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Biomechanical Assessment of Electric Lifting Chair for Persons with Disability

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***Abstract*—Electric lifting chair is a typical assistive product to aid for standing up and sitting down for persons with disability, and it is particularly useful for the elderly persons whose muscular system is weakened by degenerative joint disease. This paper describes a biomechanical assessment of electric lifting chair with hip-up function. In experiments we measured 3D motion data and electromyogram (EMG) on the femoral muscle when subject performs the standing motion on the predetermined seat height. The experimental results show that 15 degree of the hip-up angle is adequate for the hip-up function, and that the higher seat position is more effective to assist for standing up motion.**

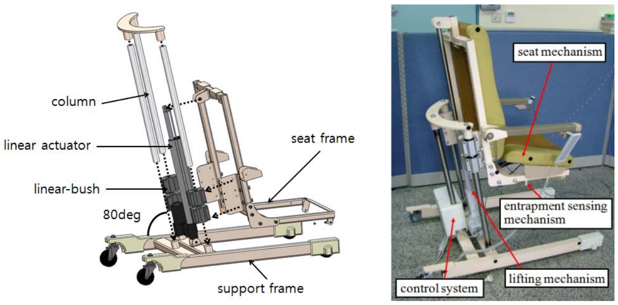
Lifting chair;biomechanical assessment; hip-up function; standing

I. INTRODUCTION

Standing and sitting are the basic motions in activities of daily living (ADL). However persons with disability including elderly persons whose muscular system is weakened by degenerative joint disease are difficult of such motions, so they need care services or assistances by family or caregivers for their ADL. But it is not simple job for the caregivers to care the standing motion, and the caregivers are often injured in their muscular-skeleton system by unstable postures while doing the care services [1]. Assistive product [2] is device and equipment especially produced or generally available for preventing and compensating for impairments, activity limitations and participation restrictions, therefore it is widely used. In recent the needs of the assistive product have increased highly as to be the aging society. It is easy to find such products in our living surroundings.

Many researches related on postures such as standing up and sitting down, and the assistive products to change postures, have been studied in wheelchair field. In [3] a seat mechanism for standing up assist was proposed. By rotating a seat to the upright direction by an external force by actuator, user can stand easily. A wheelchair with posture-changeable function was presented in addition to the standing assist function [4]. A reclining function to adjust back-rest angle [5], and a tilting function to tilt the whole body of chair [11] were presented. However the posture change should be performed with fastening the wheelchair user on the seat for safety. A similar research to assist standing up on bed was presented [10]. The standing up assist was implemented by controlling bed height.

There were studies related on chair to assist standing and posture change in ADL [6,7]. When user performs standing up motion, seat is to rotate to user's view direct by a power assist[6]. We call the seat rotation as *hip-up function*. Then user's body lifts up to upright direction. The hip-up function can be applied to various types of chair. Komura [7] had developed a standing assist chair of which seat descends to a floor. We call it as *lifting chair.* Such type of lifting chair is useful for Far-East Asian living styles that the indoor ADL such as lying and sitting takes on the floor ordinarily.



(a) design (b) developed lifting chair

Figure 1. Prototype electric lifting chair.

The lifting chair is able not only to relieve difficulties but also to prevent risks like the falling to be occurred when the elderly and persons with disability have the standing up and sitting down motions in ADL. It is also a useful device to wheelchair users to transfer from floor to wheelchair seat. In recent functional lifting chairs with reclining, tilting, and hip-up function have been produced with considering user facility. However they were developed without a biomechanical analysis, and did not present any theoretical basis of the effects on human body.

This paper presents a design concept of the lifting chair with hip-up function based on biomechanical assessments. It also describes assessment of the lifting chair by five subjects. The research procedure is as follows. First, a prototype electric lifting chair is developed, and then 3D motion data and EMG on rectus femoris muscle are measured when subject tries standing up motion from the lifting chair. After analyzing the measured data, we select a *hip-up angle* from the analyzed results, and then develop a hip-up mechanism applied to the lifting chair. Finally, the subjects try the standing up motion at the predetermined initial height, and the biomechanical assessment based on the measured 3D motion data and EMG

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signal is performed by a statistical analysis method. From the experimental results we show that the lifting chair with hip-up function can reduce the muscle force while standing up, and that it is a useful assistive product to assist standing up motion for the persons with disability.

II. ANALYSIS OF STANDING MOTION

A. *Design of Lifting Chair*

First, a prototype electric lifting chair was designed (see Fig. 1(a)). The electric lifting chair was composed of lifting mechanism, seat mechanism, entrapment sensing mechanism, and control system (see Fig. 1(b)). The lifting mechanism to lift seat frame up and down is the basic function of the lifting chair, so the design of the lifting mechanism is important more than anything else. The lifting mechanism designed in this study consisted of a support frame to support the seat frame, two columns fixed on the support frame, linear-bushes fixed into the columns and to move along the columns with less friction force, and a linear actuator for the lifting force (see Fig. 1(a)). The seat frame was connected to the columns by the linear bush. The column angle connected to the support frame was selected with consideration of biomechanical and functional stability. In previous research [8], the desirable angle between the trunk and the femur of the human body sitting on chair is 105 degrees or more. Therefore the column angle equal to the back-rest angle would be better to keep 75 degrees at least. In this study, however, we designed the column angle with 80 degree because the main function of the lifting chair is to assist the standing up and the sitting down (see Fig. 1(a)).

The maximum lifting height was selected with considering the Korean standard anthropometric data DB [15] in which the maximum popliteal height of adults between fifties to seventies was 428 mm. Accordingly we selected 450 mm as the maximum lifting height in order to enable everybody to use the lifting chair despite differences in body structure. The lowest height for descent was set to 80 mm which was limited by the structure of seat backside.

B. *Methods*

Human body motion is induced by muscle force generated by muscle contraction. The standing motion analysis, accordingly, is performed by measuring joint angles or estimation of muscle force from EMG on the agonist muscle [12]. Since this paper focused on the standing motion by hip-up function, we did not analyze the human body motion, but we only analyzed the standing motion using a change of the *thigh angle* and EMG amplitude measured from the rectus femoris muscle related on the extension of knee joint [13].

We selected five subjects (26±0 yrs., 169±5cm, 76±6kg), that all subjects are male and healthy persons. The femoral angle was measured by a 3D motion capture system (HWK-200, MotionAnalysis Co.) that was composed of six high-speed infrared cameras. EMG of the rectus femoris was measured by a dynamic EMG measurement system, Bagnoli-4, produced by Delsys Co..

First, we measured the standing motion by the initial height of seat. In [14], they proposed various methods to measure body angles during standing motion. In this study we attached the reflection makers on the hip and knee joint, and the corner of the seat frame. Fig. 2 shows the position of attached makers and measured 3D motion data.

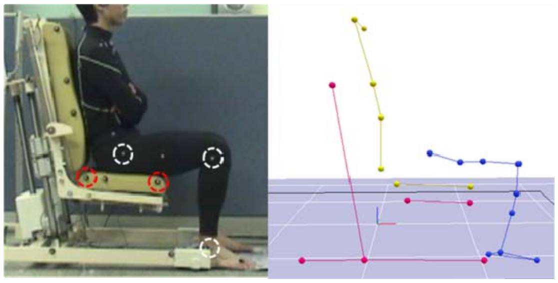

(a) marker positions (b) measured 3D data

Figure 2. 3D motion capture.

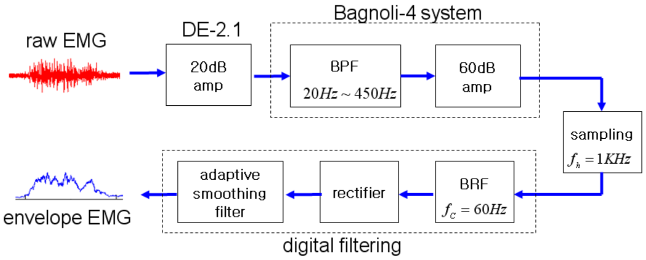


Figure 3. EMG signal processing.

The EMG of the rectus femoris was measured by a dry-type active electrode (DE-2.1, Delsys Co.). Then the EMG amplified 20 dB was inputted into the dynamic EMG measurement system that amplifies 60 dB after filtering the signal by a band pass filter with 20Hz to 450Hz bandwidth. As the results, the raw EMG is amplified by 80dB (10,000 times amplification). It was synchronized with the 3D motion data, and sampled by 1 KHz. The inputted EMG was filtered by 60Hz band rejection filter (BRF) to cut off the power-line noise, then it was processed by full rectification and smoothing filtering. The final output signal of EMG is envelope data. Fig. 3 shows the signal processing procedure from raw EMG to the final envelope data. Because time delay or time difference between EMG and 3D motion data due to the measurement system makes motion analysis be difficult to derive a meaningful result, we used an adaptive smoothing filter [9] that time width for moving average is changed by a differential algorithm based on data property.

Subjects performed the standing motion at a predetermined initial height of the seat. Because the body structure of subjects would be different, it needs to determine a consistent method to select the initial height in spite of the difference of the popliteal height of subjects. In this study we set the initial height to the thigh angle when subject was seated on the chair. The initial thigh angle corresponding to the initial height of seat was set to 7, 14, and, 21 degrees (see Fig. 4). The initial angle 21 degree corresponds to the maximum height of seat when the heel of subject is not off. Each subject performs five standing trials at the initial height, and the motion and EMG of the rectus femoris were measured synchronously.

(a) 7 degree (b) 14 degree (c) 21 degree

Figure 4. Initial height of seat plate based on initial femoral angle.

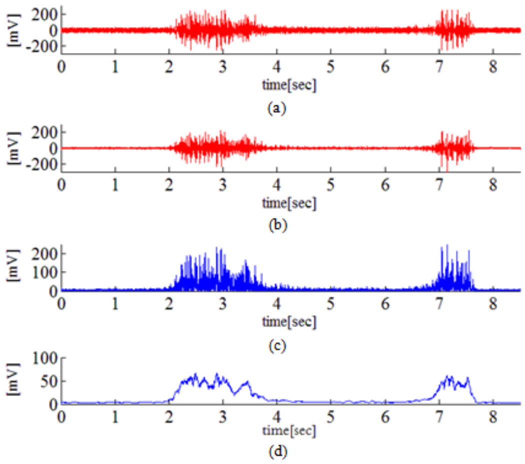
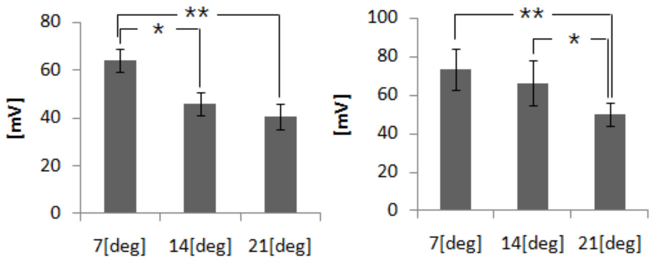


Figure 5. Results of EMG signal processing measured from the rectus femoris muscle when standing up (a) input EMG (b) 60 Hz noise rejection (c) full rectification (d) output envelope.

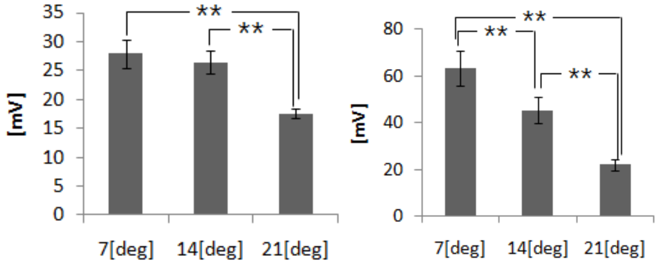
Fig. 5 shows the measured EMG when subject tried a standing up motion; the first is the input EMG to be sampled by 1KHz from the output of the EMG measurement system, the second is the signal filtered out by 60Hz BRF, the third is the full rectified signal, and the final graph shows the envelope EMG obtained by the adaptive smoothing filter. In this study we used the peak value of the envelope EMG for the analysis of the standing up motion.

C. Results and Analyses

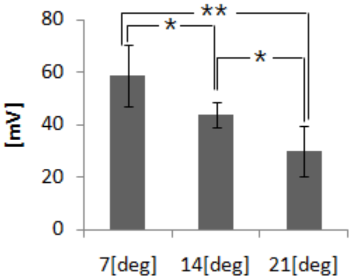
Fig. 6 shows the mean and the standard deviation of the peak EMG measured when the subjects tried the standing up motion at the initial height. The horizontal axis is the initial thigh angle, and the vertical axis is the amplitude of the envelope EMG. This result shows that the peak EMG is lower as the initial height is higher. We performed a significance test of the seat height using the analysis of variance (ANOVA) test method that provides a statistical test of whether or not the means of several groups are all equal. The results of ANOVA test were indicated in the figure as '*' for p-value < 0.05 and '**' for p-value <0.0005. Even though subject C showed lower EMG than other subjects, the test result showed a distinct significance (p<0.0005) except the result between 7 and 14 degrees. The subject D and E show meaningful results as shown in Fig. 6(d) and (e). From these results, we can see that the higher seat position is effective to assist the standing up motion. This can be verified certainly from the significance results between 7 to 21 degrees.



(a) subject A (b) subject B



(c) subject C (d) subject D



(e) subject E

Figure 6. Results of ANOVA test of EMG peak value according to initial femoral angle (* p<0.05, ** p<0.0005).

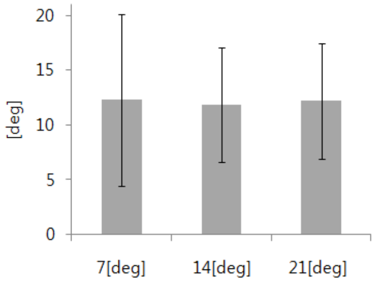
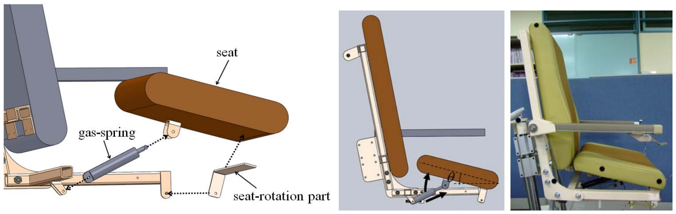


Figure 7. The mean and variance of relative femoral angles measured when the peak EMG is appeared.

III. DESIGN OF HIP-UP MECHANISM

A. Selection of Hip-up Angle

To implement hip-up function a design for hip-up mechanism is needed. However the possible design area is restricted because the hip-up mechanism is constructed in the seat backside. Consequently the hip-up angle to be designed must be restricted. We utilized a gas spring to not need any electric power for the hip-up mechanism. The specification of the gas spring is 27mm diameter, 200mm length, and 50mm stroke. The hip-up angle was determined by analysis of the EMG measured on the rectus femoris and the thigh angle when



(a) design (b) prototype hip-up mechanism

Figure 8. Hip-up mechanism.

subjects tried the standing up motion. From the measured results we extracted the peak EMG and its corresponding thigh angle to detect the position to need for the maximum muscle force. Fig. 7 shows the relative thigh angle from the initial thigh angle when the peak EMG is detected. The all mean values of the relative thigh angle were smaller than 15 degrees. Then, we determined the hip-up angle of the lifting chair to 15 degrees that covers the thigh angle appeared the peak EMG.

B. *Design of Hip-up Mechanism*

Fig. 8 shows the design and its prototype of the hip-up mechanism developed. The gas spring is fixed on the seat frame, and pushes the seat to upright direction by its spring force of 60kgf. Fig. 8(b) shows the seat posture to be lifted up to 15 degrees by the hip-up mechanism.

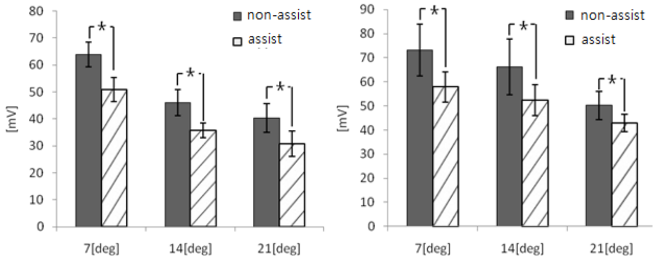
IV. EXPERIMENTS AND RESULTS

After applying the hip-up mechanism to the lifting chair, we performed experiments for the standing motion assessment with five subjects. Each subject performed five trials at the initial height with and without the hip-up function. Experimental environment was set to the previous test shown in subsection II.B.

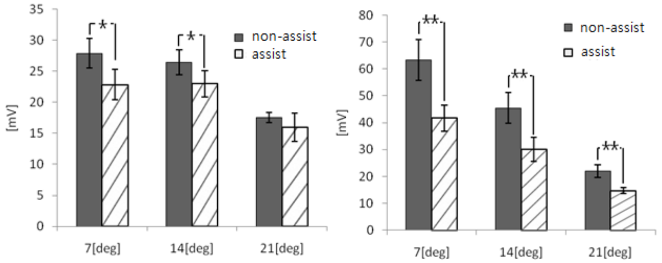
Table 1 shows the mean and the standard deviation of the peak EMG by the hip-up assist or not. The results show that the peak EMG is lower when the hip-up assist is given. We verified the significance using ANOVA test.

TABLE I. EMG PEAK VALUE BY HIP-UP ASSIST [MV]

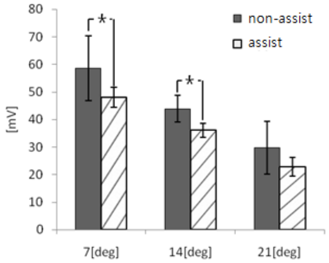
sub.	**7 degree**		**14 degree**		**21 degree**	
	Non-ass.	*Assist*	*Non-ass.*	*Assist*	*Non-ass.*	*Assist*
A	63.8±4.6	50.8±4.4	46.0±4.8	35.6±2.7	40.3±5.3	30.8±4.6
B	73.2±10.6	59.1±8.2	66.2±11.5	52.4±6.4	50.1±5.8	42.9±3.5
C	27.8±2.41	22.8±2.4	26.4±1.9	22.9±2.1	17.5±0.8	15.9±2.2
D	63.3±7.5	41.6±4.7	45.4±5.71	30.0±4.4	22.0±2.3	14.6±1.1
E	58.6±11.7	48.1±3.6	43.8±4.8	36.1±2.5	29.7±9.6	22.9±3.4



(a) subject A (b) subject B



(c) subject C (d) subject D



(e) subject E

Figure 9. EMG peak value and ANOVA test results by hip-up assist and non-assist (* $p<0.05$, ** $p<0.0005$).

Fig. 9 is the results to be put into the form of graph from Table 1. The test results are indicated in the figure as the same manner in subsection II.C; '*' for p-value < 0.05 and '**' for p-value <0.0005. The peak EMG with the hip-up function was lower than the non-assist state, and its significance was also shown by the ANOVA test results. But when the initial thigh angle was 21 degree, the test results for subject C and E were p>0.05. This is thought of which the standing assist by the higher initial position offsets the hip-up assist, and of which the standing up motion is depended on the personal characteristics such as body structure, muscle activity and motion postures. But we can see that the mean of peak EMG is lower when the hip-up function is given. Therefore we can say that the hip-up function proposed is effective to the standing up motion assist.

V. CONCLUSIONS

In this paper the standing assist by the seat height and the hip-up function was experimented and analyzed. First, the prototype lifting chair was developed in order to adjust the seat height, and then the peak EMG of the rectus femoris was measured without the hip-up function. At the same time the thigh angle was measured by a 3D motion capture system. The experimental results show that the peak EMG was lower as the initial height of seat was higher. The significance test result also showed the higher seat position was effective to the standing assist.

Second, the thigh angle was analyzed when the peak EMG was appeared by the standing motion at each initial height. The results showed that the relative thigh angle was smaller than 15 degrees when the peak EMG was detected. Therefore we determined the hip-up angle to 15 degrees, and developed a prototype of the hip-up mechanism.

Third, we performed biomechanical assessments of the standing up assist when the hip-up function was applied. The results showed that the hip-up function was effective to the standing up assist. However, a part of the results was not significance. This was thought of which the standing up assist depends on the personal characteristics such as body structure, muscle activity and motion postures when the initial position is set to high height. But the mean of peak EMG was lower by the hip-up function. As the results, the lifting chair to be adjustable seat height is effective to the standing up assist, and the hip-up function reduces the muscle force of the rectus femoris.

In this paper we performed the biomechanical assessment by three initial heights only. To analysis the standing motion at the various heights is needed too. In addition it is necessary to combine the hip-up function with the various initial heights. The experiments and assessments may be useful for design an optimal mechanism for the standing up assist. This is the future work.

ACKNOWLEDGMENT

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