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Effects of Variation in Cushion Thickness on the Sit-to-Stand Motion of Elderly People

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Abstract. This study was done to investigate whether cushion thickness affected elderly people during the sit-to-stand motion (STS motion). Fourteen elderly subjects aged 79 or over were recruited from the out-patients at a rehabilitation clinic. Their STS motions were evaluated and analyzed using a digital video camera and analyzing software. As the thickness of the cushion increased, it was difficult to identify the pelvic movement during STS motion, although the trunk was inclined more anteriorily and the load to the knee extensors was greater. Furthermore, three of the fourteen subjects had difficulties performing STS motion when the pelvis was contoured by a thick cushion. These results suggests that if an older person has a knee extensor strength below an appropriate level and/or the cushion thickness is enough large to contour the subject's pelvis, the risk of falling during STS motion is higher.

Key words: Sit-to-stand, Cushion, Elderly people

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INTRODUCTION

The use of a chair is a relatively new concept which has become common in Japanese daily life. Due to its popularization, the chair has become essential to our daily life. Therefore, in the field of ergonomics, research is being done on the chair from a functionality standpoint. It is common to focus on comfort and design when choosing a chair; however, most ergonomic studies pursue the best posture during sitting. Various activities in our daily life are accompanied by a transfer motion. The sit-to-stand motion (STS motion) is one of the motions performed most frequently. Although STS motion is not a concern for healthy people, Tinetti et al. reported that elderly people, who can perform STS motion without a risk may not feel the fear of falling during STS motion[1)]. Moreover, Nyberg et al. reported many falls among elderly people take place at the time of transfer[2)], and for elderly and disabled people, STS motion can be a motion with a high risk of falling. STS motion may be connected with applied motion of transferring or walking. Therefore, to perform STS motion with safety is essential for independent life for elderly people.

As mentioned above, a lot of studies on STS motion have been reported[3, 4)]; but there are few discussions about the influence of the chair on STS motion. In fact, many elderly people need some assistance during STS motion, particularly from specific features of a chair, such as armrests. Furthermore, when choosing chairs for elderly people, especially those who have osteoarthritis of the lower extremities, an important factor which should be examined is the ease of STS motion[5)]. If safe and smooth STS motion cannot be achieved with comfort and design, it cannot be said that the chair has achieved sufficient function. Moreover, at present, studies related to the impact of different chair seat conditions on STS motion have seldom been reported.

The purpose of this study was to investigate the effect of differences in cushion thickness on STS motion of elderly people. We think that the results of this study provide an understanding of the advantages and disadvantages of cushion use and make suggestions regarding on prevent of falls during STS motion.

METHODS

Subjects

The subjects, 14 elderly patients (a man, 13 women), were randomly chosen from the outpatients at a rehabilitation clinic who were able to perform STS motion without using the upper extremities and who did not experience pain during STS motion (Table 1). The subjects had no past or present medical history of severe disease affecting the central nervous system, such as stroke. In addition, prior to the experiment, we explained to the subjects the purpose and method of this study and that they had the right to withdraw from the study at any time. We also explained that the privacy of all subjects was strictly protected according to the content of the study description. This was orally explained, and then the subjects' written consent was obtained.

Table 1. Basic information on the subjects (n=14)

age (years)	82.1 (79~87)
height (cm)	147.2 ± 7.8
weight (kg)	49.7 ± 9.3
BMI (%)	22.8 ± 2.9

Means ± SD.

Measurements

Four different sitting conditions were adopted: direct sitting on the chair (0 mm) and on low repulsion cushions (Toyo Chemical/Industrial Products Sales, Soflan) of various thicknesses (30 mm, 60 mm and 90 mm). Considering the subduction of the buttocks caused by the elasticity of each cushion, the seat height was adjusted so that the greater trochanter was situated at the same level from the floor for each cushion condition. The seat height during initial direct sitting, that is, the vertical distance from the subject's caput fibulae to the floor was adopted. The lower legs were adjusted so that they were vertical, and the bare foot position was adjusted so that the medial borders of the feet were at 40 degrees[6)]. The sitting depth was set up so that the center of the greater trochanter and lateral knee joint space could be aligned at the anterior edge of the seat. The subjects were instructed to peer forward and cross the arms on the chest in order not to obscure the markers during sitting. The trial was judged satisfactory and the data analyzed only when both the examiner and the subject accepted that the STS motion was naturally symmetrical. Here we define the action in which a subject rose slightly off the chair and then sat down again as sitback[7)]. Those trials in which sitback was identified were defined as failed trials.

In this study, the STS motion was assumed to be done symmetrically, since all of the subjects were free from any neurological and orthopedic pathologies affecting the STS motion. Accordingly, we measured parameters in the sagittal plane. The body movement was videotaped from the right side using a digital video camera (Sanyo, IDC-1000Z) placed 5 m from the subject. Kinetic data was obtained using two force plates (Anima, G-620). Before the subject sat on the chair, the chair was set on one of the force plates as an offset. The subjects sat on the chair with the feet located at the center of another force plate and performed the STS motion (Fig. 1).

The position of each marker during STS motion was captured by the digital video camera at 30 frame/s. Markers were attached to 11 landmarks on the top of the head and tragus, acromion, the lowest rib, anterior superior iliac spine (ASIS), posterior superior iliac spine (PSIS), great trochanter, lateral knee joint line, lateral malleolus, calcaneal tuberosity, and the tip of the toe. The center of gravity (COG)[8)] and the joint angles (pelvis, hip, knee and ankle), based on the marker position data, were calculated by NIH Image Ver.1.63. The center

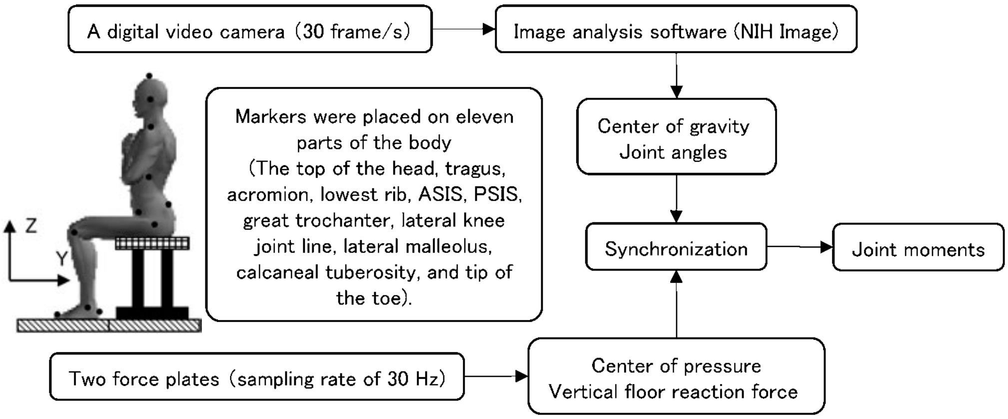

Fig. 1. Measurement system.

of pressure (COP) of the buttocks and feet, and the vertical floor reaction force were calculated by a force plate (Anima, G-620) at a sampling rate of 30 Hz. Kinematic and kinetic data were synchronized and presumed lower extremity joint moment (hip, knee and ankle), were obtained with the formulas given below[9]. The influence of the anteroposterior floor reaction force and acceleration are not taken into consideration by these formulas. However, Ishii[10] reported that the extent to which floor reaction force accounts as an external force on the body is very large, since there is not such a large change of motion in normal body movement. Therefore, lower extremity joint moment could be estimated by observing the vertical floor reaction force, the foot COP, the COG of each body component, and the joint position of the lower extremities.

$$M_H = N(X_H - X_P) - m_1\boldsymbol{g}(X_H - X_1)$$
$$M_K = N(X_K - X_P) - m_2\boldsymbol{g}(X_K - X_2)$$
$$M_A = N(X_A - X_P) - m_3\boldsymbol{g}(X_A - X_3)$$

M_H, M_K, M_A: hip, knee and ankle moment
hip extension, knee extension and ankle plantar flexion: +
(H: hip, K: knee, A: ankle)
X_H, X_K, X_A: anteroposterior coordinates of each joint (posterior: +)
m_1, m_2, m_3: metamere mass
(1: femur + crus + foot, 2: crus + foot, 3: foot, and so on)
X_1, X_2, X_3: anteroposterior coordinate of the metamere COG (posterior: +)
X_P: anteroposterior coordinate of the foot COP (posterior: +)
$\boldsymbol{g}$: acceleration of gravity
N: vertical floor reaction force

The total time of the STS motion was defined as the duration between the times of initiation of the posterior displacement of the COP and of the maximum hip extension. Each time component was converted percentage of the total time (100%) for comparison between the subjects. Analyses were performed on the STS motion duration, the maximum horizontal velocity of the COG, and joint angles and the joint moments (pelvis, hip, knee and ankle) at the time of the buttocks off.

The mean data for 3 trials of STS motion were adopted. Each parameter is described as mean ± standard deviation. One-way analysis of variance (ANOVA) was used to identify the influence of the cushion thickness. Scheffe's F for multiple comparisons of seat pressure, and Fisher's PLSD were used for other multiple comparisons. Statcel 97 (OMS)[13] was used for the statistical analysis and a P value below 5% was adopted as the statistical significance level.

RESULTS

Because three subjects aged 79 to 87 belonged to a group (difficult group) who showed sitback under at least one condition, their data were excluded from the analysis. The residual 11 subjects' data (possible group: 79 to 85 years) was adopted for the analyses. The range of movement of the pelvic, hip, knee and ankle joints at the buttocks off in the sagittal plane are shown in Table 2. The hip flexion

Table 2. Joint angles at buttocks off

Cushion thickness (mm)	Pelvis(deg)	Hip (deg)		Knee (deg)	Ankle (deg)
0	26.9 ± 8.7	112.0 ± 9.0		87.4 ± 5.5	10.8 ± 5.4
30	27.2 ± 9.6	115.0 ± 8.5		86.9 ± 6.9	10.6 ± 6.9
60	28.4 ± 10.4	118.1 ± 8.8	*	88.2 ± 6.0	10.4 ± 6.8
90	28.3 ± 11.0	120.2 ± 7.4		89.5 ± 5.9	11.7 ± 4.8

Mean ± SD, *: p<0.05.

Table 3. Joint moment at buttocks off

Cushion thickness (mm)	Hip (Nm/kg)	Knee (Nm/kg)	Ankle (Nm/kg)
0	0.909 ± 0.186	0.301 ± 0.138	0.081 ± 0.138
30	0.933 ± 0.179	0.377 ± 0.148	0.014 ± 0.173
60	0.975 ± 0.228	0.380 ± 0.178	0.013 ± 0.208
90	0.975 ± 0.226	0.439 ± 0.189	0.006 ± 0.149

Mean ± SD.

angle at buttocks off was significantly increased with a cushion of 90 mm compared to without one (0 mm) ($p<0.05$). There were no significant differences in the other joint angles at buttocks off. Joint moments of the hip, knee and ankle joints at the buttocks off are shown in Table 3. The knee extension moment tended to be increased at 90 mm compared to at 0 mm ($p=0.05$).

A comparison between the possible and difficult groups during STS motion with no cushion (0 mm) was performed using the Mann-Whitney U Test. Figures 2 and 3 demonstrate the change of the hip, knee and ankle joint moments. In the possible group, hip extension moment was dominant rather than knee extension moment from the buttocks off to the motion termination. In contrast, the knee extension moment was dominant rather than the hip extension moment in the difficult group. Comparisons of each parameter between the possible and difficult groups are shown in Table 4. In the difficult group, the total STS motion time tended to be prolonged ($p=0.06$), and the maximum horizontal velocity and anterior pelvic tilt angle at buttocks off tended to become smaller ($p=0.06$, $p=0.07$). Hip flexion angle and knee extension moment at buttocks off was significantly large ($p<0.05$). Hip extension moment and ankle flexion moment at buttocks off were small ($p<0.05$).

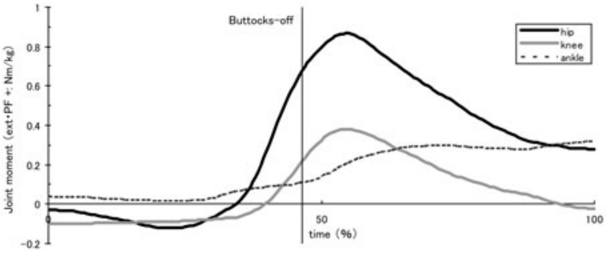

Fig. 2. Lower extremity joint moments of the possible group subjects.

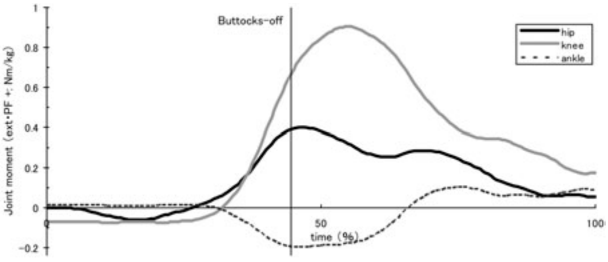

Fig. 3. Lower extremity joint moments of the difficult group subjects.

DISCUSSION

In STS motion, it is necessary that the trunk is tilted forward from the sitting posture as the buttocks and feet make a stable base of support. Also, the COG is moved into the narrow base of support between the feet when the buttocks leave the seat. Controlling the COG at this instance is most difficult during STS motion, and sitback will result if this controlled movement cannot be achieved. Alexander et al.$^{14)}$ also reported a study

Table 4. Comparison between the possible and difficult groups

		Possible (n=11)	Difficult (n=3)	p
Total STS time(s)		2.38 ± 0.53	3.16 ± 0.68	0.06
maximum velocities (cm/s)	Horizontal	47.9 ± 10.0	33.8 ± 10.7	0.06
	Vertical	41.7 ± 8.5	31.3 ± 6.4	
Joint angles at buttocks off (deg)	Pelvis	26.9 ± 8.7	14.9 ± 11.0	0.07
	Hip	112.0 ± 9.4	125.1 ± 9.6	*
	Knee	87.5 ± 5.5	99.0 ± 1.2	*
	Ankle	10.8 ± 5.4	18.7 ± 2.0	*
Joint moments at buttocks off (Nm/kg)[a)]	Hip	0.91 ± 0.19	0.41 ± 0.05	*
	Knee	0.30 ± 0.14	0.65 ± 0.14	*
	Ankle	0.08 ± 0.14	–0.19 ± 0.10	*

a) Each joint moment was normalized by dividing the raw value by the subject's body weight. Mean ± SD, *: $p<0.05$.

based on rising from a cushion-covered chair, but they compared STS motions performed under two seat-height conditions, that is, lower leg length and 80% of lower leg length plus a cushion and a question remained as to whether the results showed only the influence of the cushion. We avoided this by adjusting the height of the seat so that the great trochanter was maintained at the same height, in order to investigate the influence of only the cushion. The hip flexion angle at the buttocks off increased significantly with a cushion of 90 mm compared to at 0 mm. Ishii[15)] reported that a larger forward bend of the trunk and moving the COG in the anterior direction were effective strategies for performing this dynamic task. As mentioned above, the results suggest that even if the position of the great trochanter at the initial sitting posture is kept at the same height, the upper body produces higher momentum before buttocks off and the COG tends to be closer to the base of support made by the feet because the trunk is tilted forward as the cushion is thicker. The knee extension moment tended to increase with a cushion of 90 mm compared to 0 mm, but there were no significant differences in other joint angles at buttocks off. These results suggest that the subjects' trunk strategies were to tilt more forward as the cushion became thicker, but they have no other strategy to choose in which the pelvic movement cannot be demonstrated and the buttocks off depends on the knee extension moment because of subduction of the buttocks. Yoneda et al.[16)] showed that since there is upward acceleration by the hip and knee extension and rapid load accompanying buttocks off, STS motion can also be considered to be a jumping motion the legs attached to the floor. Tomita[17)] showed that the buttocks have no pushing off activity that can push on the base of support and accelerate the motion at the buttocks off. As mentioned above, at the buttocks off during STS motion, it is necessary to transfer the upper body momentum generated by forward tilting of the trunk to the whole body. However, the results suggest that as the cushion thickness increases, this movement will be performed less efficiently, and more knee extension moment is necessary.

Kojima et al.[18)] reported that elderly subjects could not perform STS motion from a chair with a 20 cm seat height; an increase in total STS motion time, trunk anteversion angle at buttocks off, and a decrement of the maximum horizontal velocity of the COG were seen. In this study, STS motion from 0 mm (no cushion) in the difficult group showed prolongation of the total STS motion time, decrease of the maximum horizontal velocity of the COG, and increase of the hip flexion angle. The same results were obtained by Alexander et al.[14)] who showed that an extension of motion time reflects the difficulty of a task, and Hughes et al.[19)] who showed that elderly people who feel difficulty with STS motion have this extension of motion time. Regarding the forward tilting angle of the trunk, Usuda et al.[20)] showed that increasing the forward bending of the trunk increased the forward rotation moment of the upper body, making forward and upward movement of the COG easier: the trunk was made to tilt more anteriorly, enabling COG to approximate to the base of support, and the subjects were able to dynamically rise off the chair with a stable position. It has been reported that the COG velocity is fastest at the buttocks off, and that kinetic energy is put to effective use as the center of the hip joint tilts forward while the trunk is kept in extension[21]. It is noted that kinetic energy generated at buttocks off strengthens extensors of the lower extremity right after upward movement of the COG[22]. We suggest that the difficult group could not produce this high kinetic energy even though they tended to tilt the trunk more anteriorly.

The difficult group of this study had a tendency to make a smaller anterior pelvic angle at buttocks off. Sakuma et al.[21] reported that maintaining the body longer during the task was available for utilizing rotational energies around the hip joint. None of the subjects in this study had limitation of range of motion in the lower extremities. Nevertheless, in the difficult group, the results suggest the subjects raised their buttock from the seat without dynamic stabilization[23, 24], linking movement of the head, thorax and pelvis together with muscle activities at the anterior truncal tilt, while maintaining a desirable posture using potentially favorable ranges of joint motion. In addition, the knee extension moment at buttocks off in the difficult group was significantly larger than in the possible group and they performed STS motion with a knee joint moment dominant motion. This means subjects in the difficult group had larger anterior truncal tilt at buttocks off with smaller tilt of the pelvis and they were not able to generate higher kinetic energy. We suggest they performed STS motion dependent on the knee extensor because they could not transfer the COG closer to the base of support made by the feet. The problems seen in the difficult group suggest that elderly people who have difficulty with pelvic movement linked to truncal movement and have weaker knee extensors would be susceptible to sitback and to falling backwards when rising from a chair without armrests or to be in the giving way leading to a forward fall. To prevent such types of falls, a motion strategy using upper extremities and the foot-repositioning strategy, placing the feet more posteriorly before the buttocks off, is required.

Dynamic balance ability is a prerequisite of STS motion which utilizes kinetic energies. Kojima et al.[18] reported that subjects of a difficult older group did STS motion in a less energy-required and stability-regarded pattern compared to healthy younger subjects. Generally, from the aspect of energy, the energy required for STS motion from any chair with the same seat height is the same value even though the rising pattern is different, and the higher the stress on the larger joints the lesser the stress the subject feels[24]. For this reason, for subjects having difficulty with rising from a chair, it is important to provide a physical therapy approach developing truncal dynamic stabilization tilting the pelvis sufficiently, and decreasing stresses on the knee extensors.

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