Assessing Postures and Mechanical Loads during Patient Transfers

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Abstract: Socio-Demographic developments in industrialized countries cause a discrepancy between potential recipients and providers of care. Caregivers experience high musculoskeletal loads during their daily work, which leads to back complaints and a high rate of absenteeism at work. Ergonomically correct working can significantly reduce musculoskeletal load. In a study with 13 caregiver students, we analyzed body postures, muscle activities, and loads during the transfer of a patient from bed to wheelchair. Our measurement system consists of a full-body motion capture system and a Multi Kinect System. Additionally, muscle activities were measured via surface electromyography. According to recommendations for ergonomic working in the care sector, a system was developed that recognizes potentially harmful postures based on the motion capture data. A result report visualizes the skeleton model together with color-coded information about inclination and torsion angles. The motion capture data was also related to EMG data and analyzed according to biomechanical assumptions.

1 INTRODUCTION

Socio-demographic developments of industrialized countries are characterized by low birth rates and an increasing life expectancy. Therefore, the number of people reaching old age increases. The discrepancy between the supply of caregivers and the demand for caregivers will continuously grow. In an international comparison, Germany already has the worst patient-to-caregiver ratio in Europe, with measurable effects on patient mortality rates and the stress experience of caregivers (Höhmann et al., 2016; Aiken et al., 2012). Manual patient handling is one of the physiological risk factors and leads to high mechanical loads in the lower back of caregivers (Kliner et al., 2017; Hwang et al., 2019; Choi and Brings, 2016; Jäger et al., 2013). Particularly non-ergonomic movements and postures lead to health problems. This results from various strenuous activities such as deep bending or twisting during manual patient transfer, e.g. transferring a patient from bed to wheelchair (Hwang et al., 2019; Choi and Brings, 2016; Jäger et al., 2013). But also working in harmful postures leads to back complaints. Caregivers spend a total of two hours per shift in a bent posture or bend down 1500 times per shift (Weißert-Horn et al., 2014). High musculoskeletal strains and related spinal complaints are one of the main reasons for the high rate of absenteeism at work as well as for leaving the profession in professional nursing (Jäger et al., 2013; Weißert-Horn et al., 2014). It is therefore important to relieve and support caregivers. Musculoskeletal stress can be significantly reduced by an ergonomically correct method of caregiving (Hwang et al., 2019; Choi and Brings, 2016). Also, prevention programs including various ergonomic measures can improve the well-being of the back and reduce the physical strain on caregivers (Michaelis and Hermann, 2010).

To prevent back complaints, it is therefore important to train caregivers to work in a back-friendly way and to avoid harmful postures and actions. Therefore, we developed a system that can be used for the training of caregivers and the detection of harmful postures.

2 STATE OF THE ART

Manual movement of persons in need of care leads to high mechanical stress in the lower back area of caregivers (Weißert-Horn et al., 2014). Unfavorably long-lasting trunk postures as well as lifting, holding

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Table 1: Classification of the upper body (UB) postures into angle ranges (Freitag et al., 2007). Sagittal inclinations above 60° are classified as critical. Lateral incliniations and torsions above |20|° are also harmful.

UB posture	acceptable	limited acceptable	un-acceptable
sagittal	0°-20°	20°-60°	>60°
lateral	0°-|20|°	-	>|20|°
torsion	0°-|20|°	-	>|20|°

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 (Jäger et al., 2013).
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 (Freitag et al., 2007). Weißert-Horn et al. found similar results and state that caregivers spend a total of two hours per shift in a bent posture or bend down 1500 times per shift (Weißert-Horn et al., 2014). Recurring loads can cause pain and injuries in the back and upper extremities. It is therefore important to identify and avoid harmful postures.

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. Theilmeier et al. captured postures via an optoelectronic motion capturing system and video cameras (Theilmeier et al., 2010). Additionally, a care bed was equipped with a framework attached to the bedstead and connected to the bedspring 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 (Jäger et al., 2013). 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 (Wei et al., 2018). A Microsoft Kinect V2 camera was used to record skeleton data during three different care activities (Agrawal and Ertel, 2018). 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 (Lin et al., 2018). However, the possibilities of ergonomic work design and assessment have hardly been used systematically in nursing and health care up to now (Ding et al., 2014). This points to the necessary need for ergonomic work teaching systems for caregivers.

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 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 (Freitag et al., 2007). The classification is listed in Table 1. Here angles in the range of 0°-20° belong to the neutral position. But according to the DIN standard *DIN EN 1005-4* (German Institute for Standardization, 2005) lateral inclinations and torsions above ten degrees are also classified as critical.
In the literature are many recommendations for back-friendly working in patient care (Michaelis and Hermann, 2010), especially from professional associations (Baum et al., 2012; Kusma et al., 2015).

In the present work, we focused on the transfer from the bed edge to a wheelchair. Additionally to our "Healthcare Prevention System" (Brinkmann et al., 2020), we developed a posture recognition system based on a motion capture suit to identify potentially harmful postures considering the recommendations for ergonomic working in the care sector.

3 MATERIALS AND METHODS

In the following, the study design, the biomechanics, and the used sensors and methods are described.

3.1 Study Design

To analyze typical care activities and their ergonomic execution, we conducted a study with 13 caregiver students, aged between 18 and 55 years (10 women, 3 men). In this article, we analyzed the transfer from the edge of a bed to a wheelchair. The transfer was carried out by each of the 13 students. Additionally to the sensors, a Kinaesthetics teacher observed and evaluated the performance of the care activity under consideration of ergonomic working methods and kinaesthetic aspects. A member of the research staff

acted as a patient so that no real patients were involved. To avoid overloadings, the patient cooperates during the treatment.
The test procedures were approved by the local ethics committee (ethical vote: Carl von Ossietzky University Oldenburg and conducted in accordance with the Declaration of Helsinki.

3.2 Applied Sensor Systems

Several sensor systems were used in the study and are described in the following.

3.2.1 Motion Capture System

The caregiver students were equipped with a full-body motion capture system of Motion Shadow (Shadow, 2020). The system includes 17 motion nodes. Figure 1 shows the human joints (blue dots) and the positions of each motion node (green boxes) of the motion capture system. 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.

3.2.2 Multi Kinect System

In addition, the nursing process was recorded with a Multi Kinect System (Fifelski et al., 2018). This system contains 4 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

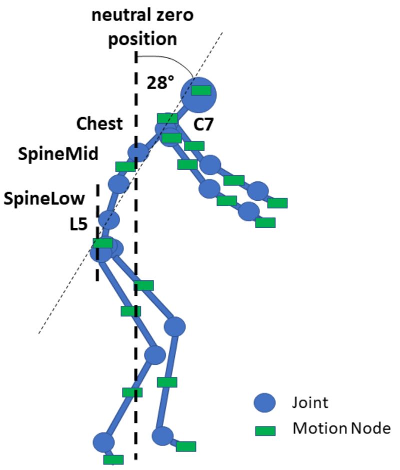

Figure 1: Calculation of sagittal inclination angle: The total angle α results from the segment angles SpineLow, SpineMid and Chest.

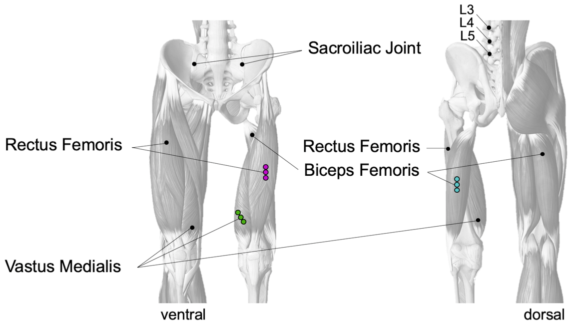

Figure 2: Anatomy of human thigh. Electromyography electrodes are on rectus femoris, vastus medialis and biceps femoris. The dots on the muscles indicate the positions of the electrodes. Image courtesy of Complete Anatomy (Essential Anatomy 5) (3D4Medical, 2020).

to ensure that the four point clouds of cameras are aligned. The Multi Kinect System enables a 3D view.

3.2.3 Electromyography

Surface Electromyography (EMG) was also used to record the muscular activities associated with muscle contraction in order to gain information on the activation behavior of selected muscle groups during the transfer from bed to wheelchair: vastus medialis (VM), rectus femoris (RF), biceps femoris (BF) (see Figure 2). Preparation, collection and processing protocols were consistent with SENIAM guidelines (Hermens et al., 1999). Signals of the bipolar surface electrodes (14 mm diameter and 10 mm inter-electrode distance, GE Medical/Hellige) were amplified with 2500 Hz by local amplifiers, then filtered (bandpass 10–700 Hz) and sent to Biovision Inputbox. 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.

3.3 Posture Analysis System

Figure 3 shows the system-workflow for processing the IMU data of the motion capture system and automated analyzing and reporting risky postures during care treatments. The IMU data is exported in bvh-format and integrated into our system. The body model defines an object-oriented data structure for the motion data according to the recommendation of the International Society of Biomechanics (Wu et al., 2002). The model realizes access to the data of body sections such as joints and realizes data related operations. The identification component reads the raw

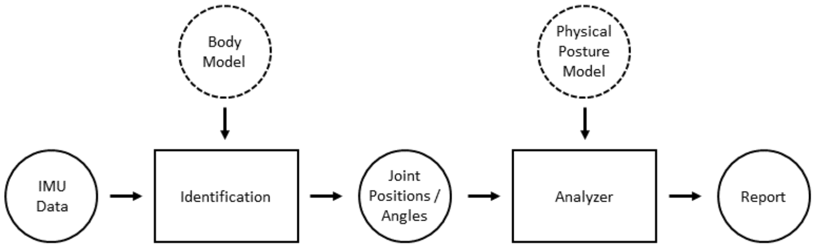

Figure 3: System-Workflow for processing the IMU data of the motion capture system and analyzing and reporting physical loading during care treatments.

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 (Freitag et al., 2007) mentioned in Table 1.
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.

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 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 Figure 1. To estimate the angle between L5 and C7, the angles of segments SpineLow, SpineMid and Chest were considered to calculate the total inclination angle. 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 Figure 4) during the execution of the care activity and indicates harmful posture by specifying which of the defined rules were exceeded.

3.4 Manual Patient Handling and Biomechanics

The transfer from the edge of a bed to a wheelchair can be divided into three main phases: Stand the patient up, turn the patient, and sit the patient down into a wheelchair. In the following, the three main phases and their subphases will be examined concerning their ergonomic execution and biomechanics. Figure 4 shows the phases exemplarily for one student. In the top of the Figure, 3D camera images of the Multi Kinect System of each of the subphases are shown. In the bottom of the Figure, the corresponding skeleton models measured by the motion capture system are visualized. 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-

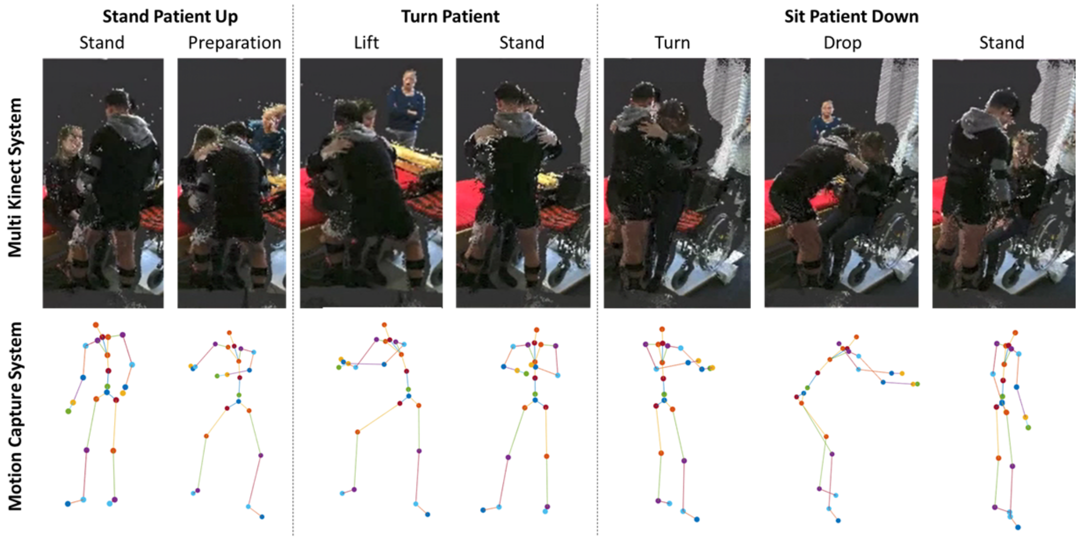

Figure 4: In the first phase of the transfer from the edge of the bed to a wheelchair, the caregiver lifts the patient into a standing position. In the second phase the caregiver turns the patient in small steps until the patient is standing directly in front of the wheelchair. In the third phase the caregiver lowers the patient into the wheelchair.

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.

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 (Jäger et al., 2013). 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 Figure 2), 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 (Vleeming and Stoeckart, 2007). 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 (Vleeming and Stoeckart, 2007). Effective load transfer is achieved, when muscle forces cause compression of the SIJ, and thereby, preventing shearing of the joints (Richardson et al., 2002; van Wingerden et al., 2004). Both the muscles of the lower limb and the back extensors influence the SIJ movements and its stabilization mechanisms via lever arms (Vleeming and Stoeckart, 2007). In the present study, the muscles of 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 (Hammer et al., 2015) (see Figure 2). The rectus femoris (RF) is one of the extensors of the knee and the flexors of the hip (Garrett and Kirkendall, 2000). The vastus medialis (VM) is also involved in knee extension (Mansfield and Neumann, 2008). It is assumed that increased activity of the RF can lead to pain in the SIJ, and therefore may cause lower back pain (Hammer et al., 2015). Furthermore, due to the connection to the pelvis, the biceps femoris (BF) performs knee flexion and hip extension and thus affects the SIJ.

4 RESULTS

4.1 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. Figure 5 shows the inclination and torsion angles during the transfer. The inclination angles were calculated according to Figure 1. The main phases are marked in the graph.

The transfer itself took about 30 seconds. As expected, the highest inclination angles occur in the first and last phase: stand up the patient and sit down the patient. The first phase begins with a stand in a neutral position with inclination angles below 20°. The caregiver is only slightly inclined to the patient. In the preparation phase, the caregiver squats. The upper body also inclines in the sagittal direction. In this preparation phase as well as during the lift, angles of up to 40 degrees are reached, so that the

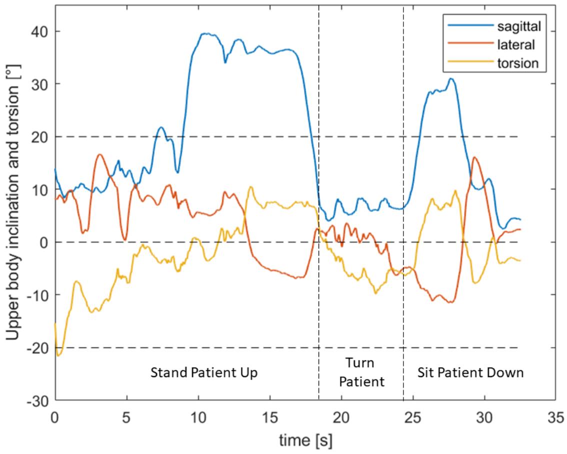

Figure 5: Sagittal and lateral upper body inclination as well as upper body torsion during the transfer from the edge of a bed to a wheelchair.

limit to the neutral range (<20°) is exceeded. The range between 20°-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. During lift phase, part of the patient's weight acts on the body. 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 bents 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. 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 (sagittal inclination angle between 20 °-60°) or red (sagittal inclination angle >60°) and the posture is classified as potentially harmful.

The lateral inclination remains in an acceptable position during the entire care activity. In the preparation phase, the student takes a slightly right-bent posture (positive inclination angles). During the lift and the patient's descent, the student shows a slight inclination to the left (negative inclination angles). During the rotation, the angle is almost zero so that the student has a straight upright position.

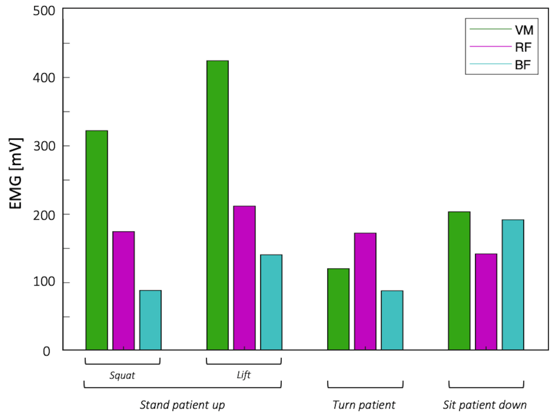

Figure 6: Mean muscle activity of vastus medialis (VM), rectus femoris (RF), and biceps femoris (BF) during the phases of the transfer.

A short torsion of more than 20° can be seen at the beginning of the recording and thus before the actual care action. During the care procedure itself, the student remains in an acceptable position. Based on this diagram, a distinction can also be made between the preparation phase and the lift. During the preparation phase, the student is squatting and is inclined in the sagittal direction. During the lift, the direction of torsion and lateral inclination changes. Special attention should be paid for coupled movements (torsion + inclination, sagittal + lateral inclination) since they can be particularly harmful (Panjabi and White, 1990).

4.2 Analysis of Muscle Activities

To evaluate the specific caregiving phases, the acquired data of the applied sensor systems are related to the surface EMG data and analyzed and interpreted according to biomechanical assumptions. Figure 6 shows the mean muscle activity of rectus femoris (RF), vastus medialis (VM), and biceps femoris (BF) during the phases of the transfer. The mean muscle activity of RF, VM and BF in the squatting position are 322 mV, 175 mV and 77 mV. While lifting the patient the muscle activities are 425 mV, 212 mV and 141 mV. Turning the patient leads to mean muscle activities of 121 mV, 173 mV and 88 mV and while sitting the patient down the mean muscle activities are 204 mV, 142 mV and 192 mV.

5 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 (Brinkmann et al., 2020; Weißert-Horn et al., 2014). However, the possibilities of ergonomic work design and assessment have hardly been used systematically in nursing and health care up to now (Ding et al., 2014). In consequence, we developed a posture recognition system which is able to identify potential harmful body postures according to the recommendations for ergonomic working in the care sector and integrated it into our Healthcare Prevention System (Brinkmann et al., 2020). The posture recognition system analyzes the data of a full-body motion capture system. A result report visualizes the skeleton model together with color-coded information about inclination and torsion angles during the care activity.

In the present work, we focused on the transfer from the bed into a wheelchair and analyzed the posture in terms of sagittal and lateral inclination angles as well as torsions. We could show the concept of the system and see its application mainly in the training of nursing students. An advantage of this 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. 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 (Fifelski et al., 2018; Brinkmann et al., 2020) 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.

As it is not possible to determine loads on the basis of 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. For more precise load estimations we used surface electromyography to analyze the muscle activities during the patient transfer. The higher activity of the VM in comparison to the RF while squatting and lifting was also observed in other studies (Brinkmann et al., 2020; Dionisio et al., 2008; Garrett and Kirkendall, 2000; Slater and Hart, 2017) and can be considered as realistic. The mean activity of VM were 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 (Garrett and Kirkendall, 2000). Increased activity of the RF can lead to an increased hip flexor/extensor torque and may cause pain in the SIJ, and therefore lower back pain (Garrett and Kirkendall, 2000; Hammer et al., 2015). 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 (Garrett and Kirkendall, 2000; Dionisio et al., 2008; Slater and Hart, 2017). 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 (Brinkmann et al., 2021). Also, an intra- as well as an interindividual similarity of EMG muscle activation pattern regarding time and shape of the signals for the selected muscles of the lower limb could be observed.

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