Experimental Evaluation of an Assist Chair for Sit-To-Stand

On Speed of flipping up a seat of chair

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Abstract— **Assist chairs with simple mechanism to flip up a seat at the front edge to assist sit-to-stand (STS) is well known as commercial products developed from around 1980. The speed of flipping up the seat on the assist chairs would play a key role how to adjust assisting STS in individual cases, but there is almost no discussion how the speed of flipping up the seat affects the benefit of assisting STS. The aim of study is to investigate the optimised speed of flipping up the seat of the assist chairs. As a first step, a motorised assist chair with controllable speed of flipping up the seat was developed and tested with four healthy participants in three seat height conditions; High:520mm, Middle:420mm, and Low:320mm without and with flipping up the seat at maximum speed 30degree/second. Significant main effect of assisting was found on peak vGRF at Low seat height ($p<0.005$) by Wilcoxon rank test. There was no significant effect at Middle ($p=0.126$) and High seat height ($p=0.507$). With assisting at the Low seat height, the reduction of peak vGRF means that the flipping up the seat successfully supports trunk movement and knee function to lift up the hip from the seat. All participants felt the assisting was effective to reduce the hardness of STS at the Low seat height. With further studies to optimise the speed of flipping the seat, the motorised assist chair in this study would provide a proper assist for individual STS movement, with leaving certain part of physical load for keeping muscle functioning.**

Keywords— assist chairs; sit-to-stand; mechanical motion; Wilcoxon rank test

I. Introduction

Sit-to-stand (STS) movement is one of important skills to make transitions of movements in daily activities. The inability of STS can increase a risk to hesitate activities of daily living [1]. The difficulty of STS movement contains main three factors; chair seat height, use of armrests, and foot position [1]. Elderly people and the people with mobility impairment are suffering the impairment of STS movement because of leg weakness or the impairment of balance control and coordination of joints [2]. To improve STS movement and other motor skill like walking, STS training are very popular as physical therapy in hospitals. For traumatic brain injury, the exercise programs of STS showed 62% improvement in patient's motor performance [3], and STS training with feedback of foot placement for stroke patients improved 95% of the quality of STS movement [4].

Mechanical assist system of STS movement could increase the benefit of physical STS therapy with adjustment of weight load along with the improvement of patients, and can also reduce a risk of falling during STS training. Simple mechanisms to raise the seat to assist STS movement has been developed so far. Raising the seat to lift vertically a hip to upper position for people with spinal cord injury [5], with STS impairment [6], and with aged[7], were introduced and showed the reduction of the load in STS movement. Natural hip movement performed by thigh and shank in STS has a S shape trajectory from the point at sitting to at standing, with dynamic change of hip orientation [8]. To assist STS by pushing hip, two-link system would be suitable to cover any type of STS movement, compared with vertical lifting of the seat, as human leg system has mainly two-link; thigh and shank. Exsoskelton types [9-11] are one of reasonable solutions and have potential capabilities to adapt various motor skills in daily activities. However, the weight of the exsoskeltons is heavy over 20kg for wearing and sporting an exsoskelton needs time, so the usability of exsoskeltons needs to be improved.

The design of simple mechanism to flip up the seat at the front edge to assist STS would be well known as commercial products developed from around 1980. The flipping up the seat would provide better assisting STS compared with lifting the seat vertically. The investigation with one of products called "Ejector chairs" having spring loaded mechanism shows evidences to reduce the muscle activities in STS [12-15], however the investigations in the previous studies were done in limited condition of only two different seat height 450 and 540mm, and the speed of flipping up the seat by the Ejector chair was unchanged and unknown. The speed of flipping up the seat on the Ejector chairs would play a key role how to adjust assisting STS in individual cases, but there is almost no discussion how the speed of flipping up the seat affects the benefit of assisting STS.

The aim of this study is to investigate the optimised speed of flipping up the seat to maximise the benefit of assisting STS in individual cases. As a first step for this purpose, we developed a motorised assist chair with controllable speed of flipping up the seat and tested it with four healthy participants at maximum speed 30degree/second. The motorised assist chair had a similar kinematics in seat flipping that the popular commercial products have.

II. Method

A. Motorised assist chair

Fig. 1 shows a prototype of the assist chair, which was converted from a steel pipe chair without armrest. The seat size was 410x430mm. The assist chair has a motorised mechanism to flip up the seat by two arms. The movement of flipping up the seat was designed to move from normal horizontal position at 420mm to inclined position of 80degree with swivelling at the front edge of the seat at maximum speed 30degree/second. A switch controlled flipping up the seat, and its speed was adjustable with a dial. Seat flipping automatically stopped at 80degree. Both side guides of the seat were able to create this movement while the two arms pushed up the seat from underside. The two arms with 500mm link length were driven by two electric AC servo motors (300W, maximum 25rpm). The two motors were mounted on the base of the assist chair. One motor with gear drove a lower arm rotating on its bottom part around a bearing, which was fixed on the bottom of the assist chair. The other motor with chain drove an upper arm rotating on its bottom part around a revolute joint connected with the top part of the lower arm. The two motors have local speed feedback with maximum torque 125Nm and work cooperatively with the two arms to generate stable force to flip up the seat at a constant speed against the body weight up to 100kg of a participant sitting on the assist chair.

B. Experimental validation

Fig. 2 shows an experiment set-up to investigate the assist chair in this study. This study tested three seat height conditions; High: 520mm, Middle: 420mm, and Low: 320mm without and with assisting. To change the seat height, the assist chair was placed on blocks to lift from the ground level so that High condition was able to be provided. The vertical positions of feet in Middle and Low conditions were adjusted with blocks with 100mm height. The hip position in all experiments was aligned to the same position on the seat, and foot position was determined after shanks aligned in vertical so that knee angle was 90degree in an initial sitting position at the Middle seat height.

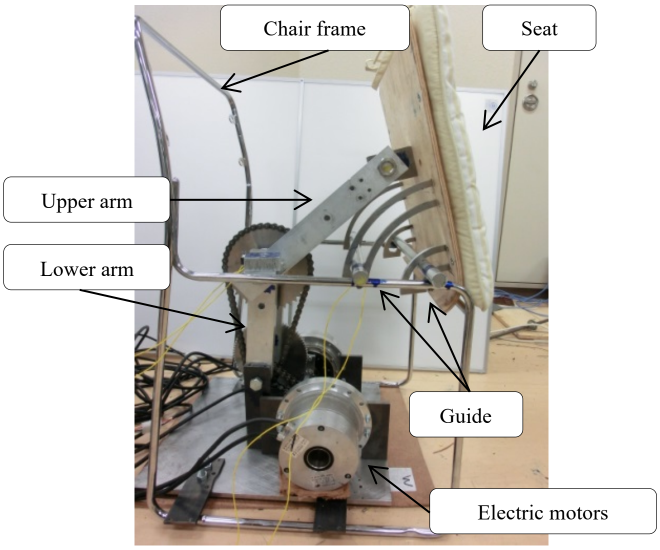

Figure 1. A prototype of the assist chair. The angle of the flipped seat by a motorised mechanism was at 80degree in the photo.

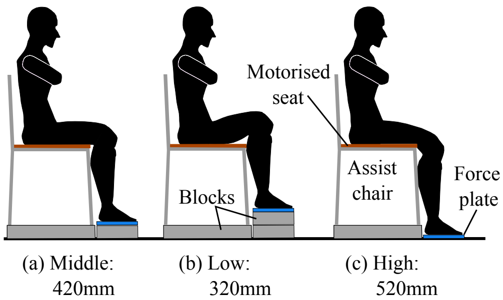

Figure 2. Experimental conditions with three different heights. The seat height of the chair was 420mm, and blocks with 100mm height were used to produce each seat height condition.

The force plate to measure vertical ground reaction force (vGRF) was placed under feet position, and a pressure sensor to detect hip lifting from the seat was placed on the position of sitting bone in an initial sitting posture. The STS movement of sagittal plane was recorded by video camera at 30Hz. Three reflective markers were put on the right side of Humerus greater tubercle, Femur greater trochanter, Femur Lateral Epicondyle, and Fibula Apex of Lateral Malleolus as the positions of shoulder, hip, knee, and ankle joint respectively. Also four inertial measurement units (Xsens Technologies B.V) were attached at back of neck, pelvis, thigh, and shank to record acceleration, angular velocity, and Eular angles.

The participant performed STS movement with holding both hands in front of the chest in all trials. Each seat height had three trials and the order of changing seat height was Medium, Low, and High, and the trials without assisting was done first and with flipping up the seat was next. With assisting, the seat was controlled to flip up from 0 degree to 80degree at 30degree/second. Before each trial, the participant was asked to sit on the seat of the assist chair with upright trunk posture holding both hands in front of the chest, and then was asked to start natural sit-to-stand movement after a voice sign. In the trials with assisting, the seat started to flip up at the same time of the voice sign. Four participants in age range 21 - 49 years old (Mean: 34years old) without any musculoskeletal disorder joined this study after consenting the purpose and risk of the experiment, which had been approved by the National Institute of Technology, Maizuru College. The mean height and weight of the participants were 1.71m (std:0.06m) and 59kg (std:5kg) respectively.

III. Results

This study focused on dynamic change in vGRF as a first stage analysis. Fig. 3 shows dynamic vGRF changes of a participant in his around 50 in STS with three seat height conditions without and with assisting. The time at 0 in a horizontal axis shows the time at hip lifting detected by the pressure sensor on the seat. Averaged time series of vGRF in three trials at each condition was used to plot. The normalised vGRF by participant weight sharply increased with having a peak from initial feet loading at sitting to the body weight at standing, after starting hip lifting. In this participant case, the peak vGRFs at the Low and Middle heights were reduced by assisting STS. Before hip lifting, the main part of the body weight was supported by the chair, so initial vGRF was low around 0.2. After hip lifting the main body weight was being supported by both feet and vGRF was increasing to 1 at standing. This participant finished STS in 2s as the vGRF after 2s was almost stable at around 1, which means that the participant was standing still. The time at hip lifting from the seat with assisting, occurred slight earlier than the time without assisting as the participant performed STS following the movement of flipping up the seat.

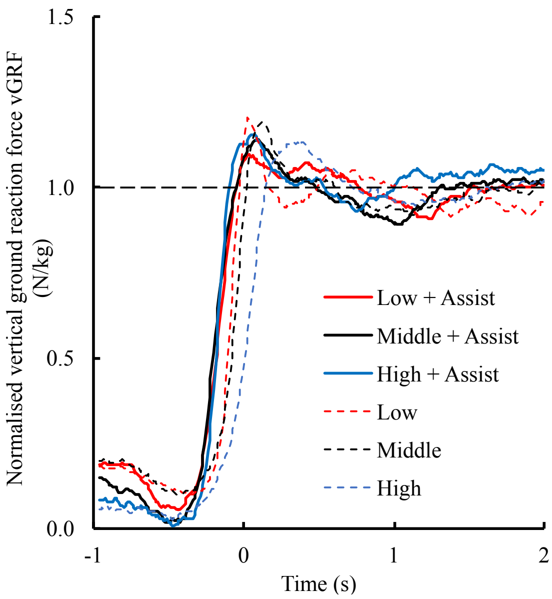

Figure 3. Time series plot of normalised vGRF by a participant weight. Peak vGRFs were reduced by assisting sit-to-stand in this case.The time at 0 in a horizontal axis shows the time at hip lifting detected by the pressure sensor on the seat. Averaged time series vGRF of three trials at each condition was used to plot.

Fig. 4 shows box plots of peak vGRF in all participants on three seat heights without and with assisting. The assisting STS at Low seat height reduced peak vGRF from without assisting and this reduction was found as significant main effect ($p<0.005$) by Wilcoxon rank test. Some trials at Middle height with assisting reduced peak vGRF, however there was no significant effect at Middle ($p=0.126$). In the High seat condition, no effect of assisting was confirmed ($p=0.507$). Lowering the seat by 100mm step from 520mm increased the peak vGRF proportionally. Significant main effect of the lowering seat height without assisting was found on the increased peak vGRF ($p<0.005$).

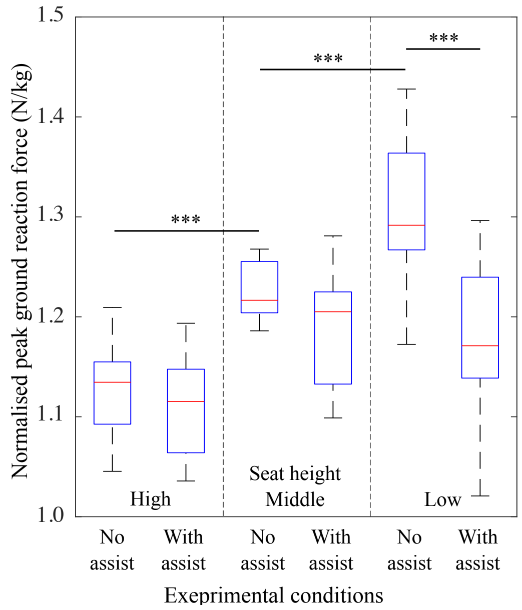

Figure 4. A boxplot of peak vGRF in all trials. Assisting sit-to-stand showed significant effect at Low seat height, which was the hardest condition in this study.

IV. Discussions

The experimental investigation in this pilot study to test assisting STS with flipping up the seat at 30degree/second, showed the reduction of peak vGRF at the Low seat height with assisting. This would mean that the flipping up the seat successfully supports trunk movement and knee function to lift up the hip from the seat. All participants felt the assisting was very effective to reduce the hardness of STS at the Low seat height. The trend of dynamic changes of vGRF in this study was consistent with previous studies [16]. The time at the peak in the vGRF shows the end of preparation phase, which includes leaning trunk forward with lifting hip, and also shows the beginning of rising phase, which includes straightening lower extremity by knees to stand up [16]. In the preparation phase, the participant had to lean the trunk forward at certain speed to secure balance for next rising phase, and the reaction force by ankle joint stabilises this trunk movement using tips of feet. Besides knee starts extending to stand up in the beginning of the rising phase. These factors would be main causes to increase the peak vGRF with the decrease of seat height. The required angular velocity of the trunk increases with the lowering of chair height [17]. In the case that trunk's angular velocity is not enough, a person in STS movement falls back to the seat as centre of mass in whole body remains backside. At the Low seat height without assisting, the participants had to perform rapid trunk movement so that the centre of mass of the whole body was moved over the foot area to keep balance in rising phase. The increase of required trunk movement and knee function supports the finding of the significant effect on the increased peak vGRF by the decrease of seat height, and all participant felt lower seat height was very hard in STS.

The benefit of assisting STS would depend on individual physical strength and balance performances [15]. These factors affect the time of STS, and dynamic control of the speed of flipping up the seat would provide more suitable assisting for individual cases affected by the decline of physical strength and balance performance by age and various diseases. To improve the speed control of flipping the seat, further investigations about hip trajectory with rotation and dynamic change of hip velocity would be important.

This study only investigated one speed of flipping up the seat at 30degree/second. It took 2.7s to flip the seat from 0dgree to 80degree in this study. In the case that the speed of flipping up the seat is faster than hip movement in natural STS, a person using the assist chairs could need more ankle counter moment to stabilise upper extremity and lose body balance in the end of preparation phase in STS in the worst case. The peak vGRF would have a strong link with trunk movement, so the peak vGRF could be used as an index to optimise the speed of flipping up the seat.

In preliminary test with two different speed 8 and 30 degree/second, participants said slow seat rising could cause forward falling with sliding down from the seat, as the participant waited for standing until the seat flipped up at certain upright angle. It means that the flipping up the seat at a proper speed could persuade a person to stand up. The level of support STS with the assist chair needs to be taken into account as "automatic full support" of STS could cause the decline of individual physical strength and balance performance [12], so dynamic speed control of flipping up the seat based on STS movement, could be better because this type of assist-as-needed control can control the level of assisting as well as it doesn't provide assisting if a person doesn't intend to stand.

Only peak vGRF was used in analysis of this study. Further analyses and experiments with larger number of participant is planned to investigate more detailed benefits of assisting STS in parameters such as STS time, power, and rising time in vGRF with posture movements and joint torques computed with recordings of video camera and inertial measurement units. With further studies to optimise the speed of flipping the seat, the motorised assist chair in this study would provide a proper assist for individual STS movement, with leaving certain part of physical load for keeping muscle functioning.

V. Conclusion

The assist chair with flipping up the seat reduces the hardness of STS at the Low seat height. To improve the benefit of assisting STS with flipping up the seat, the investigation of hip trajectory with rotation and dynamic change of hip velocity on larger number of people would be important. Also the development of feedback control system to provide effective and safe assisting of hip movement in various individual STS would bring more improvement of assisting STS.

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