Determining sex-related behavioral differences in manual material lifting and lowering movements during daily life

Mithat Yanıkören [a,*], Sezcan Yılmaz [b], Ömer Gündoğdu [c]

a. *Mechatronics Programme, Department of Electronics and Automation, Vocational School, Bilecik Şeyh Edebali University, Bilecik, Türkiye*

ORCID ID: 0000-0003-1075-313X

b. *Department of Mechanical Engineering, Eskisehir Osmangazi University, Eskisehir, Türkiye*

ORCID ID: 0000-0001-9329-5423

c. *Department of Mechanical Engineering, Atatürk University, Erzurum, Türkiye*

ORCID ID: 0000-0003-2656-4181

* Corresponding author,

Tel: +90 228 214 2418 (M. Yanıkören); +90 222 239 3750 (S. Yılmaz); +90 442 231 4861 (Ö. Gündoğdu)

E-mail addresses: mithat.yanikoren@bilecik.edu.tr (M. Yanıkören); sezcanyilmaz@ogu.edu.tr (S. Yılmaz); omergun@atauni.edu.tr (Ö. Gündoğdu)

Abstract

Individuals who rarely engage in manual lifting and lowering operations in their daily lives (novices) are more likely to be injured by these actions than experts. While there are many studies in the literature on manual material handling in industrial applications, studies evaluating the risks for novice individuals are limited. This study aims to determine the reasons that cause the preference of load-lifting and load-lowering behavior that changes depending on sex-related differences in people who are novices in lifting. In this context, the subjects were asked to perform squatting manual material lifting, stooping manual material lifting, symmetrical manual material lowering, and asymmetric manual material lowering actions. Kinematic calculations were made by the Denavit-Hartenberg method using the 3D human skeleton model. The iterative Newton-Euler method was used to calculate the net reaction moments at the L5/S1 joint, which has the highest risk of injury. As a result, it was observed that females behaved differently from males during the act of manual material lifting but exhibited similar behavior during the act of manual material lowering.

Key words: *Sex-related; Wearable sensors; L5/S1; Manual material handling; Lifting tasks*

1. Introduction

Manual material lifting is one of the daily activities performed by humans. People's lack of knowledge and training in manual material lifting techniques leaves them vulnerable to musculoskeletal disorders. For this reason, musculoskeletal disorders continue to be an important health problem.

Depending on the size of the load and the technique of manual material lifting and lowering the load, the muscle groups that are forced develop over time in experts who constantly carry out manual lifting. Experts, with their training and experience, create a unique lifting behavior in a way that minimizes the moment acting on the musculoskeletal system in the manual material lifting action. It is known that the contractor muscles have a smaller cross-sectional area than experts in people who rarely do manual material lifting and lowering in their daily lives [1,2]. Compared to experts performing manual material lifting, the musculoskeletal systems of novices are both less durable and face much greater force and moment effects due to incorrect lifting behavior [3–7]. This event exposes novices to higher risks for musculoskeletal disorders that may occur due to the lifting actions they perform in their daily activities.

In the evaluation of joint damage risks, it may be necessary to determine the reaction forces and moments acting on the joints. It is not possible to measure the reaction force and moment magnitudes acting on the joints directly on the musculoskeletal system in today's conditions. Net reaction moments can be calculated using data from kinematic measurements over the limbs [8–18]. The effects of net reaction forces on the joint are quite small compared to muscle forces working continuously in the pulling direction. It is very difficult to determine the muscle forces, which are the major components of the joint reaction force. For this reason, the net reaction moment resulting from the mutual operation of the muscles becomes the most important parameter that can be used in comparisons [19]. It is known that L5/S1 is the joint that is exposed to the greatest moment effects on the musculoskeletal system in manual material lifting actions [20–23].

Since the action of manual material lifting in the industry is generally carried out by men, the studies carried out with women remained limited [7,24,25]. It is known that women have 31-39% smaller muscle cross-sectional area than men due to gender-related anatomical differences [24]. Some researchers working on manual material lifting have preferred to adjust the load according to the actual individual capacity of the people in order to control the power difference between the gender [26–29]. In these studies, using relative loads, it is emphasized whether the manual material lifting style depends on the load or other factors. In a study on the effect of gender on different lifting behaviors [24], it was stated that the difference in the lumbar joints when lifting with absolute load was due to kinematic differences as well as body mass. As a result, it has been shown that females adopt a lifting style that uses their hips more, whereas most of the lifting movement in males is from the lumbar spine [30]. In another study [7], it was stated that males and females exhibited equivalent behavior when manual material lifting with relative load was performed.

In daily life, females and males may have to lift loads of the same mass. In such cases, females and males show different muscle development due to their anatomical differences [1]. There is a widespread view that squatting lifting of ground-level loads is much safer in terms of the potential to damage the joints than stooping lifting [31,32]. However, this common view has generally been confirmed in studies using only male subjects. It has been reported in the literature that women generally prefer to lift the load by stoop over in studies [24,33,34] in which the loads at ground level are lifted freely.

In this study, it was aimed to determine the reasons that cause the preference of lifting and lowering behavior that changes depending on sex differences in people who was novice in lifting. In this context, the subjects were asked to perform the task with an absolute weighted load at ground level, in restricted behavior patterns, such as squatting/stooping-lifting and symmetrically/asymmetrically lowering it onto a platform. The behavioral differences between the sexes were evaluated by considering the kinematics and the net reaction moments occurring in the L5/S1 joint.

2. Material and methods

Ethics committee approval for the acquisition of the data used in this study was obtained from the Ataturk University Faculty of Medicine Clinical Research Ethics Committee with the decision dated 02/15/2018 and numbered 44 of the 2nd meeting.

2.1. Participants

Participants were selected from people who did not have any health problems that could prevent weight lifting, such as cardiovascular disease and musculoskeletal system disorder. The male and female subject groups presented in Table 1 are formed in such a way that their ages $p = 0.946$ and body mass index $p = 0.221$ are not significantly different from each other. When the subject groups are evaluated in terms of height $p < 0.001$ and mass $p = 0.002$, they are significantly different from each other. However, as can be seen from Table 1, the female and male subject groups formed in this study represent the general age range of the relevant sociodemographic community [35,36]. In this study, similar to the studies in the literature [1,8,34,37,38], the moments obtained were normalized according to the masses of the subjects in order to make meaningful comparisons between the experimental results of subjects with different heights and masses. At the same time, in this study, thanks to the comparison with linear acceleration, the errors that may occur due to the height difference in addition to the mass are also minimized.

Before starting the experiment, all participants were informed about the experiment in accordance with the Atatürk University ethics committee approval decision and signed a consent form.

2.2. Experimental setup

In order to measure the height and mass of the subjects, Tem Eko brand electronic weight/height scale with 0.1kg precision was used. A 5kg box with handles measuring 47cm (width) x 32cm (depth) x 25cm (height) was used so that the subjects could do manual material lifting comfortably. The height of the platform on which the load taken from the ground will be lowering is determined as 70cm. STT-IWS wearable sensor set of STT Systems was used to obtain data on the change of joint angles while performing manual material lifting and lowering movements of the participants. As described in the user manual and shown in Fig. 1, the 16 IMUs of STT-IWS are located on various parts of the body: feet (2), lower legs (2), upper legs (2), waist (1), hands (2), lower arms (2), upper arms (2), chest (1), thoracic vertebra T3 (1), and head (1).

2.3. Experiment procedure

First of all, the participants were informed about the experiment to be carried out and the equipment to be used. After the information was given, the height and mass values of the subjects were measured. Anthropometric measurements of the subjects were carried out to be used in determining the kinematic dimensions and calculating the mass moment of inertia. These measurements were foot length, foot width, ankle height, lower leg height, lower leg circumference, upper leg height, upper leg circumference, hip height, torso width, torso height, upper arm length, upper arm circumference, lower arm length and elbow circumference.

During the experiments, the participants were asked to perform two different types of lifting (squatting / stooping) and lowering (symmetrical / asymmetrical) movements to analyze the loads on the spine. Squatting is the lifting style in which the ankle, knee and hip joints move simultaneously and the back is kept straight throughout the movement. Stooping manual material lifting is a style of lifting in which the hip joint is mobile, the ankle is in the normal position, and the knee joint is in the open position, and both are motionless. Symmetrical manual material lowering is the act of lowering the load, which is being held with both hands, onto a platform in front of the subject. Asymmetrical manual material lowering action is when the subject lowering the load onto the platform next to her/his by turning her torso without breaking the contact of her feet with the ground. In this context, the subjects have asked to perform these movements in four different combinations.

- Squat lifting - symmetric lowering
- Squat lifting - asymmetric lowering
- Stoop lifting - symmetric lowering
- Stoop lifting - asymmetric lowering

These actions begin with the participants picking up the load from the ground and end with the hands coming to the sides of the body after leaving it on the platform.

During the experiment, the participants were asked to work with a 5kg load. In the manual material lifting task, a metronome was used to enable subjects to begin each procedure step (stooping/squatting, holding the load, lifting and lowering) at the same time. Before starting the experiment, the participants were trained on the experimental procedure. The experiment was carried out by wearing an inertial measurement unit (IMU) set to the subjects who completed the training. During the experiments, the subjects were asked to spread their feet shoulder-width apart and keep them stable on the ground. In order to reduce the accumulated fatigue in the muscles, a rest period was given between work cycles, provided that the subjects' bodies did not cool down. Each work cycle was repeated three times during the experiments. Common actions in work cycles were repeated twice. In this case, each subject repeated each of the squatting lifting, stooping lifting, symmetrical lowering and asymmetrical lowering actions 6 times and produced a total of 24 data sets. During the experiments, a total of 336 data sets were obtained from 14 subjects.

2.4. Data collection and processing

The raw data needed for the calculation of the joint angles were collected at 100 Hz using 16 IMUs positioned on the subject in a certain order. The angular position data of the joints were obtained by processing the collected raw data in the iSenV2020.0 program of the STT System. The forward direction numerical derivative method was used to obtain the angular velocity and angular acceleration values of the joint movements from the angular position data. Angular velocity and angular acceleration values calculated by forward numerical derivative method are very sensitive to small measurement errors in angular position. To reduce this sensitivity, the angular position data was filtered using a low-pass Butterworth filter. The cut-off frequency of the Butterworth filter used is 2.5 Hz and the number of poles is 6.

The model used in this study to estimate the total net reaction moments at the L5/S1 joint was previously described in detail in a study by Yanikören et al. [39] and validated for L5/S1 moments. In this model, for kinematic and dynamic calculations, the skeletal system of the human body consists of 15 rigid limbs (feet, calves, thighs, pelvis, torso, upper arms, forearms, hands, and head) and 14 joints with a total of

38 degrees of freedom (ankles (3 dof), knees (3 dof), hips (3 dof), L5/S1 (3 dof), shoulders (3 dof), elbows (1 dof), wrists (3 dof), and neck (3 dof)) [39]. The Denavit-Hartenberg (DH) method, which provides a systematic approach in multi-limb systems, was used to determine the joint angle relations between the limbs. With the DH method, transformation matrices that define the orientation and translation relations between two limbs connected by a joint were created. An forward kinematic solution has been realized by using rotation matrices and translation vectors, which are the components of the transformation matrix. Thanks to the forward kinematic solution, the center of mass accelerations of each limb was calculated. Net reaction moments on the joints were calculated using the iterative Newton-Euler method.

The components of the total reaction force acting on any joint are net reaction and muscle forces. Since the muscles that work constantly in the pulling direction have small moment arms, they cause much larger force effects on the joints than the net reaction forces. Although it is not possible to calculate the forces of muscles, it is possible to calculate the net reaction moments caused by mutually working muscles. Net reaction moment refers to the magnitude of muscle force needed to perform a movement. In many cases, the net reaction moment is the most important parameter to be verified [19].

Subjects should have approximately the same average height and mass in order to be able to objectively evaluate behavioral difference over net reaction moments. Subjects with a wide range of masses were studied in this work. For this reason, the moment result of each subject is divided by sum of the upper body mass (head, trunk and arms) and the load mass he/she lifts. In this way, the results obtained were made independent of the mass.

It is difficult to make an accurate assessment with the net reaction force acting on the joints, since it does not contain information on muscle strength [19]. In previous studies [40,41], net reaction force/body mass data were used to compare the results obtained. Comparison data is usually obtained by dividing the net reaction forces acting on the L5/S1 joint by the subjects' full body or upper body masses. This comparison data and the motion acceleration of the upper body are interdependent variables. In this case, the acceleration data of the center of mass of the upper body can be used when comparing the actions of the subjects. In this way, it will be possible to work with a more physically meaningful comparison data. In calculating the acceleration, Newton's second law can be applied by considering the components of the upper body as a single object of mass m

$$\sum \vec{F} = m\vec{a} \tag{1}$$

The net force consists of the net reaction force $\vec{F}_{L5/S1}$ $\vec{F}_{L5/S1}$acting on the L5/S1 joint and the weight $m\vec{g}$ resulting from the total mass,

$$\vec{F}_{L5/S1} + m\vec{g} = m\vec{a} \tag{2}$$

In this equation, $\vec{g} = \begin{bmatrix} 0 & -g & 0 \end{bmatrix}^T$ is the gravitational acceleration vector ($g = 9.81$ m/s²). In this case, the acceleration can be calculated,

$$\vec{a} = \frac{\vec{F}_{L5/S1}}{m} + \vec{g} \tag{3}$$

It is known that the upper body mass (head, trunk and arms) in the human body is approximately 50% of the total body mass m_p [42,43]. The maximum net reaction force $\vec{F}_{\max}$ acting on the L5/S1 joint occurs when the center of mass of the upper body, where the inertia force is also maximum, moves with the maximum acceleration $\vec{a}_{\max}$. In load-lifting and load-lowering actions, the lifted load m_L will create an inertia force directly acting on the change of the force acting on the L5/S1 joint. Thus, the total mass causing the inertia effect will be $0.5m_P + m_L$. In this case, the maximum acceleration can be calculated,

$$\vec{a}_{\max} = \frac{\vec{F}_{\max}}{0.5m_P + m_L} + \vec{g} \tag{4}$$

Comparison datasets were created by using the maximum acceleration and moment values of each subject acting on the L5/S1 joint in each action.

2.5. Statistical analysis

When the results obtained for the movements performed by the subject groups in different styles were compared, the t-Test was used to determine whether there was a significant difference between the data sets in terms of the differences between the data set means.

3. Results and discussions

During experiments, it was observed that females and males exhibited noticeably different kinematic behaviors in manual material lifting. To evaluate this behavioral difference, the angular motion-time graphs of the right hip joints of the subjects are given in Fig. 2 and the correlation relationships between them are given in Table 2. During the squatting action, the average flexion/extension angle of females' hip joints can reach up to 110°, while males' remains around 100°. Flexion/extension angle distribution range of males is wider than females. Despite these small differences, it is seen that the correlation coefficients between the manual material lifting behaviors of female and male according to the flexion/extension angles given in Table 2 are all greater than 0.972. In this case, when viewed from the sagittal plane, it can be said that the sexes exhibit very similar behaviors. However, when viewed from the frontal and traverse planes, it has been observed that females tend to keep their knees close together during the squatting motion and try to maintain this position throughout the action. Females' behavior of keeping their knees together during the squatting activity has prevented them from maintaining their balance. It was observed that the males performed a more balanced movement by keeping the distance between their knees during squatting manual material lifting. From Table 2, it is seen that the correlation coefficients of the relationship between the sex related behaviors of squatting actions are 0.317 and 0.714 according to abducation/adducation and rotation angles. In this case, when viewed from the frontal and transverse planes, it can be said that there is a significant difference between male and female behaviors during the squatting action. Table 2 shows that the correlation coefficients of the relationship between the sex- related behaviors of stooping actions are 0.978 and 0.797 for Abduction/Adduction and Rotation angles. In this case, it can be said that there is no significant difference in the behaviors of females and males during the stooping action when viewed from the frontal plane and there is a significant difference when viewed from the transverse planes.

The net reaction forces on the joints are not suitable for meaningful comparison of different behaviors [19]. When comparing different lifting and lowering styles, the acceleration of the upper body center of mass, which is a value directly related to these forces, can be used instead of the force values acting on the L5/S1 joint. In Fig. 3, the maximum acceleration values of the upper body center of mass were obtained using Equation (4).

The net reaction moments on the joints are suitable for meaningful comparison of different behaviors [19]. However, in order to compare the net reaction moments affecting the L5/S1 joint between different lifting and lowering styles, the subjects' masses should have a narrow range of variation. In this study, the masses of the subjects comprised of novices have a wide range of distribution. Therefore, in Fig. 4, the net reaction moments acting on the L5/S1 joints of the subjects are given by dividing them by the sum of their upper body masses and the weight of the load they lifted, for an objective comparison [2].

The movement of lifting a load by stooping over is only dependent on the hip joint. However, in the action of lifting a load by squatting, the knee and ankle joints also contribute to the movement in addition to the hip joint. As seen in Fig. 3, this situation causes a much larger linear acceleration of the center of mass compared to lifting the load by stooping over during the lifting action. Some studies in the literature [44,45] have reported that the lifting speed and therefore the acceleration during squat lifting is higher than during stoop lifting. As can be seen in Fig. 3, when the load lifting actions are analyzed in terms of acceleration values, it is seen that the greatest acceleration occurs during the squatting lifting action of females. In this context, Table 3 shows that there is a significant difference between the squatting lifting actions of females and males (FSQ-MSQ) with $p = 0.002$, and the squatting and stooping actions of females (FSQ-FST) with $p < 0.001$ in terms of acceleration.

In symmetrical manual material lifting and lowering, the body of subjects is expected to remain symmetrical with respect to the sagittal plane throughout the movement. For this reason, no moment is expected in the abduction/adduction and rotation axes, except for the asymmetrical lowering action. However, when the graphics given in Fig. 4 are examined, it can be seen that the moments on the abduction/adduction and rotation axes affecting the L5/S1 joint are different from zero. This situation occurs as a result of the center of mass of the subjects and/or the lifted load moving out of the sagittal plane during the lifting and lowering of the load, that is, the symmetry is disturbed. In a balanced load lifting or lowering action, the deviations of the centers of mass from the lateral plane are expected to be at a minimum level. However, the moments of the L5/S1 joint in different axes (Flexion/Extension, Abduction/Adduction, and Rotation) are expected to show a proportional distribution. However, as can be seen from the results obtained for the stooping-lifting action in Fig. 4, the opposite situation occurred in the abduction/adduction axes, although the males were exposed to greater moments in the flexion/extension axes than the females.

In a study [7] conducted with an experimental group consisting of expert female and male subjects and novice male subjects, the maximum lifting forces that the subjects could apply during the lifting action were measured. As a result of this measurement, it was seen that males can apply much larger lifting forces than females during lifting due to their anatomical differences. In our study, all subjects were asked to lift a load of the same size. The ratio of this load to the maximum load the subjects can lift is much larger for female subjects. Despite this, novice female subjects move with a higher acceleration in squat lifting than male subjects as shown in Figs. 3 and 4, causing much larger reaction moments in the L5/S1 joints. As seen in Table 3, there is a significant difference between FSQ-MSQ with $p = 0.002$ for acceleration and $p < 0.001$ for normalized moments of flexion/extension direction. This is thought to be due to the fact that novice female subjects, who have less muscle mass than male subjects, try to move with an even higher acceleration in order to reach the upright position in a much shorter time to get rid of the strain caused by the lifting action.

During the squatting action, the male subjects performed a comfortable lifting movement with their legs spread to the sides, knees apart and had no difficulty in keeping their body in an upright position. On the other hand, since most of the female participants kept their knees in a very close or even adjacent position while squatting, they had difficulty in maintaining the upright position of their torso while holding and lifting the load, and thus they exhibited a hunched posture during load lifting. This difference in behavior between male and female caused male to hold the load close to the center of mass during lifting and female to hold the load away from the center of mass. As a result, as can be seen in Fig. 4, the moment values affecting the L5/S1 joint of the female subjects in the squatting manual material lifting action were significantly greater than those of the male subjects. As seen in Table 3, there is a significant difference between FSQ-MSQ in terms of normalized moments of flexion/extension direction, which is the largest component of the total moment, $p < 0.001$. This situation is thought to show that in the act of lifting a load by squatting, females not only had difficulty due to the size of the load they lifted, but also exhibited a lifting behavior that would disrupt their balance.

As seen in Table 3, there is no significant difference in the stooping manual material lifting action (FST-MST), especially $p = 0.183$ for acceleration and $p = 0.805$ for moments normalized in flexion/extension direction.

During the load-lowering actions, the joint movements of the subjects are very limited and the subjects cannot predict exactly when the load will contact the platform. Due to these situations, the subjects move with a much lower linear velocity and acceleration in load lowering actions than in lifting actions. When the load-lowering actions given in Fig. 3 are examined, although the accelerations of females have a wider distribution range than that of males, there is no obvious difference ($p > 0.286$) as seen in Table 4.

It was observed that the subjects used the ankles and hip joints instead of using the L5/S1 joint while rotating their trunks in the direction of rotation during the asymmetrical load lowering action. For this reason, there is no significant difference in L5/S1 joint rotation direction moments in asymmetric load release compared to symmetric load release, except $p = 0.024$ between FSM-FASM as seen in Table 4. At the same time, as seen in Table 4, there is no significant difference between sexes in terms of abduction/adduction axis moments in symmetrical $p = 0.393$ and asymmetrical $p = 0.725$ load-lowering actions. However, there is a significant difference $p < 0.001$ between symmetrical and asymmetrical load-lowering actions in terms of abduction/adduction axis moments of individuals of the same sexes.

In a study where expert male and female participants lifted a weight from one pallet and moved it to another for storage [34], the participants were asked to perform the lifting and storing actions in a manner they were accustomed to. In the related study [34], normalized maximum moment data obtained by dividing the maximum moments acting on the L5/S1 joints of the subjects by the static moment created by the effect of upper body weight were used for comparison. The results of the reference study and our study are compared over the normalized moment values in Table 5 and Table 6. It is seen that there is no significant difference between the results obtained by the comparison. In particular, it is seen that the results obtained for the novice subjects in this study are much more compatible with the results obtained for the expert subjects in the reference study. The reason for this is thought to be due to the fact that the subjects in this study were lifting loads of 5 kg, while in the reference study the subjects were lifting loads of 15 kg. In the reference study, it was observed that female subjects mostly used back and hip joint movements in a synchronized way in the action of lifting loads at ground level, while male subjects used more back, hip and knee joint movements in a synchronized way. Considering the joint coordination of the expert subjects in the related study [34], it is seen that females exhibit behaviors similar to lifting loads by stooping more, whereas males exhibit similar behaviors to lifting loads by squatting more.

In previous studies on the effects of strain on the L5/S1 joint caused by load-lifting actions, there is a widely held belief that squatting is safer than stooping [31,32]. This common view emerged when studies strictly practiced a certain squat-lift behavior, in which studies often used male subjects. However, in studies in the literature, including freestyle lifting of ground-level loads by female subjects [2,24,33], female subjects' back and hip joints during the lifting action were compared to other joints. It has been reported that they use it more dominantly, that is, they exhibit a behavior similar to bending over. In our study, novice female subjects were asked to perform a load-lifting action by both stooping and squatting. As can be understood from the results obtained, female subjects had more difficulty lifting loads by squatting than by stooping over due to their acquired habits. As a result, contrary to the common view, it can be said that females are more inclined to lift loads by stooping over, while males are more likely to lift loads by squatting.

It would be appropriate to state that there are some limitations in this study conducted. Firstly, the study did not consider the effects of fatigue on manual material lifting kinematics. Although the subjects were sufficiently rested between the task cycles, there is a potential for fatigue effects, albeit partially, since there is a priority-posteriority relationship in the actions performed. In order to minimize the effects of this potential, each iteration of the work cycles was performed after the complete work cycles had been performed once. In addition, in order to minimize the fatigue effects of the two groups, the work cycles were performed in the same order for all subjects. The effects of fatigue-induced kinematic changes on manual material lifting and lowering will be important for future research. Secondly, the use of 16 wearable IMUs during the experiments is important for accurate measurement and accurate kinematic calculation. However, the use of a large number of wearable sensors may cause a slight restriction of the natural movements of the person performing manual material lifting and lowering. Thirdly, the load lifted in this study was not normalized to the strength of each subject. But in natural everyday life, individuals can scale the load according to their own power capacity. It is not possible to know whether the act of manual material lifting of the imposed weight is too stressful for females. However, the female subjects did not have much difficulty finishing the task and their physical fatigue was equivalent to that of the male subjects after both lifting and lowering tasks. In future research, different weights of loads can be used to investigate the effect of lifted load on sexes behavior. Fourthly, although the subjects in this study were selected from non-professional participants, they may have partially differed among themselves in terms of lifetime past manual material lifting and lowering experience. As a result, it can be said that the effects of these restrictions on sexes groups are identical, so their effects on differences between sexes groups are limited.

4. Conclusions

In this study, in which the sex differences related conditions of the strains occurring in the L5/S1 joint during manual material lifting and lowering to a certain platform were investigated, significant behavioral differences were observed depending on sex differences, especially in lifting loads at ground level. During experiments conducted with novice subjects, it has been observed that males tend to spread their legs apart while squatting, whereas females tend to keep their knees close or even together. In this case, when the males squatted to lift the loads at ground level, they were able to bring the load very close to their bodies, but the females had to keep the load away from their bodies. As a result, the additional moment caused by the lifted load caused females to have much more strain because the moment arm was higher in females than in males. In studies with female subjects consisting of experts from previous studies and novices from this study, it was determined that females were prone to lifting loads by stooping over. Expert and novice males were found to be more prone to squatting lifts. It has been observed that males and females exhibit similar behaviors in the actions of lowering a load on a high platform. Experimental data on lowering the load to ground level were not collected in this study. It is foreseen that if the load is left to the ground level, similar results can be obtained to the action of lifting it from the ground level. It is planned to evaluate this issue in future studies.

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CRediT authorship contribution statement

Mithat Yanıkören: Conceptualization, Methodology, Software Writing – review & editing, Validation.
Sezcan Yılmaz: Methodology, Software, Writing – review & editing, Validation, Supervision.
Ömer Gündoğdu: Methodology, Supervision.

Declarations

Conflict of interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Biographies

Mithat Yanıkören is a Lecturer at Bilecik Seyh Edebali University, Bilecik, Turkey since 2019. He received his Ph.D (2021) degree in Mechanical Engineering from Atatürk University, Erzurum, Turkey. His research interests include biomechanics, robotics, and vibration analysis

Sezcan Yılmaz is an Assistant Professor at Eskisehir Osmangazi University in Eskişehir, Turkey. He received his PhD (2014) from the Mechanical Engineering Department at Eskisehir Osmangazi University. His research interests include robotics, biomechanics, vibration analysis and haptics

Ömer Gündoğdu is a Professor, Department of Mechanical Engineering, Ataturk University, Turkey. He received his Ph.D. degree from Rensselaer Polytechnic Institute in USA in 2000. His research interests include structural vibration and biomechanics

Figure Captions

Figure 1. The experimental setup.

Figure 2. The variation of hip joint movements of subjects in Flexion/Extension (FE), Abduction/Adduction (AA), and Rotation (Rot.) directions during squatting and stooping load lifting. The solid line represents the mean motion curve of the subject group and the gray area represents a region of standard deviation. (FSQ: Female Squat Lifting, MSQ: Male Squat Lifting, FST: Female Stoop Lifting, MST: Male Stoop Lifting)

Figure 3. Maximum acceleration values of the upper body center of mass of the subjects in different lifting and lowering styles. (FSQ: Female Squat Lifting, MSQ: Male Squat Lifting, FST: Female Stoop Lifting, MST: Male Stoop Lifting, FSM: Female Symmetric Lowering, MSM: Male Symmetric Lowering, FASM: Female Asymmetric Lowering, MASM: Male Asymmetric Lowering)

Figure 4. Maximum net reaction moment/mass values acting on L5/S1 joint of subjects in different lifting and lowering styles (FSQ: Female Squat Lifting, MSQ: Male Squat Lifting, FST: Female Stoop Lifting, MST: Male Stoop Lifting, FSM: Female Symmetric Lowering, MSM: Male Symmetric Lowering, FASM: Female Asymmetric Lowering, MASM: Male Asymmetric Lowering).

Table Captions

Table 1. Characteristics of participants.

Table 2. Correlations of hip joint movements of subjects during squatting and lifting loads by stooping

Table 3. Comparison of sex behavior difference combinations for load-lifting behavior.

Table 4. Comparison of sex differences in load-lowering behavior combinations.

Table 5. Comparison of the results of the normalized maximum net reaction moment acting on the L5/S1 joint in load-lifting behavior with the results of the reference study.

Table 6. Comparison of the results of the normalized maximum net reaction moment acting on the L5/S1 joint in load lowering behavior with the results of the reference study.

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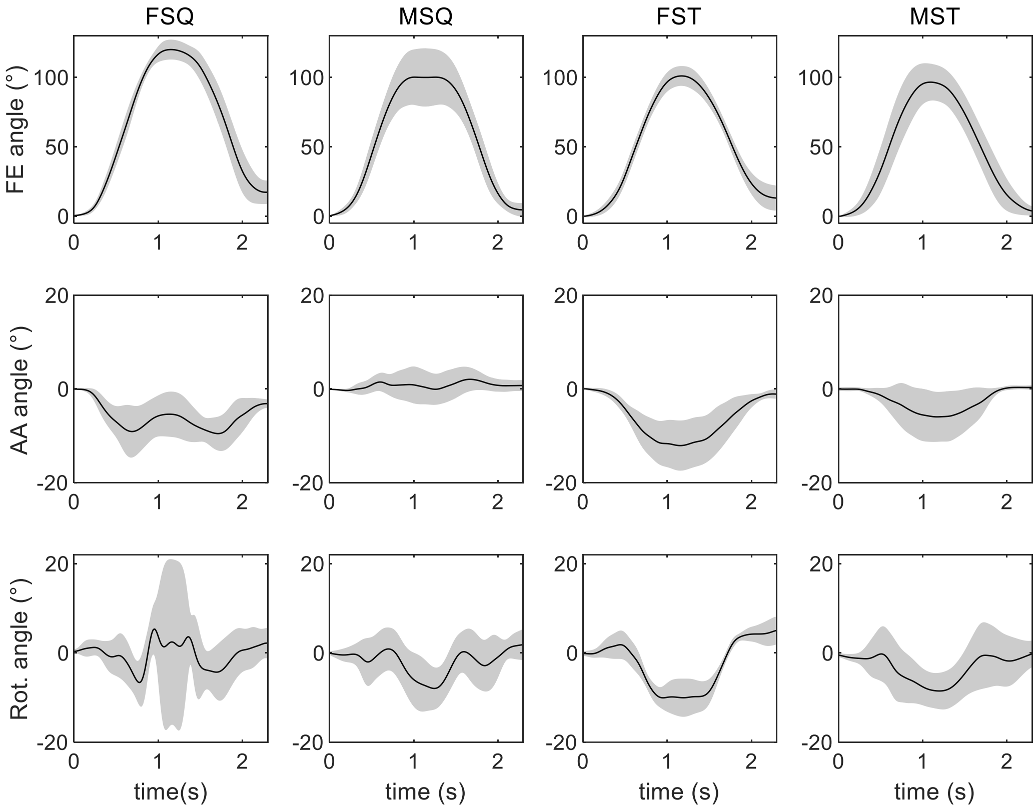

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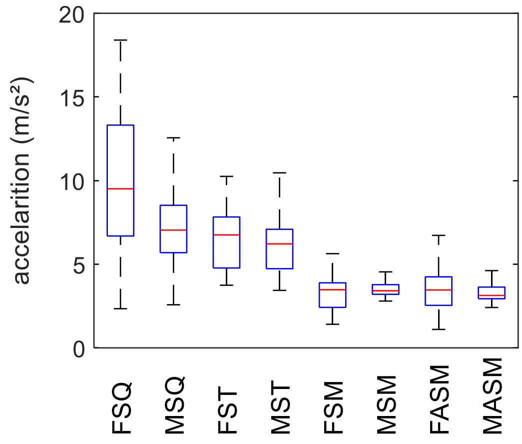

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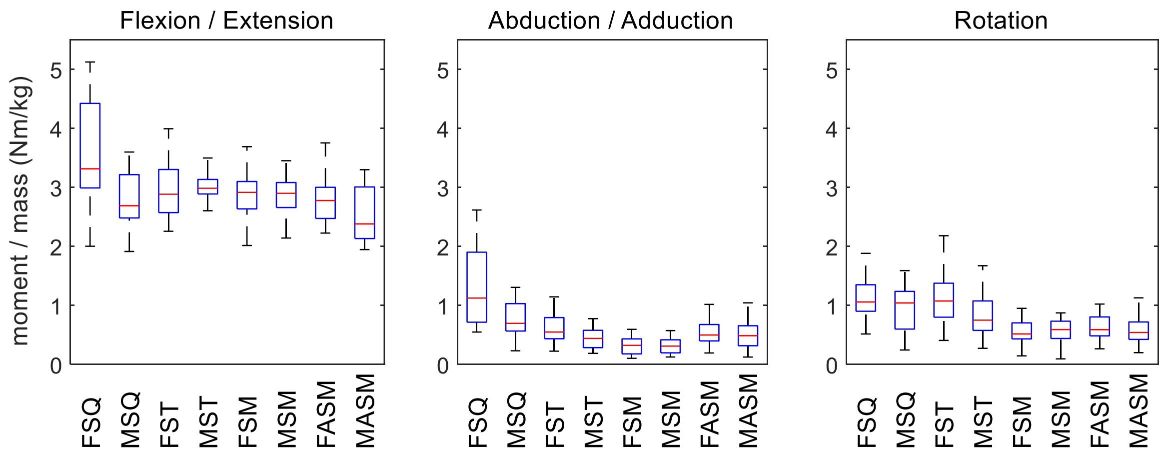

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Table 1. Characteristics of participants.

		This study			Reference study [35]			Reference study [36]		
		M	SD	p*	M	SD	p**	M	SD	p**
Participants	f	7	-	-	163	-	-	399	-	-
	m	7	-		390	-	-	399	-	-
Age (year)	f	25.4	5.6	0.946	18 - 29	-	-	24.6	8.7	0.809
	m	25.6	5.2		18 - 29	-	-	24.6	8.7	0.762
Height (cm)	f	160.4	5.8	**<0.001**	162.0	7.0	0.552	162.3	6.4	0.436
	m	179.5	6.7		176.1	6.3	0.158	176.6	6.5	0.243
Mass (kg)	f	57.0	12.9	**0.002**	59.3	9.8	0.549	59.0	10.0	0.602
	m	81.7	10.6		77.5	10.6	0.299	72.6	10.6	0.080
BMI (kg/m²)	f	22.0	3.9	0.221	22.9	3.6	0.519	22.4	-	-
	m	24.4	3.0		25.0	3.0	0.600	23.3	-	-

M: Mean, SD: Standard deviation, p: Probability using a bilateral t-Test, f: Female; m: Male; BMI: Body mass index

*: Probability between male and female in this study, **: Probability between this study and reference study.

Bold values are significantly different at $p < 0.05$

Table 2. Correlations of hip joint movements of subjects during squatting and lifting loads by stooping

	Flexion/Extension				**Abduction/Adduction**				**Rotation**			
	FSQ	**MSQ**	**FST**	**MST**	**FSQ**	**MSQ**	**FST**	**MST**	**FSQ**	**MSQ**	**FST**	**MST**
FSQ	1	0.988	0.998	0.987	1	0.317	0.730	0.607	1	0.714	0.598	0.767
MSQ	0.988	1	0.980	0.972	0.317	1	0.816	0.880	0.714	1	0.701	0.808
FST	0.998	0.980	1	0.986	0.730	0.816	1	0.978	0.598	0.701	1	0.797
MST	0.987	0.972	0.986	1	0.607	0.880	0.978	1	0.767	0.808	0.797	1

FSQ: Female Squat Lifting, MSQ: Male Squat Lifting, FST: Female Stoop Lifting, MST: Male Stoop Lifting

Table 3. Comparison of sex behavior difference combinations for load-lifting behavior.

	Acceleration (m/s^2)			Moment/Mass (Nm/kg)								
				Flexion/Extension			Abduction/Adduction			Rotation		
	M	SD	p	M	SD	p	M	SD	p	M	SD	p
FSQ	10.13	4.31	**0.002**	3.56	0.86	**<0.001**	1.30	0.62	0.092	1.20	0.46	0.086
MSQ	7.50	3.15		2.81	0.46		1.02	0.89		1.01	0.53	
FST	6.69	1.91	0.183	2.98	0.50	0.805	0.61	0.23	0.516	1.13	0.44	**<0.001**
MST	6.15	1.77		3.00	0.27		0.56	0.41		0.83	0.36	
FSQ	10.13	4.31	**<0.001**	3.56	0.86	**<0.001**	1.30	0.62	**<0.001**	1.20	0.46	0.501
FST	6.69	1.91		2.98	0.50		0.61	0.23		1.13	0.44	
MSQ	7.50	3.15	**0.018**	2.81	0.46	**0.021**	1.02	0.89	**0.003**	1.01	0.53	0.077
MST	6.15	1.77		3.00	0.27		0.56	0.41		0.83	0.36	
FSQ	10.13	4.31	**<0.001**	3.56	0.86	**<0.001**	1.30	0.62	**<0.001**	1.20	0.46	**<0.001**
MST	6.15	1.77		3.00	0.27		0.56	0.41		0.83	0.36	
FST	6.69	1.91	0.158	2.98	0.50	0.103	0.61	0.23	**0.005**	1.13	0.44	0.259
MSQ	7.50	3.15		2.81	0.46		1.02	0.89		1.01	0.53	

FSQ: Female Squat Lifting, MSQ: Male Squat Lifting, FST: Female Stoop Lifting, MST: Male Stoop Lifting
M: Mean; SD: Standard deviation; p: Probability using a bilateral t-Test
Bold values are significantly different at $p < 0.05$

Table 4. Comparison of sex differences in load-lowering behavior combinations.

	Acceleration (m/s^2)			Moment/Mass (Nm/kg)								
				Flexion/Extension			Abduction/Adduction			Rotation		
	M	SD	p	M	SD	p	M	SD	p	M	SD	p
FSM	3.53	1.35	0.980	2.92	0.46	0.298	0.32	0.14	0.393	0.55	0.19	0.192
MSM	3.53	0.53		2.83	0.35		0.35	0.23		0.70	0.71	
FASM	3.62	1.47	0.342	2.81	0.44	**0.005**	0.55	0.20	0.725	0.65	0.24	0.127
MASM	3.38	0.70		2.53	0.44		0.57	0.35		0.58	0.22	
FSM	3.53	1.35	0.771	2.92	0.46	0.247	0.32	0.14	**<0.001**	0.55	0.19	**0.024**
FASM	3.62	1.47		2.81	0.44		0.55	0.20		0.65	0.24	
MSM	3.53	0.53	0.286	2.83	0.35	**<0.001**	0.35	0.23	**<0.001**	0.70	0.71	0.305
MASM	3.38	0.70		2.53	0.44		0.57	0.35		0.58	0.22	
FSM	3.53	1.35	0.523	2.92	0.46	**<0.001**	0.32	0.14	**<0.001**	0.55	0.19	0.486
MASM	3.38	0.70		2.53	0.44		0.57	0.35		0.58	0.22	
FASM	3.62	1.47	0.693	2.81	0.44	0.809	0.55	0.20	**<0.001**	0.65	0.24	0.719
MSM	3.53	0.53		2.83	0.35		0.35	0.23		0.70	0.71	

FSM: Female Symmetric Lowering, MSM: Male Symmetric Lowering,
FASM: Female Asymmetric Lowering, MASM: Male Asymmetric Lowering
M: Mean; SD: Standard deviation; p: Probability using a bilateral t-Test.
Bold values are significantly different at $p < 0.05$

Table 5. Comparison of the results of the normalized maximum net reaction moment acting on the L5/S1 joint in load-lifting behavior with the results of the reference study.

			Lifting in reference study [2]					
			Experts		**Novices**		**Females**	
	This study		**M**	**SD**	**M**	**SD**	**M**	**SD**
	M	**SD**	1.77	0.68	1.94	0.63	1.91	0.57
FSQ	2.03	0.44	p = 0.297		p = 0.704		p = 0.597	
MSQ	1.76	0.32	p = 0.963		p = 0.385		p = 0.441	
FST	1.68	0.19	p = 0.641		p = 0.161		p = 0.176	
MST	1.63	0.18	p = 0.467		p = 0.096		p = 0.101	

FSQ: Female Squat Lifting, MSQ: Male Squat Lifting, FST: Female Stoop Lifting, MST: Male Stoop
M: Mean; SD: Standard deviation; p: Probability using a bilateral t-Test.

Table 6. Comparison of the results of the normalized maximum net reaction moment acting on the L5/S1 joint in load lowering behavior with the results of the reference study.

			Lowering in reference study [2]					
			Experts		**Novices**		**Females**	
	This study		**M**	**SD**	**M**	**SD**	**M**	**SD**
	M	**SD**	1.4	0.61	1.57	0.63	1.61	0.58
FSM	1.36	0.14	p = 0.813		p = 0.237		p = 0.134	
MSM	1.36	0.05	p = 0.805		p = 0.220		p = 0.119	
FASM	1.37	0.15	p = 0.860		p = 0.262		p = 0.152	
MASM	1.34	0.07	p = 0.713		p = 0.184		p = 0.096	

FSM: Female Symmetric Lowering, MSM: Male Symmetric Lowering,
FASM: Female Asymmetric Lowering, MASM: Male Asymmetric Lowering
M: Mean; SD: Standard deviation; p: Probability using a bilateral t-Test.