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The ergonomic impact of a mattress lift tool and bottom sheet type on hotel room cleaners while making beds

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ABSTRACT

The purpose of this study was to quantify biomechanical and cardiovascular exposure while making beds with and without interventions (mattress lift tool and fitted sheet). Sixteen female hotel room cleaners participated in this multifactorial (tool and sheet) laboratory study of crossover design. Exertion in the upper extremity (< 2) and back (< 3) was consistently lower when using the tool and fitted sheet ($p < 0.05$). The average number of lifts per bed was reduced by 48% with an 18 s increase in cycle time per bed. Peak forearm flexor activity was significantly lower when using a tool($p < 0.05$). Spinal lateral plane range of motion ($p < 0.02$) and maximum twisting velocity ($p < 0.03$) were lowest using the tool and fitted sheet together. Interventions such as a mattress lift tool used with a fitted sheet reduced the number of mattress lifts and lowered perceived exertion among hotel room cleaners while making beds.

1. Introduction

According to the Bureau of Labor Statistics (2017), there are approximately 922,660 people work as maids and housekeeping cleaners, more than half of which work in hotels. Additionally, hotel housekeepers comprise about 23.5% of the employees in their industry and have the greatest risk for developing musculoskeletal disorders (MSDs) based on psychosocial (Krause et al., 2009) and physical risk factors (Krause et al., 2005). Hotel room cleaners are primarily female, many of whom have immigrated from other countries(Wial and Rickert, 2002), and are required to clean up to 15 rooms per shift, which could require making up to 25 beds.

The rate of overall injuries and MSDs among hotel room cleaners is higher than any other type of hotel worker at 7.9/100 workers and 3.2/100 workers, respectively (Buchanan et al., 2010). In a study by Premji and Krause (2010), 78% among those surveyed had work-related pain in the past 12 months and 47% missed at least one day of work due to their symptoms. The average number of days lost due to work-related pain was six days. Sixty-two percent visited a medical doctor for their pain and 66% reported taking medication just to get through their workday. Hotel room cleaners are acquiring injuries and it is affecting their ability to work.

According to the New York Times (2006), the Westin Hotel chain introduced a luxurious mattress in 1999 that set off “hotel bed wars”, which resulted in hotels installing increasingly larger, luxurious mattresses. Consultants have documented increased lifting when making the luxurious mattresses that could be contributing to the higher injury rates reported in this job sector. However, there is a lack of literature on quantified biomechanical and physiological workloads while making hotel beds.

Two existing interventions could modify the workload while making beds. A mattress lift tool advertised to reduce lift requirements for hotel bed making is commercially available, yet has not been assessed for usability nor impact on workload. The tool is a wedge with a handle (Fig. 1) that is placed between the box spring and the mattress elevating the mattress just enough to allow tucking of the sheets and comforter (Fig. 2b). The tool weighs 12oz and is 13.3 cm tall by 39.8 cm long by 7.8 cm with a 22.5° slope. There is only one size for all users. The concept is to slide the wedge between the box spring and the mattress causing enough of a gap to allow the tucking of bedding without any

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Fig. 1. Picture of the mattress lift tool from the (a) side and (b) top.

Fig. 2. Laboratory set up of hotel room bed with side tables showing a corner lift (a) without a tool and (b) with a tool.

manual lifting of the mattress. The use of fitted bottom sheets (sheets with elastic on the corners) instead of flat sheets (no elasticity on the corners; a simple rectangular sheet) may also impact workload during bed making. Hotels prefer the flat sheets because they are easier to clean and maintain; fitted sheets tend to lose their elasticity. However, hotel room cleaners argue that flat sheets require more mattress lifting and tucking to adequately secure them, preferring instead to use appropriately sized fitted sheets which require minimal to no lifting of the mattresses. There are no rigorous laboratory or field studies published on the impact of either intervention used individually or together. Therefore, the primary purpose of this study was to quantify the biomechanical and physiological workload on hotel room cleaners while making luxurious beds with and without a mattress lift tool, and while using a flat versus a fitted sheet. Additionally, the usability of both interventions was explored.

2. Methods

2.1. Participants

Sixteen English, Cantonese or Spanish-speaking female hotel room cleaners from the local San Francisco and East Bay Unions with at least six months of experience were invited to participate in this laboratory study. Participants who provided informed consent were surveyed for information on personal characteristics, work experience, discomfort, and prior injuries. Exclusion criteria included an active or recently filed (within 1 year) workers compensation claim, or severe pain (6 or greater on a 10 point pain intensity scale) in the spine or extremities during the past week. This research complied with the American Psychological Association Code of Ethics and was approved by the Institutional Review Board at Samuel Merritt University.

2.2. Study design

This was an intervention study with four conditions of crossover design performed in a laboratory setting, which is treated as a one-way repeated-measures design, with four levels. There were two interventions being tested: a mattress lift tool (versus no tool) (Fig. 1; Bedmade EZ, Cadence Keen, West Palm Beach, Fl), and a fitted bottom sheet (versus a flat bottom sheet). The bed used was a luxury queen sized pillow top mattress (60″wide x 80″long x 13.5″high) and boxspring (9″ high) offered by the Hyatt (www.hyattathome.com). The top of the mattress was set at a height of 30″ from the floor. Nightstands were created out of PVC pipes to prevent camera obstruction of body landmarks and placed by the head of the bed to mimic the hotel room environment. Bedding (sheets and comforter) was from the Hyatt at Home series. The luminance in the laboratory was consistent across all conditions at 570 lux.

2.3. Procedures

After informed consent was collected, a questionnaire was administered to collect information on demographics, typical work patterns, and discomfort experience. Height, weight, and blood pressure were measured. Participants were introduced to the tool and allowed up to 20 min of practice followed by an equal amount of rest. To control for the effects from fatigue, the order of testing was randomized and included 2 trials each of 4 conditions (tool/flat sheet; tool/fitted sheet; no tool/flat sheet; no tool/fitted sheet) for a total of 8 trials. Each trial was timed and there was approximately 2–5 min of rest time provided between trials with a 15-min rest after 4 trials (2 conditions). Data were collected on the task level and included removal of bedding (sheets and comforter), placement of new bedding (sheets and comforter), and tucking of bedding. Although pillows were removed and replaced each time, pillow case removal/placement was not part of the bedmaking task.

2.4. Instrumentation & outcome measures

Muscle surface electromyographical (sEMG) activity of the flexor digitorum superficialis (FDS), extensor digitorum (ED), biceps brachii (BB), and middle deltoid (MD) muscles was collected at a sampling rate of 2000 Hz during each trial using bipolar pre-amplified surface sEMG electrodes (Delsys, Inc., Natick, MA), and placed according to recommended anatomical locations (Perotto, 2005). These muscles were chosen to assess hand exertion (FDS & ED), elbow flexion (BB) and shoulder abduction (MD) while making the bed; other muscles of interest for the back and shoulder were not possible due to interference from the lumbar motion monitor. Three maximum voluntary contractions (MVCs) for each muscle were elicited by maximally resisting appropriate joint motions that best isolated each muscle for 3–5 s (Kendall et al., 2005). All sEMG data were band-pass filtered (10–400 Hz), full-wave rectified and low-pass filtered using a Butterworth 2nd order filter with a 5 Hz cut-off creating linear envelope sEMG (LE-sEMG). Ultimately, the MVC was the mean value for each maximum muscle contraction calculated from the middle 2 s of the LE-sEMG and used to normalize subsequent values. The signal for each muscle was normalized to %MVC, then the median (APDF 50) and peak (APDF 90) amplitude probability distribution functions were calculated to represent the %MVC by which 50% and 90% of all data points fell below per trial, respectively (Jonsson, 1982); thus the APDF 50 was the %MVC that the person was at or below 50% of the time and the APDF 90 was the % MVC the subject was at or below 90% of the time.

Three-dimensional kinematics of the spine were collected using the Lumbar Motion Monitor (LMM), an exoskeletal electrogoniometer (Chattecx Corp, Hixon, TN) which allows the capture of continuous angular position, velocity and acceleration of the lumbar spine during task performance (Marras et al., 1993, 1995). Nine parameters including position, velocity and acceleration of the spine in 3 planes (sagittal, frontal and transverse) were collected at a sampling frequency of 60 Hz and summarized across the entire bed making task (removal, placement and tucking of sheets). The average and maximum value of each parameter per trial (ie., over the course of the entire bed making task) was quantified and certain parameters were used to calculate the probability of being in the high risk group for low back disorders (Marras et al., 1993). Additionally, the % time spent beyond thresholds observed in groups with high risk for developing low back disorders were quantified while tucking the sheets including sagittal posture ($>30°$), lateral velocity($>10.8°$/sec) and twist velocity ($>8.71°$/sec) (Marras et al., 1995).

Digital color video sampled at 25 Hz (Qualisys, Gothenburg, Sweden) was used to quantify the duration and number of mattress lifts per each trial of bed-making. A force gauge (Shimpo MF-100, Wilmington, NC) was used to quantify the force required to lift the corner of the mattress up 20 cm, a typical mattress lift distance required to tuck sheets and a comforter. The same force measurement was used for all subjects. Heart rate (HR) was monitored (Garmin, Olathe, KS) throughout the entire test period. The average heart rate reserve was calculated for each trial and averaged by condition using the following: (Average Working HR-Resting HR)/(Maximum HR- Resting HR) (Swain and Leutholtz, 1997). Resting HR was collected after 5 min of quiet sitting; maximum HR was estimated using the participants age: (Maximum HR = 220-age). A follow-up survey assessing ease of use (6 point scale) and perceived exertion in the neck, shoulder, forearms, hands/wrists, low back, and legs using the Borg CR-10 scale (Borg, 1998) was administered after each of 4 test conditions (tool versus no tool with fitted versus flat bottom sheet). A comparison survey assessed participants' tool and sheet preferences after all the conditions were completed.

The primary upper extremity outcome measures included the mean and peak muscle activity as summarized by the APDF 50 and APDF 90 for the FDS, ED, BB and MD muscle activity. The primary outcome measures for the spine included the average lifts/bed by condition, mean and average position, velocity and acceleration of the lumbar spine, and the % time spent beyond kinematic thresholds observed in people with high risk for low back disorders. Additionally, HR, perceived exertion (Borg CR-10), and various usability features of both interventions were compared.

2.5. Statistical analysis

All outcome measures were averaged across trials within subject and condition. A one-way repeated-measures ANOVA with four levels was used to determine statistical significance of each model, and the Tukey *post-hoc* test was used to determine differences between the 4 conditions. An alpha level of 0.05 was used in all of the statistical tests. For non-normally distributed data, the Skillings–Mack nonparametric test, an extension of the Freidman test for incomplete block design or missing data, was used to compare conditions with a Bonferroni adjustment for multiple comparisons (Chatfield and Mander, 2009).

3. Results

3.1. Demographics

Sixteen females who worked as hotel room cleaners for an average of 10.8 years (SD = 5.5), and were mostly Hispanic (N = 11), participated in this laboratory study (Table 1). Forty percent (n = 6) did not have a high school education and 63% were overweight or obese. The average pain at baseline was highest (moderate to severe) in the low back and the wrist/hands (Table 1). Half of the participants reported taking medication for pain over the past month and 19% reported taking days off of work due to pain. Four individuals (25%) reported having difficulty maintaining their quality or pace of work due to pain.

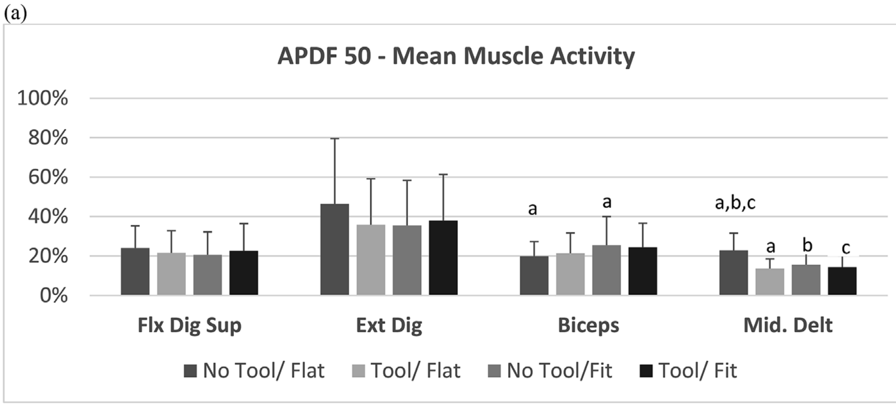
3.2. Muscle activity

Mean (APDF 50) muscle activity of the MD and ED ($F(3,32) = 1.04$, $p < 0.33$) was higher when using the flat sheet and no tool versus the other conditions; yet only the MD ($F(3,32) = 6.20$, $p < 0.02$) was statistically significant (Fig. 3a). Additionally, the mean APDF 50 BB ($F(3,32) = 3.92$, $p < 0.04$) activity was slightly lower in the flat sheet/no tool condition compared to the no tool/fitted sheet. There were statistically significant differences in mean FDS activity ($F(3,32) = 1.56$, $p < 0.22$). Peak APDF 90 FDS ($F(3,32) = 6.29$, $p < 0.00$) activity was higher in the no tool/flat sheet condition versus the conditions that used a mattress lift tool(Fig. 3b); there were no

Table 1
Basic Demographics and discomfort experienced over the past 4 months.

	Mean (SD)	Range
Age	47.9 (7.9)	32–63
BMI	28.1 (6.0)	19.4–42.0
Years Worked	10.8 (5.5)	3.0–24.8
Worst Discomfort		
Neck	2.0 (2.2)	0–6
Shoulder	3.3 (2.6)	0–8
Forearm	2.8 (3.2)	0–8
Wrist/Hand	4.3 (3.4)	0–10
Low Back	5.0 (3.4)	0–10
Hip	1.7 (3.1)	0–10
Knees	3.9 (3.7)	0–10

(a)



(b)

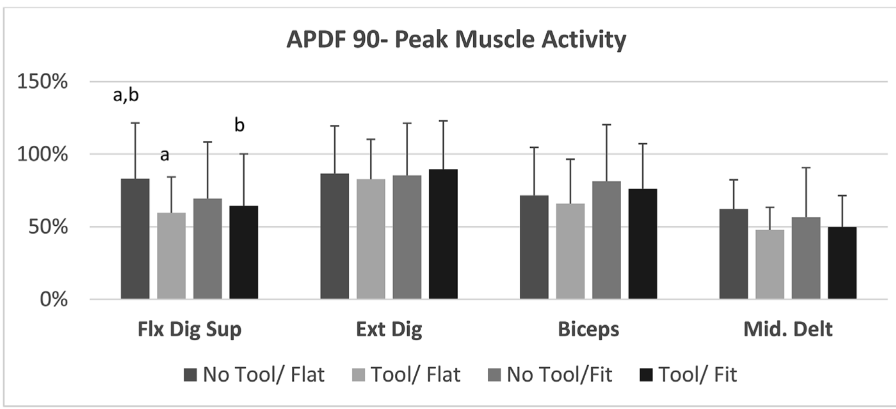


Fig. 3. (a) Mean (APDF 50) and (b) Peak (APDF 90) muscle activity of the Flexor Digitorum Superficialis, Extensor Digitorum, Biceps Brachii and the Middle Deltoid of the dominant upper extremity across intervention conditions.

statistically significant differences in peak ED ($F(3,32) = 0.54$, $p < 0.64$), BB ($F(3,32) = 1.21$, $p < 0.32$) or MD ($F(3,32) = 1.14$, $p < 0.33$) muscle activity.

3.3. *Spinal kinematics*

The average and maximum postures, velocities and accelerations of the spine were consistently high across all conditions with average measures exceeding the high risk reference values. (Table 2). Across all conditions, 17–18 of the 18 measured kinematic values exceeded the high risk reference values. Side bend range of motion was statistically lower in the tool/fitted sheet condition compared to the no tool/flat sheet condition. The maximum twist velocity was significantly lower in the tool/fitted sheet condition versus the tool/flat sheet condition.

3.4. *Productivity*

The duration to make a bed across all trials ranged between 2.0 and 9.6 min. Within a condition, the *average* duration to make a bed ranged between 4.7 and 6.3 min (Fig. 4). The number of lifts ranged between 3 lifts (tool and fitted sheet) and 22 lifts (no tool and flat sheet) and the average number of lifts within each condition ranged between 7.8 and 15.0 lifts/bed. Using the tool/fitted sheet had a statistically significant reduction in number of lifts per bed ($F(3,30 = 39.48$, $p < 0.00$). Using the tool with a flat sheet led to a significant increase in the duration required to make a bed.

3.5. *Heart rate*

The average, range, and % relative heart rate reserve were similar across all conditions with no statistically significant differences. The average heart rate was 105 bpm and ranged between 71 bpm and 129 bpm across individuals($F(3,33) = 0.73$, $p < 0.51$). The average maximum heart rate was 120 bpm and ranged between 93 and 147 bpm ($F(3,33) = 1.13$, $p < 0.35$). The average % heart rate reserve was 33% and ranged between 19% and 55% across conditions ($F(3,33) = 0.72$, $p < 0.52$). The maximum % heart rate reserve was 47% and ranged between 33% and 73% across conditions($F(3,33) = 1.01$, $p < 0.40$).

3.6. *Perceived exertion*

There were statistically significant reductions of effort in the low back when using the tool alone or with a fitted sheet ($F(3,42) = 3.15$, $p < 0.05$) (Fig. 5). Although use of the fitted sheet also appeared to reduce effort when compared to using the flat sheet without the tool, findings were not statistically significant. Use of the fitted sheet with the tool had the biggest impact for all body regions, reducing effort by an average of 1.5–2 points on the 10-point scale, with statistically significant reductions in the low back. Non-statistically significant reductions when using both the fitted sheet and tool were observed in the neck ($F(3,42) = 2.06$, $p < 0.14$), shoulder($F(3,42) = 1.48$, $p < 0.24$), forearm($F(3,42) = 1.75$, $p < 0.18$), hand/wrist($F(3,42) = 1.60$, $p < 0.22$) and legs($F(3,42) = 2.02$, $p < 0.14$).

3.7. *Subjective preference*

One of the 16 subjects did not have complete data due to equipment failure. Two individuals reported having used a mattress lift tool at work. Seventy-three percent of the participants preferred use of the tool and 100% preferred the fitted sheet (Table 3). Two individuals (13%)

Table 2
Summary of (a) kinematics (posture, velocity and acceleration) of the spine during the entire bed making task; (b)Probability of low back disorder for the bedmaking task; and (c) the % time spent above key threshold values while tucking sheets in.

Mean (SD)	High Risk Reference	No Tool/Flat	Tool/Flat	No Tool/Fit	Tool/Fit	F (df)	p-value
Sagittal Plane							
Maximum Extension (°)	−8.3 (9.1)	−8.7 (5.5)	−10.2 (8.8)	−8.5 (6.0)	−7.5 (6.4)	F(3, 39) = 0.48	0.69
Maximum Flexion (°)	17.85 (16.6)	79.5 (20.9)	77.1 (19.7)	75.7 (20.8)	82.0 (22.9)	F(3,39) = 1.59	0.21
Range of Motion(°)	31.5 (15.7)	88.2 (23.5)	87.3 (21.3)	84.2 (22.5)	89.5 (22.7)	F(3, 39) = 1.59	0.21
Average Velocity (°/sec)	11.74 (8.14)	12.27 (4.16)	12.32 (4.44)	11.83 (3.87)	12.86 (4.36)	F(3, 39) = 0.65	0.56
Maximum Velocity (°/sec)	55	135.58 (43.52)	141.72 (50.27)	135.90 (47.31)	147.55 (51.99)	F(3, 39) = 0.67	0.58
Maximum Acceleration (°/sec^2)	316.73	771.46 (196.31)	810.51 (190.42)	782.18 (196.60)	775.87 (190.05)	F(3, 39) = 0.1.06	0.38
Lateral Plane							
Maximum Left Bend (°)	−1.47	−18.6 (10.7)	−18.8 (6.7)	−22.1(7.6)	−19.9(7.0)	F(3, 39) = 1.41	0.26
Maximum Right Bend (°)	15.6	29.3 (13.5)	25.6 (6.7)	24.2 (6.7)	23.9 (8.1)	F(3,39) = 3.08	0.08
Range of Motion(°)	24.44	47.9 (11.2)[a]	44.4 (11.2)	46.3(11.6)	43.8 (11.1)[a]	F(3, 39) = 4.05	0.02
Average Velocity (°/sec)	10.28	7.73 (1.38)	7.72 (1.26)	7.82(1.60)	7.89 (1.52)	F(3, 39) = 0.19	0.90
Maximum Velocity (°/sec)	46.36	60.95 (15.10)	61.36 (10.80)	61.30(12.03)	60.51 (15.41)	F(3, 39) = 0.23	0.84
Maximum Acceleration (°/sec^2)	301.41	376.52 (101.15)	407.58 (80.13)	391.51 (78.42)	402.78 (97.35)	F(3, 39) = 0.72	0.52
Twisting Plane							
Maximum Left Twist (°)	1.21	−19.9 (9.6)	−17.6 (5.4)	−19.9 (5.9)	−15.9 (6.2)	F(3, 39) = 1.99	0.16
Maximum Right Twist (°)	13.95	19.1 (6.2)	21.6 (7.5)	18.6 (6.9)	22.8 (8.7)	F(3,39) = 2.12	0.13
Range of Motion(°)	20.71	39.0 (10.6)	39.2 (9.7)	38.5 (8.7)	38.6 (8.6)	F(3, 39) = 0.24	0.80
Average Velocity (°/sec)	8.71	8.62 (1.93)	8.14 (1.84)[a]	8.88 (2.18)[a]	8.54 (1.86)	F(3, 39) = 3.33	0.03
Maximum Velocity (°/sec)	46.36	73.18 (19.47)	78.1 (18.39)[a]	75.45 (20.64)	68.92 (16.53)[a]	F(3, 39) = 3.26	0.03
Maximum Acceleration (°/sec^2)	304.55	522.17 (125.19)	546.62 (128.17)	506.01 (127.48)	497.94 (131.73)	F(3, 39) = 1.27	0.30
Probability of Low Back Disorder							
Lift Rate (lifts/min)		14.9 (3.5)[a,b,c]	9.4 (3.4)[a]	9.7 (2.2)[b,d]	7.6 (3.4)[c,d]	F(3,30) = 39.25	0.00
Average moment (Nm)	55.26	62.5	62.5	62.5	62.5		–
Probability of High Risk LBD Group	–	88.3% (5.5)	87.5% (4.0)	88.2% (4.6)	89.1% (6.0)	F(3,27) = 0.17	0.86
% Time Spent in							
> 30.0° flexion	–	67.4% (16.8)[a]	67.7% (15.3)[b]	57.0% (18.7)[a,b,c]	67.6% (16.5)[c]	F(3,40) = 3.54	0.03
> 10.8°/sec avg lateral velocity	–	10.8% (5.3)	9.0% (3.8)	9.8% (5.6)	9.9% (5.5)	F(3,40) = 1.08	0.37
> 8.71°/sec avg twist velocity	–	11.5% (4.6)	9.7% (4.0)[a]	12.3% (5.4)[a]	11.1% (4.4)	F(3,40) = 4.10	0.01

preferred not using the tool and cited concerns that it would impact the quality or speed of making beds.

4. Discussion

4.1. Main contributions

Results of this study indicate that the mattress lift tool and fitted sheet, whether used alone or together, reduced biomechanical exposures associated with making hotel beds. The implementation of both the fitted sheet and a mattress lift tool demonstrated the most favorable results for lift reduction (7.8 lifts), however the implementation of either intervention alone was also effective in reducing the number of mattress lifts per bed. Compared to the use of no tool and a flat sheet (5.3min), there was a increase in average cycle time of about 1 min while using the mattress lift(6.3min). The implementation of fitted sheets alone, which requires minimal to no training, reduced both average cycle time (4.7min) and the average number of lifts (10.1 lifts). Overall, both interventions reduced median middle deltoid and peak flexor digitorum superficialis forearm muscle activity.

The high prevalence of pain in this subject population is consistent with other studies that have reported even higher levels (Krause et al., 2005). We may have had a slightly healthier population given our exclusion criteria of not being in severe pain in the past week. Despite this, 50% of this "healthier" population reported taking pain medication while 19% reported taking time off of work due to pain, indicating that reductions in physical exposures are warranted. This should be of concern to hotels as well as policy makers who are responsible for

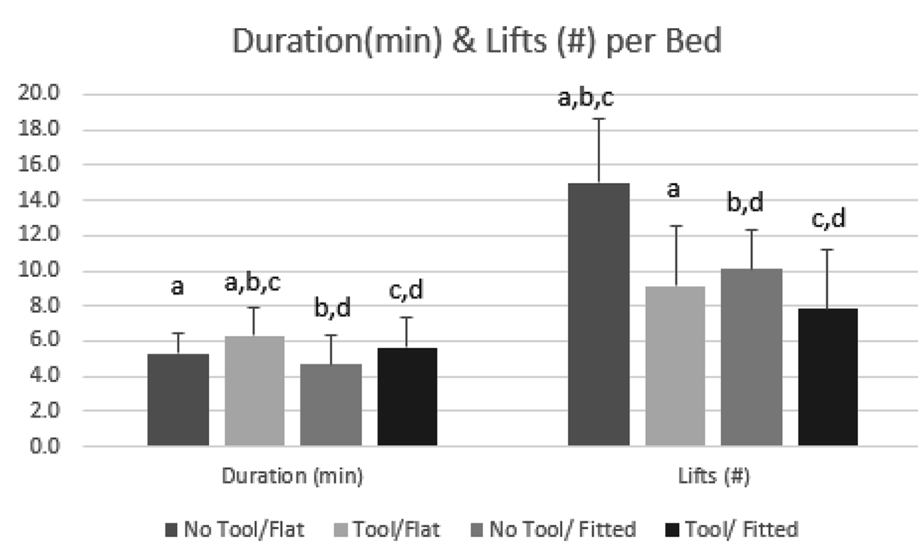


Fig. 4. Average duration and number of lifts per bed using flat or fitted sheets with and without the mattress lift tool.

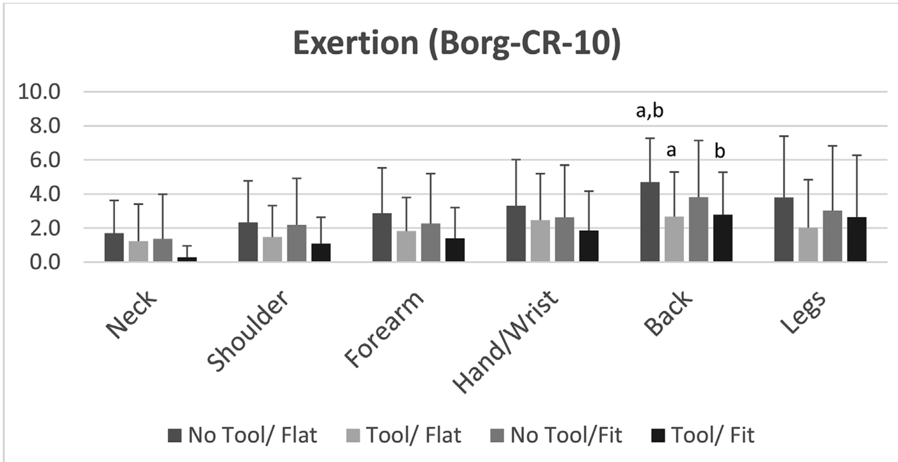


Fig. 5. Exertion (Borg CR-10) by body region rated after the completion of 2 trials for each condition.

protecting workers' health and their ability to safely perform their job.

4.2. Biomechanical assessment

One concern with implementing the use of hand tools is the potential increase in forearm muscle activity from gripping and utilizing the tool (Keeratihattayakorn et al., 2015). The results of this study showed a trend for reduced forearm flexor activity and middle deltoid activity with use of the tool and fitted sheet together.

The reduction in the number of lifts when using the fitted sheet and the tool together was the most impactful result. When the two interventions were used together, the number of lifts was reduced by almost half. Over the course of a work shift, this reduction is dramatic; assuming 20 beds/shift, hotel room cleaners will complete an average of 300 lifts/shift when using no tool with flat sheet, 202 lifts/shift when using no tool with a fitted sheet, 182 lifts/shift when using a flat sheet with a mattress lift tool, and 156 lifts/shift when using both a fitted sheet and a mattress lift tool. Further, it was clear that participants did not yet have a systematic approach when using the mattress lift tool considering the tool's novelty and the participant's limited practice. Video footage showed inconsistent patterns of tool use both between subjects and within the same subject. Developing best practice guidelines on tool placement and insertion techniques may lead to further lift reductions, if not complete elimination of lifts while making hotel beds. For example, the slight increase in biceps brachii muscle activity while using the fitted sheets without a tool was unexpected and may indicate a need for using the mattress lift tool at the head of the bed while putting on a fitted sheet, similar to how the tool was used while putting on the flat sheets. Additionally, there may be other less obvious uses for the tool. One participant cleverly used the tool to raise the mattress before removing the sheets and comforters. This allowed her to effortlessly remove the bedding while other participants used considerable pulling forces to strip bedding from the mattress.

4.3. Productivity assessment

The use of the fitted sheet alone reduced cycle time and saved approximately 12 min over the course of a work shift. However, use of the tool with a flat sheet increased cycle time; hotel room cleaners would initially need an extra 20 min to make an estimated 20 beds per shift. Using the tool with the fitted sheet was the most favorable option where the initial impact would require only seven extra minutes to make an estimated 20 beds per shift. Perhaps a participatory approach that includes ergonomists, hotel room cleaners, and management should be utilized when introducing the mattress lift tool to ensure that best practices are identified and accepted by all stakeholders (Hignett et al., 2005). Future research should consider the development of best practices, including training and phase-in periods (i.e., short periods of reduced productivity requirements to develop new motor patterns).

Independent of tool use and bottom sheet type, the spinal kinematic data indicates that hotel room cleaners are at a high probability of being in a high risk group for low back disorders. In fact, nearly every measure of maximum and average position, velocity and acceleration in all 3 planes exceeded high risk group references (Marras et al., 1993, 1995). This could be due to the high sagittal flexion required to make the beds and/or the high velocity of motion observed suggestive of the hotel room cleaners haste required while cleaning rooms. As sagittal flexion increased, the length of the moment arm, and thus the moment from the head/arm/trunk increased, placing increased stress on the spine.

4.4. Physiological assessment

The consistently high cardiovascular workload across all conditions of bed-making was not anticipated. Despite the difference in lifting loads across conditions, there was no difference in heart rate. This could be due to inadequate rest time between conditions. In this study, participants made eight beds successively with some rest after each condition, or every two trials. It is possible that the other room cleaning

Table 3
Usability and preference assessment.

	Tool Prefer.	No Tool Prefer.	No Prefer.	N(obs,exp)	p-value	Fitted Sheet Prefer.	Flat Sheet Prefer.	No Prefer.	N(obs,exp)	p-value
Accuracy	9	3	3	12(3,6)	0.07	15	0	0	15(0,7.5)	0.00
Speed	6	4	5	10(4,5)	0.38	14	1	0	15(1,7.5)	0.00
Consistency	10	2	3	12(2,6)	0.02	13	1	1	14(1,7)	0.00
Ease of use	10	2	3	12(2,6)	0.02	14	0	1	14(0,7)	0.00
Comfort	10	1	4	11(1, 5.5)	0.01	15	0	0	15(0,7.5)	0.00
Overall Preference	11	2	2	13(2,6.5)	0.01	15	0	0	15(0,7.5)	0.00

tasks provide an "active rest" period for the hotel room cleaners. Other tasks can take approximately 20 min or more to complete before hotel room cleaners make another bed. Therefore, the workload differences between conditions may be realized in the field where the strenuous task of bed making is interspersed among other less strenuous tasks. It is also possible that the cumulative effect of doing multiple physically demanding tasks results in a consistent elevation of cardiovascular load. Given that recent literature (Korshøj et al., 2014) has identified that workers in occupations of heavy workloads may be at increased risk of cardiovascular disease, and that the average % relative HR in this study's population was 33%, with some individuals reaching 55%, further research on cardiovascular strain and viable interventions to reduce risk of cardiovascular disease in this population is needed.

The subjective perceptions of exertion and usability suggest that the tool and fitted sheet together were most effective at reducing exertion in the low back and hands/wrist. There was high acceptance of both the tool and the fitted sheet, although there were concerns regarding a lack of training for proper use of the tool. This could indicate that the implementation of the tool may fail if there is inadequate training, weak supervisor support, and/or insufficient phase-in periods; providing the tool without any adjustment to productivity requirements could increase the stress associated with cleaning the expected number of rooms in the required time. Therefore, an additional strategy to support successful implementation of the tool could be to reduce the overall productivity requirements as a tradeoff for also reducing biomechanical workload. Based on the findings of this study, there would need to be a higher reduction in productivity requirements when implementing the tool with a flat sheet versus the tool with a fitted sheet.

4.5. Limitations

Participants had minimal training and practice time in this laboratory study. It is plausible that with increased training and adequate practice over a week or more, the number of lifts and cycle time per bed when using the tool would decrease further. Due to equipment issues, we lost either muscle activity, lumbar motion monitor and/or video data for some subjects. Additionally, a total of two beds were made under each condition. It is possible that differences in perceived exertion would be greater across the conditions if the assessment were made over the course of an entire shift. It is also possible that changes in the heart rate would be different across conditions when observing the heart rate over the course of the entire shift in a field setting where other tasks are interspersed between the making beds. The erector spinae muscle activity was not able to be assessed using electromyography because of the physical interference between the electrodes the lumbar motion monitor.

5. Conclusion

The implementation of both the fitted sheet and a mattress lift tool reduced the biomechanical workload without having any negative impact on forearm muscle activity or physiological workload. Despite minimal practice time using the interventions, the number of lifts was reduced significantly with minimal impact on cycle time. The use of the fitted sheet with the mattress lift tool significantly reduced perceived exertion in the lower back and hands/wrists and was preferred by the majority of participants. However, spinal kinematic measurement still indicates that there is a high probability of hotel room cleaners being in the high risk group for low back disorders even with using both interventions. Thus, the development of additional alternatives to reduce the workload associated with making beds is warranted.

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