Development of a Chair to Support Human Standing Motion -Seat movement mechanism using zip chain actuator-

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Abstract— **Many elderly people suffer from declined motor ability, and it is important to develop an assistive device to support their daily life. Some assistive device have been developed previously to help human sit-to-stand motion, but they generally help body extension slowly and thus the user of the device could not utilize their own muscles. Here, we develop a chair type assist device which lift up the seat to push the hip joint for supporting hip rising and body extension. Our developed device employed a zip chain actuator which realizes fast and strong support to follow the user's movement and provide assistance. Evaluation experiment was performed to assess the effect of developed device on muscle activation of lower limbs during sit-to-stand motion. Results show that the muscle activation of knee extensor decreased significantly compared to that without device support. However, the activation level of flexor is found to be increased to deaccelerate the body extension.**

I. INTRODUCTION

According to a survey by Department of Economic and Social Affairs of the United States, the number of people aged 60 and over has risen to 1.05 billion, which is 13.5 point of the total population [1]. As a result, the proportion of the elderly population with declining physical functions is expected to increase , making assistance and nursing care an even more important issue for society. Therefore, it is important to prevent the decline of physical functions of the elderly by using devices that support motor functions. Sit-to-stand is a frequent activity in the daily life of the elderly people, and it is expected to reduce the burden on the caregiver and to have a great impact on society by improving sit-to-stand (STS) motion. In previous studies, various devices have been developed to support STS movements [2], [3], [4]. In these studies, the users are asked to hold the bar by their arms or to lean their upper body against the bar. The bar leads the users to the desired trajectory to achieve STS motion. As another way, we have previously developed chair type assistive device to rise the seat to provide a start cue of STS motion [5]. However, the previous system could not fully follow the user's motion, and thus it results in slowing down the user's movement. Therefore, in this study, we aim to develop a chair type assistive device which could generate faster motion to lift up the buttocks of the users. When the motor ability of elderly people is declined, they prefer to employ more stabilized strategy than those who have enough motor ability [6]. In the stabilization strategy, the elderly people tend to flex their trunk deeper to move center of mass on the feet and perform extension. If people have enough motor strength, they would bend their trunk faster to the generate momentum and utilize it for body extension. For development of an assistive device of STS motion, it is important to provide a wide range of support depending on the user's ability. Therefore, the goal of this study is to develop a chair type assistive device that can adjust its supports take a little different way in which they according to the user's physical functions. we develop an assistive device that can follow different movement of the users (e.g. stabilization strategy and momentum strategy). As shown in Figure 1, there are four states in human standing: forward bending, hip rise, full body extension, and stabilization of posture[8], [9]. In this study, we focus on supporting the motion of hip rise and body extension because these motions control when to move forward and when to extend the body, and are important states that determine movement strategies. First, the trajectory and movement of the buttocks, which is a part of the body that is close to the seat and good for indicating the body movements of standing, will be used as a reference trajectory, and it will be verified whether the chair can reproduce similar body movements. Next the effect of assistive device is evaluated by muscle activation of the users during STS motion. This study aims to develop a chair that supports standing by reducing muscle activity during standing.

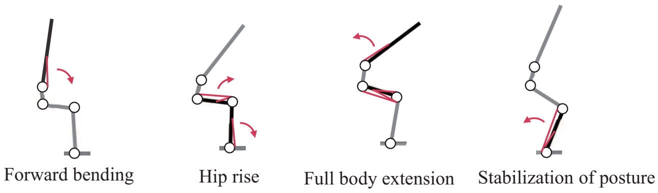

Fig. 1. The four phases of the standing movement

II. DEVELOPMENT OF CHAIR TYPE ASSISTIVE DEVICE

In this study, we propose a device that assists the user's movement by pushing up the user's buttocks with the seat of the chair. The chair is designed to assist the user in

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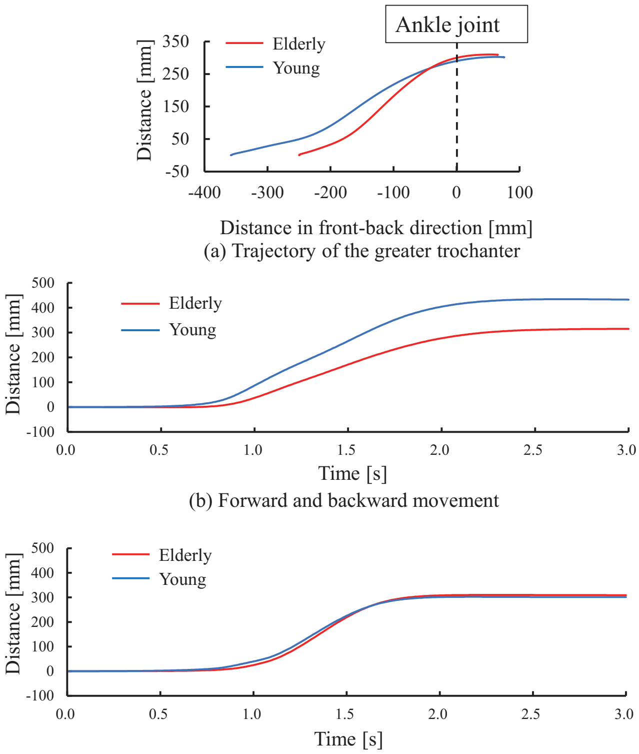
the range from hip rise to full body extension in Figure 1. The trajectory and speed of the support part are determined from the movement of the buttocks during the actual human movement. In this section, first we explain the measurement experiment of buttocks movement during STS motion of the young and elderly people. Next, the assistive device is developed to realize the same trajectory as measured in the experiment.

A. Measurement experiments

To determine the reference trajectory for supporting the user's buttocks in assistive devices, experiments were conducted to measure human standing movements and investigate the actual trajectory of the buttocks. Nine elderly people (66.5±6.2 years old) and eight young people (24.5±2.2 years old) participated at the experiment. Because some elderly also use the momentum strategy, we used young to obtain trajectories and velocities for the momentum strategy. Optical motion capture system (MAC3D, Motion Analysis Corp) is used to record the marker position attached to participant's body. The sampling frequency of measure marker position was 100 Hz. To develop a chair which elevating a seat to support STS motion, the marker attached to the greater trochanter is focused. A force plate (TF-3040, Tec Gihan Co., Ltd.) was placed on the seat to measure the reaction force applied to the buttocks. The reaction force is measured in 2,000 Hz and it is processed with Butterworth second order low-pass filter with cutoff frequency 20 Hz. The moment when the floor reaction force in the vertical direction applied to the buttocks became less than 5 N was considered to be the subject's release time of the subjects from the seat, and the data from 1.0 s before to 2.0 s after the release is analyzed. In the experiment, the subject was asked to cross their arms in front of the chest and perform STS motion with their comfortable speed.

B. Results of Greater Trochanter Movement

The trajectories of the greater trochanter averaged over all procedures in young and elderly subjects during the STS motion are shown in Figure 2. In Fig. 2 (a), the origin in the backward and forward direction is the horizontal position of the ankle joint. The vertical direction shows the change of marker position from the initial sitting position. It can be seen that both the young and the elderly subjects first move their hips forward and then stand upward. Compared with the younger subjects, the older subjects started to stand with the greater trochanter close to the ankle and the feet close to the body. Figure 2 (b) shows time-varying horizontal movement of the greater trochanter. It is found that the maximum distance and speed of movement were smaller for the elderly than for the young, similar to the results reported in a previous study by [10]. Figure 2 (c) shows the vertical movement of the greater trochanter. It is shown that there was no significant difference between the elderly and the young in the vertical direction.



(a) Trajectory of the greater trochanter

(b) Forward and backward movement

(c) Vertical movement

Fig. 2. Experimental results of the measurement of the greater trochanter.

C. Design of Assistive Device

Based on the obtained trajectories of the greater trochanter of the elderly and young, a chair to support the STS motion is designed. The chair was designed to move the seat in two directions, forward and backward, and vertically, according to the movement of the hips. A ball screw and a motor (Maxon Motor, RE40148867) were installed at the left-right seid of the chair to realize the forward-backward movement. The chair is driven from both ends to prevent the seat from deflecting too much and to support the chair even with a weak force. For vertical movement, a zip-chain actuator (Tsubakimoto Chain ZCA35N050EL) and the motor (Oriental Motor BXM6200M-GFS and GFS6G20) were installed under the seat, and vertical movement was realized by pushing up the seat from below with the ZCA. The ZCA was used because it can operate at high enough speed to achieve the speed of the greater trochanter, and also because it has high torque and high rigidity to support the weight of a person. Mechanism of a zip-chain actuator is shown in the left side of Fig. 3. By turning the shaft, the two zips engage each other and move in a straight line. In particular, the use of a zip-chain actuator for pushing up in the vertical direction enables high-speed driving to withstand the load of the user. By placing shafts at both ends of the seat surface, vertical movement is promoted, and by supporting the load on the zip-chain actuator in the front-back and left-right directions, smooth vertical movement is achieved. The developed support device is shown in Figure 3. The upper two figures in Fig. 3 show the zip chain actuator, which

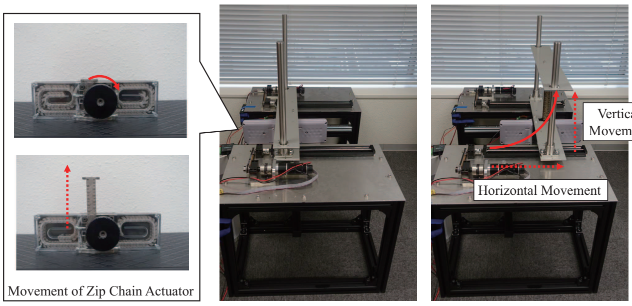


Fig. 3. Developed assistive devices.

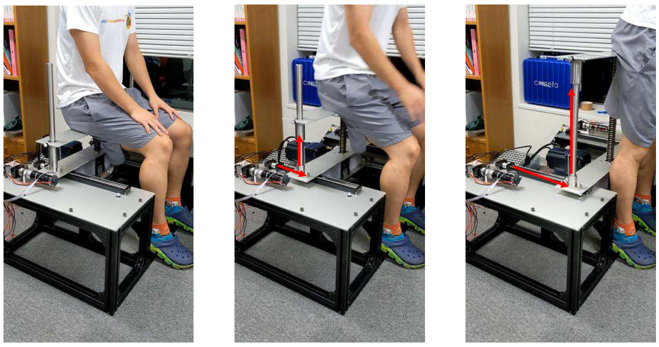


Fig. 4. STS motion with support by developed assistive device.

engages the chain and pushes it upward when the drive unit turns. The seat is the yellow frame shown in the figure, and the zip chain actuator is installed under the seat and connected to the seat. Verification experiments were actually conducted using this device.

D. Validation Experiment

In this study, it is verified whether the greater trochanter trajectories of the elderly and the young, which were determined in the measurement experiment of STS, could be reproduced by the seat of this machine. An optical motion capture system (OptiTrack, V120: Trio) is used to measure the trajectories of the marker positions on the seat surface to determine whether the target trajectories could be realized. The trajectories of the elderly and the young in the forward-backward and vertical directions measured in the former measurement experiment were used for comparison. It is investigated whether the target trajectories could be achieved in the two patterns for the elderly and the young, and whether the assistive devices could make a difference between the two patterns. In this study, a 35-year-old healthy young person sat on the developed assistive device and was instructed not to perform voluntary motions. It was examined whether the motions were reproduced only by pushing up with the seat of the assistive device.

E. Results of the Reproduction

Figure 4 shows that the user of the system perform STS motion with the assistive device. The results of reproducing the movement of the greater trochanter are shown in Fig. 5, where the results obtained in II-B are shown as the target trajectory with dotted lines, and the trajectory of the seat of the assistive device measured with the subject actually riding on it is shown with solid lines. In the forward direction of the movement of the greater trochanter of the young subject, the maximum distance was about 150 mm shorter than the target distance. In the vertical direction, the vertical direction moved about 50 mm less in the standing position, but the target trajectory was almost reproduced. On the other hand, the maximum distance in the forward direction of the elderly was 15 mm shorter from the target distance, but the trajectory was closer to the target compared to the support movement of the young. The vertical direction moved about 50 mm less in the standing position as in the case of the young person, but the trajectory overlapped with the target and the speed achieved the target value. Although the developed device could not fully follow the trajectory of the greater trochanter, it shows that the device could lift up the user at the same speed as they stand up by themselves.

III. Evaluation Experiment

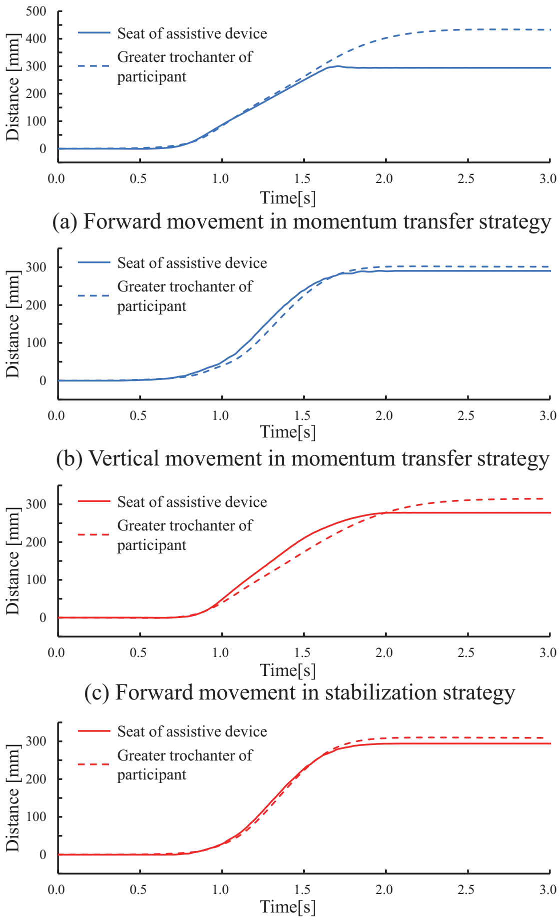
In this chapter, the effect of support provided by the assistive device on muscle activation during STS motion is investigated. Although the developed device could support whole period of STS motion, this study focuses on assisting the hip rise motion and beginning part of body extension.

A. Support Methods

The flow of support by a chair is shown in Fig. 6. First, it is judged whether the user of the device performs the momentum strategy or the stabilization strategy. We hypothesized that the users who utilize the momentum strategy bend their trunk faster than the users who performed the stabilization strategy. Therefore, flexion angle of the trunk is measured and its angular velocity is used to judge the STS strategy. If the angular velocity is less than 70 deg/s at 15 deg of upper body forward bending, it is judged to be a stabilization strategy and the trajectory of the elderly person is reproduced by the assistive device. If the angular velocity is larger than 70 deg/s at the same posture, the movement is considered to be momentum strategy and the trajectory of the young person is reproduced. In both cases, feed-forward control is used to generate part of the trajectory of the greater trochanter reproduction. These threshold values were determined by preliminary experiments. When evaluating the effect of assistive device, it does not reproduce whole period of the movement. The assistive device generates the trajectory between 0.4 s before and 0.4 s after the hip rise for the stabilization strategy and between 0.3 s before and 0.5 s after the hip rise for the momentum transfer strategy. These periods were determined as the approximation time when the trunk flexion angle was 15 deg. The same trajectories as in Fig. 2 is used for reference trajectory.

B. Evaluation Experiment

The method of the evaluation experiment using a chair is shown below. Two healthy young subjects(35 years old



(a) Forward movement in momentum transfer strategy

(b) Vertical movement in momentum transfer strategy

(c) Forward movement in stabilization strategy

(d) Vertical movement in stabilization strategy

Fig. 5. Reproduction results of the orbit of the greater trochanter.

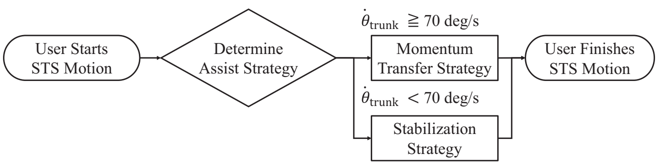


Fig. 6. Flow of support by chair

and 23 years old) intentionally performed two strategies; ten natural STS motion (the momentum strategy) and ten STS motion simulating the elderly (stabilization strategy) respectively. Because it is dangerous to conduct experiments with the elderly, young subjects were used. An optical motion capture system (OptiTrack, V120: Trio) was used to measure the trajectories of the marker positions on the acromion and adductor in 120 Hz. The angle between the vector formed by these two markers and horizontal direction is defined as trunk flexion. In order to adjust the timing of leaving the seat during the STS motion, the marker attached to the greater trochanter was used to detect hip rise timing. When the marker moved 10 mm upward from the initial position, it is determined as hip rise timing. As with the same process in the previous chapter, 1.0 s before and 2.0 s after the hip rise is used for analysis.

To evaluate the support by assistive device on movement, muscle activation is measured from extensor and flexor of the hip, knee, and ankle joints by wireless surface EMG sensors (Cometa Corp., Mini Wave Infinity). In total, seven muscles are measured; gluteus maximus muscle (Gmax; hip extensor), vastus lateralis (VL; knee extensor), semitendinouse muscle (SemiT; knee flexor), tibialis anterior (TA; ankle plantar-flexor), and gastrocnemius (GAS; ankle dorxi-flexor). The muscle activation is measured in 2,000 Hz and it is band-pass filtered with fourth-order Butterworth fitler with cut-off frequency 40-400 Hz [11]. Then the signal is rectified and low-pass filtered with fourth-order Butterworth filter with cut-off frequency 4 Hz [12]. The muscle activation is normalized by the maximum activation level which was obtained by measuring maximum voluntary contraction.

C. *Results of Muscle Activation*

The results of the evaluation experiments are shown below. First, the results of muscle activation when the participants performed the momentum strategy is shown in Fig. 7. In the figure, blue lines indicate the average of muscle activation when people stand up with support from the assistive device and black lines indicate the average of muscle activation when people stand up by themselves. Error bar indicates the standard deviation at each time.

A t-test was used to determine if the maximum value was significantly changed. The results of average and standard deviation of maximum muscle activation at each condition and p-values are shown in Table I. The muscle activity of TA and VL decreased when our developed device support STS movement. This indicates that our device helps the participants move forward and it results in decrease of muscle activation of TA. Similarly, the device rises the seat to push the buttocks so that the muscle activation of knee extensor decreased as well. GAS increased and SemiT decrease statistically significantly, but the amount of change is rather small compared to TA and VL so that the effect of assistive device is considered to be small on these two muscles. These results imply that our developed system could reduce the burden of the participant by supporting their hip rise and body extension.

Figure 8 shows comparison of muscle activation when the participants intentionally performed the stabilization strategy. The blue and black lines show the average muscle activation obtained from the condition with device support and without device support respectively. Similar to the condition that the participants performed the momentum strategy motion, muscle activation of TA and VL decreased statistically significantly when the developed device assist the participants. However, GAS, SemiT and Gmax increased significantly. These muscles are attached at the back side of the human body, and they mainly deceleration of forward body movement. This implies that the participants activate these muscle to brake the forward movement and increase the stiffness of the joint to resist the seat movement. This could be attributed to the fact that the seat of the device could not fully follow the buttocks movement of the participants.

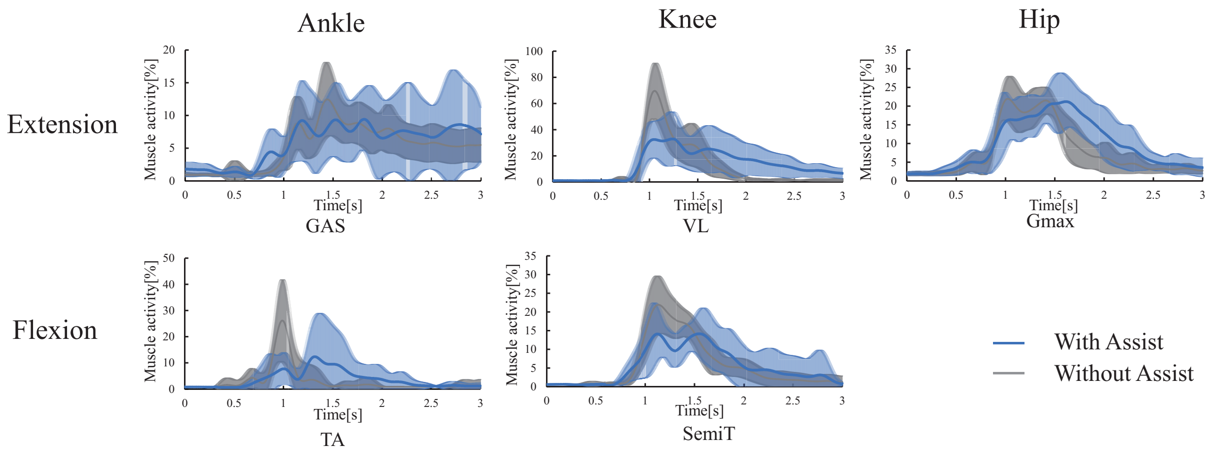


Fig. 7. EMG results during momentum strategy

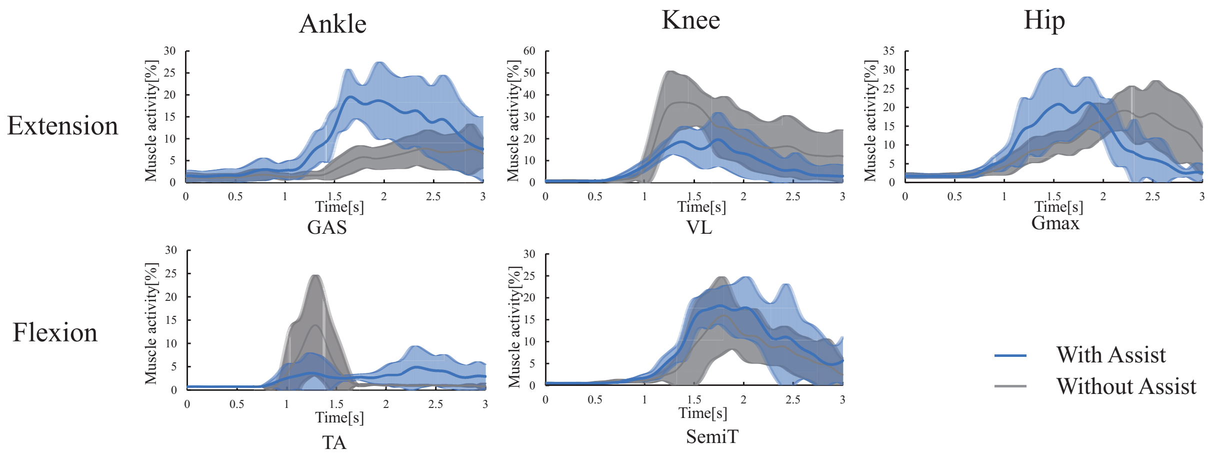


Fig. 8. EMG results during stabilization strategy

TABLE I
RESULTS OF T-TEST FOR MAXIMUM VALUE

	Momentum Transfer Strategy			Stabilization Strategy		
	Without Assist [%]	With Assist [%]	P-value	Without Assist [%]	With Assist[%]	P-value
GAS	14.6±4.2	16.8±8.4	1.2E-5	10.6±4.6	26.2±8.7	3.8E-127
TA	28.1±14.6	20.0±18.1	1.5E-8	19.4±10.5	8.8±5.8	2.7E-57
VL	72.0±20.6	44.0±19.7	2.3E-46	44.4±12.8	25.1±8.9	3.2E-95
SemiT	24.4±6.7	21.9±7.4	2.9-E5	18.8±8.7	24.7±8.0	7.7E-21
Gmax	27.0±3.9	27.0±7.3	0.47	25.6±5.5	27.5±9.7	9.0E-4

IV. CONCLUSIONS

The assistive device of STS motion is developed in this study. The device employs a zip chain actuator to realize the fast and strong support for hip rise and body extension enough for achieve STS motion. It is found that our developed device could support the forward movement and body extension after the hip rise despite the motion strategies of the participants (momentum transfer or stabilization strateiges). This device is expected to support wide range of STS motion depneding on the motor ability of the users. However, unintentional support might cause the increase of muscle activation that results in deceleration of body movement and increased joint stiffness. One of our future directions is to enable our assistive device to adjust the user's movement. In the future study, it is necessary to monitor the user's movement by additional sensors and adjust the movement of the device to the user.

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