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DOI 10.2478/ama-2024-0036

acta mechanica et automatica, vol.18 no.2 (2024)
Special Issue "New Trends in Biomedical Engineering"

BIOMECHANICAL ASSESSMENT OF CRITICAL FACTORS DURING PATIENT LIFTING: SHOULDER GIRDLE AND CUMULATIVE MOMENT ERGONOMIC EVALUATION

Karolis SENVAITIS*, Kristina DAUNORAVIČIENĖ*, Aušra ADOMAVIČIENĖ**

*Vilnius Tech (Department of Biomechanical Engineering), Lithuania
**Vilnius University (Department of Rehabilitation, Physical and Sports Medicine), Lithuania

karolis.senvaitis@vilniustech.lt, kristina.daunoraviciene@vilniustech.lt, ausra.adomaviciene@mf.vu.lt

received 17 September 2023, revised 30 November 2023, accepted 7 January 2024

Abstract: This study examines the ergonomics of the patient lifting motion often used by healthcare professionals, focusing on the shoulder area, as manual weight management is still an important part of daily work. Data acquisition was made with the 17 IMU sensors, Movella Xsens system. A total of 25 quality measurements were acquired for further data processing. A mathematical model with the defined assumptions is presented in this research calculating shoulder moment-kinematics. The load engagement profile was determined based on the hip extension as a variable size for different test subjects and trials. Shoulder flexion-extension range of motion (ROM) variance was estimated, determining each test subject's technique, together with shoulder moment and cumulative shoulder moment. Cumulative shoulder load varied from −31.46% to 27.78% from the mean shoulder moment value. During the estimated accumulation of a 5-year work span, the difference in worst to best techniques accumulated to 1.86 times. Recommendations on how the technique and the further scope of the research could be improved were given.

Key words: shoulder girdle, range of motion, cumulation, lift motion

1. INTRODUCTION

Manual weight handling is still a significant part of everyday work in today's rapidly evolving healthcare segment. The working nature of healthcare specialists impacts them which is becoming a concern. The demanding nature of their work often requires them to engage in physically intensive tasks, such as patient lifting or transferring. While these activities are essential for providing healthcare, they also pose potential risks. It has a significant impact on various musculoskeletal disorders [1].

Scientific evidence shows that ergonomic intervention can effectively lower the physical demands of manual labour tasks [2]. As different industry manual weight handling tasks are being changed with the machinery, it is relatively hard to impact patient handling in the healthcare sector. Although there are various equipment that might help to lift and transport patients, lifting procedures done manually by nursing staff specialists are not yet extinct. Different rooms, procedures and surfaces make it hard and costly to implement automated solutions. Not only the circumstances, but the patients themselves are different; not to mention that patient lifting and nursing might be required at patient homes.

Rapid injuries can often be defined and predicted by the force applied to different muscle skeletal segments and to the strain of different types of tissues [3]. Chronic musculoskeletal diseases are harder to predict and define as not only it take time but it is hard to replicate. Although this is true, chronic traumas of musculoskeletal apparatus can be reduced if we limit the accumulation of non-ergonomic positions, high-strain movements and loads in general to a different segment of the body [4]. Measuring and evaluating the motions involved in patient lifting is a critical step in identifying potential stress points and areas of strain on the human musculoskeletal system. This involves the utilisation of advanced motion capture technologies that allow for precise tracking and quantification of joint angles, range of motion (ROM), and forces exerted during lifting activities. By collecting and analysing such data, researchers can gain insights into the biomechanical dynamics of various patient lift techniques. This would enable the identification of problematic movement patterns that may lead to overexertion and subsequent injuries. ROM is relatively easy to calculate and requires input in many calculations and estimations. This makes ROM one of the most impactful factors and highly associated with ergonomics since it is crucial for force moment evaluation. ROM amplitude can magnify moment by at least a few times. If we count its possible accumulation, the impact of correct posture of movement might be drastic.

There are a lot of advancement in lower back and leg research and studies, while shoulder, neck and arms are relatively unresearched and problematic areas. Research done in 2021 shows that 53% of the 233 test population experienced shoulder pains, related to work-related activities [5]. Patient lifting motions, involving repetitive movements of the shoulders, neck and arms, have been observed to lead to discomfort, pain and even chronic musculoskeletal issues among healthcare professionals. At the same time, shoulders were the body part that experienced work-related muscle skeletal disorders most frequently in Hong Kong [6] and Norway [7]. The choice to analyse shoulder segments can be further supported by consulting healthcare sector specialists. The significance of maintaining a healthy workforce within the healthcare sector cannot be understated, as their ability to provide

DOI 10.2478/ama-2024-0036

optimal patient care is directly linked to their physical well-being. Addressing the ergonomic aspects of patient lifting has the potential to alleviate the physical burden on healthcare specialists and also enhance their overall job performance and satisfaction. Furthermore, mitigating the risks associated with repetitive stress injuries and chronic pain can lead to a healthier and more resilient healthcare workforce, resulting in improved patient outcomes and reduced healthcare costs.

Evaluating the forces exerted on the body and the ROM limitations during patient lifting serves as a crucial aspect of biomechanical analysis [8–10]. By quantifying forces, researchers can identify thresholds beyond which tissues and structures may become compromised, leading to discomfort or injuries. Similarly, assessing the ROM limitations helps pinpoint potential constraints that might hinder proper lifting techniques and contribute to musculoskeletal strain. Such evaluations provide valuable insights into the critical parameters that must be considered when designing ergonomically sound patient lift protocols. This research delves into the intricacies of healthcare specialists' everyday patient lift motions. It places a significant emphasis on the biomechanics of shoulders – the area most commonly reported to experience discomfort and pain. By understanding the underlying ergonomic factors contributing to these issues, effective interventions and strategies can be developed to optimise patient lifting techniques. Consequently, this research seeks to bridge the gap between the demands of patient care and the well-being of healthcare specialists, fostering an environment where both patient safety and provider health are equally prioritised.

In the following sections of this research article, patient lift motion is analysed with the evaluation of the cumulative load's impact, progressing to recommendations and discussions on the following topic. Methodology on how to calculate shoulder moment with accumulated load is presented. The initial goal of this study was to find quantitative assessment methods that would allow accurate assessment of shoulder girdle injury risk in medical staff during patient transfer. This research aims to contribute to the ongoing efforts to create a safer, healthier and more sustainable healthcare environment for both practitioners and patients alike.

2. MATERIALS AND METHODS

2.1. Test subjects and analysed motion

For the test subjects, various body type scholars were chosen. This research includes five participants doing at least five quality repetitions. This makes in total 25 quality measurements. Test subjects' anthropometry data needed for the scope of this research is listed in Tab. 1.

The test environment was represented by two chairs each 0.5 m tall and 0.5 m apart from the starting position of the test subject (**Fig. 1**) One indicates the surface from which the patient is being lifted while the other represents the surface at which the patient has to be put down. Same height surfaces were chosen to emphasise the motion and its ergonomics and not the environment itself. A weight of 5 kg was given to have better representable lift motion. It was chosen not to use representation of the patient to avoid possible injuries as this was not professionally trained personnel and multiple measurements were taken in a short period.

Tab. 1. Test subjects anthropometry data

	Subject 1	**Subject 2**	**Subject 3**	**Subject 4**	**Subject 5**
Sex	Female	Female	Fe-male	Male	Male
Full body height (cm)	168.00	164.00	170.00	184.00	187.00
Upper arm length, cm (l_{ua})	30.35	29.63	30.72	38.79	39.42
Lower arm length, cm* (l_{la})	35.61	34.76	36.04	42.68	43.37
Full body weight (kg)	80.00	82.00	68.00	84.00	83.00
Upper arm weight (kg)	2.32	2.38	1.97	2.72	2.69
Lowe arm weight (kg)	1.89	1.94	1.60	2.23	2.21

*Elbow to the middle of the hand, where grip of the load is expected.

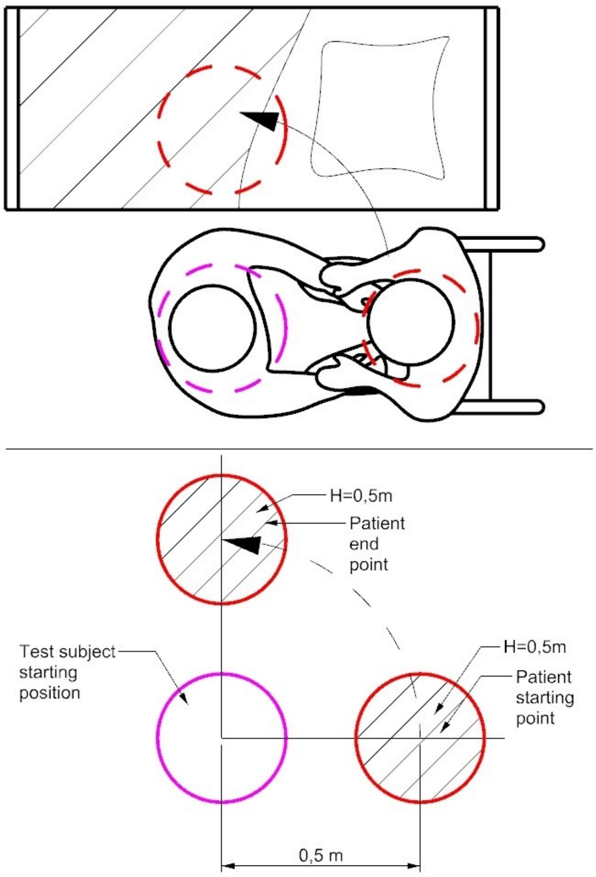

Fig. 1. Simplified researched motion scene schematics

For this research, imitated patient lift motion was chosen. It is based on the physiotherapists' ergonomic lift techniques and safe lifting recommendations. Techniques were practiced by the test subjects before conducting a recorded movement. The correct technique was not enforced to have a broader spectrum of movements and their impact on the research. The movement sequence combines three basic motions – lifting the patient up, pivoting while transferring body weight and putting the patient down. The test subject approaches the patient so they have their waist at their reach and hugs the patient. After stabilising their posture and securing the grip, they stand up, by lifting a patient's weight. Afterwards, left leg is being transferred to align body weight and position to the destination of the lift. Left leg repositioning is followed by the right leg, keeping a steady posture and firm stance. After both legs are repositioned and pivoting is done, the patient is being put down by gradually squatting. Subsequently, the grip is released and the patient is secured on the new surface [11, 12].

Analysed motion definition starts when the test subject is present in from of the patient (has both feet firm on the ground) and starts bending motion to hug the patient preparing for transfer. Motion end is recorded when patient is transferred to the end surface and test subject releases patients body weight and stands in neutral standing position with hands to his sides.

2.2. Equipment and research procedure

In this research, measurement of the whole body is made. From there, upper body limbs can be analysed while having full body movement as a context. Researched movement was recorded with the Movella Xsens inertia measurement units (IMU) costume. This costume has custom marker layout for the main body segments. In total, 17 IMU sensors were used. Finger movements are not measured in this research. Sensors are placed in approximate centre of gravity (COG) positions on each segment. Movement noise is removed with the high-definition post processing of the Xsens MVN 2023.2.0 software version. Recording was done with a 60 Hz data acquisition frequency.

The study was performed in the sequence shown in the Fig. 2.

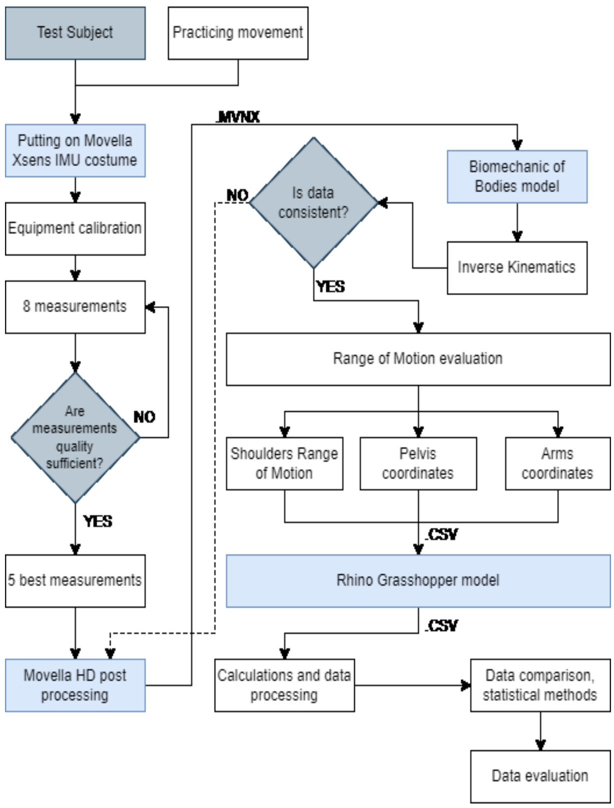

Fig. 2. Research sequence. IMU, inertia measurement units

First, as aforementioned, test subjects were instructed and practiced given motion. Then, IMU costumes were equipped and calibrated. Eight measurements were taken to have broader volume, so five with the most consistent data would be taken. As a rule of thumb, first measurement of every test subject was excluded from the measurement as additional practice, while performing movement under-recording. In total 43 data recordings were made with 25 chosen to progress.

All 25 measurements were then batch HD post-processed. This helped to remove noise, and motion inconsistencies, interpolate any gaps, etc. Afterwards, data was exported in MVNX format file. This data then was imported to biomechanics of bodies software 10.5 and after inverse kinematics, ROM data were taken. Data was compared with the original Xsens ROM data to make sure that it is consistent and does not show any significant visual differences. For further analysis, these main input points were needed: Shoulders ROM, pelvis sensor coordinates and arms sensors' coordinates (shoulders, arms, hands). These coordinates were imported into Rhino Grasshopper version 7-SR26 for further analysis since neither Movella, nor biomechanics of bodies models exports needed angles. In Rhino Grasshopper, model was made to find spine angle, which is necessary for shoulder moment calculation, the same as sagittal arm angle. Since arm angle can be impacted by various ROMs, it was decided to take sensor coordinate systems and project them on the created sagittal plane. After this, data were taken out from the model, so further calculations and data processing could be made. It was chosen to calculate shoulder moment, with cumulative moment evaluation, that would contribute to data comparison and final results evaluation [13]. Grasshopper is an algorithmic modelling plugin that is a power tool widely used by various engineers and designers. It is flexible that is able to read, write, process or manipulate various data with pre-integrated tools [14].

2.3. Tools and mathematical methods for kinematics and shoulder moment evaluation

Shoulder moments were calculated as quasi-static, without taking the acceleration of individual segments into account. The quasi-static analysis assumes that the system or segment remains similar or in equilibrium with negligible dynamic effects such as inertia and time-dependent behaviour.

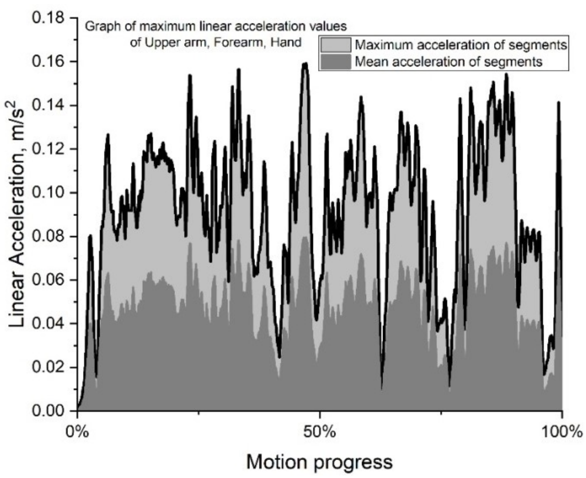

Fig. 3. Maximum linear acceleration of Upper arm, Forearm and Hand evaluated altogether

DOI 10.2478/ama-2024-0036

Based on the linear acceleration values of the analysed segments, shown in **Fig. 3**, the maximum acceleration is 0.159 m/s^2. As this is only 1.62% of gravity constant, the dynamic load is being accounted as negligible effect to further calculations and therefore, further analysis is quasi-static.

Since the average pelvis width is 20 cm, load COG was taken 10 cm from the grip and directed to the test subject's body.

Shoulder moments were calculated from equations as follows [15]:

$$SM = sm_{ua} + sm_{la} + sm_{\text{load}}$$

$$sm_{ua} = F_{ua\,.} \cdot D_{sua} = m_{ua} \cdot g \cdot D_{sua}$$

$$sm_{la} = F_{la\,.} \cdot D_{sla} = m_{la} \cdot g \cdot D_{sla}$$

$$sm_{\text{load}} = F_{\text{load}\,.} \cdot D_{sl} = m_{l} \cdot g \cdot D_{sl}$$

Shoulder moment consists of three key components: shoulder moment of upper arm (sm_{ua}), moment of lower arm (sm_{la}) and moment of load (sm_{load}). Note that g is a gravity constant, taken as a 9.81 m/s^2 and m represents the mass of a specific segment or load: upper arm, lower arm and load respectively – is a projected distance from shoulder acting as moment arm. Each of these components is a multiplication of its gravity force and projected distance between the shoulder and COG. **Fig. 4** illustrates the main forces impacting shoulder moment.

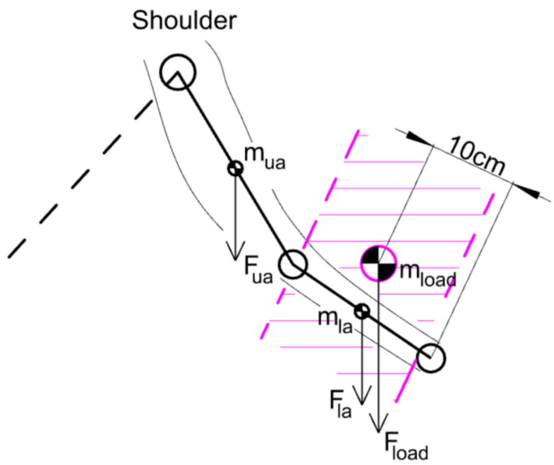

Fig. 4. Diagram of forces impacting shoulder moment

In this calculation, the hand is accounted as a part of the forearm and is being evaluated together as a lower arm. Since the wrists are mostly acting in a locked position relative to the forearm during the motion, it was decided to treat them in conjunction. The weight and length were recalculated to fit the segment as if the hand would have fingers bent 90° as this is the closest pose of hand participants had during recorded motion. Generalised human body parameters were used, the centre of mass for the upper arm being 0.436 of its length ratio, located closer to the shoulder. After recalculating lower arm parameters, including forearm and hand centre of mass is located at 0.496 of segment length ratio, located closer to the elbow.

Loads are relatively static, but distances are constantly changing depending on body posture. That's why the emphasis is on posture and its overall impact on the shoulder moment and its accumulation. Moment arm distances were calculated as follows:

$$D_{sua} = 0.436 l_{ua} \cdot \sin(\alpha - \beta)$$

$$D_{sla} = 2 \cdot D_{sua} + 0.496 l_{la} \cdot \cos(\delta)$$

$$D_{sl} = 2 \cdot D_{sua} + (l_{la} - 0.1) \cdot \cos(\delta)$$

$$\cos(\delta) = \cos(180° - (90° - \beta) - \beta - \gamma = \cos(90° - \gamma)$$

Schematics of calculation inputs can be found in **Fig. 5**. α represents shoulder flexion-extension joint angle. β is a spine angle in a reference to vertical line, calculated from the parametric model. γ is arm angle projected to the ground plane, calculated as a derivative size from elbow joint angle in a parametric model. Hand anthropometric data were taken from the Tab. 1.

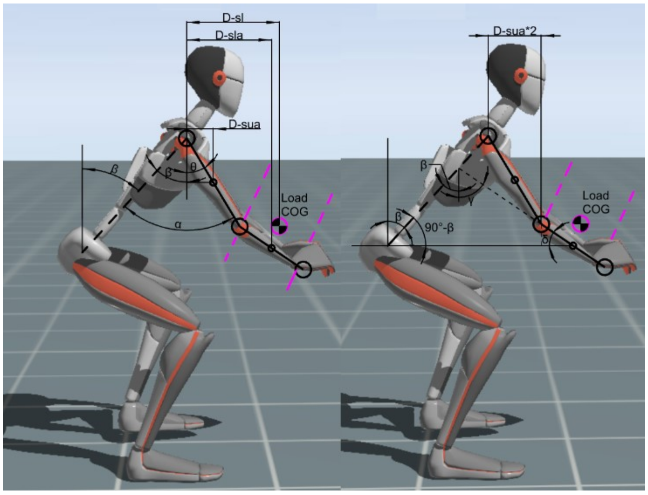

Fig. 5. Mathematical scheme of project shoulder distance calculations

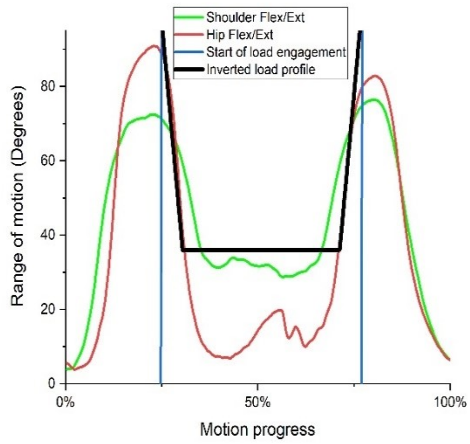

Fig. 6. Load engagement step configuration graph

During lift motion, the load is engaged gradually and is not present during the whole motion. This is important to define as the load size of this particular study is set to be 36 kg. Patient whose weight is 60 kg was taken as a baseline for patient load with the assumption that the patient can still carry 40% of its body weight on his own, during transportation motion. During motion, the load of a patient to the test subject is applied when the test subject is standing up, it has been decided to replicate the slope of hip extension joint angle. It is understood, that load is being engaged after the grip is initiated and the hip starts to extend. illustrates the relation between hip and shoulder flexure-extension joint angles. It can be observed that hip starts to extend at first and only afterwards shoulders follow. As hips are extending, more and more weight is being lifted until the whole load is engaged on the subject arms. The assumption is made that the load is fully engaged on the subject when shoulder extension stops. The black line () indicates inverted load profile from the start of load engagement to its full capacity.

In this research, it has been found that a spine angle with reference to a vertical line is needed for shoulder moment calculation. This is required to calculate moment arms as shoulder flexion and extension joint angle can yield different shoulder moment arm results depending on the body posture. Furthermore, a projected arm angle is needed so the moment arm of load can be determined more accurately. For this purpose, the parametric model was designed in Rhino Grasshopper so the whole motion can be evaluated at once [13].

The spine angle to the vertical line (β in **Fig. 5**) was identified as an angle between the vertical line and line, constructed between the pelvis marker and midpoint of an imaginary line between shoulder points. The vertical line was created from the pelvis marker to act as a measurement baseline for β angle calculation. Baseline vertical line always belongs to the sagittal plane constrained as a middle plane between shoulder points, with pelvis marker set as origin point. This acts as a reference plane for angle measurements. Evaluating main parameters is crucial, to lower the approximation level, as different components can transform the final shoulder moment calculation. Especially for such complex motions, involving different bending, squatting and rotating motions. The parametric model was defined with the geometrical constraint in **Fig. 5**.

2.4. Evaluating and representing results

Statistical methods were used to process and represent the results of this research. Origin 2018 SR1 software was used for processing of final result and presentation. Data comparison was done by calculating mean values of the different lift motions, together with the range, in which repetitive motions happen. Peak and cumulation evaluation was conducted to understand the critical limits of the motion and aggregate effects of the loads. Graphs were compared by overlaying them for visual estimation, together with statistical difference calculation and evaluating deviation from mean values.

To have a comparable data, normalisation of shoulder moments in relation to individuals' body weight and height ratios was conducted. This normalisation process enabled us to establish a common baseline for evaluating shoulder moments across participants, irrespective of their physical attributes. By doing so, more comparable data is gained so more insightful assessments could be made. Together with physiology data, time normalisation was conducted so motion could be overlayed in the same progress of the movement axis [16, 17].

Furthermore, for data to be comparable, shoulder moments were normalised in time and expressed as 100% of the motion completion. The motion of average duration was taken as a set-point to shrink and extend the remaining data sets. Afterwards, results were normalised in the ratio of body weight to height [18, 19].

The root mean square error (RMSE) serves as a statistical metric in this study, providing a quantitative measure of the accuracy of biomechanical measurements. By calculating RMSE, the disparity between observed and predicted values is being assessed, such as joint angles and ROM, providing a clear indication of the fidelity of the data [20].

Utilising the standard deviation in the scope of this research aids in comprehending the variability and consistency within the data. It serves as a base statistical measure, allowing one to gauge how individual data points deviate from the mean or average. A low standard deviation implies that the data points tend to cluster closely around the mean, indicating a high degree of consistency in presented biomechanical measurements. Conversely, a higher standard deviation suggests greater variability, prompting the investigation of potential sources of variation or error [21].

3. RESULTS

Shoulder ergonomics during lift motion were evaluated throughout temporal values and ROMs intervals. Initial motion kinematics determination yielded results as shown in Tab. 2. Total average duration of performed lift motion is 9.61 s out of 25 calculated trials. Time data shows that most of the motions are consistent, having less than second of variance between different mean values and different repetitions.

Tab. 2. Motion duration characteristics

Test subject	Mean motion duration (s)	RMSE
Subject 1	10.29 ± 0.81	0.73
Subject 2	8.70 ± 0.40	0.35
Subject 3	10.70 ± 1.02	0.91
Subject 4	8.75 ± 0.34	0.31
Subject 5	9.59 ± 0.44	0.39

RMSE, root mean square error.

By time normalising each of the subject's trials and overlaying them, variance ROMs can be seen (**Fig. 7**). Subject 1 data was not included as it shows a similar trend as test subject 2 results. These ROMs identify the highest and lowest boundaries of performed motion. This allows to judge the consistency of the motion and general trend. From this shoulder flexion extension graphs, different techniques can be identified. Test subjects 1 and 2 show consistent shoulder engagement during whole motion. This indicates potentially bigger loads in the shoulder area, without resting arms and putting additional strain. Test subject 3 releases the shoulder after lifting the patient but not as much as test subjects 4 and 5. During test subjects 4 and 5 motions, a few key aspects of the motion can be identified: first peak represents squat to hug and lift the patient, while second peak identifies squat to put down and release the patient. Furthermore, less variance can be seen on test subjects 4 and 5 technique as the range areas from lowest to highest ROM values are visually smaller.

From recorded motions, none of the test subjects reached 90˚ ROM, which is identified as risky by ISO or Rapid Upper Limb Assessment (RULA) standards. To be able to further evaluate data, the risky joint angle was set to 70˚. Medium risk is treated

DOI 10.2478/ama-2024-0036

when shoulders are >45˚. These values are taken lower than the aforementioned standard since the handled load is bigger too. Values were adapted to the analysed motion, so estimation would yield insights on the ergonomics and motion parameters. Exposure evaluated in percentage of motion duration is shown in Tab. 3:

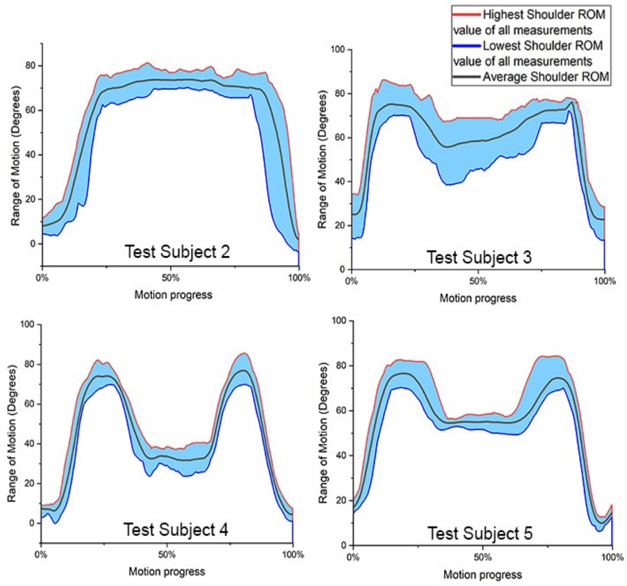

Fig. 7. Test subjects' shoulder flexion-extension ROM. ROM, range of motion

Tab. 3. Shoulder flexion exposure to different joint angles

Test subject	Mean time portion of movement >45˚	Mean time portion of movement >70˚
Subject 1	81.68%	38.61%
Subject 2	76.08%	54.61%
Subject 3	85.47%	33.69%
Subject 4	43.13%	20.90%
Subject 5	81.25%	24.11%

Shoulder flexion that is >45˚ can be seen as dominant for most of the test subjects' movements. 3 out of 5 test subjects have >80% of their motion >45˚. 3 out of 5 test subjects have their movements with >30% exposure time >70˚ with subject 2 having the most exposure – 54.61%.

Fig. 8 shows different ROMs and angle components. Motion characteristics can be identified – lift, pivot and put down motions. Furthermore, it can be seen that these angles translate to same motion pattern.

Projected distances are shown in **Fig. 9**. As they are calculated from the anthropometric data and ROM angle, similarities can be seen with the appropriate **Fig. 8** angles. Projected load distance is a sum of both, shoulder and forearm distances.

Normalised total shoulder moment is shown in **Fig. 10**. On average, shoulder moment contributed from the body weight ranges at 10.70 ± 2.67%. Subjects 1, 2, 3 and 5 overlap for at least part of the motion, while subject 4 has the lowest shoulder moment through the whole motion when load is engaged. This acts as a baseline to further evaluate the technique of subject 4 determining benefits of the posture and recommendations for the rest of the test subjects' techniques. An observation has been made that by shifting the grip position lower towards the patient's waist, it is possible to reduce the required shoulder range to execute the motion. Furthermore, this brings the patient's body weight into closer proximity to the lifting individual. This approach, involving relaxing the shoulders and trying to tie the patient to the lifting person closer, can serve as an additional prompt for minimising shoulder strain.

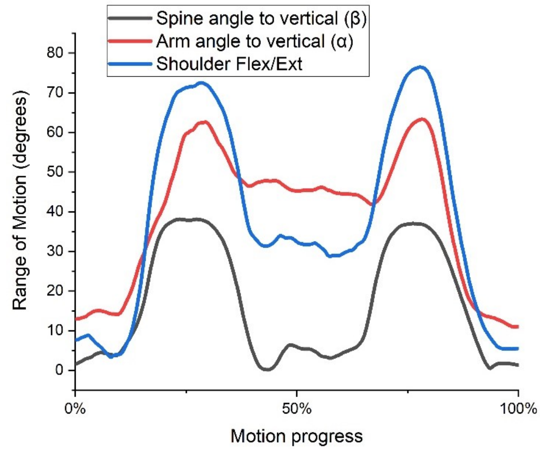

Fig. 8. Test subject 4 ROM components for shoulder moment calculation. ROM, range of motion

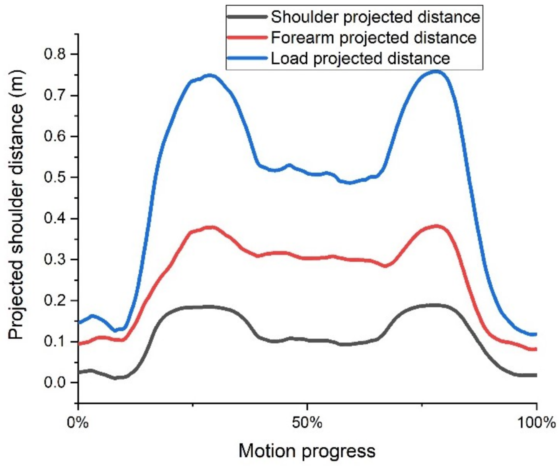

Fig. 9 Test subject 4 projected distance components for shoulder moment calculation. Forearm distance is shown as a component from elbow, instead of shoulder as for other components.

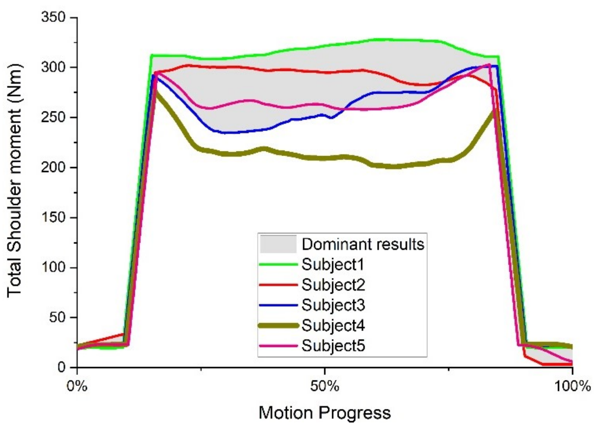

Fig. 10 Time and Body height/weight ratio normalised total shoulder moment data. Grey area covers dominant trend of the results

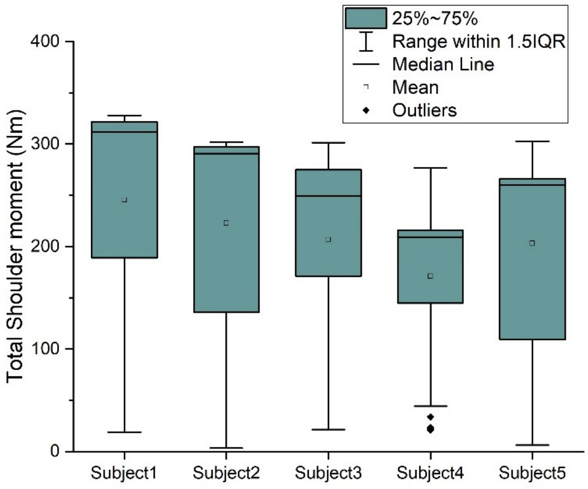

Fig. 11. Box plot of total shoulder moments

The box plot shown in the **Fig. 11** shows that subjects 3 and 4 have least distribution throughout the results. All of the results' mean values are below median and only few outliers observed in the results. Based on this consistency, results can be considered reliable.

Cumulative shoulder moment was calculated as Nm, seconds considered as dt and they are shown in Tab. 4. Mean values of cumulative shoulder load per single repetition range from 791 Nm to 1,475 Nm. The mean value of the cumulative moment is 1,154 Nm with the standard deviation of ±225 Nm. By evaluating each subject's cumulative shoulder moment difference from the mean value, a final assessment of their technique can be observed. Subject 1 has the least effective ergonomics of lift motion with 27.78% above the mean value, while subject 4 has the most efficient ergonomics with cumulative shoulder moment 31.46% below the mean value.

Tab. 4. Cumulative shoulder moment results

Test subject	Mean cumulative load per single repetition (Nm)	Mean Cumulative load per second of repetition (Nm/s)	Mean value (Nm)	Mean difference (%)
Subject 1	1,475 ± 134	151	1,154 ± 225	+27.78
Subject 2	1,103 ± 101	142		–4.46
Subject 3	1,279 ± 97	131		+10.86
Subject 4	791 ± 92	98		–31.46
Subject 5	1,123 ± 112	139		–2.72

In order to estimate the possible long term effects and thus, possible chronic traumas, assumptions for further calculations were made. Assumptions were made together with the ergotherapy specialists and nurses, to have approximated, but representative values:
– Every lift within the trend estimation is taken as a mean value of 5 measurements from the test subject.
– 5 patient lifts per day as calculated in this research is estimated.
– 21 work days per month, 252 work days per year is estimated.

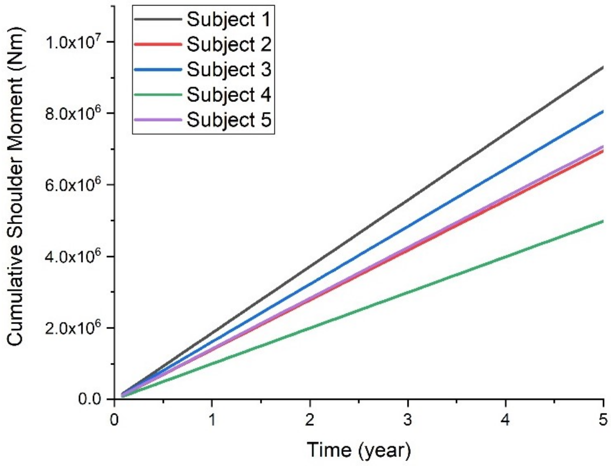

Fig. 12. Cumulative shoulder moment trend during years of repetitive manual labour

The cumulative shoulder moment shown in **Fig. 12** is an estimation of the different technique impacts through the multiple years of work. If we were to compare the lowest and highest shoulder moments, the difference would be 46.37%. By taking the best ergonomics posture with the lowest cumulative shoulder moment as a baseline, we can estimate how many extra lifts are being done with worse techniques within the defined time. By comparing lowest and highest shoulder moment accumulations within 5 years, we are getting 6,300 repetitions versus 11,748 repetitions. That is 1.86 times more strain on the shoulders of what it could have been if best technique within this scope of research had been performed.

4. DISCUSSION

In this study, ergonomics of shoulder movement during patient lift was assessed. The methodology for cumulative load evaluation was presented. In the context of temporal kinematics within the scope of this research, the initial estimate of motion duration revealed an average duration of 9.61 s across all 25 trials, with relatively minimal variance observed between different repetitions. This consistent timing suggests that the lift technique can be performed at a relatively stable pace during patient lift task without extensive experience. Pace can be essential for both, execution of the motion and settings for easier recommendations for improvement and research applications [22]. To project long-term effects of these observed techniques, cumulative shoulder moments over multiple years of work were estimated. The higher the cumulative shoulder moment was calculated, the higher was contribution of own body weight to the sum moment. This can be explained by the general posture and shoulder ROM of the test subjects. During calculation arm, forearm and hand weight impose bigger moment force the bigger amplitudes are. The results demonstrate that utilising the preferred ergonomic posture could potentially reduce shoulder strain drastically over 5 years. That means an even bigger difference in senior healthcare specialists' work experience. This emphasises the significance of promoting and implementing optimal lifting techniques to mitigate the risk of chronic traumas and musculoskeletal disorders among healthcare specialists [23].

Although temporal parameters are analysed, this research focused on spatial parameters. ROM and joint angles were evaluat-

DOI 10.2478/ama-2024-0036

ed, with the addition of hip ROM and further extension of parameters such as spine angle to the vertical. This research was based on well-known ergonomic recommendations, putting effort into analysing constraints and determining what would be the risk factors of analysed movement. The analysis of ROM helps to identify distinct techniques employed by the test subjects during patient lifts. Some of the analysed test subjects exhibited continuous shoulder engagements throughout the entire motion, potentially indicating higher loads on the shoulder area. This could have happened due to reduced opportunities for testing the arms. In contrast, some of the test subjects displayed variation in their technique with discernible peaks corresponding to different phases of the lift. Putting even bigger emphasis not to only analysing motion with quantifiable sizes, but with exact motions and movements that determines those metrics, can improve analysis and prognosis of the ergonomics and whole research. The calculation of shoulder moment considered both time and body weight to height ratio normalisation. Furthermore, it required some additional inputs that were not default export parameters of the data processing software like spine angle to vertical or projected arm angle. In the scope of this research, it has been shown how hip extension is related to the shoulder flexion during lift motion. This implies the importance of understanding whole body motions even when single segment of the body is being targeted for the analysis [24]. Especially, when technique is being analysed to determine the best motion solutions and patterns. Hand joint angles' relations in the mathematical model explain the coherence between different body segments and how one segment load can be increased or decreased by the motion of the other one.

Ergonomic recommendations from recognised standards such as the RULA or ISO 11228-1-2021 emphasise the importance of shoulder flexion in patient lifting tasks. Shoulder flexion >45˚ is identified as risky ROM that might require changes and >90˚ poses a significant risk. From recorded motions, none of the test subjects reached 90˚ ROM, although they were close to the aforementioned boundary – 80˚.

During this research, a few limitations were identified:

- Ergonomic standards that were used to evaluate researched motion define ROMs where the risk of musculoskeletal strain increases. However, during the scope of this research, it was foreseen that limitations given in the RULA or ISO 11228-1-2021 standards are very generalised and simplified, possible in order to have them more applicable. Due to this generalisation, it lacked some biomechanical constraints that might ease the evaluation of risk zones, ROMs, exposure times, etc.
- Although it has its variance, techniques and motions were not analysed very deeply, leaving a gap in understanding what are the specifics that determined one of the other analysed motion ergonomics.
- Additional limitation to the uncertainty and constraint of this calculation was the load engagement profile that was not evaluated in the scope of this research due to the lack of equipment and the additional margin of complexity that this would add. Furthermore, the load that has been used suggests that with the real patient overall kinematics of the motion would change. Since only dummy weights were used for recalculating as it would be part of the patient's body weight, no exact ergonomic recommendations or technique advice could be drawn from the research.
- One additional limitation of conducted research is the assumption that lift motion is static, without taking acceleration into account. Including acceleration in calculation could possibly yield different accumulated load results as the technique might not be only defined by the posture, but by how fast motions should be made. Further evaluation of accelerations of the motion might shed some further light on how the shoulders and whole body react to the given load [25].
- Population of the research is not as large as it could be. 25 trials pose statistical significance for methodological purposes but would require a bigger sample to make more certain conclusions.
- To have a more in-depth understanding of the motion and its long-term effect, more of a body should be taken into account, as it was shown in this research how different body segments can impact load and changes on overall posture.
- The well-known limitation of similar research is biomechanical simplifications. In this study, it was sought to grasp the implications needed to fill the gaps in the calculations and their analysis. This implies the necessity for formulating fundamental or supplementary assumptions upon which further calculations were based on. By formulating assumptions, an estimation of the cumulative load and its cumulation trend could be formed, to better illustrate how ergonomic choices during manual handling tasks translate into disparities of data [26].
- Although models are getting better and mostly kinematics were evaluated for this research, only 17 sensors were used for the recording of body motion. Further simplification assumptions were made during mathematical model and parametric model evaluation. These models, while informative, may not fully capture the individual variations in musculoskeletal structures and neuromuscular control among healthcare specialists. This research is a low-volume evaluation of different body types and technique effects on the same lifting task in the most similar conditions. It was assumed that if the lift conditions are relatively similar between different test subjects, we will see impact on their motion ergonomics allowing us to do make first assumptions that would be later on backed up by a larger volume measurement.
- Shoulder moment calculation does not include body and tendon structures, so the load calculated on shoulders is not directly associated with the tissue that might be at risk of damage [27]. However, these simplifications and assumptions might be critical in order to evaluate a bigger population. Increasing the count of participants or measurements limits the amount of data that can be processed, observed and concluded.

The goal of this research was to deepen the knowledge and methodologies to calculate shoulder moment and understand the strain that occurs during lift motion, although this research has limitations, it is thought that this might still pose some valuable insights and methodologies.

5. RECOMMENDATIONS

It is recommended to broaden the spectrum of this research with increased availability of concerned persons/factors to solve mentioned limitations. To better understand the impact and variance of different techniques, professional healthcare specialists are recommended to participate. This way, the scope of the research will have more practical and experience-based techniques. A bigger population sample is highly recommended, as that might yield better results possibly introducing new and different trends and insights.

From the ergonomics that were observed during this research, it is recommended to invest in lifting techniques if there is no availability of additional equipment. Furthermore, it has been noticed that lowering the grip, to the waist of the patient lowers the shoulder ROM and allows to have patient body weight closer to the lifting person. Releasing the shoulders and trying to drag the patient that is being lifted might work as an additional reminder on how to focus on lowering the strain of the shoulders.

6. CONCLUSION

In conclusion, the results of this study offer valuable insights and techniques into the biomechanics and ergonomics of general analysis of the lift motion, particularly with the healthcare specialists' patient lift technique. The results of the conducted research showed that a relatively small variance in technique can yield a significant cumulative load during the year. In a 5-year span, it was estimated that the difference between the worst techniques in the scope of this research, compared to best, would induce 1.86 times more strain on the shoulders.

Moreover, the implications of these findings extend beyond the immediate scope of the research. They underscore the critical need to broaden methodologies of evaluating more of a critical muscle-skeletal segments. The substantial disparity in cumulative shoulder loads between suboptimal and optimal techniques identifies the possible cause of chronic musculoskeletal disorders. Thus, it is important not to only broaden research but implement evidence-based interventions and training programs to mitigate risks.

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Karolis Senvaitis: https://orcid.org/0009-0003-2703-0517

Kristina Daunoravičienė: https://orcid.org/0000-0003-0898-4860

Aušra Adomavičienė: https://orcid.org/0000-0002-5946-6265