**Posture and Mechanical Load Assessment During Patient Transfers**

Sandra Hellmers¹ · Anna Brinkmann¹ · Conrad Fifelski-von Böhlen¹ · Sandra Lau² · Rebecca Diekmann¹ · Andreas Hein¹

Received: 12 October 2021 / Accepted: 19 June 2022 © The Author(s) 2022

**Abstract**

Caregivers experience high musculoskeletal loads during their daily work, which leads to back complaints and a high rate of absenteeism at work. This reinforces the already existing discrepancy between the supply and demand of caregivers. Ergonomically correct working can significantly reduce musculoskeletal load. Therefore, we developed a system that recognizes potentially harmful body postures. In a study with 13 caregiver students, we analyzed the body postures, as well as muscle activities, and loads during the transfer of a patient from bed to wheelchair. The body postures were measured by a full-body motion capture system and a Multi-Kinect System. Muscle activities and loads were recorded via surface electromyography and a force plate. The posture analysis system is based on the motion capture data and considers the recommendations for ergonomic working in the care sector. The system generates a result report visualizing the skeleton model as well as color-coded information about inclination and torsion angles. The motion capture data were also related to EMG and force data and analyzed according to biomechanical assumptions.

**Keywords** Motion capture · Care · Musculoskeletal · EMG · Posture · Kinect

---

**Introduction**

Due to the demographic change the number of people reaching old age increases. For example, 33% of the German population will be 65 years and older by 2060 [1]. There is already an existing discrepancy between the supply of caregivers and the demand for caregivers. An international comparison shows [2], that the average ratio of patients to nurses across hospitals ranged from 5.4 in Norway to 13.0 in Germany. It could also be shown that the patient-to-caregiver ratio has measurable effects on patient mortality rates and the stress experience of caregivers [2, 3].

Besides the high workload, caregivers experience high musculoskeletal loads during their daily work, which leads to back complaints and a high rate of absenteeism at work as well as for leaving the profession in professional nursing [4, 5]. Manual patient handling is one of the physiological risk factors [4, 6–8] and especially non-ergonomic movements and postures lead to health problems. For example activities like deep bending or twisting during manual patient transfer or working in harmful postures for a longer period can result in back complaints [4, 7, 8]. Caregivers spend a total of two hours per shift in a bent posture or bend down 1500 times per shift [5].
It is therefore important to relieve and support caregivers in their work. Musculoskeletal stress can be significantly reduced by an ergonomically correct method of caregiving [7, 8]. Thus, caregivers should be trained to work in a back-friendly way and to avoid harmful postures and actions. Also, prevention programs including various ergonomic measures can improve the well-being of the back and reduce the physical strain on caregivers [9]. In addition to the caregivers, patients also benefit from ergonomic working. Ergonomic working includes concepts of activating care [9] by involving the remaining resources of the patient and thus promoting them. In addition, ergonomic working methods avoid jerky movements, which prevents force peaks and is, therefore, more comfortable for patients. Furthermore, there is always a risk of accidents when handling larger loads. This risk can also be reduced by ergonomic foresighted working. In long term, another advantage is the higher patient-to-caregiver ratio due to fewer disease-related absences.

The objective of our study was to developed a system that can be used for the training of caregivers and the detection of harmful postures. We analyzed body postures, muscle activities, and loads during the transfer of a patient from the bed to the wheelchair and presented our work in [10]. In this article, we extend our previous investigations by a deeper analysis of the body postures and muscle activities especially regarding different execution strategies of the transfers. Additionally, we added analysis of force plate measurements to supplement the load examinations.

State of the Art

Harmful Postures

Sharan and Rajkumar [11] stated that lower back pain was the commonest reported musculoskeletal symptom (65%) in caregivers of children with cerebral palsy followed by knee pain (46%), neck pain (40%) and shoulder pain (36%). Freitag et al. reported that nurses working on a geriatric ward take an average of 1390 upper body inclinations above 20 degrees per work shift [12]. Weißert-Horn et al. found similar results and stated that caregivers spend a total of two hours per shift in a bent posture or bend down 1500 times per shift [5]. Recurring loads can cause pain and injuries in the back and upper extremities. It is therefore important to identify and avoid harmful postures. Manual movement of persons in need of care leads to high mechanical stress in the lower back area of caregivers [5]. Unfavorably long-lasting trunk postures as well as lifting, holding, and pulling large parts of the patient’s weight without the use of aids such as lifts or sliding mats lead to a compression of the intervertebral discs of the carers up to 9 kN during this activity. This is far above the upper limit of 3.4 kN for lumbosacral-disc compressive forces [4].

Since this upper limit applies only to young, healthy workers, Kudo et al. [13] developed injury risk curves, which clarify the risk level of injury to the lumbar spine due to lumbar compressive force for individuals within a wide age range. However, work postures and musculoskeletal disorders are strongly related to each other [14]. For example, torques are closely connected to the body posture and should be reduced to decrease lumbar loads. This can be achieved by shortening the lever arm, for example, through a suitable foot position [15].

Posture Analysis Systems

OWAS (The Ovako Working posture Analysis System), RULA (Rapid Upper Limb Assessment) and EAWS (Ergonomic Assessment Work Sheet) are validated and widely empirically applied methods for the assessment of ergonomic working practices. While OWAS and RULA only cover parts of the musculoskeletal load, EAWS combines these elements and thus enables its application to nursing work and especially to patient transfer. EAWS is used to assess the stresses that affect the body [5, 16].

Movement and posture analysis systems based on different types of sensors can be used to identify harmful postures and to estimate the stresses and strains that occur in the musculoskeletal system of both the carer and the person being cared for. Theilmeyer et al. captured postures via an optoelectronic motion capturing system and video cameras [17]. Additionally, a care bed was equipped with a framework attached to the bedstead and connected to the bed-spring frame via force sensors at the four bed-corners. Jäger et al. analyzed nine different activities with a patient transfer in or at the bed or chair with the same system. They found that the load on the lumbar spine can be reduced through biomechanically optimized transfer instead of conventional methods [4]. Wei et al. described a system that uses data from depth-image cameras to estimate the skeletal poses and joint forces of wheelchair users during transfers [18]. A Microsoft Kinect V2 camera was used to record skeleton data during three different care activities [19]. Lin et al. used both inertial sensor technology and a marker-based motion detection system on the patient to evaluate the transfer performance by the nursing staff [20]. However, the possibilities of ergonomic work design and assessment have hardly been used systematically in nursing and health care up to now [21]. This points to the necessary need for ergonomic work teaching systems for caregivers.

Recommendations for Ergonomic Working

One aspect of working in a back-friendly manner is avoiding excessive upper body inclination angles and working with a straight back. Thereby, the movements of the upper
SN Computer Science           (2022) 3:375
Page 3 of 13   375

Free body should be considered in all three directions: Movements in the sagittal direction mean the forward inclination of the trunk. The lateral movement - away from the central axis - is called a lateral inclination. The torsion of the upper body between the thoracic spine and the lumbar spine is defined as torsion.

Freitag et al. made a classification of the upper body postures into angle ranges and their degree of risk [12]. They decided between acceptable, limited acceptable, and unacceptable angle ranges. The classification is listed in Table 1. Angles in the range of 0–20° belong to the neutral position. Critical angles for sagittal inclinations lie above 60° and above 20° for lateral inclinations and torsions.

### Table 1: Classification of acceptable, limited acceptable, and unacceptable upper body postures regarding angle ranges [12]

| Upper body posture | Acceptable | Limited acceptable | Unacceptable |
|--------------------|------------|--------------------|--------------|
| Sagittal           | 0–20°      | 20–60°             | > 60°        |
| Lateral            | 0–20°      | –                  | > 20°        |
| Torsion            | 0–20°      | –                  | > 20°        |

Angles in the range of 0–20° belong to the neutral position. Critical angles for sagittal inclinations lie above 60° and above 20° for lateral inclinations and torsions.

In the literature, there are many recommendations for back-friendly working in patient care [9], especially from professional associations [23, 24]. According to Michaelis and Hermann [9] the utilization of biomechanical and ergonomic principles for load reduction during patient transfers is achieved by pushing or pulling instead of lifting, reducing friction, utilizing height differences and inclined planes, using ramps, using the patient’s body levers, making the patient compact, working in stages, shifting the center of gravity of the own body, maintaining a straight longitudinal axis of the body, foresighted ergonomic planning of the transfer with consistent use of aids, and emphasizing patient activation.

The posture recognition system, presented in this article, is based on a motion capture suit and is used to identify potentially harmful postures during the transfer from the bed edge to a wheelchair. Thereby, we consider the recommendations for ergonomic working in the care sector in our analysis.

### Materials and Methods

The study design and our analysis system as well as the applied sensors are described in the following. Moreover, we examine the manual patient transfer from a biomechanical point of view.

### Study Design and Applied Sensor Systems

We conducted a study with 13 caregiver students, aged between 18 and 55 years (10 women, 3 men) to analyze typical care activities and their ergonomic execution. Thereby, we concentrated on the transfer of a patient from the edge of a bed to a wheelchair. The transfer was carried out by each of the 13 students. A member of the research staff (female, 28 years, 63 kg) acted as a patient so that no real patients were involved. To avoid overloading, the patient cooperates during the treatment. For this purpose, specific movement sequences were pre-defined by the kinaesthetic teacher. Therefore, the patient was already sitting on the bed’s edge at the beginning of each task, acting like a movement-impaired older adult with abdominal stability. This was maintained throughout the entire study. We used a motion capture system and our analysis system to analyze the body postures. Additionally, we used a Multi-Kinect System to visually record the scene and surface electromyography was...
used to measure muscle activities during the transfer task. Mechanical loads are measured by a force plate. Figure 1 shows the measurement setup and the sensor systems used in the study.

In addition to the sensors, a Kinaesthetics teacher observed and evaluated the performance of the care activity under consideration of ergonomic working methods and kinaesthetic aspects.

The test procedures were approved by the local ethics committee (ethical vote: Carl von Ossietzky University Oldenburg No. Drs. EK/2019/004) and conducted in accordance with the Declaration of Helsinki.

**Applied Sensors**

We used several sensor systems in our study to analyze the manual patient transfer regarding the aspects of ergonomic working as well as harmful postures and loads. Each system is described in the following.

**Multi-Kinect System**

In addition to the motion capture system, we used a Multi-Kinect System [25] to visually record the nursing process. This system includes four Microsoft Kinect v2 depth cameras. Each Kinect v2 is connected to an Intel NUC Mini-PC, which acquires the data from the camera and sends it to the main computer, where the data of the four cameras is fused into a colored point cloud. The depth cameras have to be registered to each other to ensure that the four point clouds of cameras are aligned. This is done through a calibration program and with the help of a styrofoam sphere, which is inserted into the scene on three different spots. The four cameras are placed around the height-adjustable care bed and are focusing an area of approximately 2m x 2m in front of the bed (see Fig. 1). The Multi-Kinect System enables a 3D view of the scene and is suitable to review the care action in retrospect from different perspectives. Therefore, it can be used, for example, for education purposes of caregiver students.

**Motion Capture System**

The caregiver students were equipped with a full-body motion capture system of Motion Shadow [26]. The system includes 17 motion nodes, which were distributed on the body. A motion node is a measurement unit, which includes a 3D-accelerometer, 3D-gyroscope, and 3D-magnetometer. The sampling rate of each sensor is 100 Hz. Figure 2 shows the human joints (black dots) and the positions of each motion node (green boxes) of the motion capture system. By distributing the sensors over the entire body, the posture of the back, as well as the movements of the extremities and the head, can be recorded.

**Electromyography**

Surface Electromyography (EMG) was used to record the muscular activities associated with muscle contraction to gain information on the activation behavior of selected muscle groups during the transfer from bed to wheelchair. We measured the muscle activities of the vastus medialis (VM), rectus femoris (RF), and biceps femoris (BF) (see Fig. 3).

Preparation, collection and processing protocols were consistent with SENIAM guidelines [28]. Therefore, the skin was prepared by removing the hair with a disposal shaver, then abraded with fine sandpaper and cleaned with 70% alcohol to reduce the skin electrode impedance, before the EMG electrodes were attached to the caregiver’s left thigh [28]. EMG was recorded, using bipolar surface electrodes (14 mm diameter and 10 mm inter-electrode distance, GE Medical/Hellige) which were attached with adhesive rings and placed in a direction parallel to the general direction of
muscle fibers for a given muscle. Signals were amplified with 2500 Hz by local amplifiers, then filtered (bandpass 10–700 Hz) and sent to the input box (Biovision Inputbox) via analog-to-digital conversion unit (National Instruments USB 6009, 14 bit). The estimation of muscle activity in the caregiving process was based on the potential level and set in relation to the chronological sequence of the caregiving activities. The processing of the raw EMG signals was done via rectification, Root Mean Square (RMS), and mean value.

**Force Plate**

An AMTI AccuPower force plate was positioned in front of the care bed to measure the forces and to estimate the loads during the manual patient transfer. Therefore, the caregiver stands on this plate during the transfer. The wheelchair is positioned next to the plate (see Fig. 1). The force plate measures the vertical forces as well as the forces in mediolateral and anterior–posterior direction. In addition, torques are also measured with the force plate. The sampling rate is 200 Hz. The raw data are filtered by a second-order Butterworth low-pass filter with a cutoff frequency of 20 Hz.

The data of the forces and their directions allows estimations about the acting loads. Here, not only forces in vertical direction are interesting but also forces in mediolateral and anterior–posterior direction. The direction of the forces is connected to the body position during manual patient handling. Based on the torque measurements, further conclusions can be drawn about the body postures, since torques are related to the force and position vector (lever arm).

**Posture Analysis System**

The posture analysis system is based on the motion capture system. A simplified view of our posture analysis framework is shown in Fig. 4. The systems’ architecture uses a modular approach, with defined interfaces among each component. Therefore, the system can be easily adapted to specific use cases by exchanging the components. It also enables repeated analysis with different analysis strategies (e.g. by altering algorithms’ parameter settings). The IMU data are exported in BVH format and integrated into our system. A body model defines an object-oriented data structure for the motion data according to the recommendation of the International Society of Biomechanics [29]. The model realizes access to the data of body sections such as joints and realizes data-related operations. The identification component reads the raw data streams and converts them into the structure of the defined data model. The identification component returns the data object with the joint positions and angles. The analysis component uses the data object for motion analysis and executes the analysis strategy. We implemented an algorithm for the analysis of risky postures during care activities based on the physical posture model. The physical posture model contains various threshold values, which indicate harmful postures. We implemented rules for the identification of risky postures regarding the classification of [12] mentioned in Table 1.

Figure 2 shows the calculation of the upper body inclination and torsion. Joint positions are measured based on the neutral-zero method. According to the joints’ neutral position within the different body planes, a predefined perpendicular is marked to measure the range of movement (ROM) in degree. This procedure is most common for peripheral joints of the lower and upper limbs. Assessing the ROM of the spine is more complex since each vertebra is naturally located slightly different to another. ROM increases with every involved segment. While segments of the lumbar spine show the highest ROM for flexion compared to the thoracic spine with an average of up to 18 degrees including ranges from 12 to 26 degrees (L4/L5), whereby intersegmental ROM is even less than 10 degrees [30, 31].

Thus, the measurement of the spinal inclination angle is challenging - especially in different postures. In this approach, we decided to analyze the angle by dividing the spine into three segments. The segments in the skeleton

---

**Fig. 4** System-workflow for processing the IMU data of the motion capture system and analyzing and reporting physical loading during care treatments.
model are called SpineLow, SpineMid, and Chest. The upright neutral-zero position in the sagittal plane is taken as the perpendicular which is, in this case, identical to the longitudinal axis. To calculate the sagittal inclination angle during transfer, we shifted the perpendicular horizontally to L5, the fifth lumbar spine vertebra. A straight line between L5 and C7 (which covers all relevant segments) indicates the angle corresponding to the perpendicular, whereby C7 is the seventh cervical vertebra. The system’s calculation of the sagittal inclination angle is illustrated in Fig. 2. To estimate the angle between L5 and C7, the angles of segments SpineLow, SpineMid, and Chest were considered to calculate the total inclination angle $\alpha_{C7-L5}$:

$$\alpha_{C7-L5} = \alpha_{\text{SpineLow}} + \alpha_{\text{SpineMid}} + \alpha_{\text{Chest}}.$$

Lateral inclination angles, as well as torsions, are calculated accordingly.

In summary, the analyzer executes the analysis algorithms and returns the result object. We implemented a rule-based algorithm in the analyzer component, which monitors the upper body inclination and torsion and the compliance of the threshold values of the physical posture model. If a threshold value is exceeded, the posture is classified as potentially harmful. The report (result object) is a 3D virtual object, which shows the visualization of skeleton model (similar to the skeleton models in Fig. 5) during the execution of the care activity and indicates harmful posture by specifying which of the defined rules were exceeded. Additionally, the inclination and torsion angles are represented in a graph similar to Fig. 7.

**Manual Patient Handling and Biomechanics**

The transfer from the edge of a bed to the wheelchair can be divided into three main phases: Stand the patient up, turn the patient, and sit the patient down into the wheelchair. In the following, we will focus on two different transfer strategies and examine the three main phases and their subphases concerning their ergonomic execution and biomechanics.

Figure 5 shows the phases of the execution strategy of caregiver 1. At the top of the figure, 3D camera images of the Multi-Kinect System of each of the subphases are shown. Due to data protection and ethics committee requirements, only colorized depth images were recorded. Therefore, the images are not based on RGB images but on colorized point clouds derived from the three-dimensional depth data (see “Applied Sensors”). This makes the images appear somewhat pixelated. At the bottom of the figure, the corresponding skeleton models measured by the motion capture system are visualized. According to Michaelis and Hermann [9], the transfer is executed in stages and foresighted ergonomic planned with consistent use of aids. Therefore, the care bed is adjusted to the appropriate height, so that the patient could sit on the bed with his feet flat on the floor. Here, the height gradient can also be used to relieve the caregiver. A forward-looking ergonomic working method also includes placing the wheelchair in the correct position in advance. At the beginning of the transfer, the person requiring care sits at
the edge of the bed. The caregiver positions himself frontally to the patient (stand). In the preparation phase, the caregiver gives instructions to the patient and bends down to the patient while squatting. The upper body remains as straight as possible. The caregiver puts his arms around the patient. The patient is also asked to put his arms around the caregiver. In the lift phase, the patient is lifted into a standing position by the caregiver. At the end of the lift, the patient and the caregiver stand in an upright position. In the second main phase, the caregiver rotates together with the patient in small cradle steps until the patient is standing directly in front of the wheelchair. The rotation in small steps prevents harmful upper-body torsions. In the third phase of the transfer, the caregiver carefully lowers the patient into the wheelchair. The transfer ends with an upright standing position.

Figure 6 shows the execution strategy of caregiver 2. This transfer can also be divided into three main phases. The care bed is also adjusted to an appropriate height and the wheelchair is positioned next to the care bed. In contrast to the first strategy, this caregiver spends more time in the preparation phase and positions the patient carefully in several steps directly on the edge of the care bed near the wheelchair. Additionally, the caregiver prepares the transfer also by placing the patient’s feet in a desired position on the floor. During the preparation phase, the caregiver works from a squat position to keep the back as straight as possible. Before lifting, the patient and caregiver both put their arms around each other. In this strategy, the caregiver lifts, turns, and drops the patient in one flowing movement. The patient is not lifted completely into an upright position, but only as much as needed to transfer him or her to the wheelchair. In consequence, the patient’s remaining functions are not as involved as in the strategy of caregiver 1, and therefore the load reduction due to the activation of the patient was not optimally used.

In a biomechanical view, manual patient handling leads to a compression, flexion, and torsion of the caregiver’s intervertebral discs depending on the patient’s weight and the executed transfer mode [4]. Therefore, the intervertebral discs are affected vertically by different compressive forces. These forces are almost parallel to the flat geometry of the sacroiliac joints (SIJ) (see Fig. 3), which are the direct connection between pelvis and sacrum and primarily responsible for load transmission to the hip joints and finally to the legs and vice versa [32]. Additional muscle groups are essential in order to transfer loads isolated and effectively from the lumbar spine to the pelvis and to compensate for potential overload effects [32]. Effective load transfer is achieved, when muscle forces cause compression of the SIJ, and thereby, preventing shearing of the joints [33, 34]. Both the muscles of the lower limb and the back extensors influence the SIJ movements and its stabilization mechanisms via lever arms [32]. In the present study, the muscles of the lower limb are analyzed. During hip flexion, torsional forces are transmitted to the SIJ due to the connection of the rectus femoris (RF) to the pelvis [35] (see Fig. 3). The rectus femoris (RF) is one of the extensors of the knee and the flexors of the hip [36]. The vastus medialis (VM) is also involved in knee extension [37]. It is assumed that increased activity of the RF can lead to pain in the SIJ, and therefore may cause lower back pain [35]. Furthermore, due to the connection to the pelvis, the biceps femoris (BF) performs knee flexion and hip extension and thus affects the SIJ.

Results

In the following section, we analyze the measurements of the posture recognition system and relate the motion capture data to force and EMG data for mechanical load estimations.

Analysis of Inclination Angles

After focusing on the different phases of the transfer, the sagittal and lateral upper body inclination, as well as the upper body torsion, were examined by our posture analysis.

Figure 6 Execution strategy of caregiver 2. In contrast to Fig. 5, the caregiver spends more time in the preparation phase and lifts, turns, and drops the patient directly in one flowing movement.
system. Figure 7 shows the inclination and torsion angles during the transfer for both execution strategies. The differences between both strategies can be seen in detail. The phases are marked in the graphs. The inclination and torsion angles were calculated according to Fig. 2.

Caregiver 1 (left figure) prepares the transfer by explaining the next steps to the patient. The preparation phase begins with a stand in a neutral position with sagittal inclination angles below 20°. The caregiver is only slightly inclined to the patient and squats down a bit. The lateral inclination remains in an acceptable position during the entire care activity. In the preparation phase, the caregiver takes a slightly right-bent posture (positive inclination angles).

Caregiver 2 (right figure) spends more time in the preparation phase than caregiver 1. The caregiver does not include the patient’s functions in the transfer and positions the patient and the patient’s feet in a suitable position by hand. Caregiver 2 works from a squatting position in a slightly bent posture during the preparation phase. The sagittal inclination angles remain mainly in the neutral range. However, torsion angles of more than 20° occur while positioning the patient. The patient is placed at the edge of the bed in several steps (several peaks in torsion). In the last step, the lateral inclination angle also exceeds 20°.

Caregiver 1 divides the standing patient up, turning and sitting patient down phase into separate steps. During the lift, angles of up to 40 degrees are reached, so that the limit to the neutral range (< 20°) is exceeded. The range between 20 and 60° is limited acceptable (cf. Table 1). Therefore, the time spent in this potentially harmful position should be as short as possible. Additional loads acting on the body or the back in such a posture are particularly associated with a risk of back injuries. The stand the patient up phase ends in an upright position. The upright position is maintained during the rotation so that the sagittal inclination angle remains in the neutral range during the entire phase. The turning phase has three peaks. The number of peaks indicates the number of double steps executed during the rotation.

In the last phase, the caregiver bends again to lower the patient into the wheelchair. Here, angles significantly above 20° are achieved, which indicates again a potentially harmful posture. After setting the patient down, the caregiver returns to an upright position.

Caregiver 2 lifts, turns, and drops the patient directly in one flowing movement. The sagittal inclination angles exceed 20°, but remain below 30° except for a short time during the sitting patient down phase. Lateral inclination and torsion angles remain in a neutral range. Because caregiver 2 does not include the patient’s functions, a higher force is acting on the back. However, the transfer is performed very quickly, so that the time in an unfavorable posture with load is kept as short as possible.

As already described, the system generates a result report that shows the corresponding color-coded angles as well as the visualization of the skeleton model during the care activity. If the threshold values are exceeded, the corresponding angle is marked in yellow (e.g. sagittal inclination angle between 20 and 60°) or red (e.g. sagittal inclination angle > 60°). Postures with red-marked angles are classified as potentially harmful. Special attention should also be paid to coupled movements (torsion + inclination, sagittal + lateral inclination) since they can be particularly harmful [31].

To determine the loads acting on the back, force and moment measurements must be contextualized with the upper body posture. During upper body bending, the load in the vertebrae has both a vertical and a horizontal component.
and thus generates a compressive and a shear force. The distribution of both forces depends on the orientation of the spine. Therefore, the consideration of the upper body posture is essential for load estimation.

**Analysis of Forces**

Lifting in non-ergonomic postures can result in an unfavorable distribution of force on the intervertebral discs. Working with a straight back ensures a more uniform force distribution. Besides the considering of postures, it is also important to analyze the loads acting on the caregiver’s body. Manual patient handling can lead to compressions of the intervertebral discs of the carers up to 9 kN, which is far above the recommended upper limit of 3.4 kN for lumbosacral-disc compressive forces. Therefore, we analyzed force plate measurements to supplement load examinations.

Figure 8 shows the force measurements in anterior–posterior (AP), mediolateral (ML), and vertical direction (V) of the two presented transfer strategies. The highest forces act in the vertical direction (red line). In the first phase, the caregiver stands alone on the plate and prepares the transfer. The weights of the caregivers differ about 20 kg and explain the higher load in the vertical direction for caregiver 2 (right figure). The weight of the patient is equal in both examples and amounts 63 kg. During the preparation phase, the forces vary due to the movements and the associated weight shifts on the plate. There are also forces in the anterior–posterior direction (forward or backward, blue line) and forces in the mediolateral direction (to the side, green line). The algebraic sign of the forces indicates the direction. During the high force plateau, the weight of both persons (caregiver and patient) is on the force plate. The increase in vertical force starts in the lifting phase and a short force peak can be seen in both strategies. Caregiver 1 (left figure) uses cradle steps to position the patient directly in front of the wheelchair. The weight shifts due to these cradle steps can be seen in this phase (19–24 s) in ML and AP direction. Caregiver 2 skips this phase and places the patient directly in one movement into the wheelchair. Here, force peaks occur during lift and drop.

In this example, the two caregivers chose different execution strategies although they had the same setting. In both strategies, the loads were kept as short as possible. Caregiver 1 chose a short load during lift and drop and a load break in the repositioning phase by activating care (cradle steps). Caregiver 2 chose a continuous load by performing lift and drop in one movement.

**Analysis of Muscle Activities**

To evaluate the ergonomic execution of the transfers and the mechanical loads in more detail, the EMG data is analyzed and interpreted according to biomechanical assumptions exemplarily using the strategy of caregiver 1. Figure 9 shows the EMG data and therefore the muscle activities of the muscles vastus medialis (VM), rectus femoris (RF), and biceps femoris (BF) during the entire care activity. Muscle activity was quantified by rectification and RMS, thus reflecting the mean power of the signals and smoothing them (Fig. 9). The mean value (Fig. 10) was used to qualify the gross innervation input for each selected muscle.

The first phase starts with the initial caregiver’s weight shift through trunk inclination and knee flexion. The caregiver positions his feet flat on the floor at shoulder width and remains in a squatting position to lift the patient in the
next step of this phase. The leg muscles are used to distribute the caregiver’s weight evenly. While squatting (Fig. 9, 13–17 s), the vastus medialis (VM) works with maximum support from the rectus femoris (RF) due to the fact that these muscles are involved in the extension of the knee (VM, RF) and the flexion of the hip (RF). The smaller the knee angle, the higher VM’s muscle activity [38]. When rising from a squatting position and lifting the patient (Fig. 9, 18–19 s), both the biceps femoris (BF) and RF contract at the same time, despite they are antagonists [39, 40].

Due to the increase of BF while lifting, the hip and the knee are probably stabilized, avoiding an excessive hip flexion [41]. The mean muscle activity of VM, RF, and BF in the squatting position are 322 mV, 175 mV, and 77 mV (Fig. 10). The mean muscle activity of VM, RF, and BF while lifting the patient are 425 mV, 212 mV, and 141 mV. The higher activity of the VM in comparison to the RF while squatting and lifting was also observed in other studies [36, 38, 41, 42]. The mean activity of VM was around 46% higher in the squat position and around 50% higher while lifting the patient in comparison to the RF. This is assumed to be due to the RF’s biarticular function as hip flexor and knee extensor [36]. Increased activity of the RF can lead to an increased hip flexor/extensor torque and may cause pain in the SIJ [35, 36]. Furthermore, the mean muscle activity of the BF increases around 45% during the squat ascent compared to static squatting. This was also observed in previous studies [36, 41, 42]. Moreover, Brinkmann et al. found in a further study conducting three different dynamic lifting tasks that the mean activity of the quadriceps and hamstring musculature increases with lifting higher loads [43].

In the turning phase, both the caregiver and the patient are in an upright position. When the lifting is done, the caregiver extended his hip to stand upright again. The RF is the only bi-articular ventral thigh muscle and initiates hip extension. During the complete stance phase with approximately equal weight on both legs of the caregiver, the BF increases its activity (Fig. 9, 19 - 20 sec) and takes over the upright posture under the additional load of the patient’s weight. The mean muscle activity of VM, RF, and BF while turning the patient are 121 mV, 173 mV, and 88 mV (see Fig. 10).

The preparation for sitting the patient in the wheelchair starts again with an enlargement of the supporting surface. To be able to set the patient down safely without losing one’s balance, the body’s center of gravity is brought into position again by an upper body tilt and a simultaneous lunge. The load on the standing leg in the lunge requires a rapid increase in the muscle strength of the VM and BF (Fig. 9, 27–28 s) before the patient is placed in the wheelchair (Fig. 9, 29 s). Then, the caregiver straightens up and returns to the initial position. The mean muscle activity of VM, RF, and BF while sitting the patient down are 204 mV, 142 mV, and 192 mV (see Fig. 10).
Discussion

Caregivers experience high musculoskeletal loads during their daily work, which leads to back complaints and a high rate of absenteeism at work. It has been shown, that ergonomically correct working can lead to a significant reduction in musculoskeletal load [5, 38].

Therefore, we developed a posture recognition system based on a motion capture system that can identify potential harmful body postures according to the recommendations for ergonomic working in the care sector. A result report visualizes the skeleton model together with color-coded information about inclination and torsion angles. The systems' architecture uses a modular approach and can be easily adapted to specific use cases or other professions and their recommendations by exchanging the components.

In the present work, we focused on the transfer from the bed into the wheelchair and analyzed the posture in terms of sagittal and latero inclination angles as well as torsions. A member of the research staff acted as a patient so that no real patients were involved. To avoid overloading, the patient cooperates during the treatment but simulated a movement-impaired older adult with abdominal stability to ensure a realistic manual patient transfer. This enables comparability to real patients. But it has to be noted that the variety of patient behavior is not reflected in this study and it still has to be distinguished from transferring a real patient. It can be assumed that muscle activities and forces may be higher under realistic circumstances than provided in this work.

We demonstrated the concept of the system by showing two different execution strategies for the transfer. The transfer strategies differed mainly in the inclusion of the patient's remaining functionality and the related different processes of the transfer. For load estimations we used surface electromyography and force plate measurements to analyze the muscle activities and forces. As it is not possible to determine loads based on pure body postures, further information is needed to assess the risk potential for a care activity. Contextual information about the nursing action itself and the weight of the patient can be used to make rough estimations about mechanical loads, which act on the caregiver’s body. But the upper body posture is essential for load estimation, since it has an influence on the acting forces and their directions. We used a segmented model to approximate the spine from L5 to C7 and to calculated the upper body postures. More complex segmented models and musculoskeletal models have been presented in literature [44, 45] as well as modeling the spine as an elastic beam [46] to derive lumbar compressive forces. Further work is needed to link the body postures to the loads. Therefore, we plan investigations on longitudinal (compression) and transverse (torsion) forces as well as bending moments and torsional moments in the future.

One benefit of our system is the report and its visualization of the nursing handling which allows a retrospective discussion of the activity with objective angle information. In addition, the visualization of the skeleton model can be rotated, so that the nursing activity can be evaluated from different perspectives. We, therefore, see its application mainly in the training of nursing students. The advantage of using a full-body motion capture system over cameras is that the field of vision cannot be obscured and the system does not require additional space. The disadvantages are that the patient is not recorded and therefore context information may be missing.

The Multi-Kinect System [25, 38] was used to record the scene by depth camera data. This system also allows a 3D view and therefore a viewing from different perspectives. We are currently working on merging skeletal models from the Kinect data to make posture analysis with this data as well. So the camera system and the motion capture system can be used interchangeably depending on requirements.

Funding Open Access funding enabled and organized by Projekt DEAL. The development of the posture analysis system based on the motion capture suit was funded by the Lower Saxony Ministry of Science and Culture under grant number 11-76251-12-10/19 ZN3491 within the Lower Saxony “Vorab” of the Volkswagen Foundation and supported by the Center for Digital Innovations (ZDIN).

Declarations

Conflict of Interest The authors declare that they have no conflict of interest.

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the ethics committee (ethical vote: Carl von Ossietzky University Oldenburg No. Drs. EK/2019/004) and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article’s Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article’s Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by/4.0/.

References

1. Statistisches Bundesamt (Destatis): Koordinierte Bevölkerungs- berechnung, Wiesbaden, Germany; 2015.
2. Aiken LH, Sermeus W, Van den Heede K, Sloane DM, Busse R, McKee M, Bruyneel L, Rafferty AM, Griffiths P, Moreno-Casbas MT, et al. Patient safety, satisfaction, and quality of hospital care: cross sectional surveys of nurses and patients in 12 countries in europe and the united states. BMJ. 2012;344:e1717. https://doi.org/10.1136/bmj.e1717.

3. Höhmann U, Lautenschläger M, Schwarz L. Belastungen im pflegeberuf: Bedingungsfaktoren, folgen und desiderate. PflegeReport, 2016;73–89.

4. Jäger M, Jordan C, Theilmeier A, Wortmann N, Kuhn S, Nienhaus A, Luttmann A. Lumbar-load analysis of manual patient-handling activities for biomechanical overload prevention among healthcare workers. Ann Occup Hygiene. 2013;57(4):528–44. https://doi.org/10.1093/amo hyster.

5. Weißheit-Horn M, Meyer MD, Jacobs M, Stern H, Raske H-W, Landau K. Ergonomisch richtige arbeitweise beim transfer von schwerpflegebedürftigen. Zeitschrift für Arbeitswissenschaft. 2014;68(3):175–84.

6. Kliner K, Rennert D, Richter M. Gesundheit und arbeit-blickpunkt gesundheitswesen: Bbk gesundheitsatlas, 2017; 2017.

7. Hwang J, Kuppam VA, Chodraju SSR, Chen J, Kim JH. Commerially available friction-reducing patient-transfer devices reduce biomechanical stresses on caregivers’ upper extremities and low back. Human Factors. 2019;61(7):1125–40. https://doi.org/10.1177/0018720819827208.

8. Choi SD, Brings K. Work-related musculoskeletal risks associated with nurses and nursing assistants handling overweight and obese patients: A literature review. Work. 2016;53(2):439–48. https://doi.org/10.3233/WOR-152222.

9. Michaelis M, Hermann S. Evaluation des pflegekonzepts rücken vergengergerchter patiententransfer in der kranner-und altenpflege. Langzeit-Follow-up zur Ermittlung der Nachhaltigkeit präventiver Effekte. Schriftenreihe der Bundesanstalt für Arbeitsschutz und Arbeitsmedizin (F2196). Dortmund; 2010.

10. Hellmers S, Brinkmann A, Böhlen C, Lau S, Diekmann R, Hein A. Assessing Postures and Mechanical Loads During Patient Transfers. In: Proceedings of the 14th International Joint Conference on Biomedical Engineering Systems and Technologies, pp. 2021:29. SciTePress, HEALTHINF. https://doi.org/10.5220/001015530010029. INSTICC.

11. Sharan D, Rajkumar JS. The burden of caregiving: musculoskelet- tal disorders in caregivers of children with cerebral palsy. In: Congress of the International Ergonomics Association; 2018:717–718. Springer.

12. Freitag S, Fincke I, Dulton M, Ellegast R, Nienhaus A. Position and lumbar loads while turning patients on a bed: an investigation via computational simulation and electromyography. Int J Online Biomed Eng. 2021;17(10):131–43.

13. Kado N, Yamada Y, Ito D. Age-related injury risk curves for the lumbar spine for use in low-back-pain prevention in manual handling tasks. Robomech J. 2019;6(1):1–10.

14. Kushariyadi Hakam M, Nabilah N. Impact of work posture on musculoskeletal disorder in nurses. In: The 3rd Joint International Conference, 2021:2:278–282.

15. Kitagawa K, Yamamoto K, Wada C. Relationship between foot position and lumbar loads while turning patients on a bed: an investigation via computational simulation and electromyography. Int J Online Biomed Eng. 2021;17(10):131–43.

16. Schaub K, Caragnano G, Britzke B, Bruder R. The European assembly worksheet. Theoret Issues Ergon Sci. 2013;14(6):616–39. https://doi.org/10.1080/1463922X.2012.678283.

17. Theilmeier A, Jordan C, Luttmann A, Jäger M. Measurement of action forces and posture to determine the lumbar load of health-care workers during care activities with patient transfers. Annals Occup Hygiene. 2010;54(8):923–33. https://doi.org/10.1093/ anhyg/meq063.

18. Wei L, Tsai C-Y, Kooontz AM. The relationship between joint ranges of motion and joint kinetics during sitting pivot wheelchair transfers. Proceedings of the Conference of the Rehabilitation Engineering and Assistive Technology Society of North America; 2018.

19. Agrawal A, Ertel W. Automatic nursing care trainer based on machine learning. In: KHD® ICAI. pp. 2018:53–59.

20. Lin C, Kanai-Pak M, Maeda J, Kitajima Y, Nakamura M, Kawa-hara N, Ogata T, Ota J. Translational acceleration, rotational speed, and joint angle of patients related to correct/incorrect methods of transfer skills by nurses. Sensors. 2018;18(9):2975. https://doi.org/10.3390/s18092975.

21. Ding J, Lim Y-J, Solano M, Shadle K, Park C, Lin C, Hu J. Giving patients a lift-the robotic nursing assistant (rona). In: 2014 IEEE International Conference on Technologies for Practical Robot Applications (TePRA), pp. 2014:1–5. https://doi.org/10.1109/ TePRA.2014.6869137. IEEE.

22. Safety of machinery - Human physical performance - Part 4: Evaluation of working postures and movements in relation to machinery; German version. DIN EN 1005-4:2005.

23. Baum F, Beck B, Fischer B, Glüssing R, Graupner I, et al. Präven- tion von rückenbeschwerden; topas_r-konzept der bww für pflege und betreuung. Hamburg, Germany: Berufsgenossenschaft für Gesundheitsdienst und Wohlfahrtspflege; 2012.

24. Kusma B, Glaesener J-J, Brandenburg S, Pietsch A, Fischer K, Schmidt J, Behl-Schön S, Pohrt U. Der pflege das kreuz stärken - individuallfähigkeit reiben bei der berufsgenossen- schaft für gesundheitsdienst und wohlfahrtspflege. Trauma und Berufskrankheit. 2015;17(4):244–9. https://doi.org/10.1007/ s1039-015-0093-6.

25. Fifeleksi C, Brinkmann A, Ortman SM, Isken M, Hein A. Multi depth camera system for 3d data recording for training and educa- tion of nurses. In: 2018 International Conference on Computational Science and Computational Intelligence (CSCI), pp. 2018:679–684. https://doi.org/10.1109/CSCI46756.2018.00137. IEEE

26. Shadow Motion Workshop, Motion Capture System, www motionshadow.com, accessed: 28/04/2020 2020. http://www.motio nshadow.com

27. 3D4Medical: Essential Anatomy 5 (5.0.8). 3D4Medical, Dublin, Ireland. accessed 10.05.2019 2020. https://3d4medical.com/apps/ essential-anatomy-5

28. Hermens HJ, Freriks B, Merletti R, Stegeman D, Blok J, Rau G, Disselhorst-Klug C, Hägg G. European recommendations for surface electromyography. Roessingh Res Dev. 1999;8(2):13–54.

29. Wu G, Siegler S, Allard P, Kirtley C, Leardini A, Rosenbaum D, Whittle M, D’Lima D, Cristofolini L, Witte H, et al. Isb recommendation on definitions of joint coordinate system of various joints for the reporting of human joint motion-part i: ankle, hip, and spine. J Biomech. 2002;35(4):543–8.

30. Van Minnen JH. Kapitel 3: Biomechanik der wirbelsäule. In: Westerhuis, R, Pieter und Wiesner (ed.) Klinische Muster in der Manuellen Therapie, pp. 106–107. Georg Thieme Verlag, Stuttgart, 2nd edn; 2014.

31. Panjabi MM, White A. Clinical biomechanics of the spine; 1990.

32. Vleeming A, Stoeckart R. The role of the pelvic girdle in coupling the spine and the legs: a clinical-anatomical perspective on pelvic stability. Movement Stability Lumbopelvic Pain. 2007. https://doi.org/10.3390/ s18092975.

33. Richardson CA, Snijders CJ, Hides JA, Damen L, Pas MS, Storm J. The relation between the transversus abdominis muscles, sacro- iliac joint mechanics, and low back pain. Spine. 2002;27(4):399– 405. https://doi.org/10.1097/00007632-200202150-00015.

34. van Wingerden J-P, Vleeming A, Buurk H, Raissadat K. Stabilization of the sacroiliac joint in vivo: verification of
35. Hammer N, Möbius R, Schleifenbaum S, Hammer K-H, Klima S, Lange JS, Soisson O, Winkler D, Milani TL. Pelvic belt effects on health outcomes and functional parameters of patients with sacroiliac joint pain. PloS One. 2015. https://doi.org/10.1371/journal.pone.0136375.

36. Garrett WE, Kirkendall DT. Exercise and sport science; 2000.

37. Mansfield PJ, Neumann DA. Essentials of kinesiology for the physical therapist assistant; 2008.

38. Brinkmann A, Fifelski C, Lau S, Kowalski C, Meyer O, Dickmann R, Isken M, Fudickar S, Hein A. The aal/care laboratory - a healthcare prevention system for caregivers. Nanomater Energy. 2020;9(1):1–10. https://doi.org/10.1680/jnaen.19.00021.

39. Longpré HS, Acker SM, Maly MR. Muscle activation and knee biomechanics during squatting and lunging after lower extremity fatigue in healthy young women. J Electromyogr Kinesiol. 2015;25(1):40–6. https://doi.org/10.1016/j.jelekin.2014.08.013.

40. Lombard WP, Abbott F. The mechanical effects produced by the contraction of individual muscles of the thigh of the frog. American J Physiol-Legacy Content. 1907;20(1):1–60. https://doi.org/10.1152/ajplegacy.1907.20.1.1.

41. Dionisio VC, Almeida GL, Duarte M, Hirata RP. Kinematic, kinetic and emg patterns during downward squatting. J Electromyogr Kinesiol. 2008;18(1):134–43. https://doi.org/10.1016/j.jelekin.2006.07.010.

42. Slater LV, Hart JM. Muscle activation patterns during different squat techniques. J Strength Conditioning Res. 2017;31(3):667–76. https://doi.org/10.1519/JSC.0000000000001323.

43. Brinkmann A, Böhlen C, Hellmers S, Meyer O, Dickmann R, Hein A. Physical burden in manual patient handling: Quantification of lower limb emg muscle activation patterns of healthy individuals lifting different loads ergonomically. In: Proceedings of the 14th International Joint Conference on Biomedical Engineering Systems and Technologies, pp. 2021:451–458. SciTePress, HEALTHINF. https://doi.org/10.5220/0010247804510458.

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.