from one of the transfer surfaces until they were comfortable with both devices. Once

the participant and the clinical investigator were confident about each participant's capability to use both devices to perform a transfer, data collection began.

Each participant was asked to transfer the mannequin with both devices to and from a C500 Permobil power wheelchair and three different surfaces: (1) toilet (ST) located in a simulated bathroom that was compliant with the Americans with Disabilities Act standards,[23] (2) a clinical rehabilitation bench (196 × 81 × 46 cm) (MT),[27] and (3) shower chair without backrest (71 × 56 × 48 cm) (TB).[28] Both the SA and the HL used the same initial starting position within the transfer workspace. SA, which operates with 6 degrees of freedom, was positioned on the forward corner of the wheelchair closest to the transfer surface. For safety purposes, only one direction of movement of SA could be activated at any time, making diagonal movements impossible. The wheelchair was driven by the participant to the transfer service and aligned to his/her preference. Participants positioned the HL as they preferred to begin a transfer, owing to the 1 degree of freedom of the arm. The EMG data from each participant were collected and split into three phases: lift, transport, and placement. Each transfer was conducted three times (2 devices × 3 surfaces-3 trials × 2 directions = 36 transfers). The order of the transfer surface and the transfer device was randomized to minimize the effects of fatigue, although 5 mins of rest was allotted after completing each device + surface transfer and anytime a caregiver requested a break. After all transfers were completed, recorded video footage was used to note down the time to complete a transfer. The participants were not informed about the collection of the transfer times, to ensure naturality.

Transfer Phases

Determination of the phases was based on the Patient Lift Safety Guide provided by the Federal Drug Administration.[29] The lift phase was defined as mannequin movement vertically from the surface (Fig. 2, photo 1). The transport phase was defined horizontal movement in the air to the desired location (Fig. 2, photos 2 and 3). The placement phase involved moving the mannequin vertically to the surface (Fig. 2, photo 4).[23] By defining these phases, comparisons could be made, even when the transfer techniques are not identical.

Data Analysis

By observing the collected video footage and the abovementioned phase definitions, while accounting for variability by detecting fixed patterns with each device, the frame numbers of the beginning and end of each phase were noted manually. A customized MATLAB (Version R2017a) program was then used to split the raw EMG data into three phases based on the frame numbers.

The split raw EMG data files were then analyzed with a second customized MATLAB code. Data were filtered with a fourth-order bandpass Butterworth filter, with cutoffs between 10 and 400 Hz, before they were demeaned and rectified. A low-pass filter (8 Hz) was used to smoothen the data. This provided the conditioned EMG (cEMG), which was used to identify the peak percentage EMG (pEMG) and integrated EMG (iEMG). The peak data were normalized by dividing the peak cEMG value for each trial by the peak cEMG value for the MVC times 100 (i.e., peak cEMG values for each trial were a percentage of each individual's peak value for their cEMG during the MVC).[30] In other words, the pEMG was defined as the highest muscle activation within the trial expressed as a percentage of the MVC (%MVC). The integrated cEMG (iEMG) values were calculated for each trial as the area under the cEMG curve over the total time of each trial.[30] The iEMG was calculated as the total area under the curve over the duration of the trial. After determination of the pEMG and iEMG of each trial at each transfer surface, the means of both the pEMG and iEMG at each surface were calculated to increase power.

Postprocessed data were exported to IBM SPSS Statistics V25, where a three-way repeated-measures analysis of variance was used to determine the main effect of the device. When an interaction effect was found within the outcomes, a subanalysis of the Bonferroni corrected pairwise comparisons between all interactions was performed. The alpha was set at $P = 0.05$ and Cohen f to present effect sizes was set at $f = 0.4$ for a large effect. Each transfer that was performed to the transfer surface and back was analyzed separately. No analysis was performed on the set-up differences (e.g., sling placement) or transfer techniques between the two devices. Any missing data were not included in the statistical analysis.

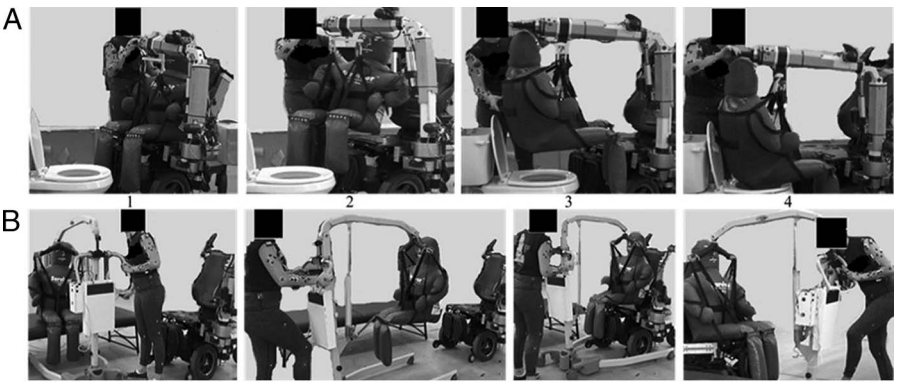

FIGURE 2. A participant performing a transfer with the Hoyer Advance (A) and SA (B) at two different transfer surfaces. 1, lift phase; 2–3, transport phase; 4, placement phase.

RESULTS

Participants

Participants (N = 20) were predominantly female (75%) and right handed (85%). The most represented profession was that of a personal care attendant (40%), and half of the participants were working in a home/community-based setting (50%).

Transfer Completion Times

The HL took significantly less time for each phase (P = 0.011, f = 0.39) transferring to the surface (Table 1). Specifically, lower transfer times are seen at MT (P < 0.001, f = 0.61). When transferring in the opposite direction, less time was necessary when using the HL at MT (P = 0.015, f = 1.18) and the lift phase (P < 0.001, f = 0.73).

Lower Back Muscles Peak and Integrated Percentage EMG

Erector Spinae

An overview of the pEMG and iEMG is provided in Table 2 (lower back muscles) and Tables 3 and 4 (shoulder muscles). When transferring from the wheelchair to surface, participants obtained significantly lower erector spinae pEMG values for SA for both their right (P = 0.003, f = 0.73) and left (P < 0.001, f = 1.07) sides. In addition, lower iEMG was found at the left side (P = 0.015, f = 0.65). The pairwise comparison was significantly lower using the SA for the left iEMG at the ST (P = 0.006, f = 1.1) and TB (P = 0.010, f = 0.75), in addition to the left iEMG during the lift (P < 0.001, f = 1.12) and placement (P = 0.011, f = 0.73) phases. Furthermore, the left pEMG lift (P < 0.001, f = 1.46), transport (P = 0.05, f = 0.60), and placement (P = 0.004, f = 0.92) phases were also significantly lower using the SA.

When transferring from a surface to the wheelchair, SA showed significantly lower values at the right (P = 0.006, f = 0.70) and left (P < 0.001, f = 1.07) pEMGs and left iEMG (P = 0.022, f = 0.69). No significant differences were found between the surfaces for the right and left pEMGs. The left side showed lower iEMG values for SA when transferring from the ST to the wheelchair (P = 0.003, f = 0.63). Lower pEMG was seen for the left side at the lift (P = 0.001, f = 1.07), transport (P = 0.003, f = 0.91), and placement (P < 0.001, f = 1.05) phases and the iEMG placement phase (P < 0.001, f = 1.43) with the use of SA.

Latissimus Dorsi

When using SA, the right latissimus dorsi showed significantly lower pEMG (P < 0.001, f = 1.13) and iEMG (P = 0.008, f = 0.75), and for the left pEMG (P = 0.008, f = 0.95), no differences were found between surfaces. Significantly lower pEMG was found at the right latissimus dorsi when using SA during the transport (P < 0.001, f = 0.97) and placement (P < 0.001, f = 1.29) phases.

When transferring the mannequin in the opposite direction, from surface to wheelchair, participants obtained significantly lower latissimus dorsi values for SA on the right pEMG (P < 0.001, f = 1.19) and iEMG (P = 0.001, f = 0.96), as well as left pEMG (P = 0.024, f = 0.97). The SA showed significantly lower right iEMG values for all three surfaces, ST (P < 0.001, f = 1.29), MT (P = 0.028, f = 0.78), and TB (P = 0.012, f = 0.65). Caregivers showed lower iEMG values for the right side during the transport (P = 0.007, f = 0.80) and placement (P < 0.001, f = 1.42) phases.

TABLE 1. Demographics (N = 20)

Sex	
Male	5 (25)
Female	15 (75)
Age, years	33 ± 15
Height, cm	163 ± 15
Weight, kg	68 ± 18
Dominant hand	
Right	17 (85)
Left	3 (15)
Profession	
Personal care attendant (i.e., nurse)	8 (40)
Physical therapist	6 (30)
Occupational therapist	4 (20)
Informal caregiver	2 (10)
Experience, years	9 ± 12
Current employment setting	
Home/community based	10 (50)
Inpatient/hospital	3 (15)
Outpatient	4 (20)
Other	2 (10)
Not known	1 (5)

Data are presented as n (%) or mean ± SD.

Shoulder Muscles Peak and Integrated Percentage EMG

Pectoralis Major

When transferring from wheelchair to surface using the HL, the left pectoralis major muscle activation was lower for iEMG (P = 0.035, f = 0.73), whereas SA was lower for the pEMG on the right side (P = 0.030, f = 0.87). The HL showed significantly lower iEMG values in the left pectoralis major when transferring from wheelchair to MT (P = 0.008, f = 0.78) and was also lower during the transport phase (P < 0.01, f = 1.02). The right pectoralis major showed lower pEMG values using SA during the lift (P = 0.017, f = 0.71) and transport (P = 0.011, f = 0.75) phases.

When transferring from a surface to the wheelchair, significantly lower pEMG values were found at the right side (P = 0.007, f = 1.01) when using SA. No other significant differences were found.

Anterior Deltoid

When transferring from the wheelchair to a surface, lower iEMG values were found for the right anterior deltoid when using HL (P = 0.016, f = 0.55) and lower iEMG values were found during the transport phase (P < 0.001, f = 1.12). However, SA showed lower pEMG values (P = 0.005, f = 1.12).

TABLE 2. Transfer completion times by phase in seconds

		Wheelchair-Surface Transfer (n = 20)			Surface-Wheelchair Transfer (n = 20)		
		L	T	P	L	T	P
Accessible toilet (ST)	HL	14.5 ± 5.2	24.5 ± 7.8	13.3 ± 5.0	12.9 ± 3.0	25.0 ± 7.8	10.8 ± 3.9
	SA	15.3 ± 4.3	21.0 ± 5.9	13.4 ± 2.5	15.7 ± 4.6	22.9 ± 5.9	11.3 ± 5.9
Rehab bench (MT)	HL	11.6 ± 3.7	17.1 ± 4.9	10.0 ± 3.1	11.1 ± 2.7	19.3 ± 7.0	10.0 ± 2.8
	SA	14.1 ± 3.7	20.9 ± 4.6	14.0 ± 8.2	15.5 ± 7.7	19.7 ± 4.9	10.9 ± 4.3
Tub chair (TB)	HL	11.9 ± 3.8	19.6 ± 6.9	9.7 ± 3.7	10.0 ± 2.7	20.0 ± 7.5	9.6 ± 3.3
	SA	15.4 ± 5.6	20.6 ± 6.4	13.0 ± 5.7	14.2 ± 3.7	17.3 ± 3.8	11.3 ± 5.3
Pairwise comparison (*) and P			SA > HL[a] HL*MT[b] HL*TB[c]			HL*MT[a] HL*L[b]	

Data are presented as mean ± SD.

L indicates lift; T, transport; P, placement.

[a] $P < 0.05$.

[b] $P < 0.001$.

[c] $P < 0.01$.

When transferring from a surface to the wheelchair, HL showed significantly lower values for the iEMG on the right side ($P = 0.030$, $f = 1.06$) and left side ($P = 0.001$, $f = 1.03$). No differences were found between the surfaces. The left side showed lower iEMG when using HL for the transport ($P = 0.05$, $f = 1.12$) and placement ($P = 0.050$, $f = 1.06$) phases. The right side showed lower iEMG values when using the HL for the lift ($P = 0.001$, $f = 1.40$) and transport ($P < 0.001$, $f = 1.02$) phases, whereas the placement ($P = 0.015$, $f = 1.42$) phase showed lower values using SA.

DISCUSSION

Overview

The purpose of this study was to compare lower back and shoulder muscle activation during caregiver-assisted transfers using a robotic-assisted transfer device and mechanical lift. When looking at the lower back muscles, significantly lower pEMG values were found in 50% of the cases for the SA *vs.* the HL, and in the other cases, no significant difference was found. Significantly lower iEMG values were found in 25% of the cases in favor of SA *vs.* HL; there were no significant differences in the other cases. Lower iEMG was seen with SA when performing transfers to the toilet. Therefore, the first hypothesis is accepted, that the lower back muscles show lower muscle activity during a SA transfer when compared with those performed with the HL.

When examining the shoulder muscles, significantly lower pEMG values were found in 18% of trials in favor of SA *vs.* 0% in favor of HL. Significantly lower iEMG was found in 0% using SA *vs.* 25% when using HL. No differences were found within the three surfaces. When adjusted for phase, lower muscle activation was required for the HL transfers in the transport phase in 25% of cases, compared with 7% for the SA. However, SA required lower activity in 13% of the cases in the placement phase. Therefore, the second hypothesis is rejected, that shoulder muscles would show lower muscle activity over the entire transfer when using HL as compared with lower peak activity with the use SA.

Despite the statistical significance between the two devices, there is not enough evidence to show a clinically meaningful difference in EMG values between the two transfer devices. For instance, although pEMG and iEMG values were smaller, in addition to large effect sizes, in the erector spinae and latissimus dorsi using the SA, those values alone are not enough to ensure a clinically significant reduction in muscular demand of SA as compared with HL for reducing the risk of musculoskeletal injury in caregivers performing assisted transfers. In addition, a main effect difference of 2 secs was found for transfer times; however, that is not enough to prove a clinical significance. Nevertheless, the implementation of robots does improve the efficiency and reduces self-perceived demand required to complete a transfer. These facets, combined with the statistically lower EMG values, reveal interesting implications of the SA's clinical capabilities.

Statistical Interpretation

Lower muscle activation at the placement phases implied that the SA required lower muscle activation in the erector spinae and latissimus dorsi. This is potentially because of the automated components of the SA in contrast to the manual components of the HL, which uses more space to complete a safe and effective transfer. The automated controls, coupled with reduced back muscle activation, potentially reduced push and pull effort on the caregiver, in addition to the spatial constraints that caregivers typically experience in a real-world environment.[7] This may explain the appeal of the SA at the toilet as reported by the participants.[23]

The results of this article, accompanied by those reported by Greenhalgh et al.,[23] which assessed task demand from caregivers, indicate lower strain when using the SA versus the HL. The lower muscle activation in the back reported in this article supports Greenhalgh et al.'s findings: that caregivers reported significantly lower physical demand with SA compared with the mechanical floor lift.[23] This indicates a potential correlation

TABLE 3. Peak percentage EMG and integrated percentage EMG per second during a wheelchair to surface transfer

Wheelchair to Surface			Accessible Toilet (ST)			Rehab Bench (MT)			Tub Chair (TB)			Comparison (*), *P*
			L	T	P	L	T	P	L	T	P	
R-erector spinae	Peak (%MVC) (n = 19)	HL	58 ± 67	41 ± 29	35 ± 23	40 ± 29	57 ± 63	46 ± 41	38 ± 30	86 ± 114	58 ± 82	HL > SA[a]
		SA	23 ± 16	29 ± 23	26 ± 15	21 ± 12	32 ± 22	29 ± 14	21 ± 14	33 ± 23	26 ± 15	
	Integrated (%MVC.s) (n = 19)	HL	3,701 ± 2,989	5,974 ± 4,036	3,703 ± 3,133	2,490 ± 2,294	3,407 ± 3,109	4,302 ± 2,596	3,079 ± 3,191	3,331 ± 3,643	4,508 ± 3,103	SA*ST[b]
		SA	2,824 ± 2,467	4,420 ± 3,548	2,672 ± 2,021	2,309 ± 1,792	5,035 ± 3,801	3,354 ± 3,754	2,398 ± 2,405	4,918 ± 4,318	2,599 ± 2,390	SA*P[a]
L-erector spinae	Peak (%MVC) (n = 18)	HL	78 ± 70	41 ± 32	42 ± 19	50 ± 25	85 ± 84	46 ± 32	51 ± 33	107 ± 125	62 ± 84	HL > SA[c]
		SA	18 ± 12	30 ± 16	27 ± 15	20 ± 15	36 ± 25	27 ± 15	17 ± 13	31 ± 18	23 ± 13	SA*L[c] SA*T[a] SA*P[a]
	Integrated (%MVC.s) (n = 18)	HL	5,136 ± 3,630	5,533 ± 4,148	4,466 ± 2,783	3,355 ± 1,988	4,008 ± 2,942	4,117 ± 2,541	4,120 ± 3,180	3,933 ± 3,073	4,430 ± 3,064	HL > SA[b]
		SA	1,978 ± 1,625	4,309 ± 2,008	2,832 ± 1,870	2,044 ± 2,479	5,190 ± 3,492	3,357 ± 3,323	1,741 ± 1,482	4,204 ± 2,721	2,209 ± 1,725	SA*ST[a] SA*TB[a] SA*L[c] SA*P[b]
R-latissimus dorsi	Peak (%MVC) (n = 17)	HL	74 ± 58	65 ± 63	31 ± 25	50 ± 90	77 ± 70	47 ± 35	47 ± 85	84 ± 84	67 ± 75	HL > SA[c]
		SA	18 ± 9	24 ± 16	18 ± 10	19 ± 10	27 ± 17	26 ± 23	17 ± 10	25 ± 15	20 ± 19	SA*T[c] SA*P[c]
	Integrated (%MVC.s) (n = 17)	HL	4,862 ± 3,500	7,329 ± 5,614	3,059 ± 3,429	2,586 ± 3,665	4,500 ± 4,436	4,739 ± 3,348	3,340 ± 6,485	4,324 ± 4,218	5,558 ± 4,297	HL > SA[a]
		SA	2,512 ± 2,299	4,276 ± 4,360	2,146 ± 1,780	2,174 ± 1,791	4,401 ± 3,729	3,335 ± 5,552	2,104 ± 1,850	3,948 ± 3,641	2,230 ± 2,871	
L-latissimus dorsi	Peak (%MVC) (n = 18)	HL	49 ± 47	74 ± 59	35 ± 21	47 ± 42	45 ± 35	59 ± 40	55 ± 93	113 ± 150	98 ± 114	HL > SA[a]
		SA	28 ± 22	29 ± 21	27 ± 19	29 ± 26	39 ± 39	29 ± 22	27 ± 20	28 ± 20	30 ± 23	
	Integrated (%MVC.s) (n = 18)	HL	6,075 ± 9,296	10,051 ± 10,305	5,150 ± 6,722	3,279 ± 3,274	3,072 ± 2,352	6,231 ± 5,245	3,731 ± 4,741	7,894 ± 15,262	13,784 ± 24,579	SA*ST[b]
		SA	2,759 ± 2,319	3,770 ± 1,968	2,307 ± 1,497	2,545 ± 2,686	4,926 ± 4,404	2,825 ± 3,155	2,594 ± 1,969	3,794 ± 2,472	2,819 ± 2,768	SA*P[b]
R-pectoralis major	Peak (%MVC) (n = 19)	HL	111 ± 165	82 ± 195	78 ± 213	72 ± 179	97 ± 119	61 ± 99	66 ± 143	143 ± 181	78 ± 131	HL > SA[b]
		SA	62 ± 135	45 ± 53	33 ± 38	58 ± 131	39 ± 40	36 ± 47	52 ± 103	66 ± 141	35 ± 46	SA*L[b] SA*T[b]
	Integrated (%MVC.s) (n = 19)	HL	7,100 ± 9,131	9,550 ± 20,906	5,278 ± 13,538	4,501 ± 12,130	6,333 ± 10,405	5,415 ± 9,726	3,924 ± 8,091	5,822 ± 8,028	5,961 ± 10,865	–
		SA	9,615 ± 26,450	6,523 ± 8,288	2,738 ± 3,603	6,199 ± 14,536	6,017 ± 8,200	2,747 ± 3,410	8,093 ± 21,765	8,121 ± 16,300	2,683 ± 3,226	
L-pectoralis major	Peak (%MVC) (n = 19)	HL	61 ± 70	85 ± 108	59 ± 69	71 ± 99	67 ± 66	76 ± 89	59 ± 71	106 ± 138	105 ± 129	–
		SA	61 ± 72	71 ± 90	71 ± 92	59 ± 63	76 ± 83	75 ± 75	61 ± 74	76 ± 91	63 ± 68	
	Integrated (%MVC.s) (n = 19)	HL	3,060 ± 2,619	10,531 ± 20,006	3,230 ± 4,036	2,923 ± 5,358	2,942 ± 3,319	6,051 ± 8,519	2,823 ± 3,210	3,260 ± 3,518	6,198 ± 7,728	SA > HL[b]
		SA	5,903 ± 10,891	10,173 ± 17,801	5,540 ± 7,421	4,223 ± 4,453	12,336 ± 18,543	7,081 ± 9,428	5,721 ± 11,445	10,682 ± 18,648	4,516 ± 4,933	HL*MT[a] HL*T[b]

R-anterior deltoid	Peak (%MVC) ($n = 18$)	HL	48 ± 51	24 ± 17	24 ± 16	24 ± 16	48 ± 48	23 ± 12	20 ± 10	80 ± 112	42 ± 76	HL > SA[b]
		SA	19 ± 13	33 ± 15	16 ± 9	17 ± 10	37 ± 17	19 ± 13	17 ± 12	33 ± 14	16 ± 9	
	Integrated (%MVC.s) ($n = 18$)	HL	3,239 ± 3,446	2,087 ± 1,131	1,886 ± 1,295	1,686 ± 1,505	2,303 ± 2,203	1,744 ± 9,18	1,554 ± 9,63	2,281 ± 2,359	1,817 ± 1,102	SA > HL[b]
		SA	2,875 ± 2,274	5,306 ± 2,153	1,716 ± 1,048	2,198 ± 1,664	6,052 ± 3,575	2,903 ± 3,548	2,315 ± 2,368	4,859 ± 2,436	1,515 ± 8,66	HL*T[c]
L-anterior deltoid	Peak (%MVC) ($n = 19$)	HL	9 ± 8	25 ± 15	13 ± 9	12 ± 9	11 ± 8	24 ± 13	12 ± 12	43 ± 104	47 ± 76	SA*P[b]
		SA	15 ± 12	16 ± 14	11 ± 9	20 ± 17	28 ± 18	21 ± 22	14 ± 12	20 ± 14	7 ± 3	
	Integrated (%MVC.s) ($n = 19$)	HL	1,356 ± 6,16	2,475 ± 2,375	1,293 ± 8,75	1,229 ± 1,330	2,299 ± 2,399	3,049 ± 2,683	2,610 ± 2,246	657 ± 632	1,843 ± 1,137	HL*T[a]
		SA	1,866 ± 1,748	2,459 ± 2,281	1,122 ± 1,218	2,208 ± 2,171	4,301 ± 3,203	2,198 ± 2,457	1,696 ± 1,834	2,589 ± 2,025	938 ± 1,628	SA*P[b]

Data are presented as mean ± SD.
Peak denotes %MVC; Int, %MVC.s.
L indicates lift; T, transport; P, placement.
[a] $P < 0.01$.
[b] $P < 0.05$.
[c] $P < 0.001$.

between self-reported physical demand and muscle activation in both formal and informal caregivers. The mannequin was lifted using a joystick instead of a lever, requiring less repetitive movements and thus potentially reducing the chance of overexertion in the lower back and shoulder. This indirectly provides evidence that SA has the potential to reduce risks for low back and shoulder pain in caregivers. With lower self-reported transfer demands and required muscle activity, caregivers should be less likely to report work-related pain and fatigue, potentially improving the quality of care delivery.

Whereas muscle activation was lower in the lower back muscles when using SA, the integrated muscle activity was lower in the shoulder muscles, particularly during HL transfers. An explanation is that the shoulder handling needed for SA's joystick required more static positioning of the shoulders and chest while pushing and pulling the HL. To control the joystick, extension of the shoulder was needed throughout much of the trial, owing to the placement of the joystick around shoulder-height.

Clinical Interpretation

The results of this study indicate that transfers using the robotic-assisted transfer device were as effective, and some cases better, than those performed using the clinical standard.[19,23,31,32] Between International Observational Standards/National Institute of Occupational Safety and Health standards and results of previous literature, the HL mechanical floor lift is intended to reduce the load that a caregiver experiences during patient handling and moving tasks.[2,3,5] The SA design, coupled with reduced muscle activation in the back, indicated reduced load required by the caregiver to assist with transfers.[32] For instance, the SA joystick used in this study required no more than 3 N of operating force when performing transfers.[19,32] Data on transfers using an automated ceiling lift showed higher forces than those required to operate the SA.[3] A conventional floor lift, similar to the HL, has been shown to require 86 N of initial forward force to push and pull a care recipient to a target destination on a vinyl covered concrete floor.[33,34] Because of the lower operating force required for SA, compared with a floor lift, lower back muscles may not fire with the same intensity as they would during an HL transfer. This was confirmed with this study's muscle activation data. In addition, erector spinae pEMG in caregivers using the SA were similar to erector spinae pEMG in caregivers using the automated ceiling lift, which represented lower activation than the floor lift and manual lifting in previous literature.[3] Unlike a ceiling lift, however, the SA has the potential for use outside of a clinical or fixed environment.[3,33] Based on the demographics of caregivers represented in this study, many participants were working in a home/community-based setting (50%), settings that require caregivers working in confined and challenging areas within the home, as well as inaccessible community settings, in which a traditional Hoyer lift is not an option and/or very difficult and awkward to use, thereby exposing caregivers and end users to risk of injuries. By implementing a powered system on a portable device (i.e., the wheelchair), caregivers have a mechanism to transfer a person in small confined areas within the home, as well as have use the system when out in the community, which would provide full access to all wheelchair-accessible bathrooms, which are typically not

TABLE 4. Peak percentage EMG and integrated percentage EMG per second during a surface to wheelchair transfer

Surface to Wheelchair			Accessible Toilet (ST)			Rehab Bench (MT)			Tub Chair (TB)			Comparison (*), *P*
			L	T	P	L	T	L	T	P	L	
R-erector spinae	Peak (%MVC) (n = 18)	HL	55 ± 52	47 ± 32	47 ± 41	34 ± 23	61 ± 56	54 ± 48	65 ± 87	68 ± 79	72 ± 82	HL > SA[a]
		SA	25 ± 18	33 ± 23	24 ± 14	24 ± 16	34 ± 18	23 ± 13	26 ± 19	32 ± 21	19 ± 13	
	Integrated (%MVC.s) (n = 18)	HL	3,684 ± 3,189	6,957 ± 4,428	4,591 ± 3,066	2,969 ± 2,955	4,411 ± 5,885	4,965 ± 3,303	2,348 ± 1,625	4,696 ± 4,160	3,223 ± 3,386	SA*ST[b] SA*P[a]
		SA	2,972 ± 3,036	5,148 ± 4,050	2,218 ± 2,799	2,630 ± 1,939	4,651 ± 3,505	1,842 ± 1,686	3,072 ± 3,673	4,097 ± 3,441	1,792 ± 1,947	
L-erector spinae	Peak (%MVC) (n = 18)	HL	75 ± 54	45 ± 27	54 ± 44	46 ± 23	77 ± 52	57 ± 51	72 ± 85	72 ± 77	80 ± 53	HL > SA[c] SA*L[a] SA*T[a] SA*P[c]
		SA	28 ± 15	31 ± 15	22 ± 15	35 ± 25	36 ± 24	20 ± 13	28 ± 18	33 ± 31	16 ± 12	
	Integrated (%MVC.s) (n = 18)	HL	4,663 ± 3,572	6,034 ± 4,642	4,696 ± 2,838	3,703 ± 2,668	4,914 ± 5,169	4,862 ± 3,278	3,027 ± 1,564	4,489 ± 3,823	3,502 ± 2,488	HL > SA[b] SA*ST[a] SA*P[c]
		SA	3,194 ± 1,830	4,094 ± 2,252	1,619 ± 1,631	4,193 ± 3,623	4,852 ± 4,341	1,630 ± 1,382	3,154 ± 2,288	3,635 ± 3,107	1,399 ± 1,457	
R-latissimus dorsi	Peak (%MVC) (n = 17)	HL	84 ± 89	67 ± 41	50 ± 27	40 ± 52	84 ± 71	67 ± 48	62 ± 88	72 ± 50	82 ± 72	HL > SA[c]
		SA	20 ± 11	25 ± 19	17 ± 11	21 ± 10	24 ± 13	18 ± 14	19 ± 13	22 ± 11	15 ± 13	
	Integrated (%MVC.s) (n = 17)	HL	5,072 ± 4,412	9,199 ± 7,942	5,125 ± 4,309	2,623 ± 4,148	6,456 ± 11,389	6,544 ± 5,442	2,605 ± 3,071	6,114 ± 5,331	3,539 ± 3,087	HL > SA[a] SA*ST[c] SA*MT[b] SA*TB[b] SA*T[a] SA*P[c]
		SA	2,543 ± 2,065	4,000 ± 3,799	1,755 ± 2,605	2,886 ± 2,540	3,256 ± 2,439	1,729 ± 2,271	2,740 ± 3,192	2,988 ± 2,259	1,585 ± 2,148	
L-latissimus dorsi	Peak (%MVC) (n = 17)	HL	77 ± 112	56 ± 36	71 ± 67	40 ± 25	50 ± 41	57 ± 37	76 ± 94	90 ± 123	81 ± 124	HL > SA[b]
		SA	31 ± 22	33 ± 22	29 ± 21	32 ± 25	34 ± 25	32 ± 28	30 ± 21	31 ± 21	25 ± 21	
	Integrated (%MVC.s) (n = 17)	HL	6,918 ± 11,175	14,211 ± 23,850	5,529 ± 3,611	3,258 ± 3,140	3,987 ± 5,340	9,542 ± 14,692	6,059 ± 10,445	9,028 ± 14,609	3,099 ± 2,758	SA*ST[b] SA*P[a]
		SA	2,864 ± 2,161	4,875 ± 3,946	1,869 ± 1,719	3,482 ± 3,541	4,214 ± 3,502	2,053 ± 1,907	2,496 ± 1,794	3,149 ± 2,149	1,812 ± 1,828	
R-pectoralis major	Peak (%MVC) (n = 18)	HL	116 ± 175	55 ± 90	95 ± 244	66 ± 137	126 ± 195	64 ± 116	73 ± 130	80 ± 131	99 ± 131	HL > SA[a]
		SA	69 ± 163	60 ± 124	76 ± 237	37 ± 35	41 ± 62	33 ± 62	45 ± 61	43 ± 80	34 ± 56	
	Integrated (%MVC.s) (n = 18)	HL	8,164 ± 14,733	9,399 ± 22,113	6,344 ± 14,356	4,044 ± 8,701	7,083 ± 11,248	7,811 ± 19,950	3,379 ± 7,921	6,654 ± 13,589	5,009 ± 7,152	SA*P[b]
		SA	8,202 ± 21,134	15,626 ± 50,191	4,671 ± 13,723	4,387 ± 4,467	5,799 ± 11,083	2,728 ± 5,979	6,340 ± 12,440	5,243 ± 10,835	2,939 ± 5,910	
L-pectoralis major	Peak (%MVC) (n = 18)	HL	60 ± 59	94 ± 119	101 ± 154	75 ± 96	67 ± 71	89 ± 114	95 ± 117	105 ± 156	64 ± 68	–
		SA	64 ± 62	70 ± 77	71 ± 124	64 ± 73	74 ± 83	62 ± 98	64 ± 59	63 ± 64	57 ± 69	
	Integrated (%MVC.s) (n = 18)	HL	3,347 ± 3,831	12,282 ± 19,163	7,018 ± 12,495	2,337 ± 2,273	3,599 ± 5,064	7,498 ± 10,895	4,424 ± 10,599	7,251 ± 12,165	2,365 ± 2,128	HL*TB[b] HL*L[a] SA*P[c]
		SA	4,651 ± 3,732	8,970 ± 11,744	3,408 ± 6,338	5,971 ± 7,661	8,599 ± 13,139	4,058 ± 9,253	6,014 ± 7,986	7,214 ± 10,116	3,806 ± 7,543	

R-anterior deltoid	Peak (%MVC) (n = 18)	HL	50 ± 54	27 ± 17	28 ± 15	20 ± 10	49 ± 51	28 ± 12	38 ± 79	38 ± 43	47 ± 65	SA*P[a]
		SA	33 ± 21	32 ± 19	12 ± 10	33 ± 19	35 ± 26	12 ± 7	29 ± 13	31 ± 15	11 ± 10	
	Integrated (%MVC.s) (n = 18)	HL	2,984 ± 3,066	2,384 ± 1,305	2,623 ± 1,942	1,233 ± 845	2,237 ± 2,233	1,971 ± 1,092	1,352 ± 1,154	2,146 ± 1,899	1,918 ± 2,298	SA > HL[b]
		SA	4,019 ± 2,255	5,018 ± 3,305	1,383 ± 1,667	4,700 ± 3,226	4,491 ± 3,465	1,350 ± 1,467	3,995 ± 2,854	3,661 ± 2,540	1,121 ± 1,202	HL*L[a] HL*T[a] SA*P[b]
L-anterior deltoid	Peak (%MVC) (n = 18)	HL	11 ± 10	25 ± 16	20 ± 10	10 ± 7	11 ± 10	28 ± 18	28 ± 77	18 ± 13	10 ± 10	HL*MT[b] HL*T[a]
		SA	11 ± 10	27 ± 27	21 ± 18	19 ± 18	38 ± 33	21 ± 13	19 ± 28	36 ± 31	13 ± 15	
	Integrated (%MVC.s) (n = 18)	HL	1,259 ± 738	678 ± 479	1,278 ± 670	2,869 ± 2,422	3,134 ± 2,266	1,800 ± 1,859	702 ± 510	1,416 ± 8,66	605 ± 528	SA > HL[a]
		SA	1,438 ± 1,652	5,341 ± 5,087	1,494 ± 1,313	2,475 ± 2,626	5,611 ± 4,953	1,629 ± 1,224	1,861 ± 2,439	4,846 ± 4,171	1,397 ± 1,338	HL*T[c] HL*P[b]

Data are presented as mean ± SD.
Peak denotes %MVC; Int, %MVC.s.
L indicates lift; T, transport; P, placement.
[a] $P < 0.01$.
[b] $P < 0.05$.
[c] $P < 0.001$.

accessible to end users who rely on transfer devices, and these public facilities are not equipped with mechanical transfer assist options. An important quality of life benefit of portable powered transfer devices would allow end users to expand their daily activities beyond their homes and extend time and activities out in the community, knowing that their need for safe transfers and also the need for a safe transfer option for their caregivers are met, as the results of this study show that use of the SA reduces the load placed on the muscles in the back while in unique nonclinical environments.[3,19,23,31–34]

Peak %MVC showed percentages greater than 100% in some cases, which can be interpreted in two ways. One interpretation is that transfers with the HL required more muscle activity than with the MVC collection, because all percentages greater than 100 are seen when the HL was used. Another interpretation is that the MVC was not a true reflection of the maximal muscle activation required to complete a safe transfer. It is likely that participants may have exerted more effort during the transfer tasks with the HL than during the MVC task. People do not typically maximally activate muscles during everyday life. It is important to note that there were cases with the HL where participants were exerting greater than MVC effort and it is relevant that effort is substantially decreased between devices. However, these circumstances would not influence the overall outcomes because the comparisons were performed as within-subject comparisons. Comparable methods have been used in previous studies.[3,15,35,36]

Limitations and Further Directions

This study used snowball recruiting for participants, reducing generalizability. Lack of homogeneity created potential bias in the results. These differences potentially had an impact on the transfer technique as well as familiarity with the technologies. It also potentially explains notably lower variations in EMG values when the SA is used. This was seen throughout all muscles and especially within the pEMG. For instance, at the right erector spinae, the HL showed pEMG standard deviations between 23% and 114%, whereas SA showed pEMG standard deviations between 12% and 23%. Formal caregivers possibly have more experience using the HL compared with the informal caregivers, possibly creating variability in outcomes, whereas all participants were new to the use of the SA. However, another explanation can be the consistency in the use of the SA, lowering the risk of unexpected sudden movements, making the device safer in use. The SA experienced several mechanical and software malfunctions that required some participants (n = 3) to return to the laboratory to complete the protocol.

A future ergonomic and biomechanical analysis incorporating mobility device users would be beneficial to further assess the SA as an intervention for transfer-related strain and fatigue.

CONCLUSION

Assessment of muscle activation during transfers using the robotic-assisted transfer device compared with the clinical standard of care showed reduced peak and integrated lower back muscle activation during transfers from a wheelchair to common transfer surfaces and vice versa.

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REFERENCES

1. ISO/TR 12296:2012(en), Ergonomics—Manual handling of people in the healthcare sector. Available at: https://www.iso.org/obp/ui/#iso:std:iso:tr:12296:ed-1:v1:en. Accessed April 23, 2020
2. Waters T, Collins J, Galinsky T, et al: NIOSH research efforts to prevent musculoskeletal disorders in the healthcare industry. *Orthop Nurs* 2006;25:380–9
3. Keir PJ, MacDonell CW: Muscle activity during patient transfers: A preliminary study on the influence of lift assists and experience. *Ergonomics* 2004;47:296–306
4. Santaguida PL, Pierrynowski M, Goldsmith C, et al: Comparison of cumulative low back loads of caregivers when transferring patients using overhead and floor mechanical lifting devices. *Clin Biomech (Bristol, Avon)* 2005;20:906–91
5. Hignett S, Fray M, Battevi N, et al: International consensus on manual handling of people in the healthcare sector: Technical report ISO/TR 12296. *Int J Ind Ergon* 2014;44:191–5
6. Dicianno BE, Joseph J, Eckstein S, et al: The voice of the consumer: A survey of veterans and other users of assistive technology. *Mil Med* 2018;183(11–12):e518–25
7. Sivaprakasam A, Wang H, Cooper RA, et al: Innovation in transfer assist technologies for persons with severe disabilities and their caregivers. *IEEE Potentials* 2017;36:34–41
8. Family Caregiver Alliance, National Center on Caregiving: Caregiver statistics: Demographics. 2016. Available at: https://www.caregiver.org/caregiver-statistics-demographics. Accessed January 23, 2019
9. Ribeiro T, Serranheira F, Loureiro H: Work related musculoskeletal disorders in primary health care nurses. *Appl Nurs Res* 2017;33:72–7
10. Darragh AR, Sommerich CM, Lavender SA, et al: Musculoskeletal discomfort, physical demand, and caregiving activities in informal caregivers. *J Appl Gerontol* 2015;34:734–60
11. Grindle GG, Wang H, Jeannis H, et al: Design and user evaluation of a wheelchair mounted robotic assisted transfer device. *Biomed Res Int* 2015;2015:198476
12. Pompeii LA, Lipscomb HJ, Schoenfisch AL, et al: Musculoskeletal injuries resulting from patient handling tasks among hospital workers. *Am J Ind Med* 2009;52:571–8
13. Hoyerlifts.com. Hoyer Advance-H Power Patient Lift. Available at: https://www.1800wheelchair.com/product/hoyer-advance-h-patient-lift/?acc=c9f0f895fb98ab9159f51fd0297e236d#details. Accessed February 5, 2019
14. US Food & Drug Administration: General hospital devices and supplies—Patient lifts. 2018. Available at: https://www.fda.gov/medicaldevices/productsandmedicalprocedures/generalhospitaldevicesandsupplies/ucm308622.htm. Accessed April 11, 2019
15. Daynard D, Yassi A, Cooper JE, et al: Biomechanical analysis of peak and cumulative spinal loads during simulated patient-handling activities: A substudy of a randomized controlled trial to prevent lift and transfer injury of health care workers. *Appl Ergon* 2001;32:199–214
16. Sivakanthan S, Blaauw E, Greenhalgh M, et al: Person transfer assist systems: A literature review. *Disabil Rehabil Assist Technol* 2021;16:270–9
17. Nelson A, Baptiste AS: Evidence-based practices for safe patient handling and movement. *Clin Rev Bone Miner Metab* 2006;4:55–70
18. Broadbent E, Stafford R, MacDonald B: Acceptance of healthcare robots for the older population: Review and future directions. *Int J Soc Robot* 2009;1:319–30
19. Jeannis H, Grindle GG, Kelleher A, et al: Initial development of direct interaction for a transfer robotic Arm system for caregivers. In: 2013 IEEE 13th International Conference on Rehabilitation Robotics (ICORR). Vol 2013. Seattle, WA, IEEE, 2013:1–5. doi:10.1109/ICORR.2013.6650390
20. Chung C-S, Wang H, Cooper RA: Functional assessment and performance evaluation for assistive robotic manipulators: Literature review. *J Spinal Cord Med* 2013;36:273–89
21. Joerns Healthcare: Hoyer® Advance. Available at: https://www.joerns.com/product/2473/Hoyer®-Advance.aspx. Accessed May 2, 2019
22. Wang H, Xu J, Grindle G, et al: Performance evaluation of the Personal Mobility And Manipulation Appliance (PerMMA). *Med Eng Phys* 2013;35:1613–9
23. Greenhalgh M, Landis JM, Brown J, et al: Assessment of usability and task load demand using a robot-assisted transfer device compared with a Hoyer Advance for dependent wheelchair transfers. *Am J Phys Med Rehabil* 2019;98:729–34
24. The SENIAM project. Available at: http://www.seniam.org/. Accessed January 10, 2020
25. Basmajian JV: Electromyography—Dynamic gross anatomy: A review. *Am J Anat* 1980;159:245–60
26. Dummies Unlimited Inc: Survivor. Available at: https://www.dummiesunlimited.com/survivor-. Accessed May 2, 2019
27. RehabMart.com. Mat tables | physical therapy equipment. Available at: https://www.rehabmart.com/category/mat_table.htm. Accessed April 30, 2019
28. Walgreens: Bath and shower chairs. Available at: https://www.walgreens.com/q/bath+and+shower+chairs?No=24. Accessed April 30, 2019
29. Food and Drug Administration: *Patient Lifts Safety Guide*. Available at: https://www.fda.gov/files/medical devices/published/Patient-Lifts-Safety-Guide.pdf. Accessed May 2, 2019
30. Konrad P: *The ABC of EMG. A Practical Introduction to Kinesiological Electromyography.* 2005. Available at: https://hermanwallace.com/download/The_ABC_of_EMG_by_Peter_Konrad.pdf. Accessed May 2, 2019
31. Burkman J, Grindle G, Wang H, et al: Further development of a robotic-assisted transfer device. *Top Spinal Cord Inj Rehabil* 2017;23:140–6
32. Cooper RA, Grindle GG, McCartney M: "Robotic Strong Arm"; US Patent No 9,254,234. 2016. Available at: https://patents.google.com/patent/US9254234B2/en. Accessed February 5, 2019
33. Lachance CC, Korall AM, Russell CM, et al: External hand forces exerted by long-term care staff to push floor-based lifts: Effects of flooring system and resident weight. *Hum Factors* 2016;58:927–43
34. Rice MS, Woolley SM, Waters TR: Comparison of required operating forces between floor-based and overhead-mounted patient lifting devices. *Ergonomics* 2009;52:112–20
35. Norman R, Wells R, Neumann P, et al: A comparison of peak vs cumulative physical work exposure risk factors for the reporting of low back pain in the automotive industry. *Clin Biomech* 1998;13:561–73
36. Burnfield JM, Shu Y, Buster TW, et al: Kinematic and electromyographic analyses of normal and device-assisted sit-to-stand transfers. *Gait Posture* 2012;36:516–22