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THE ANALYSIS OF STAND-UP ACTIVITY

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Abstract: *Many elderly people have a problem with getting up from the chair, therefore they use the arm support. Not everyone has a strong arm muscles to support its own weight, and not all chairs have a support for arm, then these people become dependent on the help. The market offers support developed for a generic person, and the mobile supports are very rare to find. This work aims to improve the support, which requires description of the biomechanics of motion, analysis of Sit-To-Stand movement, and obtaining the muscular activity data during the getting up. These data are necessary for design of the supporting mobile cushion, that will be suitable for almost any type of the furniture for sitting on. The major idea is based on the personalising the force that will support the start of the body movement, and prepare the body position for the next movement that will ease continuation of the movement, and safely supports the user in the movement. Created prototype was used to obtain the data during the getting up from the chair without and with support. Data were analyzed, and the additional force was calibrated to providing the personalised support for any users' weight.*

Keywords: Biomechanics, Sit-To-Stand, Muscular activity, Assistance support.

1. Introduction

Getting up from sitting is an essential part of everyone's daily activities. Some individuals may experience difficulties while getting up from the chair. That might happened due to lack of muscle strength, which can later on lead to mobility impairment. This situation may be temporary, mainly in the younger generation, or permanent for the elderly. The inability to get up from the chair limits the person's mobility, therefore even the daily activities, and the person becomes dependent on help. This situation usually leads to a loss of mobility in a relatively short time, mainly in the elderly due to muscle atrophy. Market offers variety of different supports that can be characterised as a portable, and fixed supports. The immobile supports are represented by the 'grab bars', 'riser recliner chair', 'sit-to-stand patient lift', while the mobile supports include the lifting cushion, and chair raisers. Both, last mentioned items are practical but both have some disadvantage. The chair risers are easily transported and attached to the chair's leg, but they don't fit to all leg profiles. The lifting cushion is an ideal helper for anybody, it is easily transferred, and fits to all seating furniture. The only disadvantage of it, is a lack of power adjustment according to a person's mass, as the universal power assumes an average user, to whom it was designed. The cushion's power to rise the person might be too strong for slim persons or not sufficient for the overweight ones. Considering that the person using the mobile cushion support is able to walk independently, the initiating power has to be calibrated to provide an initial impulse at the first phase of a getting up, and then the user utilises actively his muscular power in progressing to the second stage, and a final standing position. In case of the elderly, the calibration allows to set a gentle initiating force to raise the seat, and continue with the support by a controlled motion of the seat, to ensure the person's stability, and as well his muscular activity, which helps to keep muscles toned. The calibration of a system that generates the raising force is discussed in this paper.

2. Methods

Prior to calibration of the initiating force, which helps a person to get up was required to do the analysis of the sit-to-stand (STS) motion, an identification of the major muscles involved in STS, to collect data of trajectories related to the STS stages, and recording of the muscular activity during the activity. It was

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necessary to create a model that can simulate an idealised complex motion of four segments consisting of the upper torso, thigh, calf, and foot. The mass of each segment was calculated using the anthropometric data, similarly as a position of the centre of gravity. It is assumed that the resultant force is passing through the centre of gravity of the model system, which was identified accordingly, based on the recorded movement.

2.1. Biomechanics of the sit-to-stand activity

Movement, sit-to-stand (STS), is a dynamical activity that requires from the muscles to generate a power that overcomes a person's gravitational force. The transition during STS is naturally split into four phases. The first phase of STS starts with the upper-body flexion motion forward, and anterior rotation of the pelvis, that induce the upper-body momentum. This stage ends just before of lifting the buttock from the seat, while the lower limbs remain stationary. Then the movement continues to the second phase during which the head acquires an extended position upwards, in the direction of motion. The end of this phase is marked by the maximum dorsiflexion position of the ankle. At this position the transfer of momentum from the upper torso to the full body occurs, the centre of gravity exceeds the base of support, to be prepared for the upward, anterior motion. During the third stage the extension of the angle between pelvis and thigh is increasing, hip begins a small rotation between flexion and extension while stabilization is being achieved. The fourth phase is finalized as soon as the both knees are fully extended, the hip-extension velocity reaches zero, and the body is stabilized.

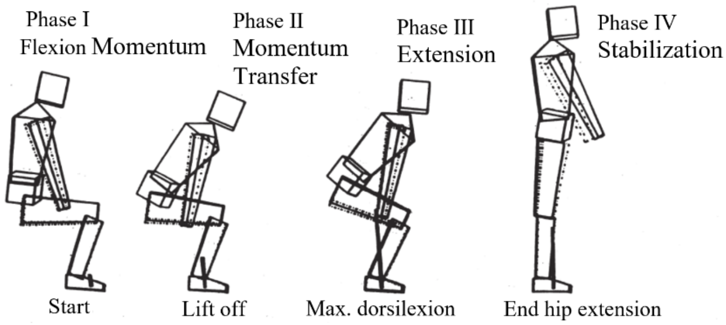

Fig. 1: Phases of sit-to-stand movement (Schenkman,1990)

2.2 Recording activity during the motion

The concentration was on the muscles contributing to the STS movement at the respective joints. Each joint is controlled by the large number of muscles but not all of them contribute to power the major movement at the joints. The muscular activity data was acquired by testing of subjects, to record the actual readings of motion trajectories of all phases, and their relevant muscle activity. The motion caption was recorded by a VICON system using eigth fast infrared cameras that recorded positions of the retro-reflective markers. Activity of muscles was documented using the electromyography (EMG). The sensor is either a needle or a surface electrodes (sEMG) to measure an electrical activity of the muscle in response to a nerve's stimulation. The later mentioned system is limited to surface muscles, without the underlaying muscles, to avoid the cross-talk.

Fig. 2: CONFORMat on the seat, MatScan on the plate to measure forces at body contacts

Further to the recording of trajectories, the voltage potential of the muscle, the forces at the seating and standing position were recorded during the STS activity, using CONFORMat Tekscan on the seat, and MatScan Tekscan placed under the feet of the subject, since it is designed for higher forces acting on the plate. Next step was the selection of measurable muscles. Different groups of muscles are recruited at different stages of the motion, therefore only the large measurable muscles with major influence on the movement, were monitored by the sEMG. These muscles were:

- Erector Spinae (ES) extends and laterally flexes trunk and neck at the spinal joints, anteriorly tilts the pelvis and extends the lower spine
- Gluteus Maximus extends, adducts, abducts, and laterally rotates the hip

- Quadriceps Femoris consists of four individual muscles; rectus femoris, vastus medialis, vastus lateralis, and vastus intermedius. Their function is to extend the leg at the knee joint, and flex the thigh at the hip. Out of these muscles only Vastus Medialis and Vastus lateralis are measurable.
- Hamstrings are formed by Biceps Femoris, Semitendinosus, and Semimembranosus muscles sharing the same origin, and attach at the posterior knee. The Biceps Femoris is a measurable muscle, with ability to flex and laterally rotated the flexed knee.
- Gastrocnemius muscles consists of two heads, both crosses the knee and the ankle, and perform plantarflexion motion of the ankle, and also flexing the knee.

2.3 Postprocessing of the measured data

The VICON system, set to recording frequency of 1000 Hz, was used to record geometrical data (x, y, z) provided by all reflective marks, to describe the trajectories. These geometric data described the segments positions, their angles, and the kinematics of the segments (the linear and angular velocities and acceleration). The raw sEMG signal in millivolts (mV), recorded with frequency of 1000 Hz, was filtered by a high pass filter with a zero-lag 4th Butterworth (30 Hz), then rectified, and passed at the low pass filter of 2-10 Hz. The potential of the measurable muscles mentioned above, recorded during the STS activity had to be converted into the force in Newton units. For this purpose the specific exercises were performed as shown in Fig.3, where a) shows the extension of the trunk, b) extension of the hip, c) knee at 900 is flexed further, d) extension of the knee, e) knees straight in a half-lying position with hips flexed at 120 degrees, and the knee initially flexed by 150. The infogram shows the movement direction by the arrow, with respect to the fixed dynamo, indicated as a brown dot, connected to the point on the moving body. The muscular forces were recorded using a dynamometer, Mark-10, Series 5, recording forces at frequency of 50Hz. The processed sEMG signal had to be synchronised with the force data, and then the both types of data were normalized, and plotted to obtain the polynomial equation, in our case of the third order.

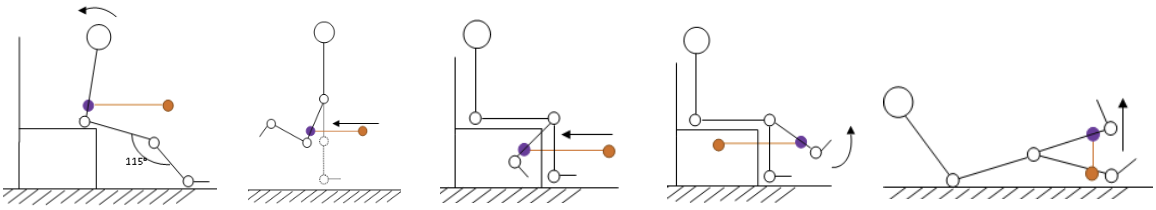

Fig. 3:Infographic exercise of a) erectus spinae, b) gluteus maximus, c) biceps femoris, d) vastus lateralis, e) vastus medialis

$$\frac{EMG}{EMG_{max}} = k_1 + k_2 \frac{F}{F_{max}} + k_3 \frac{F^2}{F_{max}} + k_4 \frac{F^3}{F_{max}} \,. \quad (1)$$

Using the polynomial equation, the sEMG millivolts were converted to muscular forces in Newtons.
Except of the collection of muscular, and kinematics data, the additional forces, provided during the STS motion, were shown on the CONFORMat, and MatScan. The first mentioned mat monitored the distribution of the upper torso mass on the seat, and the transfer of the load between the upper body and surface of chair during the STS movement. MatScan was monitoring the contact areas, and transfer of the load from the second stage of the movement till the final phase. Experiments were carried for different heights of the seat, therefore the hip angles varied in the scenarios. Both mats had to be calibrated to find the correlation between signal values in form of the colour, and force values, that lead to the equation:

$$y = -0.3944\, x^2 + 12.731\, x \,. \quad (2)$$

Thus, any mass value *x* applied to one mat's cell would create a signal *y*. Upon the test of calibration validity, it was confirmed that these mats are not suitable for laboratory research work. Thus their use was reduced to identification of the end of the phase I and phase IV.

3. Results

The experiment was done using chairs of a variable height, that influenced the initial position of a seated subject. The recorded data replicates the motion, sEMGs registered the potential voltage of the muscles, and mats mapped the center of pressure between the contact areas, therefore each data set was analyzed on its own.

Motion analyses

All stages and scenarios were analyzed using Mokka software that was reading the data recorded in the .C3D format. The three graphs in Fig. 4 are providing the position of the chest marker in the x, y, z direction. The shaded column on the left side of all graphs shows the initial position of the chest marker, which outlined the trajectory of the chest, during the motion. The flexion of the upper torso follows the chests' point trajectory, thus starts the process of STS and each stage is shown by the line. At the first phase (PI) the marker of the chest reaches the lowest position of 30% (a) of the STS, between the interval of 30-50% (b) of the PII the transfer of momentum is located. The lines (c), and (d) are marking the PIII, and final phase of the STS.

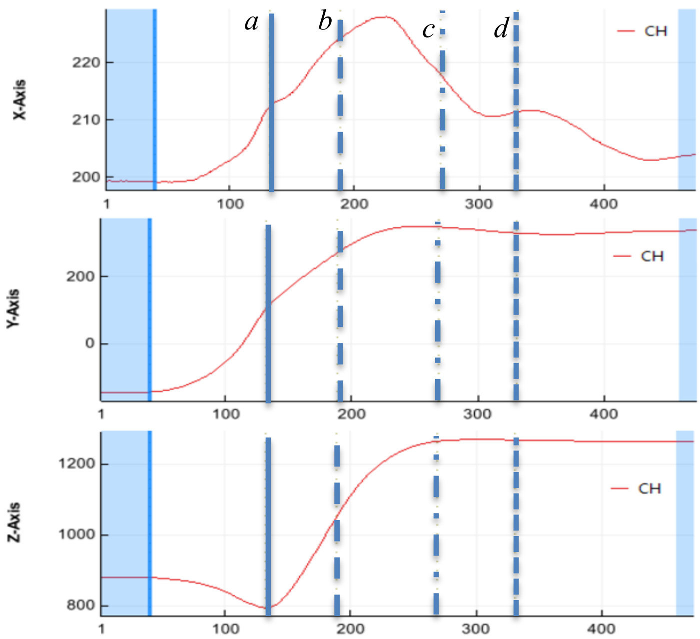

Fig. 4: Trajectory of the chest marker; PI - flexing (a), PII - momentum transfer (b), PIII & PIV – Extension and stability marked by (c) & (d)

Muscular analyses

The calibrated system for the seat according to subject's weight required the necessary data, which were provided after the conversion of eVolts to Newtons. Once the prototype of the seat was design, and manufactured then the tests with support were carried out. Then the data obtained from the initial tests without any support were compared to the data from assisted STS motion. The comparison of the muscular forces of non-assisted and assisted STS activity shows an identical force at the start and end of the STS. The muscular forces during getting up progress of unassisted activity showed magnitude of force, that varied between 10-20 N higher than the assisted force. Highest discrepancy of 80 N between assisted and unassisted STS was observed at Biceps Femoris.

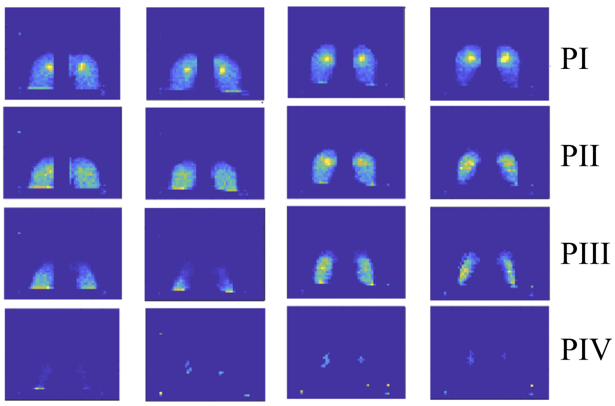

Fig. 5: ConforMat results of Phase 1 of the 4 Scenarios (Normal seating position to most elevated from left to right)

Mat force analysis

The data, obtained only in a form of the colour infogram, was used to identify the loss of contact between the two surfaces such as buttock contact with the chair, and when the full load of the body was transferred to the MatScan.

4. Conclusion

The data achieved provided the necessary information, which was used to design a prototype of the seat. Based on our tests the calibration provided the possibility to have a personalization of the aid for STS activity. For better results the used mats has to be substituted by a system that will be able to provide the conversion of 255 colour limit to forces in Newtons. At reaching a maximum dorsiflexion, the mass acting on the seat is alleviated due to the acting aid force generated by the tension spring that helps to push the subject forward. The height of the chair with the mobile seat used must provide at least an angle of 90^0 between thigh and tibia for easier start of STS motion.

References

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