Trunk Kinematics of Pulling at or Below Sub-Waist Height

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Abstract

The high prevalence of musculoskeletal disorders (MSDs) among nursing personnel are often attributed to risk factors associated with repetitive manual handling tasks such as transferring patients. MSD cases involving patient handling account for up to 98% of all MSD cases reported within the health care and social assistance industry. When transferring a patient onto a sling or a bed/stretch, the required pulling force could be as high as 75% of the patient’s body weight. Studies on the effect of pulling at or below waist level with various grip positions are scarce. Such an understanding may provide insight to the healthcare industry on improved methods when handling patients and designing assistive devices to help prevent MSD. This study aims to examine how different weight, height and grip positions when pulling affect trunk kinematics and the center of pressure of footing. Nine subjects performed tasks using a pulley workstation. Results indicated there was neither three-way nor two-way interaction among the workstation height, weight, and grip location on the trunk kinematics or center of pressure measures. Results did show significant effects from the workstation height and pulling weight on the dependent variables.

Keywords
Musculoskeletal disorders, trunk kinematics, patient handling, center of pressure

1. Introduction

Work related musculoskeletal disorders (MSD) have become a challenge and financial burden for employers in the United States because of the negative impact on worker’s compensation claims, absenteeism and productivity. MSD is defined as “structural damage, inflammation, or pain that results from injuries to nerves, tendons, muscles, blood vessels, or other supportive tissues associated with the musculoskeletal system” [1]. In 2011, MSD accounted for 33% of all worker injury and illness cases reported [2]. Healthcare was one of the leading industries with the most reported cases [2]. Since 2006, nursing occupations have been reported as one of the top ten highest risks for work-related MSD in the United States [3]. Table 1 shows nursing occupations that were reported as having the highest incident rates of injuries and illnesses with absenteeism in 2011 [2]. Nursing aides, orderlies and attendants incidence rate was more than seven times the average for all industries [4]. Recent studies show that nursing personnel has the highest back-related workers compensation claims [5].

Table 1: Incidence rates of injuries and illnesses with days away from work for selected nursing occupations[2]

<table>
<thead>
<tr>
<th>2000 and 2010 SOC Titles</th>
<th>All Cases</th>
<th>Musculoskeletal Disorders</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>Incidence Rate</td>
<td>Number</td>
</tr>
<tr>
<td>Nursing aides, orderlies and attendants (2000 SOC)</td>
<td>47,840</td>
<td>443.9</td>
</tr>
<tr>
<td>Nursing assistants (2010 SOC)</td>
<td>46,520</td>
<td>-</td>
</tr>
<tr>
<td>Orderlies (2010 SOC)</td>
<td>1,310</td>
<td>-</td>
</tr>
<tr>
<td>Registered nurses (2000 SOC)</td>
<td>27,950</td>
<td>135.7</td>
</tr>
<tr>
<td>Registered nurses (2010 SOC)</td>
<td>27,610</td>
<td>-</td>
</tr>
<tr>
<td>Nurse anesthetists (2010 SOC)</td>
<td>40</td>
<td>-</td>
</tr>
<tr>
<td>Nurse practitioners (2010 SOC)</td>
<td>280</td>
<td>90</td>
</tr>
</tbody>
</table>
Other reports also show that there is an association between lifestyle factors (e.g. obesity epidemic and the increasing number of older age people) and low back injuries among nursing personnel. Studies show that 52% percent of nursing personnel complain of chronic back pain [6]. American Nursing Association reported that the lower back followed by shoulders and knees are the most affected body parts when handling patients [5]. Registered nurses frequently changed job positions In 2003, 6 percent, 8 percent, and 11 percent of registered nurses reported changing employment for neck, shoulder and back problems, respectively [7]. It is reported that lower back injuries are also the most costly MSD [7]. The direct and indirect costs associated with only back injuries in the health care industry are estimated to be $20 billion annually, according to the [4].

Cases involving patient handling accounted for 98% of all reported MSD cases [8]. Risk factors that attribute to this large number are repetitive manual tasks associated with transferring patients: lifting, pushing / pulling and working in awkward postures. Some examples include: (1) transferring from bed to chair, (2) transferring from toilet to chair, (3) repositioning from side to side in bed (4) making a bed with a patient in it and (5) dressing the patient. These tasks have been identified as the top problematic tasks resulting in excessive stress and strain on the muscles and joints [9]. Sprain, strain and tear were the type of injuries reported and accounted for 80% of the patient handling MSD cases [8]. When positioning a patient onto a sling or transferring onto a bed/stretch, the required pulling force could be as high as 75% of patient's body weight [10]. Although, it is suggested that 50 kg is the maximum weight a person should push or pull to avoid injuries [9], it is unclear how different grip and sub-waist height positions when maneuvering the patient may affect stresses on the lower back muscles and balance of nursing personnel.

While there are several risk factors that are impacting the safety culture in healthcare workplaces, immobile and bariatric (obese) patients pose the greatest threat for significant lifting risks for nursing personnel. Results from Center of Disease Control and Prevention in 2010 indicated that in the United States, 35.7% of adults and 17% of children are obese [8]. During the past ten years, majority of European countries have experienced an increase in the frequency of obesity [11]. In certain cities in China, almost 20% of adults are obese [12]. It is predicted that the United States age population 65 and older will grow from 40 million in 2010 to 55 million in 2020 [13]. It is also suggested that adults ages 60 and over were more likely to be obese than younger adults [8]. This trend with obesity means increased physical stresses on the caretakers’ body (e.g. lower back) while handling the patients that can potentially lead to injuries.

Current research also indicates that the caretaker and clinician population is rapidly increasing. In 2004, there were 1,325,000 caretakers and clinicians [13]. This number is expected to grow by 56% by 2014 [13], with home healthcare employment expecting to grow by 55% between the years 2006 and 2016 [8]. The increase in caretakers may also lead to increase in injuries.

In addition to the aforementioned risk factors, the lack of proper handling techniques when transferring patients is also a contributing factor. Researchers have suggested that the use of assistive devices could reduce back stress for nursing personnel during patient handling tasks [14-18]. “Cost-benefit analyses have also shown that assistive patient handling technology successfully reduces workers’ compensation costs for MSD” [5]. There are many assistive devices that are commercially available. Unfortunately, the function of the devices is only to lift the patient and not to assist nursing personnel with applying the patient sling. Positioning the patient in the sling is the first task that the nursing personnel must perform before the patient can be lifted. Figure 1 is an example of an assistive device.
Positioning the patient in the sling requires the nursing personnel to push, pull and lift the patient. More attention in the development of assistive technology has been focused on decreasing back injuries when lifting the patient and less attention has been given to reducing back injuries caused by pushing and pulling patients. Although research shows that push/pulls are less strenuous than lifts [20], the recent obesity epidemic raises concerns that it may increase the risk of overexertion on the musculoskeletal system. Also, pushing and pulling increases the risk of accidents due to slipping or tripping, which can also cause injury to the musculoskeletal system [21, 22]. Therefore, with nursing personnel currently leading the nation in work related back injuries, more research is needed to identify and provide safe guidelines for patient handling that will decrease the potential risk of MSDs.

The objective of this study is to quantify the effect of pulling weight, grip position and pulling height (sub-waist) on trunk kinematics (angular velocity and angular acceleration) and posture/balance (center of pressure) measures to identify potential pulling-related risk factors on lower back disorders. The main hypothesis is that the pulling weight, grip position, and pulling height will (as well as their interactions) have an effect on trunk kinematics and center of pressure measures. Such an understanding may provide insight to the healthcare industry on improved methods for nursing personnel to handle bariatric patients and on related equipment to help prevent musculoskeletal disorders in the lower back. The intent is to provide recommendations on better patient handling/transferring guidelines to help prevent musculoskeletal disorders in the lower back.

2. Methodology

2.1 Participants

Nine participants ranging between the ages of 18-40 participated in the study. The participants consisted of three male and six female students. Anthropometric data were measured from each participant at the start of the study. Their means (and standard deviation) are as followed: stature 170.54 (9.02) cm, weight 74.89(8.56) kg, standing knuckle height 75.34 (4.18) cm, waist height 98.72 (6.55) cm, shoulder width 41.16 (3.03) cm, and right arm length 63.69 cm (3.45). None of the participants experienced injuries in the low back, hand/wrists or shoulder. The experimental protocol was approved by the University’s Institutional Review Board. A written consent was obtained from each subject prior to the participation in the experiment.

2.2 Apparatus

An adjustable pulley workstation was built to simulate an exerted pulling force that takes place during patient handling tasks (Figure 2). This workstation was constructed to allow for adjustable pulling exertion levels and workstation surface heights. It implemented a pulley system to transfer the load imposed by adjustable –weight dumbbells to the subject through ropes tied to a wooden rod held by the subject. The Industrial Lumbar Motion Monitor (iLMM) (BioDynamics Solutions, Inc., Columbus, OH) was used to collect the participants’ real-time three dimensional trunk kinematics at a sampling rate of 60 Hz. The Bertec force plate (Bertec Corporation, Columbus, OH) was used to capture the center of pressure for each participant at a sampling rate of 1000 Hz (Figure 4). The MotionMonitor data acquisition software (Innovative Sports Training, Chicago IL) was used to record the force plate data.
2.3 Experimental Design
A full-factorial repeated-measures design was used in this study. The independent variables were the surface height of the workstation (with two levels at subject-specific standing knuckle and waist heights), pulling exertion level (0 kg, 2.27 kg (5 lbs), and 6.80 kg (15 lbs)), and grip position (center, shoulder width, and wide). The pulling exertion levels were selected as a result of the pilot study, where the levels were determined to be psychophysically distinguishable from each other while well within the safety range [9]. The wide grip was defined as shoulder width
× 1.25 (symmetric bilaterally). The dependent variables were angular velocity, angular acceleration (both in the sagittal plane) and total distance traveled of center of pressure.

2.4 Procedure
Upon arrival, participants were greeted, informed on the purpose of the study, and were asked to sign an informed consent form to participate in the study. A pre-test questionnaire was administered via SurveyMonkey, an online survey tool, to collect demographic information and current health status. Next, the participant’s weight, stature, standing knuckle and waist height, shoulder width and extended right arm were measured. Participants were asked to stretch before beginning the study. They were first given a demonstration on how to use the workstation pulley station and were allowed to become familiar with the workstation. Participants were asked to stand on the force place in an upright position with heels next to the center of the X marked on the force plate. All trials were randomized according to weight, height and grip locations. When cued, the participants grabbed the bar (bending their trunk forward) and pulled the bar to their body keeping the bar parallel to the table. This was repeated 3 times per task. Each participant performed 18 tasks per two trials. Figure 5 provides a visual representation of the task procedure. One to two minute rest periods were given after completing each task to prevent fatigue. Upon completion of the experiment, the participants were asked to complete a post-test questionnaire online and thanked for their participation.

Figure 5: Task Procedure

2.5 Data Processing
The iLLM device captured the angular velocity and angular acceleration. The Bertec force plate device captured the center of pressure data. The data was processed, exported and then imported into Microsoft Excel. Microsoft Excel was used to find the participants’ peak acceleration and velocity in the sagittal plane for both trials. The peak values of the angular velocity and acceleration and the distance of center of pressure were averaged and analyzed using SAS software.

2.6 Statistical Analysis
SAS 9.3 (SAS Institute Inc., Cary, NC) software was used for data analysis. To assume parametric requirements, the dependent variables’ data should be interval or ratio and reasonably normally distributed. Shapiro-Wilk test was performed on the data. It revealed that the angular acceleration and the center of pressure data did not fit a normal distribution. The data was therefore transformed using normalization to rescale the data. All statistical tests were done on the transformed data where appropriate. The angular velocity data was normal. The magnitude of correlation between the dependent variables was also checked. The trunk kinematic data was highly correlated (r =0.908). The center of pressure data was not correlated. A MANOVA was used to examine the effects of pulling weight, grip position, pulling height, and their interactions on the dependent measures (transformed data) collectively. If statistical significance of the MANOVA (p<0.05 for the Wilks’ Lambda statistic) was found for a main effect (or interaction), then that effect (or interaction) would be tested using individual ANOVA for each measure. Student-Newman-Keuls (SNK) was used to perform the post-hoc analysis.
3. Results

3.1 Pre-Test and Post-Test Questionnaires

The pre-test questionnaire gathered information to determine if the participants met the criteria to participate in the study. No participants had any prior injuries.

The post-test questionnaire collected the participants’ overall experience with the study. The analysis measured the following: (1) the level of discomfort during the study, (2) the ability to complete the tasks required, and (3) the level of difficulty of the tasks performed. A five-point Likert scale (1=easy, 5=difficult) was used to rate participants responses to the items on the questionnaire. The average rating for each item is provided in Table 2. All participants completed the tasks; however, majority of the participants experienced some difficulty of completing the tasks.

<table>
<thead>
<tr>
<th>Item</th>
<th>Average Rating</th>
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<tbody>
<tr>
<td>Level of discomfort</td>
<td>2.18</td>
</tr>
<tr>
<td>Ability to complete task</td>
<td>3.44</td>
</tr>
<tr>
<td>Difficulty of task</td>
<td>2.91</td>
</tr>
</tbody>
</table>

3.2 Trunk Kinematics

MANOVA results did not show a difference between the independent variables (surface height, pulling exertion and grip location). Acceleration and velocity means are shown in Figures 6 and 7, respectively. The ANOVA results are shown in Table 3.

![Angular Acceleration Means](image)

**Figure 6: Angular Acceleration Means at Surface Height and Pulling Exertion Levels**

![Angular Velocity Means](image)

**Figure 7: Angular Velocity Means at Surface Height and Pulling Exertion Levels**
Table 3: Trunk Kinematics ANOVA Results

<table>
<thead>
<tr>
<th>Independent Variables</th>
<th>Avg. Velocity (sagittal plane)</th>
<th>Avg. Acceleration (sagittal plane)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface height</td>
<td>( F_{1,16} = 44.31 )</td>
<td>( F_{1,16} = 22.83 )</td>
</tr>
<tr>
<td></td>
<td>( p &lt; 0.001 )</td>
<td>( p &lt; 0.0001 )</td>
</tr>
<tr>
<td>Pulling exertion</td>
<td>( F_{2,15} = 7.32 )</td>
<td>( F_{2,15} = 5.50 )</td>
</tr>
<tr>
<td></td>
<td>( p = 0.0009 )</td>
<td>( p = 0.005 )</td>
</tr>
</tbody>
</table>

A post hoc analysis (SNK test) was performed to further explore any significant effect of the independent variables on the kinematic dependent variables (Figures 8 and 9). For the angular acceleration, the knuckle and waist surface heights are not significantly different; the center, wide, and shoulder grip locations are not significantly different. For the pulling exertion levels, 2.27 kg and 6.80 kg are not significantly different; 0 kg and 2.27 kg are not significantly different and 0 kg and 6.80 kg are significantly different. For the angular velocity, the knuckle and waist height are not significantly different; the center, wide and shoulder grip location are not significantly different. The weight, 2.27 kg and 6.80 kg are not significantly different. However, 2.27 kg and 6.80 kg are significantly different than 0 kg.

3.3 Center of Pressure

An ANOVA was performed on the center of pressure data, since the data did not correlate with the trunk kinematics data. The results only showed two significant factors: surface height \( (F_{1,16} = 34.61, p < 0.001) \) and pulling exertion \( (F_{2,15} = 55.03, p < 0.001) \). Means at different levels of exertion and surface heights are shown in Figure 10.
A post hoc analysis (SNK test) was performed to further explore any significant effect of the independent variables on the distance traveled of center of pressure (Figures 11 and 12). Both the surface heights (knuckle and waist) are significantly different, and all three exertion levels (0 kg, 2.27 kg, 6.80 kg) are significantly different from each other.
4. Discussion
In the current literature, there is a general consensus that the amount of weight when pulled or pushed in a repetitive manner over a period of time affects the lower back muscles. Injury to the lower back muscles as a consequence of patient handling is also well documented in the literature. Although many studies have determined the effect of pulling on lumbar motion, this study examined the effect of pulling specifically at sub-waist heights on lumbar motion. Studies at this height are scarce. The overall concern was that the interaction between the amount of weight, grip position and height position would cause stress and potential injuries to the lower back muscles. The MANOVA results show that there was no statistical three way interaction between weight, grip location and workstation height. Initially, the assumption was the grip location and the amount of weight would impact the angular acceleration and angular velocity. This did not hold true. There was no statistical two way interaction between weight and grip location, weight and workstation height and grip location and workstation height. The ANOVA results show that there was a statistical difference for the workstation height (knuckle and waist) and for the weight (0, 2.27, and 6.80 kg) on the angular acceleration and angular velocity. Also, the results indicated that weight increase at the knuckle location had more of an impact on the participants’ angular acceleration and angular velocity. It was observed that the knuckle height position caused the participants to bend their trunk forward more in comparison to the waist height. At the 6.80 kg weight, majority of the participants also had to bend their trunk forward more than the previous weight at the knuckle and waist height. Overall, this caused the subjects angular velocity to decrease during the extension of the trunk. The peak velocity appeared to occur during the bending phase. The angular acceleration varied between participants. The peak acceleration appeared to occur during the bending and pulling phases.

Similarly, weight and height were shown to have a significant impact on the participant’s center of pressure. Lower height and higher weight increased the distance traveled of the center of pressure. We can infer that a patient who is considered overweight/obese and/or who limbs are restricted and positioned at a workstation height below waist, will cause a caregiver to experience more stress on the lower back muscles over a period of time and potentially comprise the caregiver’s posture/balance.

5. Conclusion
There are areas of this research that can be further developed. The workstation pulley station can be redesigned to accommodate more height levels and to allow additional testing such as the effects of pushing on trunk kinematics above and sub-waist. A larger sample size is needed to examine other variables, for example, participants’ height, age and gender. Furthermore, increasing the task duration (e.g. more repetitions) and including height above waist may significantly impact the results. Although our initial thought that the interaction between grip location and weight will impact trunk kinematics did not hold true, other grip locations that cause the participants to turn their waist should be studied.

The results of this study agreed with the finding of previous literature that there is risk of lower back injury when transferring a patient. There is still a significant concern of a greater risk when the patient is bariatric, immobile and/or has restricted limbs. Currently, research is being conducted to address the following: (1) a method of attaching a sling to a patient when there is minimum bending and extension of the trunk and (2) a fluid power assistive device that the caregiver can use to transfer a patient. This device will be able to move the patient or provide support when maneuvering the patient. Finally, more testing will conducted in the future with the intention of providing patient handling guidelines for MSD prevention.

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