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Special Topic
Ergonomics in Seating

Development of Tilting Chair for Maintaining Working Position at Reclined Posture

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Objective: The aim of this study is to develop an office chair enabling to keep working at reclined sitting posture.

Background: Sedentary workers are supposed to change the posture frequently during long hours of sitting. A reclined sitting position has been recommended to reduce disc pressure. But slumped sitting posture caused by the buttock sliding forward without any adjustment of back reclining is commonly observed. The worker seems to have tendency to change the sitting posture maintaining working condition. We assumed the reason to be their hands movement away from the working space when tilting backward.

Method: Slide mechanism allowing seat to move forward was designed to maintain the hand position in working space during reclining. A prototype was manufactured and tilting motion was analyzed using motion capture system. Four experiment chairs were tested including the manufactured prototype chair and three other commercial chairs.

Results: A backward movements of the hand position were 13.0mm, 101.7mm, 156.1mm and 139.3mm at the prototype chair, compared to chair B, chair C and chair D, respectively. And the movement was remarkably small at the prototype chair.

Conclusion: The developed seat sliding chair allows back tilting maintaining hand position at working space. We expect the user tilting back more often than normal tilting chair during seated work. But further investigation is required to figure out the effectiveness of the developed chair using prolonged working hours.

Application: The developed office chair directly affects commercialization.

Keywords: Office chair, Tilt mechanism, Maintaining working position, Slide seat, Motion analysis

1. Introduction

Modern people, who spend long hours sitting in front of a computer, are exposed to musculoskeletal disorders. In the studies on healthy sitting posture, the effect of the backrest use and lumbar support has been addressed importantly so far (Grandjean and Hunting, 1997). Andersson et al. (1974) reported that pressure to disc is reduced, as the backrest is reclined more and lumbar pad is supported higher. Also, it was confirmed that when the backrest is reclined, if seat is tilted together, lumbar support gets better, due to no forward sliding of buttocks (Lengsfeld et al., 2000). If backrest rotation center matches human body hip joint, it was known that lumbar support continues even in the back tilting process (Chung et al., 2010). Through many studies, it was also revealed that reclining of the backrest has some advantages such as muscle activity (Anderson et al., 1974), and contact pressure reduction at buttocks (Vos et al., 2006).

However, it is reported that the use frequency of the backrest in actual sitting work is low. People who work sitting long hours steadily change their postures, and they take a posture tilting waist forward and concentrate on computer monitor (Grandjean and Hunting, 1997). It was also reported word processing or CAD computer workers tend to erect their trunk and head without using the backrest (Ellegast et al., 2012). From this, it is known that workers concentrating on work reduce burden to the lumbar by tilting their back, but take a posture not sufficiently supporting the lumbar by sitting in the middle of the seat. One of the causes for such a phenomenon is that interruption of work, when tilting one's back in the sitting state. Rani (2004) pointed out that when a worker reclines the backrest, his hands and head move backward or descend from the work stand, which makes it difficult for him/her to continuously work. Groenesteijn et al. (2009) pinpointed complex usability including adjustment device hinders functional use like posture adjustment.

This study aims to develop an office chair in order to increase the use rate of the backrest in computing work. By designing tilting motion so that upright and reclining postures can be repeatedly changed during work, this study intends to enhance the use frequency of the backrest. Consequently, this study expects to reduce lumbar discomfort with possible continual spinal movement. To this end, this study intends to develop a chair supporting repeated and frequent posture changes without the interruption of work by enabling hands and eyes to maintain working space during back tilting.

2. Method

2.1 Definition of dynamic sitting posture

2.1.1 Definition of variable posture for computer work

Goroh and Reiko (2002) said a posture suitable for VDT (visual display terminal) is to tilt one's back and use a foot hold, and they emphasized posture change needs to be frequently made. Since it is difficult to maintain the same position for a long time, although back tilting posture is a comfortable one, a sitting person needs to move the lumbar cyclically by erecting sitting. Because work should be continually done even in the repeated change of upright and reclining posture, hands and eyes should not be off the working space. For posture change, unnecessary hand motion should not be required, and the change needs to be made in a natural way. As such, sitting steadily changing postures, while working in a sitting position, is called dynamic sitting.

In summary, the posture suitable for VDT users defined in this study needs to meet the following three requirements: First, a posture to sit upright and back tilting posture should be taken repeatedly. Second, hand location should maintain working space during the posture change. Third, view direction during the posture change needs to retain working space. Figure 1 shows the concept mentioned above in drawing.

2.1.2 Factors to maintain hand location within working space

When one's back is tilted in the existing synchronized chair, rotation occurs in human's ankle, knee and hip joint, respectively, and thus, the backward movement and descending of shoulders were huge (Rani, 2004). When minimizing the backward movement of shoulders, as the backrest reclines, hands are expected to maintain working space. To this end, the backrest and seat all need to move forward, when the backrest is reclined. When the backrest is reclined, the seat moves forward, and thus, recovery of human body's center of mass (COM) backward movement is called seat slide type tilt.

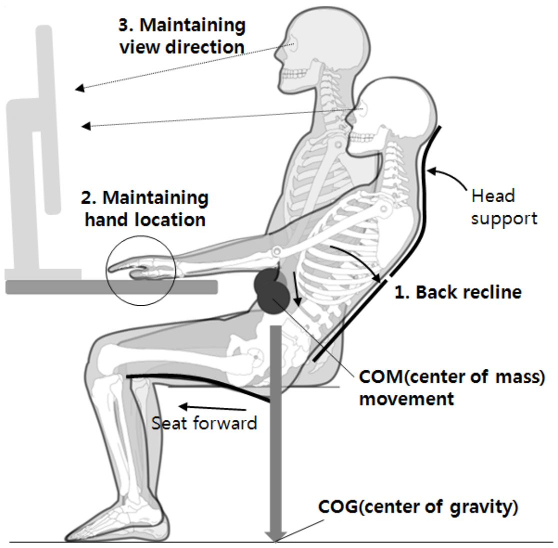

Figure 1. Optimum dynamic sitting posture for visual display terminal user

2.1.3 Factors to maintain visual working space

A sitting person causes a risky posture by erecting his neck to continuously view the monitor, when he/she tilts back (Rani, 2004). A sitting person, while he/she tilts back, needs to re-establish neck position to maintain visual working space. As shown in Figure 1, neck support is necessary to maintain view towards the monitor in back tilting state. The neck support should always be supported vertically in line with the tilting angle of the backrest.

2.2 Design of tilt mechanism

2.2.1 Design of seat sliding type synchro-tilt mechanism

For hands to maintain working space, when one tilts his back, seat needs to move forward some distance. By using a pin-in-slot joint, design for the seat to move forward some distance from the base in linkage with backrest reclining. However, information on proper sliding distance was not found in the existing literature, and thus, this study conducted kinematic simulation using a commercial human body software (ADAMS Lifemodeler^{TM}), and drew the forward movement distance of the seat. This study made a desk model with 720mm in height, and synchronized chair model for which seat and backrest tilt by 9° and 25°, simultaneously, also a human body model (170cam in height) sitting by placing hands on the desk (Figure 2). As a result of conducting inverse kinematic tilting simulation through an order of reclining of the backrest, it was observed that COM moved backward by 108mm, and hands moved backward about 81.7mm along the desk surface.

Figure 3 shows seat slide mechanism designed in reflection of the simulation results. With the function of the rollers installed in the base, and guide slots installed in the backrest, the backrest and seat simultaneously conduct backward rotation and forward movement. The forward movement distance of the seat is 80mm, and the tilting angle is about 9°.

2.2.2 Design of backrest flexion mechanism

To maintain the neck support vertically, this study designed a link system to make coupled flexion of upper backrest in linkage

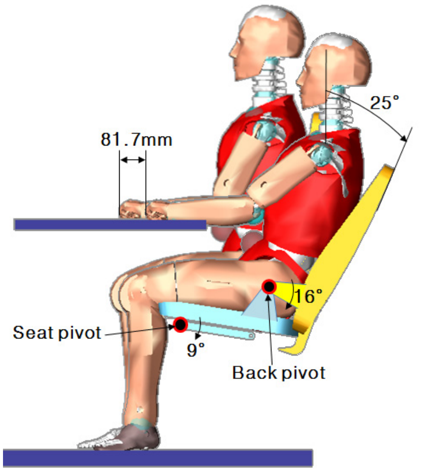

Figure 2. Backwards movement of hand position during back reclining with normal synchronized chair

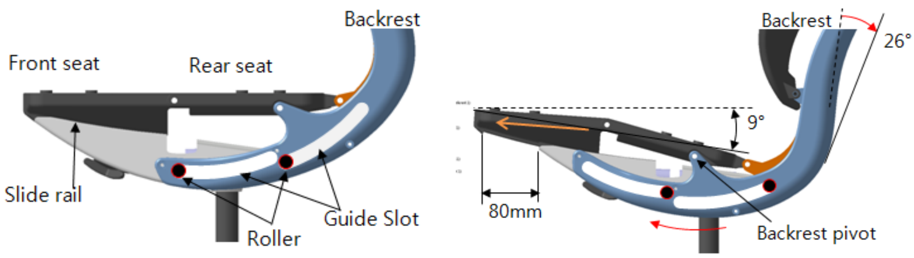

Figure 3. Designed seat slide mechanism guided by pin in slot joints

with the forward movement type slide seat. For flexion to be made in two positions of the backrest, the backrest was divided into three parts, and 4-link connecter and 5-link connecter linkage system were used. At the lower flexion part, and upper flexion part, 13˚ and 15˚ were designed to be reclined, respectively. To move in linkage with the seat, the seat connecters were applied (Figure 4). The top part, where neck support was installed, it rotates 28˚, and thus it always maintained vertical angle, irrelevant of backrest's angle.

2.3 Experiment method

2.3.1 Overview of design draft verification

This study designed a completed chair by combining seat slide mechanism and backrest flexion mechanism and manufactured a chair prototype. For design, CATIA R18 was used. The core function of the designed chair is that the seat moves forward, and the backrest reclines, and thus, neck is supported vertically, when the backrest tilts. Upon backrest reclining, sitting person's hands do not deviate from working space, and the backward movement of human body center of mass (COM) is projected small. Through sitting experiment using the prototype, the design draft was evaluated. Upon tilting the backrest, major joints movements were measured including shoulder, hand, hip and knee through human body motion analysis. Especially, whether hands maintained working space was analyzed upon backrest tilt by identifying wrist location movement. Meanwhile, this study also analyzed the location movement of COG (Center of Gravity) using the force plate. The COG is the central point of force

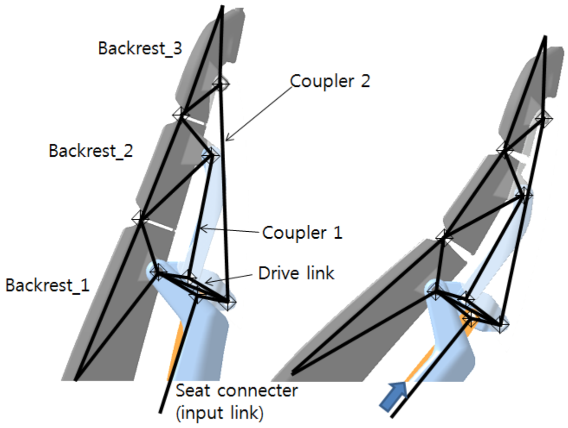

Figure 4. Experimental Chairs (Chair A is Prototype)

applied by sitting person's mass to floor, and the movement of COM can be indirectly forecast as shown in Figure 1.

2.3.2 Experiment environment

This study conducted an experiment recruiting 5 adult males who have no musculoskeletal disorders. The subjects' average [standard deviation] height was 174.6cm [41], and average [standard deviation] weight was 77.2cm [5.4]. The experiment chair was located on the cast-in-place force plate, and also a desk with 730mm height was located in front of the chair. For motion analysis, reflection markers were attached on the human body and on the side of the chair. A total of 12 markers were attached: head, shoulder, hand, pelvis, knee, and ankle for a subject, and front seat, rear seat, upper back, and lower back for a seat (Figure 6). Table 1 shows the human markers' anatomical attachment locations. This study used 3D motion analysis equipment (OP-250-8, MotionAnalysis, US), and motion was measured with 60Hz sampling speed using 8 cameras. The chairs used for the experiment were the prototype chair manufactured in this study, and other general 3 chairs, which are comparison objects (Figure 5). Chair A was the one developed in this study. Chair B was made by the U.S. H Company. Chairs C and D were made by Korea's S Company. Each chair's backrest tilting angle has some slight differences: 22°, 21°, 26°, and 24°. However, they were judged not to affect the experiment results, and thus, the experiment was carried out.

Figure 5. Coupled flexion mechanism of backrest

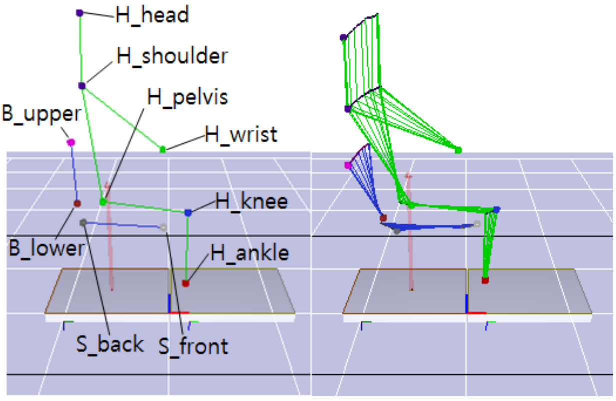

Figure 6. Captured reclining motion

Table 1. Placement of body markers

Marker name	Placement
H_head	Top of head
H_shoulder	Scapula acromioclavicular
H_pelvis	Femur greater trochanter
H_knee	Femur lateral epicondyle
H_ankle	Fibula lateral malleolus
H_hand	Ulnar-Styloid process

2.3.3 Experiment method

The subjects were supposed to adjust the chair height to one's preferred height individually by sitting in the experimental chairs. To take a posture to put hands on the desk, and maintain consistency in distance between hands and trunk, wrists are located on the desk edge (Figure 7). Also, subjects were ordered to repeat back tilting twice. Each marker's 3D coordinate data on backrest reclining motion were acquired. The backrest reclining is a plane motion, and thus, only 2D coordinate data of sagittal plan were analyzed. Meanwhile, the movement distance of COG measured from the force plate was also analyzed. As COG tilting was conducted, backward movement is a general phenomenon. But, concerning the prototype developed in this study, the seat moves forward, upon tilting, and therefore, the backward movement of COG is forecast to be compensated to quite a degree. A statistical analysis was conducted using PASW18 for the collected results.

3. Results

3.1 Result of experiment

Table 2 shows 5 subjects' average [standard deviation] as the values showing the movement distance of each maker and the backward movement distance of COG in the case of tilting. The movement of hands were 13mm, 101.7mm, 156.1mm, and 139.3mm from Chairs A, B, C and D, respectively. The backward movement distance was remarkably small in Chair A. As a result of *T*-test, statistically significant differences were shown as demonstrated in Figure 8 ($p<.001$).

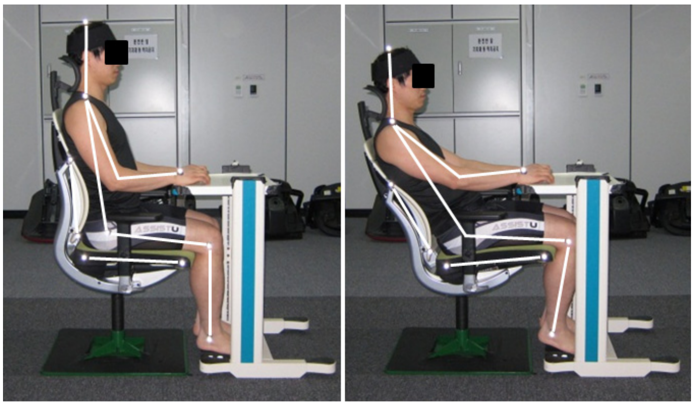

Figure 7. Experimental setup

Table 2. Movement of measured marker (unit: mm)

	Chair A (prototype)	Chair B	Chair C	Chair D
Head	239.0 [61.9]	274.3 [57.4]	484.0 [40]	431.8 [44.9]
Shoulder	196.6 [17.8]	237.2 [28.5]	372.6 [56.4]	314.0 [23.6]
Hip	65.5 [25.8]	33.1 [6.2]	74.9 [8.2]	44.4 [3.4]
Knee	66.0 [31.9]	28.5 [7.3]	53.2 [3.5]	46.0 [7.9]
Ankle	29.0 [13.5]	16.3 [10.7]	13.7 [3.7]	10.8 [7.7]
hand	13.0 [4.6]	101.7 [16.9]	156.1 [16.7]	139.3 [18.2]
COG (Center of Gravity)	10.8 [9.3]	102.8 [41.6]	128.9 [22.8]	84.3 [14.4]

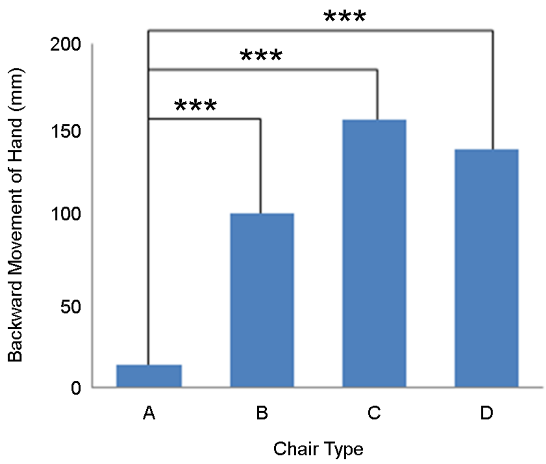

Figure 8. Comparisons of backward movement of hand marker (***p<.001)

The movement of COG, which is applied to the force plate, demonstrated 10.8mm, 102.8mm, 128.9mm, and 84.3mm, in Chairs A, B, C, and D, respectively. Likewise, the backward movement was the smallest in Chair A, and statistically significant differences were confirmed as shown in Figure 9 (p<.001). Meanwhile, the movement distances of head, and shoulder were high of 200mm and more, and therefore, remarkable difference was not demonstrated in Chair A. Rather, the movement distances of hip, knee, and ankle were relatively high in Chair A, and the reason is that it was directly affected by the moving forward motion of the seat.

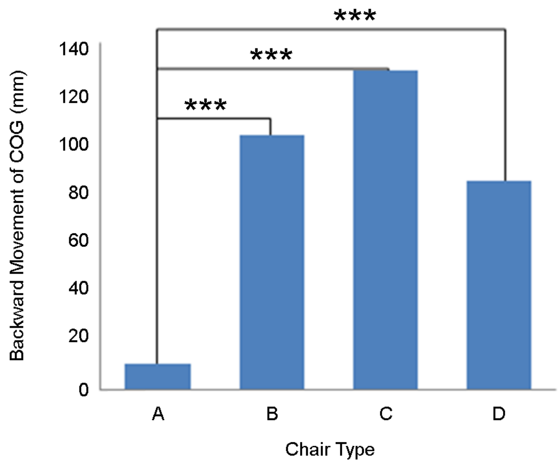

Figure 9. Comparisons of backward movement of COG (center of gravity) (***p<.001)

3.2 Consideration

In Chair A with seat's forward movement function, the hand position and COG's backward movement distance were remarkably smaller than the existing general chairs A, B, and C. The reason is that the seat moves forward 80mm upon backrest tilting, and thus, the backward movements of hands and COG in the existing chairs are mostly compensated. However, the backward movements at the head and shoulder are big, and therefore, they are difficult to be recovered with only seat's forward movement, and thus, 239mm, and 196mm of backward movements were generated, respectively. Meanwhile, the movement distances of hip and knee were the most in Chair A, and the reason is that the hip and knee that directly affected by the forward movement of the seat moved forward together. In Chair A suggested in this study, a sitting person was confirmed to maintain hands within the working space, although the sitting person tilted his back.

Peter (2009) classified sitting postures, according to the slope scope of backrest, and defined forward tilting posture was an active posture, and suitable for writing, and computing. However, he defined backward reclining posture was a passive posture, and suitable for rest, and TV watching. Rani (2004) pointed out upper body moves backwards and descends, and the backward movement distances of hands and COG are big, and thus, working position becomes difficult to be maintained. The back tilting posture is an unsuitable posture, due to backward movement of hands (Rani, 2004), and it has been recognized as a posture suitable for rest (Peter, 2009). Because, the continual movement of spine is an important factor of lumbar health (Kieran et al., 2013), this study suggested a chair that can recline one's back, maintaining working position, and this study intends to induce to repeated posture change. Because a sitting person can recline his/her back during computing work, the lumbar movement is expected to be promoted in case of working long hours in the sitting posture. In the case of the chair suggested in this study, the experiment result that COG's backward movement is small, and hands are not deviated from the working space can be significantly interpreted in that the result can induce repeated posture change.

However, it is not certain a user will show healthy sitting behavior, changing the backrest angle frequently during actual work.

Kieran et al. (2013) found that a dynamic sitting chair does not significantly promote posture change, compared to general chairs, through case study on the dynamic sitting chair to promote posture change. Rather, they said posture change frequency differences are caused, according to work type, rather than chair's characteristics, and also mentioned that ergonomic posture training, or regular posture status notice for chair users are helpful for healthy sitting (Ellegast et al., 2012). Consequently, although a chair is designed to allow user's posture change, whether the user will maintain healthy posture change is affected by various internal and external factors.

4. Conclusion

This study suggested a chair in which a user can repeatedly recline his/her back for lumbar health, when the person conducts work sitting for a long time like computing, and this study evaluated the results through an experiment. By repeatedly changing the upright and reclining postures, and simultaneously to make hands and views maintain working space, this study developed a slide type tilt chair, where the seat moves forward about 80mm, and flexion is made at the backrest upon tilting. Through prototype chair manufacture, and motion analysis experiment, this study confirmed that the hand position did not deviate from the working space upon tilting, compared to other chairs. However, verification on user's behavior according to long time sitting was not conducted, in addition to one-off variable behavior. During the work sitting by concentrating on computing, further study needs to be conducted to identify repeated posture change frequency through long time sitting behavior observation, and check user's discomfort. Interest in dynamic sitting recently increases. Also, posture change type chairs are released to actively support diverse sitting postures change during work. The seat slide type chair, developed in this study, is expected to be an alternative in such a trend.

Acknowledgements

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