

Materials and Methods

1. Participants

A total of 8 participants (5 males and 3 females) were recruited for this study. The mean and standard deviation of height and weight are summarized in Table 1. All participants did not have musculoskeletal pain in the past 7 days; current medication associated with MSDs; and restrictions in physical activities. One male participant was recruited for a simulated caregiver. The height and weight of the simulated patient were 177 cm and 84 kg, respectively. The experimental protocol was approved by the Northern Illinois University Institutional Reviewer Board, and participants reviewed and gave written consent before the data collection.

Table 1. Mean (standard deviation) of participant information.

	Males (n = 5)	Females (n=3)	Total (n=8)
Height (cm)	177.9 (5.45)	164.33 (7.09)	172.75 (8.94)
Weight (kg)	78 (13.02)	62.33 (2.52)	72.13 (12.82)

2. Passive back-support exoskeleton

The small and large sizes of Laevo V2.5 (Delft, Netherlands) were used for this study. This back-support exoskeleton is lightweight (2.9 kg) and consists of gas springs and anchors to support the back and distribute the external load to multiple body segments, such as the chest, waist, and thighs. For proper fit, each participant was instructed to adjust the engagement angle built into the exoskeleton.

3. In-bed patient handling tasks

Four different in-bed patient handling tasks were simulated. The description of each task is summarized in Table 2, and experiment photos are shown in Figure 1. The draw sheet was

positioned underneath the patient to set up consistent surface friction for all tasks. For task 1, the bed height was set as the lowest height of the bed to make the patient's initial sitting position stable and safe. For tasks 2, 3, and 4, the bed height was set at the caregiver's knuckle height. The simulated patient provided minimal assistance and effort to the caregiver during the tasks.

Table 2. Task number, name, and description of each in-bed patient handling task.

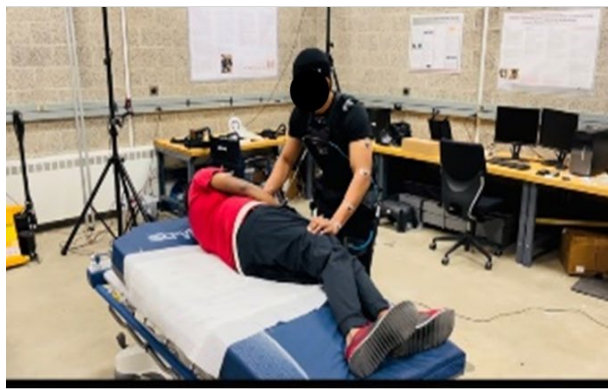
Task Number	Name	Description
1	Sitting to lying	A caregiver repositioned the patient from sitting on the bed to a supine position. The caregiver grasped the patient's shoulder and thigh.
2	Repositioning toward caregiver	A caregiver repositioned the supine patient from the middle of the bed to the bedside near the caregiver. A caregiver grasped the draw sheet to reposition the patient.
3	Turning toward caregiver	A caregiver turned the supine patient toward the caregiver. The patient turned to face the caregiver. The caregiver grasped the patient's right shoulder and knee.
4	Turning away from caregiver	A caregiver turned the supine patient away from the caregiver. The caregiver grasped the patient's left shoulder and knee.



Task 1



Task 2



Task 3



Task 4

Figure 1. The experimental setup of in-bed patient handling tasks. Task 1: Sitting to lying; Task 2: Repositioning toward caregiver laterally; Task 3: Turning toward caregiver; and Task 4: Turning away from caregiver.

4. Apparatus and outcome measures

Joint angles

The kinematic data of the participants were measured using the optical motion capture system. Eight cameras with 50 Hz (Flex 13; Optitrack; Natural Point, OR) captured the participant's movements during the task. A total of 39 reflective markers were attached to the head, torso, arms, hands, pelvis, legs, and feet of the participants. The motion capture software (Motive 2.0; Optitrack; Natural Point, OR) was utilized to record and process the kinematic data of participants.

Muscle activity

A wireless electromyography (EMG) system (Delsys Trigno; Delsys Inc.; Boston, MA) with 2,000 Hz was used to collect the muscle activities of bilateral erector spinae. Per the European recommendation for surface electromyography, the skin preparation and electrode placements were performed. The isometric maximum voluntary contractions (MVCs) were conducted for each participant to normalize the muscle activities. The participant used a roman chair to incline and maintain an unsupported torso for five seconds. The MVC tasks were repeated three times with 2 minutes' resting time between the tasks.

Heart rate

The heart rate monitor chest strap (Polar H10, Polar Electro Oy, Kempele, Finland) was utilized to collect the electrocardiogram (ECG) signals of each participant during the task. The validity and reliability of this device have been confirmed by previous studies. The moistened elastic strap with room temperature water consisting of the electrodes and the sensor was placed at the participant's chest level.