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Saving Our Backs: Reducing Low Back Forces, Investigating Pain, and Observing Multifidus

Robert Eugene Larson
Brigham Young University

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Saving Our Backs: Reducing Low Back Forces, Investigating Pain, and Observing Multifidus

Robert Eugene Larson

A dissertation submitted to the faculty of
Brigham Young University
in partial fulfillment of the requirements for the degree of
Doctor of Philosophy

Ulrike Mitchell, Chair
Wayne Johnson
Dustin Bruening
Sarah Ridge
Dennis Eggett

Department of Exercise Sciences
Brigham Young University

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ABSTRACT

Saving Our Backs: Reducing Low Back Forces, Investigating Pain, and Observing Multifidus

Robert Eugene Larson
Department of Exercise Sciences, BYU
Doctor of Philosophy

BACKGROUND: Healthcare workers are among the most injured workers in the United States. This is due to the high rate of patient handling. The low back is the most injured in this population. This study observed biomechanical factors and how these factors affect low back and ground reaction forces. This study further investigated pain and its relationship to low back force, multifidus cross-sectional area, and multifidus activation in healthcare workers.

METHODS: The 45 participants included 10 healthy subjects in the preliminary study and 35 active healthcare workers in the main study. Subjects filled out the VAS to determine current pain level. Ultrasound images of the multifidus muscles were taken. The participants were fitted with reflective markers and surface EMG sensors. A series of patient transfers at various bed heights using three different transfer devices was undertaken. The transfer devices included a Cotton sheet, a Skil-Care™ Transfer Sling, and an AirPal® device.

RESULTS: There was a downward trend in resultant low back force when comparing lower bed heights to higher. Therefore, the highest bed position was determined to be optimal. There were significant differences in low back force between self-chosen and optimal bed heights among healthcare workers. There was no significant difference between peak low back or ground reaction forces between pain and nonpain groups. There was a significant difference in multifidus cross-sectional area between these groups at S1, a trend toward significance at L5, and no difference at L4. There was a trend toward significance when comparing multifidus activation between these groups as recorded by surface EMG.

CONCLUSIONS: Healthcare workers should choose higher bed heights and appropriate equipment to reduce low back force and those who have smaller multifidus have more pain.

Keywords: sheets, nurse, posture, body mechanics, multifidus, patient handling
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Introduction

Work-related musculoskeletal injuries are a common problem among healthcare workers (Daynard et al., 2001). These workers experience musculoskeletal injury rates comparable to construction workers and other professions that require heavy lifting (Bureau of Labor Statistics [BLS], 2013). These injuries are due to the high rate of daily lifting and moving of heavy patients. The recommended lifting limit is 35 pounds for all healthcare workers, and that is only if the patient is cooperative and the task does not include trunk rotation or excessive bending (Waters et al., 1993). The healthcare workers who have the greatest risk of developing a musculoskeletal injury are nurses and nursing aids, but this category also includes occupational and physical therapists (BLS, 2013; Rice et al., 2011).

The most common injury site for healthcare workers is the low back (Owen et al., 2002), specifically the L4-L5 and L5-S1 vertebral levels. These vertebral levels are commonly implicated in low back pain caused by repetitive actions (Waters, 2007; Waters et al., 1993). These actions overstress the joints by placing a great amount of cumulative force on them (Waters, 2007; Waters et al., 1993).

Much effort has gone into figuring out ways to accurately measure the forces at these vertebral levels (Chaffin, 1997; Galbraith, 2011; Merryweather et al., n.d.). Force data at these levels have been used to establish safety guidelines for a variety of professions that require moving and lifting of heavy objects, including healthcare workers.

Bed height, frequently too low during manual patient handling tasks, can be a factor in sustaining musculoskeletal injuries in healthcare workers (Delooze et al., 1994; McGill et al., 1998; Tuohy-Main, 1997; Waters et al., 1993). This is due to poor biomechanical posture during patient handling tasks which can place undue stress on the low back. Unfortunately, the
recommendations for bed height to safely move patients are inconsistent and nonspecific (Lloyd, 2005; Fairview Health Services, 2019; Icahn School of Medicine at Mount Sinai, 2020). There is consensus that there is increased risk of low back musculoskeletal injury to healthcare workers when they use bed heights that are lower than the recommended guideline (i.e., below hip height) (Lloyd, 2005; Fairview Health Services, 2019; Icahn School of Medicine at Mount Sinai, 2020). However, the “elbow, waist or hip level” is fairly ambiguous as a landmark (Lloyd, 2005; Fairview Health Services, 2019; Icahn School of Medicine at Mount Sinai, 2020). Optimal bed height hasn’t been defined in relation to any specific bony landmark. And even if it were, some trunk and lower extremity landmarks are large and can still be ambiguous. For instance, using the iliac crest or the waist of the healthcare worker as a landmark can be several inches higher or lower depending which specific point on the landmark the worker decides to use (Caboor et al., 2000; Delooze et al., 1994; Lee & Chiou, 1994; Lindbeck & Engkvist, 1993; Murtagh & Rice, 2015). Most of the studies that take bed height into consideration allow the healthcare worker the choice to adjust the bed to his or her desired height, which is not a standardized method, and none of them report the self-chosen bed heights as either a height from the floor or a percentage of caregiver height (Caboor et al., 2000; Delooze et al., 1994; Nagavarapu et al., 2017). Other studies use a standardized height without accounting for the different heights of the healthcare workers or use a bed height that has not been shown to reduce stress on the low back (Kjellberg et al., 2003; Marras et al., 1999). Some studies have been criticized for using a height that is too low and thus still places the healthcare workers at risk of injury (Lindbeck & Engkvist, 1993; Murtagh & Rice, 2015). This project seeks to ascertain if there is an optimal bed height as a percentage of caregiver height to reduce the low back forces during the task of boosting a patient
up in bed. Once this is determined with a nonhealthcare worker population, this optimal height will be compared with a self-chosen bed height among a population of healthcare workers.

Recommended force limits have been suggested for the low back for all workers and lifting limits have been described for healthcare workers specifically (McGill & Kavcic, 2005; McGill et al., 1998; Waters et al., 1993). Many studies focus on methods for bringing these forces under the recommended limits during patient handling tasks (Bartnik & Rice, 2013; Larson et al., 2018; Larson & Rice, 2015; McGill & Kavcic, 2005; McGill et al., 1998; Waters et al., 1993). These studies have shown risks associated with the manual handling of patients, including high forces at the low back even when using safe patient handling materials. Often these forces are over recommended limits and place healthcare workers in danger of musculoskeletal injury (Larson & Rice, 2015). The materials and methods of these studies, however, often do not include the most contemporary devices available for performing patient handling tasks.

There are now air assisted devices that can potentially reduce low back and hand forces to the recommended limits (Nelson et al., 2004). The studies that include these air assisted devices either only use purely subjective outcome measures (Nelson et al., 2004) or do not use healthcare workers (Lloyd & Baptiste, 2006). One had participants perform various sliding and boosting tasks with research assistants acting as patients to examine the effectiveness of various transfer devices (Hwang et al., 2019). However, since it used only one hand gauge for this bimanual task the force data it reports are likely underestimated, and there are no low back force data. The current study seeks to obtain information on healthcare workers’ low back forces that occur during a boosting technique when using different friction-reducing devices with a
simulated dependent patient population. In addition, these peak forces will be correlated with the clinician’s self-reported low back pain to see if there is a connection between the two.

Multifidus muscle cross-sectional area in the low back has been found to be correlated with pain (Fernandez-De-Las-Penas et al., 2008; Hides, Gilmore, et al., 2008), but this has not been researched in healthcare workers. There have been some conflicting results when observing multifidus cross-sectional area (Beneck & Kulig, 2012; Evason et al., 2018; Fernandez-De-Las-Penas et al., 2008; Keir & MacDonell, 2003; Wallwork et al., 2009). Some studies have shown a significant difference between multifidus cross-sectional area among those with pain compared to healthy controls (Beneck & Kulig, 2012; Fernandez-De-Las-Penas et al., 2008; Hides, Gilmore, et al., 2008; Wallwork et al., 2009) and some have shown no difference at all (Evason et al., 2018; Hides, Stanton, et al., 2008). Of the studies listed, those that show a difference include a broader population of those with pain compared to nonpain controls while those who show no difference only incorporate highly athletic populations (Beneck & Kulig, 2012; Evason et al., 2018; Fernandez-De-Las-Penas et al., 2008; Hides, Gilmore, et al., 2008; Hides, Stanton, et al., 2008; Wallwork et al., 2009). No study could be identified that included healthcare workers. There is a need to assess if multifidus cross-sectional area in this population correlates to pain.

Lastly, atypical multifidus muscle activation, as measured by surface electromyography (EMG), can also be a factor in low back pain. The multifidus of the low back are responsible for keeping normal spinal mechanics during dynamic motions such as extension when acting bilaterally, rotation when acting contralaterally, and sidebending when acting ipsilaterally. If these are not functioning properly this can negatively affect the low back. This has been observed in different groups of people, including healthcare workers (Ahern et al., 1988;
Danneels et al., 2002; Gagnon et al., 1987; Keir & MacDonell, 2003; Wong et al., 2016). These studies highlight that there are differences in multifidus activation in populations that experience low back pain versus healthy controls (Ahern et al., 1988; Danneels et al., 2002; Gagnon et al., 1987; Keir & MacDonell, 2003; Wong et al., 2016). They inconsistently show that during bending and twisting movements the multifidus in the low back are either more or less active between individuals who have pain and those who do not depending on the intensity and type of activity (Ahern et al., 1988; Danneels et al., 2002; Gagnon et al., 1987; Keir & MacDonell, 2003; Wong et al., 2016). However, the studies that include healthcare workers do not correlate pain with muscle activation during transfers or other healthcare related tasks (Ahern et al., 1988; Danneels et al., 2002; Gagnon et al., 1987; Keir & MacDonell, 2003; Wong et al., 2016). The current study seeks to identify if there are muscle activation differences between healthcare workers who are experiencing pain based on visual analog pain scale (VAS) self-reporting and those who are not.

The overarching purpose of this project is to expand the knowledge base of safe patient handling. This project will focus on manual patient handling and pain under two main aims. The first aim is focused on biomechanics during a boosting task while the second aim focuses on potential factors in low back pain.

**Aim 1**

**Biomechanics**

1a. Determine if there is an optimal bed height for reducing the amount of overall force on the low back while boosting a patient up in bed.

1b. Observe if healthcare workers are choosing the optimal height as determined by 1a. when given the chance to change the bed height.
1c. Evaluate if the optimal bed height determined in 1a is better than the self-chosen bed height for reducing forces at the low back specifically in healthcare workers with the task of boosting a patient up in bed.

1d. Discover which of three readily accessible draw sheets is most effective at reducing low back forces

**Biomechanical Hypotheses**

1a. There is an optimal bed height as a function of a percentage of caregiver height that is effective at minimizing the amount of L4-L5 and L5-S1 force required to complete the task of boosting a patient up in bed.

1b. When allowed to adjust the bed height, healthcare workers will choose a height other than optimal for the boosting task.

1c. If healthcare workers utilize a nonoptimal self-chosen bed height, adjusting the bed to the optimal height will result in lower low back and ground reaction forces than a self-chosen bed height.

1d. The AirPal® patient positioning device will require lower peak low back force at the L4-L5 and L5-S1 joints as shown with the 3-Dimensional Static Strength Prediction Program ([3DSSPP], University of Michigan, Ann Arbor, MI) when sliding a patient up in bed than will the Skil-Care™ Super-Sling 4-Handles Transfer Sling, which will likewise require less low back force compared to sliding a patient up in bed with a typical Cotton draw sheet.
Aim 2

**Pain and the Low Back**

2a. Determine if peak low back force while boosting a patient in bed is related to current low back pain.

2b. Determine if low back multifidus cross-sectional area is related to current low back pain.

2c. Determine if low back multifidus activation is related to current low back pain.

**Low Back Pain Hypotheses**

2a. Those healthcare workers who generate higher peak forces at the L4-L5 and L5-S1 joints during boosting tasks using a Cotton sheet will have higher pain levels as measured by the VAS than healthcare workers who employ lower L4-L5 and L5-S1 forces.

2b. Healthcare workers with higher pain levels (based on VAS responses) will exhibit multifidus muscles with a smaller cross-sectional area than healthcare workers with lower pain levels.

2c. Healthcare workers with higher pain levels will exhibit either more or less symmetrical muscle activation patterns in the lumbar multifidus than those with lower levels of pain as determined by the VAS.

**Methods**

**Preliminary Study**

Determining an optimal bed height was completed as a preliminary study prior to the main part of the study. This was done to establish if there is an ideal bed height to reduce the amount of force being placed on the L4-L5 and L5-S1 levels of the low back. A convenience
sample of 11 BYU students and nonhealthcare worker, local residents was used for this part of
the study.

Participants came to the biomechanics research lab on BYU campus. They read and
signed the informed consent form and data collection immediately followed. All consent forms
and data collected during the course of both phases of this project were kept in secured locations
behind locked doors on Brigham Young University campus and on password protected
computers with further password protections to access the information.

A ten-camera Oqus motion capture system (Qualisys, Göteborg, Sweden) was used to
collect motion data using a collection rate of 100 Hz. Two force plates were used for the
collection of ground reaction forces during the boosting tasks at a collection rate of 400 Hz.
These rates were deemed sufficient for the relatively slow motion of boosting a patient up in bed
as described elsewhere (Larson et al., 2018).

Nineteen reflective markers were placed on the body for measurement by the Qualisys
system. The markers were placed as recommended by C-Motion with slight modification (2010)
(see Figure 1) for the purpose of use in 3DSSPP, which includes the following:
The markers were used to track body position throughout the patient handling task, which was recorded by the Qualisys motion capture system. Force plate data were collected throughout the session in order to pair force data with joint angles to calculate specific low back forces at the L4-L5 and L5-S1 spinal levels with the 3DSSPP program.

The participant approached the adjustable height hospital bed and started with the bed at its lowest or highest position as determined by a randomization sequence. The low and high positions were adjusted to match a certain percentage of participant height for consistency (i.e., if the participant was too short to achieve 32% of his or her height, the bed was adjusted to 35% of his or her height). For this part of the study, a standard Cotton sheet was used for all tasks. The participant was instructed in the manual patient handling task of boosting a patient up in bed.
To complete the boosting task, the participant placed one foot on each force plate initially, then on the count of three slid the “patient” (research assistant, n = 1) approximately six inches up in the hospital bed using the Cotton draw sheet for the task. The “patient” was a 202-pound female who acted as a dependent patient for all the boosting tasks. A trained occupational therapist (n = 1) was on the other side of the hospital bed to assist in making the “patient’s” movement symmetrical. This was performed three times, the bed was raised 3% of the participant’s height, and the repositioning tasks were repeated. This process continued until the hospital bed was in the opposite extreme compared to its starting position.

Motion and force plate data were filtered using a low pass Butterworth filter with a 10 Hz cutoff frequency. The moment of peak ground reaction force was found and this single frame was used for further analysis. Custom MATLAB code was used to compute planar angles as specified by 3DSSPP. It was then run through 3DSSPP, which gave specific information regarding the L4-L5 and L5-S1 joint forces, which allowed comparison of these forces at the different bed heights. It was expected that when the bed was in the lowest position it would generate the highest amount of compressive force, while the highest position would require the greatest amount of shear forces. With this assumption, it was thought that there would be an ideal bed height somewhere between the lowest and the highest bed heights. This, however, was not the case.

The low force point, the percentage of height that required the least amount of combined compressive and shear force at the low back was discovered (specifically the highest bed height) and utilized as the optimal bed height for the main study.
Main Study

Subject recruitment took place at inpatient units at hospitals and skilled nursing facilities in and around the greater Provo, UT, USA area. These are the settings with the highest incidence of musculoskeletal injury among healthcare workers, as they tend to have older and more dependent patient populations than other settings. Recruitment largely took place by word of mouth and posting flyers in the previously described facilities. The “patient” for the main study was the same research assistant as in the preliminary study.

Participants were screened using inclusion/exclusion criteria. Inclusion criteria: healthcare workers including nurses, certified nursing assistants, occupational therapists, occupational therapy assistants, physical therapists, and physical therapy assistants that were currently working in inpatient hospital, acute hospital, or skilled nursing settings between the ages of 18–65 who engage in patient handling tasks consistently throughout the work day as part of their job. Exclusion criteria: pregnant, and those who work in outpatient, pediatric, or another setting where frequent patient handling is not required. Those who currently have low back pain as reported on the VAS were included in the sample as this was an important part of the project.

Those eligible to participate were instructed in the purpose of the study, the methodology, and what was required of them. They were also given a printed informed consent form and allowed to read it and ask questions regarding anything related to the study and/or the consent form (IRB Protocol # F19017). Participants were assigned a number in conjunction with the research questionnaires and other information so identifying features could be eliminated. No identifying features of the participants were used in the reporting of this project. The participants filled out a questionnaire regarding their employment history in their current healthcare role. They also filled out the visual analog pain scale (VAS), which is a 10 cm line with anchor points
numbered 0–10 with 0 being no pain and 10 being the worst possible pain and the participant was asked to mark on the line where his or her current low back pain was. Further questions were regarding their experiences with patient handling in their current role.

There was a total of 35 participants. This included 11 occupational therapists, one occupational therapy assistant, 10 physical therapists, three physical therapy assistants, four nurses, and six certified nursing assistants. There was a total of 15 males and 20 females that ranged in age from 18 years old to 63 years old with an average age of 37.2 years of age (± 2.21). Together the participants averaged just over nine years of experience (± 1.63) ranging from six months to 35 years of experience in their respective roles. There were a variety of nations represented in this research as well including El Salvador, Haiti, South Korea, Canada, and the United States.

Based on the data by Larson et al. (2018), this sample size was expected to be sufficient to determine a difference in forces required to complete the boosting task with the three different types of draw sheets using an α = .05, and a β = .8. These numbers were based on the hand force differences between the sheet categories in the aforementioned study comparing the Cotton sheet to the Arjo Maxislide in the double sheet category (Larson et al., 2018). A similar analysis using data from another study (Hides, Gilmore et al., 2008) yielded comparable results when comparing the pain group to the nonpain group with multifidus cross-sectional areas. Participants were reimbursed $40.00 for their time in participating with this research project.

**Ultrasound**

The researcher invited the participant to enter the first phase of data collection, which consisted of ultrasound imaging of the multifidus in the low back. Methods for collecting ultrasound data were similar to those used by Evanson et al. (2018).
Ultrasound images of sacral and lumbar multifidus were taken with the participant in a prone position on a plinth with a mobile ultrasound unit in the biomechanics lab on BYU campus. Images were taken using a GE LogiQ E ultrasound machine (GE Healthcare, Wisconsin, USA) equipped with a 4 MHz convex array transducer. The participant’s shirt was rolled up to the level of the 12th rib, the waistband of the pants was lowered to just under the posterior superior iliac spine, and a hand towel was secured in the waistband of the pants with a second towel under the shirt as is conventional to prevent ultrasound gel from contacting the participant’s clothing. The ultrasound machine was placed in musculoskeletal mode, and the image was optimized.

The researcher applied ultrasound gel to the soundhead and positioned it over the sacrum with the indicator positioned to the participant’s right side. The median sacral crest was observed. The soundhead was then positioned to observe the left multifidus only and moved in a superior direction until the S1 level was identified. When the soundhead was in position, the subject was instructed to raise the contralateral leg, which engaged the multifidus muscle under observation. The subject then returned to a resting position and a retrospective cine-loop was recorded to capture the entirety of the contraction. This was completed twice for each muscle. These cine-loops were used to accurately determine the borders of the multifidus when measuring the cross-sectional area of the muscle when at rest.

The soundhead was then moved up to the L5 vertebra and the facet joint was visualized. The facet joints were used to lend consistency to the measurement locations. The process of contracting the multifidus and obtaining a retrospective cine-loop was then repeated. The process was then repeated at the L4 vertebral level followed by the entire process being done on the right side of the body starting at S1, moving up to L5, then to L4.
Still images of the multifidus were taken from the cine-loop videos with the muscles at rest. The borders of the muscles were traced by a researcher (n = 1) using internal software and the cross-sectional area was procured (see Figure 2 and Figure 3). The two measurements of each muscle were averages for a composite measurement to be used for statistical analysis at a later point. One researcher collected all of the ultrasound images for consistency.

Figure 2

*Image of Sacral Multifidus Before and After Measurement*

![Image of Sacral Multifidus Before and After Measurement](image.png)

Figure 3

*Image of Lumbar Multifidus Before and After Measurement*

![Image of Lumbar Multifidus Before and After Measurement](image.png)
After the images were procured, the subjects were phased into the next part of the research project.

**Biomechanics**

The height and weight of the participant were taken by the researcher prior to the collection of biomechanical data. If the looseness of the participant’s clothing was a concern, measures were taken to secure the clothing more tightly to his or her body, such as wrapping the loose pieces tightly against the body or securing the clothing out of the way entirely as with the shirt at the low back (see Figure 4). This was done to prevent marker excursion during the boosting tasks and to allow access to the low back for marker and EMG accuracy.

**Figure 4**

*Lab Setup*

*Note.* Figure depicts one consistent “patient,” a participant on the near side of the bed with reflective markers and surface EMG sensors, and one consistent trained healthcare worker on the opposite side of the bed during the task of boosting a patient up in bed.
Marker placement and Qualisys setup was the same as described above for the preliminary study. In addition to the reflective markers, the application of a pair of surface EMG electrodes was completed at the low back. First the skin was shaved so no hair interfered with the application of the sensors or with the signal and cleaned with alcohol prep pads to improve the contact between the skin and the sensors and reduce noise from the EMG signals. The sensors were applied to the skin with one sensor placed over the left multifidus and one over the right. The sensors were placed at the level of the L5 spinous process along an imaginary line between the posterior superior iliac spine and the L1-L2 interspace as recommended by various pieces of literature (De Luca, 1993; Seniam, n.d.).

A maximal voluntary contraction (MVC) of the multifidus was collected prior to completing the boosting tasks as a point of reference when analyzing and discussing the data (Danneels et al., 2002; Keir & MacDonell, 2003). This was done by having the participants lie in a prone position on the plinth where the ultrasound images were taken with the researcher holding the participant’s legs down. The subject then exerted maximal effort into trunk extension while the research assistant applied resistance to the trunk at the level of the scapula to produce an isometric contraction held for a count of five seconds (Danneels et al., 2002; Keir & MacDonell, 2003). Data from the surface EMGs was collected using the same computer as the motion capture and force data via a Delsys Trigno Wireless Biofeedback System (system model # DS-T03, Natick, MA). After the sensors and reflective markers were in place and MVCs completed, the participant progressed to the boosting portion of the study.

Bed Height

A hospital bed was present in the lab for the data collection and was initially placed in its lowest position. The bed included a typical hospital mattress with a fitted Cotton sheet upon
which the Cotton draw sheet was placed. The participant was instructed to complete a dependent boost as he or she normally does, including adjusting the bed. The participant had the opportunity to adjust the bed or leave it how it was positioned depending on his or her preference and complete three boosting tasks at the self-chosen height.

After performing the boosting tasks at the self-chosen bed height, the participant filled out more paperwork, including the VAS. The bed was adjusted to the optimal height during this time. The remainder of the boosts were performed with three different types of draw sheets in randomized order.

**Sheet (Device) Types**

The order of device presentation was randomized. The three devices included a standard Cotton sheet, an AirPal® patient transfer system device (short), and a Skil-Care™ Super-Sling 4-Handles Transfer Sling as depicted in Figure 5 and Figure 6. The process for the boosts was the same as described above with the subject completing a series of nine transfers at this bed height, three with each device. Data were filtered and processed as described earlier.
Figure 5

Draw Sheets Used. Top: Cotton; Middle: Skil-Care™; Bottom: AirPal®
Peak low back force was collected at the self-chosen height as described previously. This data was processed through MATLAB and 3DSSPP as described previously and compared to the VAS responses collected earlier.

**EMG**

The EMG sensors were on the body for the entirety of the boosting tasks positioned as described previously. Collection rate for EMG data was 2,000 Hz. The data collected during the transfers were processed with a band-pass Butterworth filter between 20–350 Hz. Data were then further processed with a 4th order low pass Butterworth filter with a cutoff frequency of 20 Hz to create a linear envelope. Peak EMG signal of the right multifidus was determined and the same time-point was matched for the left multifidus. Two hundred frames were taken, 100 on either side of the determined time-point, and averaged for analysis. The resulting average for the right
side was then subtracted from left, divided by the right value, and multiplied by 100 to normalize the data for use in further analysis comparing these to the VAS.

**Statistical Analysis**

There were seven different research questions in this project in two main areas. Each question was analyzed independently of the others.

First, the preliminary data looking at resultant low back forces were analyzed using descriptive statistics with means and confidence intervals noted to determine differences between bed height as a percentage of caregiver height. Observing these values showed where there were significant differences in low back forces between lower and higher extremes of the different bed heights. Resultant low back forces were used in this analysis. It was anticipated that most healthcare workers would not choose the optimal height defined as the highest position based on the results of the preliminary study. This was true 100% of the time.

The question of the difference in low back forces and GRF between the self-chosen bed height and the optimal bed height was analyzed using a paired t-test with a Holm-Bonferroni correction. Resultant forces were used in this analysis for discussion in the context of the preliminary study. The low back forces when utilizing different boosting devices were analyzed using an ANOVA followed by a Tukey test for pairwise comparisons when completing the task of boosting a patient up in bed. Separate compression and shear forces were used in this analysis to facilitate discussion in the context of other similar studies.

Participants were then divided into two groups: a nonpain group (VAS score = 0, n = 17) and a pain group (VAS score = 1–5, n = 18). Peak low back force at L4-L5 and L5-S1 along with ground reaction forces were compared between the two groups using a t-test. For this analysis the resultant low back force was used. Multifidus cross-sectional area was compared between the
nonpain and pain groups with a series of t-tests for the different vertebral levels. A Holm-Bonferroni correction was applied for the multiple comparisons at the three spinal levels for this analysis which duly adjusted the p-value outputs. Lastly, multifidus activation was compared between the nonpain group and the pain group using a t-test.

**Results**

**Preliminary Bed Height**

The first question in this study was if there is an optimal bed height to reduce forces acting on the low back during a boosting task. The data trend was the lowest bed height yielded the highest amount of resultant low back force and the highest bed height yielded the lowest amount of resultant low back force with a steady decline between the two points. See Table 1 and Figure 7.

**Table 1**

*Resultant Force at the Low Back at Various Percentages of Participant Height*

<table>
<thead>
<tr>
<th>% Caregiver Height</th>
<th>L4-L5 Resultant Force (N)</th>
<th>Standard Error</th>
<th>95% Confidence Interval</th>
<th>L5-S1 Resultant Force (N)</th>
<th>Standard Error</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>32</td>
<td>1163</td>
<td>32.1</td>
<td>1085–1242</td>
<td>1139</td>
<td>19.7</td>
<td>1091–1187</td>
</tr>
<tr>
<td>35</td>
<td>1120</td>
<td>38.5</td>
<td>1033–1207</td>
<td>1092</td>
<td>27.1</td>
<td>1032–1154</td>
</tr>
<tr>
<td>38</td>
<td>1047</td>
<td>33.9</td>
<td>970–1124</td>
<td>1038</td>
<td>26.5</td>
<td>978–1099</td>
</tr>
<tr>
<td>41</td>
<td>1018</td>
<td>42.3</td>
<td>923–1114</td>
<td>993</td>
<td>35.1</td>
<td>914–1073</td>
</tr>
<tr>
<td>44</td>
<td>901</td>
<td>32</td>
<td>829–974</td>
<td>894</td>
<td>30.8</td>
<td>825–964</td>
</tr>
<tr>
<td>47</td>
<td>851</td>
<td>37.2</td>
<td>766–935</td>
<td>843</td>
<td>32.3</td>
<td>769–916</td>
</tr>
<tr>
<td>50</td>
<td>783</td>
<td>50.7</td>
<td>668–898</td>
<td>790</td>
<td>46.2</td>
<td>685–895</td>
</tr>
<tr>
<td>53</td>
<td>707</td>
<td>40.7</td>
<td>616–797</td>
<td>697</td>
<td>40.3</td>
<td>607–787</td>
</tr>
<tr>
<td>56</td>
<td>580</td>
<td>39.3</td>
<td>479–681</td>
<td>573</td>
<td>49.9</td>
<td>444–701</td>
</tr>
<tr>
<td>59</td>
<td>446</td>
<td>24.8</td>
<td>131–762</td>
<td>491</td>
<td>33.3</td>
<td>69.2–914</td>
</tr>
<tr>
<td>62</td>
<td>519</td>
<td>12</td>
<td>367–672</td>
<td>479</td>
<td>62.2</td>
<td>−311–1269</td>
</tr>
</tbody>
</table>
Figure 7

**Means and Confidence Intervals for Low Back Resultant Force**

The 95% confidence interval data of the high bed height for the L5-S1 level had abnormally large confidence intervals compared to the other points as there were only two subjects that completed boosts at that percentage of their height, but the remainder of the points had more typical confidence intervals showing a clear difference and direction of low back force compared to bed height.

**Main Bed Height**

When given the choice, 100% of healthcare workers chose a bed height other than the optimal, highest bed height for this hospital bed. Due to this result, an analysis comparing peak low back forces at the self-chosen bed height to the forces at the optimal bed height was completed. A Holm-Bonferroni correction was used for this comparison. There were statistically significant differences between these forces as depicted in Table 2.
Table 2

Peak Resultant Low Back Force Between Self-Chosen and Optimal Bed Heights

|--------------|----------------|----------------|-------------|----------------|---------------------|----------------|----------  
| L4-L5        | 819            | 38.4           | 783         | 38.6           | 35.7                | 17.4           | 0.0240*  
| L5-S1        | 691            | 37.0           | 638         | 37.0           | 53.6                | 15.4           | 0.0014*  

* indicates a significant difference between the sheet types.

Ground reaction forces were also analyzed with means and significant differences as found in Table 3.

Table 3

Peak Ground Reaction Force Between Self-Chosen and Optimal Bed Heights

| Force Type                  | Self-Chosen (lbs) | Standard Error | Optimal (lbs) | Standard Error | Mean Difference (lbs) | Standard Error | p-Value  
|-----------------------------|-------------------|----------------|---------------|-------------------|------------------|----------------|----------  
| Ground Reaction Force       | 84                | 2.41           | 77.5          | 2.38             | 6.5              | 1.5            | <.0001*  

* indicates a significant difference between the sheet types.

Biomechanics

The draw sheet comparison analysis for low back forces was completed with the mean values and the pairwise comparisons found in Table 4.
Table 4

Various Peak Low Back Forces Between Sheet Types

<table>
<thead>
<tr>
<th>Force</th>
<th>Location and Direction</th>
<th>Sheet 1 Mean</th>
<th>Standard Error</th>
<th>Sheet 2 Mean</th>
<th>Standard Error</th>
<th>Mean Difference</th>
<th>Standard Error</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L4-L5 Compression</td>
<td>Skil-Care™</td>
<td>789</td>
<td>37.2</td>
<td>AirPal®</td>
<td>561</td>
<td>24.0</td>
<td>228</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cotton</td>
<td>782</td>
<td>38.6</td>
<td>AirPal®</td>
<td>561</td>
<td>24.0</td>
<td>221</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Skil-Care™</td>
<td>789</td>
<td>37.2</td>
<td>AirPal®</td>
<td>561</td>
<td>24.0</td>
<td>-6.71</td>
</tr>
<tr>
<td></td>
<td>L4-L5 A–P Shear</td>
<td>Skil-Care™</td>
<td>22.0</td>
<td>4.17</td>
<td>AirPal®</td>
<td>22.4</td>
<td>3.21</td>
<td>-0.432</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cotton</td>
<td>26.8</td>
<td>3.57</td>
<td>AirPal®</td>
<td>22.4</td>
<td>3.21</td>
<td>5.20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Skil-Care™</td>
<td>22.0</td>
<td>4.17</td>
<td>AirPal®</td>
<td>22.4</td>
<td>3.21</td>
<td>5.20</td>
</tr>
<tr>
<td></td>
<td>L4-L5 Lateral Shear</td>
<td>Skil-Care™</td>
<td>27.9</td>
<td>2.27</td>
<td>AirPal®</td>
<td>17.9</td>
<td>1.71</td>
<td>10.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cotton</td>
<td>29.7</td>
<td>1.87</td>
<td>AirPal®</td>
<td>17.9</td>
<td>1.71</td>
<td>11.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cotton</td>
<td>29.7</td>
<td>1.87</td>
<td>Skil-Care™</td>
<td>27.9</td>
<td>2.27</td>
<td>1.76</td>
</tr>
<tr>
<td></td>
<td>L5-S1 Compression</td>
<td>Skil-Care™</td>
<td>644</td>
<td>35.6</td>
<td>AirPal®</td>
<td>423</td>
<td>21.2</td>
<td>221</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cotton</td>
<td>629</td>
<td>37.0</td>
<td>AirPal®</td>
<td>423</td>
<td>21.2</td>
<td>206</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Skil-Care™</td>
<td>644</td>
<td>35.6</td>
<td>AirPal®</td>
<td>423</td>
<td>21.2</td>
<td>221</td>
</tr>
<tr>
<td></td>
<td>L5-S1 A–P Shear</td>
<td>Skil-Care™</td>
<td>106</td>
<td>5.34</td>
<td>AirPal®</td>
<td>91.6</td>
<td>4.12</td>
<td>14.2</td>
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<tr>
<td></td>
<td></td>
<td>Cotton</td>
<td>103</td>
<td>5.12</td>
<td>AirPal®</td>
<td>91.6</td>
<td>4.12</td>
<td>11.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cotton</td>
<td>103</td>
<td>5.12</td>
<td>Skil-Care™</td>
<td>106</td>
<td>5.34</td>
<td>-3.08</td>
</tr>
<tr>
<td></td>
<td>L5-S1 Lateral Shear</td>
<td>Skil-Care™</td>
<td>5.07</td>
<td>0.862</td>
<td>AirPal®</td>
<td>4.63</td>
<td>0.72</td>
<td>0.097</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cotton</td>
<td>4.54</td>
<td>0.703</td>
<td>AirPal®</td>
<td>4.63</td>
<td>0.72</td>
<td>-0.534</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cotton</td>
<td>4.54</td>
<td>0.703</td>
<td>Skil-Care™</td>
<td>5.07</td>
<td>0.862</td>
<td>-0.437</td>
</tr>
</tbody>
</table>

* indicates a significant difference between the sheet types.

A one-way ANOVA followed by pairwise comparisons was also completed to compare the peak ground reaction forces between sheet types with the means pairwise comparisons found in Table 5.
Table 5

Peak Ground Reaction Force Between Sheet Types

<table>
<thead>
<tr>
<th>Sheet Type</th>
<th>Mean GRF (lbs)</th>
<th>Standard Error</th>
<th>Mean GRF (lbs)</th>
<th>Standard Error</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skil-Care™</td>
<td>77.8</td>
<td>2.53</td>
<td>AirPal®</td>
<td>54.9</td>
<td>&lt; .0001*</td>
</tr>
<tr>
<td>Cotton</td>
<td>77.5</td>
<td>2.38</td>
<td>AirPal®</td>
<td>54.9</td>
<td>&lt; .0001*</td>
</tr>
<tr>
<td>Cotton</td>
<td>77.5</td>
<td>2.38</td>
<td>Skil-Care™</td>
<td>77.8</td>
<td>0.9958</td>
</tr>
</tbody>
</table>

* indicates a significant difference between the sheet types.

The last analysis to include biomechanics was comparing peak low back force with pain at the self-chosen bed height. There was not a significant difference in peak low back or ground reaction force between pain and nonpain groups as shown in Table 6 and Table 7.

Table 6

Peak Resultant Low Back Force Between Pain and Nonpain Groups

<table>
<thead>
<tr>
<th>Vertebral Level</th>
<th>Pain (N)</th>
<th>Standard Error</th>
<th>Nonpain (N)</th>
<th>Standard Error</th>
<th>Mean Difference (N)</th>
<th>Standard Error</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>L4-L5</td>
<td>812</td>
<td>59.1</td>
<td>827</td>
<td>50.7</td>
<td>−17.8</td>
<td>74.5</td>
<td>0.594</td>
</tr>
<tr>
<td>L5-S1</td>
<td>683</td>
<td>57.4</td>
<td>700</td>
<td>47.5</td>
<td>−14.8</td>
<td>77.9</td>
<td>0.575</td>
</tr>
</tbody>
</table>

Table 7

Peak Ground Reaction Force Between Pain and Nonpain Groups

<table>
<thead>
<tr>
<th>Force Type</th>
<th>Pain (lbs)</th>
<th>Standard Error</th>
<th>Nonpain (lbs)</th>
<th>Standard Error</th>
<th>Mean Difference (lbs)</th>
<th>Standard Error</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean GRF</td>
<td>80.3</td>
<td>3.36</td>
<td>87.9</td>
<td>3.3</td>
<td>−7.64</td>
<td>4.71</td>
<td>0.943</td>
</tr>
</tbody>
</table>
**Multifidus Cross-Sectional Area**

There were significant correlations between multifidus cross-sectional areas and the VAS at all three of the spinal levels, L4, L5, and S1. See Table 8 for mean values and significance levels. Those healthcare workers who marked lower pain scores on the VAS tended to have larger multifidus cross-sectional areas, while those who marked higher pain scores on the VAS tended to have smaller multifidus cross-sectional areas.

**Table 8**

*Multifidus Cross-Sectional Area Between Pain and Nonpain Groups*

<table>
<thead>
<tr>
<th>Vertebral Level</th>
<th>Pain (cm²)</th>
<th>Standard Error</th>
<th>Nonpain (cm²)</th>
<th>Standard Error</th>
<th>Mean Difference (cm²)</th>
<th>Standard Error</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>L4</td>
<td>9.88</td>
<td>0.272</td>
<td>10.6</td>
<td>0.339</td>
<td>0.72</td>
<td>0.43</td>
<td>0.0507†</td>
</tr>
<tr>
<td>L5</td>
<td>9.84</td>
<td>0.296</td>
<td>10.9</td>
<td>0.401</td>
<td>1.07</td>
<td>0.50</td>
<td>0.0360*</td>
</tr>
<tr>
<td>S1</td>
<td>8.49</td>
<td>0.307</td>
<td>10.2</td>
<td>0.470</td>
<td>1.73</td>
<td>0.56</td>
<td>0.0048*</td>
</tr>
</tbody>
</table>

* indicates a significant difference between the sheet types.
† indicates a trend toward significance.

**Multifidus Activation**

Multifidus muscle activation trended toward a significant difference between healthcare workers with pain compared to those without. Those without pain tended to have more symmetrical firing of the low back multifidus while those with pain had more active left sided multifidus. See Table 9 for details.
Table 9

Multifidus Muscle Activation Between Pain and Nonpain Groups

<table>
<thead>
<tr>
<th></th>
<th>Pain (% Left Compared to Right)</th>
<th>Nonpain (% Left Compared to Right)</th>
<th>Mean Difference (%) (Left Compared to Right)</th>
<th>Standard Error</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multifidus</td>
<td>52.4</td>
<td>21.3</td>
<td>0.619</td>
<td>14.3</td>
<td>51.7</td>
</tr>
</tbody>
</table>

† indicates a trend toward significance.

Discussion

Preliminary Bed Height

This study underscores the importance of using an appropriate bed height and patient handling materials for healthcare workers who are involved in patient handling tasks (Caboor et al., 2000; Larson et al., 2018; Larson & Rice, 2015; Li et al., 2004; Lloyd & Baptiste, 2006; McGill & Kavcic, 2005; Lloyd, 2005). It also highlights some of the problems with using certain materials that do not seem to perform their purported purpose for patient handling tasks (Larson et al., 2018; Wong et al., 2016).

The initial discussion point drawn from the preliminary portion of this study was unexpected. It was hypothesized that there would be a U-shaped curve of low back force, with the lowest point being where compression forces stopped decreasing and shear forces started substantially increasing. This would show an ideal bed height for the boosting task somewhere between the lowest bed height and the highest where these forces traded off. The initial assumption was based on recommendations for the patient handling task (Lindbeck & Engkvist, 1993; Murtagh & Rice, 2015; Lloyd, 2005; Fairview Health Services, 2019; Icahn School of...
Medicine at Mount Sinai, 2020). However, this was not what the results discovered. The general pattern was seen among all participants as a group and followed the same trend for all participants individually. There was a consistent slight increase in shear force with the increase in bed height, but it was not substantial enough to overcome the massive decrease in compressive force for this patient handling task. Therefore, for boosting a patient up in bed the bed should be positioned in a higher position (up to 62% of caregiver height) to reduce the overall amount of force at the low back. This study did not observe other areas of the body, such as the shoulders, in-depth. For these reasons, the highest bed height was used as the “optimal” bed height for the main part of the study. The first participant’s data were excluded due to overstepping the bounds of the force plate, which resulted in lost data and an inaccurate peak low back force curve.

Biomechanically speaking, choosing the highest bed height makes sense as this puts the vertebral column in a more upright position and keeps the hands well within the power zone for manual tasks that is defined as being between the midthigh and midchest (Occupational Safety and Health Administration, n.d.). However, this leads to obvious limitations in other studies that used lower bed heights as a standardized measure (Caboor et al., 2000; Delooze et al., 1994; Marras et al., 1999; Murtagh & Rice, 2015; Skotte & Fallentin, 2008) or when self-chosen bed heights were anything less than the maximum for the bed, even when the self-chosen bed height resulted in a reduction in low back forces (Delooze et al., 1994). These studies could potentially make more impactful recommendations if they used the maximum bed height regardless of the healthcare worker’s preference. This information needs to be confirmed, validated, and widely disseminated to healthcare workers in the clinic and in training in order to reduce the overall biomechanical stress of the low back. This will potentially lead to a decrease in low back injury in this population and help them stay safe and prolong their careers. However, caution needs to
be taken in this as there is a possibility that the force is being transmitted to other joints in the kinetic chain. This could lead to an increase in injuries in other parts of the body.

**Main Bed Height**

With the current, commonly accepted recommendation that the bed height should be somewhere between the hips and waist or elbow of the caregiver when performing the boosting task (Lloyd, 2005; Fairview Health Services, 2019; Icahn School of Medicine at Mount Sinai, 2020) it was not expected that many participants would choose the highest possible bed height. While none of them did, there were a surprising number of participants who did not adjust the bed at all from its low position. Only 48.6% of healthcare workers adjusted the bed at all. Those that did raised it an average of 3.19 inches, taking the bed height from 29 inches to just over 32 inches. The highest self-chosen bed height was 36.25 inches. This was an increase of 7.25 inches from the starting position. While moving in the right direction, this was still several inches lower than the maximum height of the bed. Relating to percentage of caregiver height, the range of self-chosen percentages was from 38.7% to 55.3% with an average of 45.6% of caregiver height. The participant who adjusted the bed the farthest from the starting position was 6’2” and reported a “2” on the VAS with the self-chosen bed height being 50.3% of caregiver height. The range for the optimal bed height with this group of participants was 52.0% to 63.9% with an average of 58.3% of caregiver height. The optimal bed height did reduce resultant low back force compared to the self-chosen bed heights. This shows that even among experienced healthcare workers a higher bed height reduced low back force.

Anecdotally, several of the healthcare workers commented that the boosting task was more difficult at the higher height, and when questioned further they corroborated that the increase in difficulty was felt more at the shoulders than the low back. There may be a tradeoff
between lowering the force at the low back and keeping the force low at the shoulders, as the upper extremity is the second most injured body part among healthcare workers (Lipscomb et al., 2002), but the current study does not delve into this area.

Several healthcare workers asked if they could lower the bed from its starting position. This could put them at increased risk due to a worsening of the trunk posture and associated biomechanics during the boosting task. When questioned, the common response was that they are better able to lift with their legs with the bed at a lower height, but the postural changes and ground reaction force differences show an increased load on the low back regardless of leg involvement, so these assumptions are not supported by the data.

Healthcare professionals receive at least some level of safe patient handling training through their various educational programs and on-the-job with the rationale of protecting their low backs (Menzel et al., 2007; Perlow et al., 2016; Slusser et al., 2012; Wilson et al., 2011). This means most of the healthcare workers involved in this study, and presumably many more throughout the nation and world, are ignoring a simple step that they should be aware of and placing themselves at unnecessary risk of low back injury. As mentioned previously, there may be a tradeoff between protecting the low back and the shoulders, so further investigation is warranted looking at the two in conjunction.

Another finding of note regarding the current study is that the average peak ground reaction forces at the self-chosen height were higher than at the optimal height for healthcare workers. The mean ground reaction force for the optimal bed height using the Cotton sheet was 77.5 pounds, while the self-chosen bed height using the exact same draw sheet was 84.0 pounds. This is also an important difference showing that the higher bed height requires less overall force to complete the same boosting task than the lower bed height, and that the lower bed height
requires more force being placed unnecessarily on the body of healthcare workers. This is likely because the higher bed height encourages more of a sliding action as opposed to the lower height, which makes it easier to lift the patient, thus incorporating more voluntary force to move the patient than the higher bed height. Choosing a higher bed height could result in a reduction in total weight moved of almost 300 pounds/day, which could have a positive impact over time for healthcare workers (Tuohy-Main, 1997). This means that instead of moving 1.8 tons per shift, healthcare workers would only be moving 1.66 tons (Tuohy-Main, 1997), which, while still high, is substantially less due to a fairly simple alteration in methodology.

Other studies that have compared bed heights have been unsuccessful in showing differences in force at the low back and at the hands (Lindbeck & Engkvist, 1993; Murtagh & Rice, 2015). These studies were unsuccessful due to their using a very narrow window for bed heights. The Lindbeck and Enkvist (1993) study used only 41% and 46% of caregiver heights while the Murtagh & Rice (2015) study used bed heights at only 41%, 46%, and 51% of caregiver heights. These are all lower than recommended by the current study and are a narrow enough range that there may not necessarily be a significant difference between them, especially with the former study.

Those participants who adjusted the bed to a higher percentage of caregiver height (> 52% of caregiver height) consistently had among the lowest low back and ground reaction forces of all participants. Only one participant used a self-chosen height less than 40% of caregiver height and this participant had the highest low back and ground reaction forces of all participants. Only five participants were short enough to have the potential to meet the recommended optimal bed height (62% of caregiver height) with one of these having the potential to surpass that percentage. The average optimal bed height was 58.3% of caregiver
height, which is substantially higher than any of the heights in both the Lindbeck and Enkvist (1993) and Murtagh & Rice studies (2015). This is consistent with the overall results of the preliminary study and shows the need for healthcare workers to adjust the bed to a higher height in order to reduce low back and ground reaction forces.

While healthcare workers are encouraged to adjust the bed height and use other safe patient handling methods, it is rarely enforced, although there have been studies that implement zero lift policies with extraordinary results (Charney et al., 2006; Collins et al., 2004). Those facilities which enforce safe patient handling methodologies consistently have fewer patient handling injuries and subsequent reduced worker compensation claims over time (Charney et al., 2006; Collins et al., 2004). Further implementation of this bed height guideline can potentially help to reduce worker injury and should be pursued in the future with further research.

One healthcare worker also reported that during this type of task he would typically place one of his legs on the bed to give him a better angle to push from, but this was not possible during this study as the force plates were built into the floor and placing his leg on the bed would have resulted in lost data. This same individual utilized the “patient’s” legs in the boosting task by flexing the hip and knee with the feet still on the bed. This was allowed as the instructions were to complete the boost as close to how the participant normally does it as possible. This subject’s low back and ground reaction forces were all lower than many others. However, while this subject’s forces were among the lowest values in each condition, they were not the absolute lowest in any condition. No other participant used a varied technique for the boosting task in this study.
Biomechanics

There were significant differences in low back forces and ground reaction forces when comparing the boosting task with the three different types of draw sheet. The differences were between the AirPal® and the Skil-Care™ and the AirPal® and the Cotton sheet. Surprisingly, the Skil-Care™ resulted in the greatest amount of peak low back and ground reaction force and was not statistically different from the Cotton sheet.

These results are consistent with Hwang et al. (2019) as they used a variety of draw sheets to complete various patient handling tasks. When doing so, they found a simple friction-reducing draw sheet did not produce hand force differences compared to the Cotton sheet. The results also confirmed the findings of a similar project by Larson et al. (2018). They found that the only effective reduction in force with a simple friction-reducing sheet compared to a Cotton sheet occurred when the friction-reducing sheet was doubled up on itself, creating a double layer of friction-reducing material that can slide against itself as opposed to only sliding against the lower Cotton sheet. Also important to note with the Hwang et al. (2019) study is that they performed several different patient handling tasks, but they only recorded and reported forces for the lateral transfer task, not the boosting task, which would have been more directly comparable to the current study. They also only used a force gauge in one hand, which gives a rather incomplete picture of overall force for these patient handling tasks. Lastly, they used “patients” that had less mass than the “patient” in the current study, which is less representative of typical inpatients.

These findings also corroborate a similar study by Wiggerman et al. (2020) where they systematically used “patients” of three different weights to assess the effectiveness of various patient handling materials. They also showed that there was not a significant difference between
low back forces when boosting up a patient in bed when comparing a typical Cotton draw sheet to a simple friction-reducing device, but that there were significant differences between an air assisted device and the others with the lightest category of “patient” (Wiggerman et al., 2020). Interestingly, they also found more pronounced differences in hand forces between the devices as “patient” weight increased (Wiggerman et al., 2020). This study used a bed height of the “knuckle height of the caregiver or higher” (Wiggerman et al., 2020), which according to the current study is low enough to produce more low back force than a more optimal position.

The lack of difference between the Cotton sheet and the Skil-Care™ is a concern. The Skil-Care™ purports to be a friction-reducing device but does not seem to perform its primary function as evidenced by the high low back and ground reaction forces when used per manufacturer recommendations. None of the forces was different compared to those observed when using the typical Cotton sheet. This suggests that low back and ground reaction forces are no different when using the Skil-Care™ compared to a Cotton sheet, which means it is still putting the same stresses on healthcare workers’ bodies.

The air-assisted device was the best performing device, effectively reducing most low back forces as well as ground reaction forces compared to the other devices. However, even with this best performing device, the average ground reaction forces were above the recommended lifting limit of 35 pounds. The lowest ground reaction force recorded was 37 pounds with an average of 54.9 pounds. This shows that while it is better to use than the other devices in this research study, it is still not enough. Thus, it still places healthcare workers at risk of musculoskeletal injury due to regular patient handling tasks that are a required part of the job.

Peak low back forces did not correlate significantly with the VAS. This was surprising because the assumption is that healthcare workers who put more stress on their low backs are at
greater risk of low back injury, but this did not seem to be the case. Peak ground reaction forces also did not correlate with the VAS in the direction of the hypothesis. Interestingly, all peak forces were higher in the nonpain group. This was the opposite of what was anticipated. One possible explanation for this observation could be that the workers with low back pain are attempting to reduce the risk of further increasing their pain by altering their body mechanics as a protective mechanism for themselves. This will of course need to be validated with a follow-up study specifically looking at this.

**Multifidus Cross-Sectional Area**

The multifidus cross-sectional areas yielded a significant difference between the low back pain group and the nonpain group at the L5 and S1 level with a trend toward significance at the L4 level. Those with smaller multifidus cross-sectional areas at the L5 and S1 levels had higher levels of pain and those with larger cross-sectional areas had lower levels of pain. This relationship has been shown by others who focused on different populations with varying degrees of consistency (Beneck & Kulig, 2012; Evanson et al., 2018; Hides, Gilmore et al., 2008). For example, Evanson et al. (2018) measured multifidus cross-sectional areas between the L1 to L5 levels and did not find significant differences between the pain group and the nonpain group in highly trained ballroom dancers, while Hides, Gilmore et al. (2008) measured the multifidus at the levels of L3 to L5 and found a difference in cross-sectional area between those with pain and those without pain in a general population. The important distinction between these studies is that Evanson et al. (2018) used subjects who were young and very athletic in nature, while Hides, Gilmore et al. (2008) included any participant who had low back pain and controls without distinguishing activity level.
The current study with healthcare workers is more similar to the latter Hides, Gilmore et al. (2008) study, simply exploring pain levels without factoring in overall activity levels. The age range of participants in the current study was also more varied, which lends to the overall typicality of the population compared to a highly athletic population. Also like the Hides, Gilmore et al. (2008) study, measurements were taken only at lower spinal levels, which are more consistently different in symptomatic individuals (Kjaer et al., 2005; Sweeney et al., 2014; Wallwork et al., 2009). However, one study compared cervical multifidus cross-sectional area to neck pain and found that those with smaller cervical multifidus had more pain (Fernandez-De-Las-Penas et al., 2008). This shows that not only lower level lumbar multifidus follow this pattern, but that cervical multifidus are consistent with this finding in a general pain versus nonpain population.

**Multifidus Activation**

There was a trend toward significance in multifidus activation between those with low back pain and those without pain, which is somewhat consistent with other research in this area (Ahern et al., 1988; Danneels et al., 2002). Some studies have shown less overall activity of the multifidus in those who have low back pain with certain tasks (Danneels et al., 2002), while others show a less consistent response regardless of the type of movement in individuals with and without low back pain (Lee et al., 2005), and yet others show an increase in overall muscle activation, including different muscles in low back pain groups (Ng, Richardson et al., 2002). It was hypothesized that those without pain show a more typical pattern of muscle activity. With this type of boosting movement (left rotation), it was expected that the right multifidus would be more active than the left as the multifidus muscles participate in trunk extension, ipsilateral sidebending, and contralateral rotation (Clemente, 2007; D'Antoni, 2016). Those with low back
pain were expected to have different activation patterns during this asymmetrical movement compared to asymptomatic peers (Ng, Kippers et al., 2002). While not the main purpose of the study, Ng, Kippers et al. (2002) showed that in individuals who have more low back pain there is more symmetry in muscle firing with sidebending and less symmetry with rotation when performing pure movements in the multifidus. The current study found increased symmetry in individuals without low back pain and increased asymmetry with greater left multifidus activation in those with low back pain. This could mean that those with pain employ more of a rotational movement for the boosting task while those who don’t have pain use a technique that relies more heavily on sidebending. Differences in technique will need to be dissected in a follow-up study.

All boosting tasks were done with the “patient” being boosted to the participant’s left side. The left side of the body exhibited greater muscle activity during the boosting task compared to the right in both groups. Since the left multifidus contributes to left sidebending, this finding likely indicates that sidebending had more of an influence on multifidus activation than rotation. The nonpain group exhibited 0.6% greater left sided activation in the multifidus while the pain group showed 52% greater left sided activation. However, there was a lot of variation in the results, but overall those healthcare workers who did not have low back pain trended to have a more symmetrical response than those with pain when performing a boosting task at a self-chosen bed height with a Cotton draw sheet.

**Limitations**

This study was completed in a lab setting rather than a clinical setting. The preliminary study was completed with nonhealthcare workers, which could have led to results atypical of a healthcare worker population. However, this was somewhat remediated with the comparison
between the self-chosen bed height and the highest bed height with healthcare workers in the main study. The hospital bed used in this study was not able to raise high enough for many of the participants and thus a suboptimal percentage of caregiver height was used out of necessity for those for whom it was too short. All the participants for the preliminary and main studies were living in the greater Provo, Utah, area, so the results cannot be generalized to a greater population.

There was only one healthy, young individual who acted as a patient. This was important as a control factor in order to make direct comparisons between other factors, but this individual was atypical of a general patient population. Real patients tend to be sickly, older, and less cooperative. This research assistant also only represents one height and weight, whereas genuine patients are much more varied and have individualized differences that can affect patient handling technique and experience for the caregiver.

During the preliminary study, there was a high amount of variation in estimated low back force between subjects, in part due to imprecise weight records due to self-reporting. This was remediated during the main study as the researcher weighed all participants at the time of data collection. Another limitation of this study was the relatively small sample size. The number of participants was consistent with other studies of this type. However, when comparing the multifidus cross-sectional area and activation to pain it is possible that if there had been more participants more solid evidence could have been found. Stronger conclusions could then be made to inform healthcare professionals of the relationship of these factors to low back pain.

There is some concern regarding whether surface EMG sensors are effectively capturing multifidus activation (Imai et al., 2010; Stokes et al., 2003). The preference for accuracy is currently indwelling fine wire EMG for these muscles (Imai et al., 2010; Stokes et al., 2003).
With using the surface EMG sensors there may have been inaccurate data collected during this study which limits the validity of the comparisons and conclusions.

**Future Research**

There are several areas for future research brought to light with this project. Investigating the potential to increase the cross-sectional areas of healthcare workers by giving them multifidus-specific low back exercises and seeing if this increases multifidus cross-sectional area and decreases pain is a logical next step. There is also potential to look into other sources of low back pain and how these can be ameliorated, including the influences of bony structures and intervertebral discs on low back pain in healthcare workers (Adams & Roughley, 2006; Hickey & Hukins, 1980; Lewinnek & Warfield, 1986; Luoma et al., 2000; Moore, 2006; Pfirrmann et al., 2001; Roberts et al., 2006). Another area of future study can include indwelling EMG sensors rather than surface EMG sensors as there is increased accuracy with these. This could reduce the variability and improve the results of a similar future study. Boosting technique and how it relates to muscle activation comparing healthcare workers who have pain to those who do not have pain is also merited.

It would be enlightening to compare low back forces with similar patient handling tasks with the bed at an optimal level and then a higher level to compare low back forces and include shoulder forces to see what the overall trend is at the two areas of the body. This could inform healthcare workers if there is a tradeoff in low back and shoulder safety and if there is a bed height that is too high to be considered optimal. Incorporating multiple patient handling techniques and comparing low back forces between them is also warranted. Techniques like simply bending the patient’s legs and putting their feet on the bed prior to the boosting task to placing the bed at a decline prior to the boost. It would also be important to study the tradeoff
between low back force and shoulder force during these patient handling tasks to see if by lowering the force at the low back healthcare workers place themselves in greater risk of shoulder injury and vice versa. Another future study could incorporate inclining the bed with the air assisted device and seeing if there is an angle where the air overcomes the friction of the bed and allows the patient to freely slide to the edge of the bed as this would be a safety concern. This idea would necessitate very controlled conditions with healthy individuals to prevent injury.

An interventional study focusing on bed height could also be informative for future research. Two groups could be established, one that is required to use the maximum bed height in a clinical setting and one that can continue to perform patient handling tasks as usual and low back pain can be tracked over time to see if there is a difference at the end of six months with injury rates being tracked over two years.

Conclusions

There are several clear conclusions that can be made based on the results of this study. Healthcare workers need to choose higher bed heights during manual patient handling tasks in order to reduce low back forces. This simple and relatively quick adjustment can reduce low back and ground reaction forces and potentially reduce the risk of low back injury among these workers. This can have an impact in reducing the amount of money spent on alleviating these injuries as well as improving the lives of healthcare workers. However, caution should be taken as there may be negative implications for other body parts such as the shoulders at a higher bed height. Therefore, it may be important to find a balance between reducing low back forces and the impact at the shoulder for each healthcare worker. Simple choices that take a little extra time are worth it in the long run if it reduces the risk of experiencing a musculoskeletal injury.
Reducing body strain can also include using friction-reducing materials for patient handling tasks. However, some materials that are supposed to reduce forces for patient handling tasks may not be effective at doing so. These must be evaluated on an individual basis to assess the effectiveness of the materials in reducing forces on the body and whether they should be recommended for use in healthcare settings. There are some materials that are effective at reducing the amount of force placed on healthcare workers’ bodies and should be more widely available and used more frequently for boosting tasks.

Smaller multifidus cross-sectional areas can be an important indicator in low back pain for healthcare workers. These workers can be made aware of this and take measures such as multifidus-specific exercises to ensure sufficient muscular support and care. This can keep the cross-sectional areas where they should be and potentially reduce low back pain in order to improve quality of life and longevity of career. Multifidus muscle activation may play a role in low back pain in healthcare workers during a boosting task with a dependent patient. This needs to be explored further for more concrete conclusions.
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