Communication

People Lifting Patterns - the Reference Dataset for Practitioners

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Abstract: Many professionals do not use correct person transfer techniques in their daily practice. This results in damage to correct paraspinal musculature over time, especially by lower back pains and injuries. In this work, we propose the example of an accurate multimodal measurement of people lifting and related motion patterns for ergonomic-education on applying correct patient transfer techniques. Several examples of person lifting have been recorded and processed thanks to the accurate instrumentation and the well-defined measurements of kinematics, kinetics, surface electromyography of muscles, and multicamera video. It resulted in the complete measurement protocol and unique reference dataset of correct and incorrect lifting scheme for caregivers and patients, that in multimodal form using motion patterns allows for better insight for further independent investigations.

Keywords: human motion dataset; ergonomics in people lifting; tag detection; human motion lab; decision support; recommending systems; data processing tag detection; motion analysis

Citation: Kluwak, K.; Klempous, R.; Chaczko, Z.; Rozenblit, J.; Kulbacki, M. People Lifting Patterns - Reference Dataset for Practitioners. *Journal Not Specified* **2021**, *1*, 0. https://doi.org/

Received:
Accepted:
Published:

1. Introduction

The problem of maintaining the correct body posture while performing lifting activities is very important in many professional fields. In particular, it concerns healthcare personnel and other professionals helping people on daily basis. The fundamental problem of proper doing of their daily person handling activities and setting up the most ergonomic ways are:

- identification of the appropriate ergonomic techniques for professional workers,
- selection of proper ergonomic exercises for particular groups of employees,
- determination of the quality of the performed activities,
- evaluation of the quality of their performance.

Therefore, to specify correct assessment methods and ergonomic exercises, it is necessary to carry out and record both correct and incorrect person handling activities. One of the routine and often basic procedures performed by healthcare workers is patient lifting. This task requires physical exertion for prolonged periods daily, and often resulting in MusculoSkeletal Sisorders (MSDs) or Low-Back spinal Disorders (LBDs) [1]. Correct lifting posture and the use of leg muscles, in particular the lateral, intermediate and medial heads of the quadriceps muscles, is a necessary condition for balancing the lumbosacral loads when manually moving the patient [2–4]. Although the use of equipment to lift the patient or the dependent person reduces the exposure to injuries associated with manual lifting by up to 95%, it is rarely used in out-of-hospital situations. The purpose of this study is:

- to propose rules for building a dataset of performed activities for caregivers and dependent people,

- to use recent recording techniques such as MoCap, EMG, and GRF to synchronously record selected activities,
- to suggest appropriate ergonomic exercises and carrying out registrations for a selected group of volunteers,
- to propose multimodal spatio-temporal motion patterns for easier identification of particular motion phases.

The most important improvement of this study is an observation and simultaneous registration of two mutually interacting people's motions. It presents full correlation between caregiver motion and patient at the same time of handling procedure.

In this paper we present an example of person lifting as an action that could cause injuries in caregivers and patients. The examples of correct (safe) techniques of lifting patients discuss various measurable features that can possibly occur when lifting patients in surgery. We propose a collective way of representing multi-modal movement information using Motion Tags [5–10].

The most ergonomic risk assessment methods were described in the medical literature. We also indicate works in which motion measurements and analyses were conducted, such as: [11–14]. One of the tasks of manual patient transport presented in [15] is lifting the patient from a lying position to a sitting position on the edge of the bed. In the study [16] an eighty-kilogram patient dummy was used to analyze the lifting operation. The analyzed kinematic and kinetic data of the lifting process were recorded with a set of four Kinect cameras, GRF, and five EMG [17] electrodes. The lifting sequence is divided into three phases each triad for ergonomic and nonergonomic versions. In the proposed ergonomic version, attention was paid to bending the knees and straightening the back. The number of recordings made has not been given. The proposal for an ergonomic approach showed less muscle activity in the lower back, at the expense of more activity for the leg muscles.

In the work [15], a dummy was used for the exercises, which as a rigid body does not fully reflect the mechanics of the human body in the context of joint movement and muscle tension. In this work, instead of using a human dummy when simulating lifting patients, full measurements of the real person being lifted was recorded for the analysis of the patient's kinetic and kinematic data. We focused on an important aspect of the nurse-patient cooperation because in every real situation the patient undertakes individualized cooperation with the staff. The nurse reacts to the patient's comments related to the lifting activity performed. The experiment in which the puppet is used does not reflect the actual situation of picking up a living person. The available mannequins are not able to reflect the real musculoskeletal system, in particular, realistically simulate the muscle tensions occurring during the movement of the patient and the nurse. The reaction and interaction to each actual patient's lifting are individual.

The paper proposes a scheme of lifting the real patient: an experiment was carried out to show the interaction of people by recording anatomical relationships during lifting. During the patient's lifting movement, there are interactions between the caregiver's and the patient's movements. Recorded multimodalities (image, kinematics, kinetics, electromyography) provide more information at the same time than unimodal measurements. Actions and interactions between the patient and the physicians were presented. A lot of researches were conducted into the ergonomics and safety of patient handling by medical personnel. Multimodal measurement of the movement of two people represents complex multidimensional information with plenty of mutually dependent features. By the introduction of Motion Tags [5], we presented a simple equivalent of original data emphasizing the most important features of phases of patient lifting in multiperson interaction. Accurate instrumentation and multimodal measurements increased efficacy at developing the assumed model. By combining measurement modalities, Motion Tags represent important information on the more abstract level and allow for efficient automation of the assessment between correct and incorrect movements.

2. Dataset with People Lifting Patterns (DPLP)

The Dataset with People Lifting Patterns (DPLP) has been created in September 2019 during internships of students from the Wroclaw University of Technology. The recordings took place in Human Motion Laboratory at the Research and Development Center of the Polish-Japanese Academy of Information Technology located in Bytom, Poland (http://bytom.pja.edu.pl/). The prepared dataset contains recordings of patient safe transfer from lying to sitting on a bed and squats scenarios. These scenarios have been performed by two 22 years old male actors in two variants. In the first case, the performances of the correct (ergonomic) transfer based on the right handling techniques [5], have been registered and validated by experienced health care professionals. The second case represented an incorrect (non-ergonomic) transfer, where motion has been performed incorrectly without professional training. Also, the squats have been performed with and without load both in technically correct and incorrect variants. These exercises allowed recording the maximum muscle tension values for the tested actors. In prepared recordings, the main attention was focused on the work of the hips, back, knees, and selected muscle tensions.

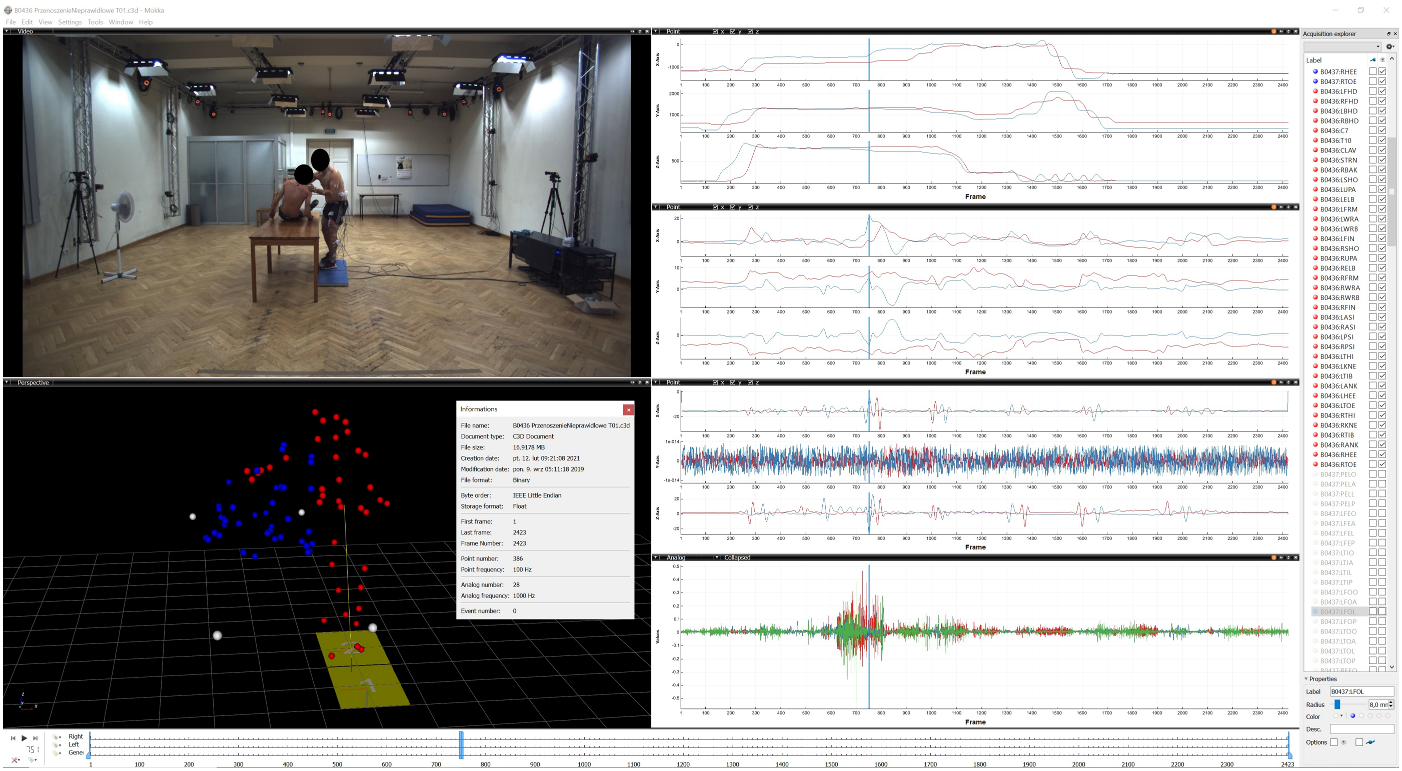

Figure 1. Visualization of the correct patient lifting with multimodal data (video, kinematics, kinetics, electromyography).

2.1. Measurement Configuration

Data were collected using Vicon software and 30 motion capture cameras, EMG with 16 channels configuration, 2 force plates from Noraxon, and 3 video Basler cameras. A detailed description of the applied measurement configuration was presented in [5]. The measurement devices were calibrated and synchronized (Tab. 1) and the system setup allowed the acquisition of 404 parameters for two people motions. The list and descriptions of EMG electrode placement can be found in Tab. 2 and Fig. 2. A description of the marker placement on the body is provided in Fig. 1. Mocap markers were placed on each performer's body (nurse and patient). And also on the table outline (4 markers) and the applied loads (2 x 4 markers).

Table 1: Configuration of the custom prepared environment for multimodal data acquisition of patient's lifting.

Data type	**Recording system**	**Recorded parameters**
Motion Capture (3D) [200 Hz]	30 Vicon cameras system (10 MX-T40, 10 Bonita, 10 Vantage)	39 markers nurse's body and 39 patient's according to the Plug-In Gait Full-Body model
Electromyography (1D) [1000 Hz]	Noraxon	16 EMG measurements (SENIAM)
GRF (3D) [1000 Hz]	Kistler Force Plates 9286BA	direction and force of two feet
Multi-camera video (2D) [25Hz]	3 DV Basler Pilot piA1900-3gc	3 video streams (back, right and left)

In addition to the data already acquired directly from the measurements, the software allowed computing additional parameters for the body motion for each actor such as virtual markers, angles, moments, forces, powers. The part of the Vicon software - plug-in Gait simplifies calculation of kinematics (angles) and kinetics (forces, moments and powers) of estimated joints from applied motion model and measured positions of the XYZ markers.

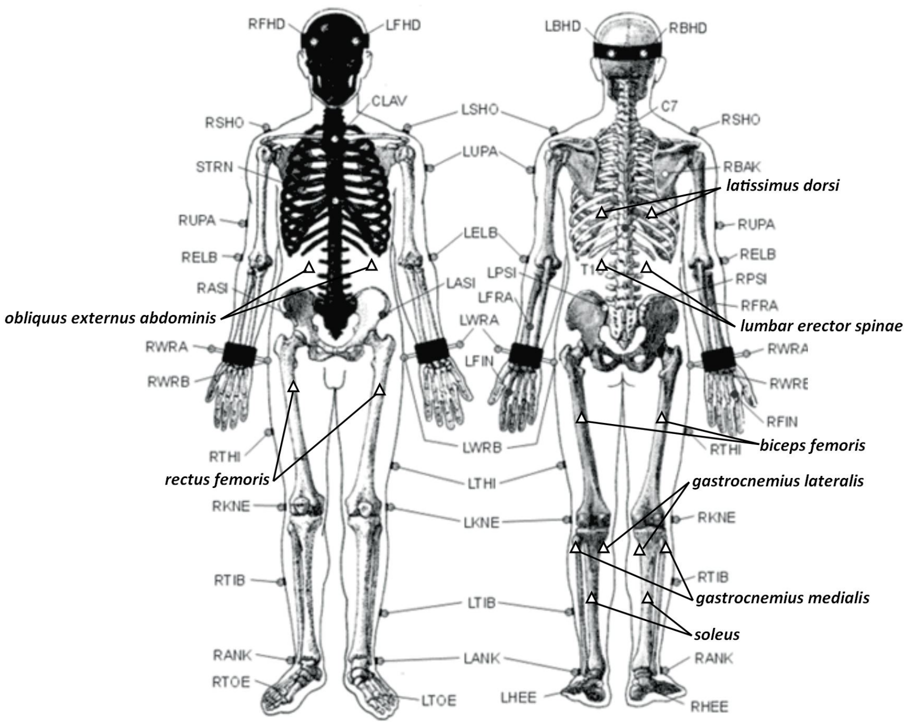

Figure 2. Placement of 39 motion capture markers and EMG electrodes on nurse, the same scheme is used for the patient (without EMG). Skeleton schema as well as markers abbreviations of markers names source: http://www.lifemodeler.com/LM_Manual_2010/A_motion.shtml

In addition to the data already created from the actual measurements, the software allowed to produce additional parameters for the body motion for each actor such as virtual markers, angles, moments, forces, powers. The Gait plug-in directly calculates kinematics (angles) and kinetics (forces, moments and powers) from the measured positions of the XYZ markers.

2.2. Measurement Protocols

The carryover is considered to be correct if it was performed according to the phases of movement from Tab. 3, and the nurse follows these principles. Correct squats are those that follow the principles: Keep the head and neck in a proper alignment with the spine; Maintain the natural curvature of the spine; do not bend at the waist (in a

Table 2: Placement of the EMG electrodes during the recording session (see Fig. 2).

Electrode (left side)	Electrode (right side)	Muscles name
Voltage.1	Voltage.9	latissimus dors
Voltage.2	Voltage.10	lumbar erector spinae
Voltage.3	Voltage.11	obliquus externus abdominis
Voltage.4	Voltage.12	rectus femoris
Voltage.5	Voltage.13	biceps femoris
Voltage.6	Voltage.14	gastrocnemius medialis
Voltage.7	Voltage.15	gastrocnemius lateralis
Voltage.8	Voltage.16	soleus

light squat); Avoid twisting the body when moving a person; Always hold a person being transferred close to your body (arms not outstretched); Keep legs shoulder-width apart for balance; Use leg muscles to lift and/or pull (knees should not cross toe line) the patient. It was assumed that the movements of patients lifting performed by a nurse without following the given rules are considered abnormal.

Table 3: Description of patient lifting movements scenarios

ID	Move	Movement name	Movement phases
0	E01	Correct Patients Lifting	F01 - Preparing to move F02 – Extending hands to the patient F03 – Patient's leg flexion F04 – Right arm position F05 – Left arm position F06 – Turning the patient over F07 – Lowering the patient's legs F08 – Seating the patient
1	E02	Incorrect Patients Lifting	F01 – Preparing to move F02 – All actions simultaneously
2	E03	Correct squats with load	F01 – Squat
3	E04	Correct squats without load	F02 – Upright
4	E05	Inorrect squats with load	
5	E06	Inorrect squats without load	

Table 4: Biometric data of registered actors

ID	Person	Role	Sex	Age	Weight [kg]	Height [mm]
0	B0436	nurse/patient	male	23-24	80	1760
1	B0437	nurse/patient	male	23-24	57	1760

2.3. Dataset Organization

The created dataset includes all files that have been created as a result of the session recording. It contains in particular **.C3D**, **.AVI** files and other files necessary for advanced processing of recorded data. The naming convention of the files in the dataset is as described in the previous chapter. Authors used *Mokka* - the open-source editor for **.C3D** data visualization. Missing markers positions were completed using Vicon Nexus software. In addition, data **were annotated** according to the time phases present in Tab. 3. The annotations are visible as start and end pose labels in the **.C3D** file.

The file naming convention is following: **YYYY name T99.c3d**, where:

- **YYYY-MM-DD** is the date of recording in the format (year, month, day),
- **name** is:
  - CorrectLifting - 3 recordings for B0436 - 3 recordings for B0437
  - InCorrectLifting - 2 recordings for B0436 - 2 recordings for B0437
  - InCorrectSquat - 2 recordings for B0436 - 1 recording for B0437
  - InCorrectSquatLoad - 1 recording for B0436 - 0 recordings for B0437
  - CorrectSquat - 1 recording for B0436 - 2 recordings for B0437
  - CorrectSquatLoad - 1 recording for B0436 - 1 recording for B0437
  - InCorrectSquatLoad2 - 1 recording for B0436 - 0 recordings for B0437
- **T99** - is the individual repetition ID number of the sequence

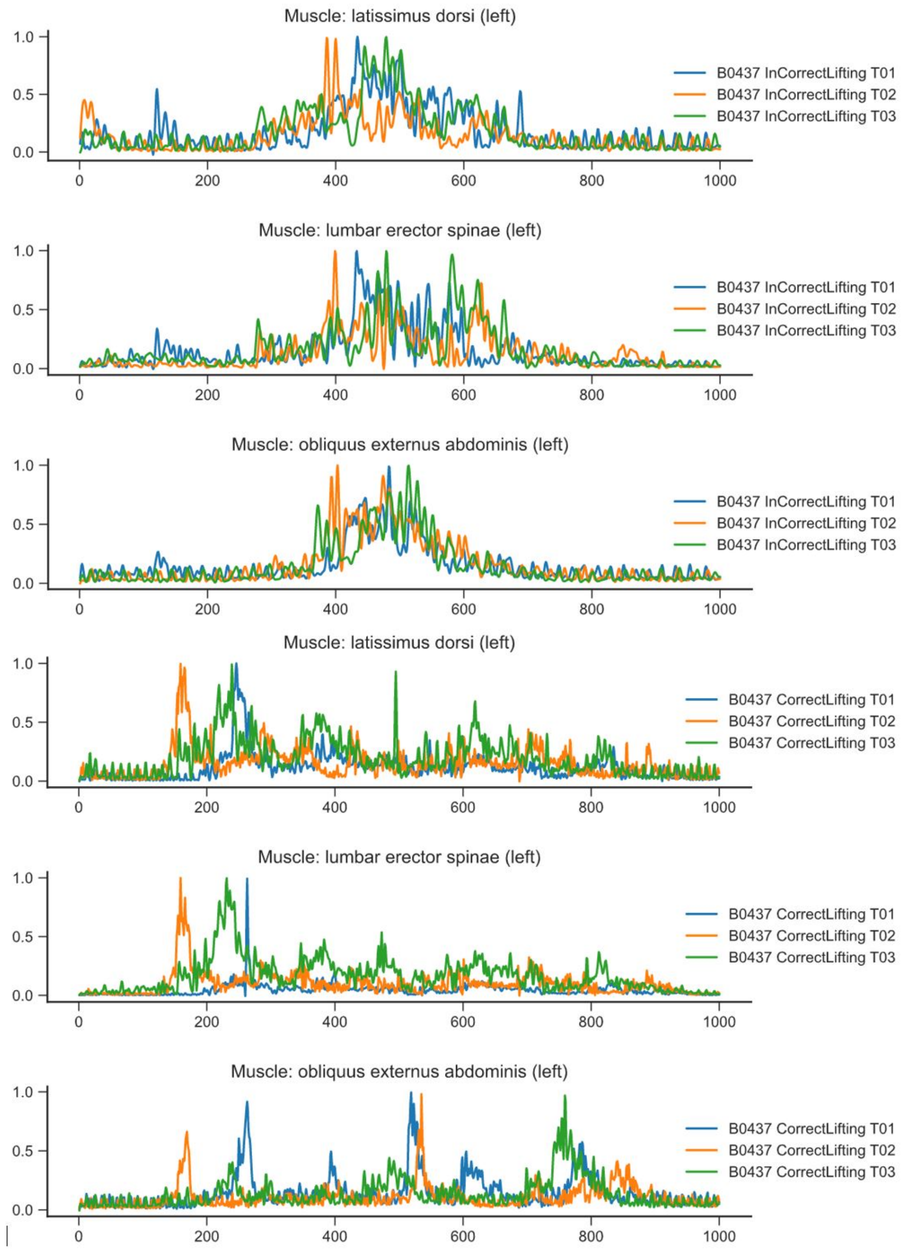

Figure 3. Activity of selected muscles for patient transfer. The first 3 graphs show the incorrect transfer, the next 3 graphs show the correct transfer.

The dataset with patient lifting - DPLP has been made public for scientific research purposes according to the initiative of Living Labs for Human Motion Analysis and

Synthesis in Share Economy [18] Model and is available in the resources of R&D Center PJAIT: https://res.pja.edu.pl.

3. Multimodal Data Representation

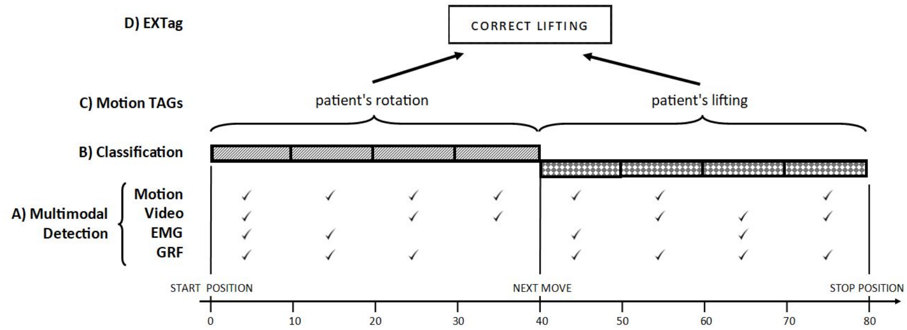

Figure 4. EXTag concept with four level of operations [5]

In the visual analysis of the recorded data, the variable behavior of muscle activity depending on the movement performed was noticed. In abnormal lifting, all muscles simultaneously generated high tensions. In contrast, in the correct approach, muscle tension was distributed throughout the exercise and activity was at a lower level. The assumptions that a correctly performed movement will decrease tension on the back muscles and increase tension on the lower extremities were confirmed. This would result in fewer injuries to medical personnel resulting from excessive pressure on the lumbar spine. The indicated observations were also noted in the work of [5], where the concept of Motion Tag (Fig. 4) was also proposed. Motion Tag is a concise, minimal representation of a given motion measurement segment that includes characteristic data blocks of the selected motion. In our case, the data blocks represent motion phases with a specific correlation between parameters. In the following analysis, we will attempt to determine the correctness of patient lifting motion based on Motion Tags.

Annotations of particular situations according to measurement protocol have been done manually by the people involved in the recordings. The start and end positions for each movement phase have been determined and marked. The proposal of the extraction of the position of the nurse and patient from markers was aimed towards automation the revealing of the movement phases described in Tab. 3.

By observing changes in the position of the patient's pose, body markers were proposed as follows:

- F02 - Approximation of markers RWRA, RWRB, LWRA, LWRB (nurse's hands) to RKNE, LKNE (patient's knees).
- F03 - Changing the values for RANK, RTOE, RHEE, LANK, LTOE, LHEE (patient's feet) and RKNE, LKNE (patient's knees)
- F04 - Change the value for RWRA, RWRB (patient hand) versus RELB (patient elbow).
- F05 - Change the value for LWRA, LWRB (patient's hand) versus CLAV (patient's chest).
- F06 - Abrupt change for most markers by 90 degrees.
- F07 - Change in value of RANK, RTOE, RHEE, LANK, LTOE, LHEE (patient's feet).
- F08 - Change of C7, T10, CLAV values (change of patient's back position from horizontal to vertical).

The individual change in the posture of the patient in synchronization with the change in the posture of the nurse is not sufficient to conclude that the caregiver's movement is correct (ergonomic). Therefore, based on the additional features from surface EMG have been marked, then checked, and chosen as proper phases of the movement where muscle shows increased activity. Raw EMG data were rectified and normalized as

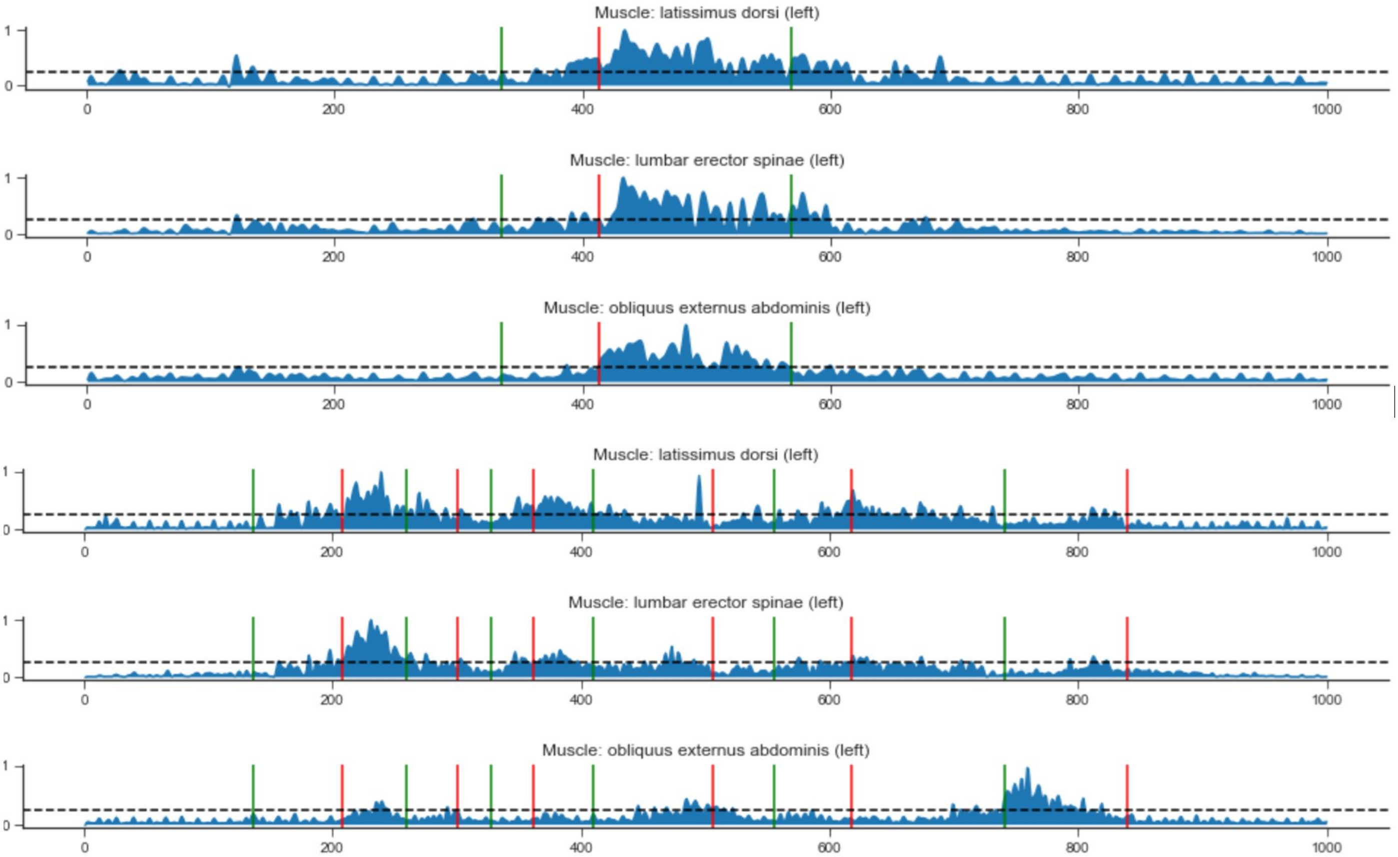

Figure 5. Activities of selected muscles for the patient's transfer divided into movement phases (see Tab. 3). The first 3 diagrams show the incorrect transfer, the next 3 diagrams show the correct transfer.

Table 5: Detected muscles (Tab. 2) activity in relation to movement phases (Tab. 3) in progress

Muscles ID	**F02**	**F03**	**F04**	**F05**	**F06**	**F07**	**F08**
Voltage.1	active	active		active			
Voltage.2		active					
Voltage.3		active			active	active	active
Voltage.4							
Voltage.5			active	active	active	active	active
Voltage.6				active	active	active	active
Voltage.7	active	active		active	active	active	active
Voltage.8							
Voltage.9	active						
Voltage.10							
Voltage.11		active			active	active	active
Voltage.12	active						active
Voltage.13		active				active	
Voltage.14	active	active				active	
Voltage.15		active			active		
Voltage.16	active	active	active	active	active	active	active

[19], and the result was presented in Fig. 3. The combined multimodal motion patterns were used for comparison of different subjects performing the movement. For each subject with selected movement phases, they were presented in Fig. 5. With this knowledge and the determined movement phases described in Tab. 3, it was detected the increased muscle activity, physiologically correct according to SENIAM recommendations[1], for each specific movement phase. For each movement and processed EMG a muscle was considered to be active, only if its activity was greater than 20% of the highest tension throughout the movement. In this way, a table of muscle activity in a particular phase for each movement was obtained. If a given activity has been repeated for at least 3 lifting samples we considered in that phase the muscle should be active for the correct movement. The described observations are included in Tab. 5.

4. Summary

The multimodal form using motion patterns allows for much more sophisticated and detailed insight for further independent investigations of ergonomic movement of lifting. It gives additional information about mutual relations between caregiver and patient. Besides such a multiperson and multimodal approach reveals quite a new kind of relationships between different motion features (e.g. muscle tension to kinematics configuration of nurse or patient being handled in a certain phase of lifting). Complete measurement protocol and unique reference dataset of correct and incorrect lifting scheme for nurses and patients were proposed and disseminated. The possibility of using Motion Tags for motion correctness detection was considered as presented in [5]. Assumptions about muscle activities and changes in marker positions were described in the paper and can be used as a basis for motion patterns.

Acknowledgments: This study was supported by the Scientific Research from Polish-Japanese Academy of Information Technology, R&D Center and DIVE IN AI and statutory funds of Wroclaw University of Science and Technology, Faculty of Electronics.

Sample Availability: Samples of the compounds ... are available from the authors.

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