Effectiveness of the Movable Seat Surface Evaluated from the Difference in the Start Time of Muscle Activity and Anticipatory Postural Adjustment

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Abstract: Objective: To examine the effects of a movable seat surface with forward tilting and forward locomotion mechanisms from muscle activation time and anticipatory postural adjustment of the trunk and lower limbs in the forward reach task.

Methods: There were 15 healthy adults, and the muscles to be examined were the deltoid muscles, which are the main muscles for reach movement, as well as the left and right external oblique muscles, the left and right erector spinae muscles, and the left and right rectus femoris muscles. The subjects performed a forward reach task using a fixed and a movable seat surface, that was created, and the examiner analyzed the reach time and the start time of each muscle activity.

Results: The reach time did not differ between the two conditions, but the start time of the erector spinae muscle was later than that of the other muscles in the movable condition. Anticipatory postural adjustment associated with reach task was not confirmed.

Conclusion: It was suggested that the movable seat surface enhances the stability of the trunk movement at the beginning of the reach movement and contributes to the reach movement with less sway of the center of gravity.

Keywords: seat surface, reach task, electromyography

Introduction

The sitting posture is the central posture in life, and healthy adults spend a lot of time sitting in their daily lives. McCrady et al. [1] investigated the time spent sitting on workdays and holidays by healthy adults and reported that they spend 400 minutes or more per day sitting on holidays. Burton et al. [2] investigated the sitting time at home for middle-aged people in their 40s and 60s and reported that they tend to spend their leisure time in the sitting position as they get older. It is speculated that this tendency is more pronounced in the elderly. Wattanapan et al. [3] reported that among stroke patients, those who were able to acquire a sitting posture at discharge had high mobility and ability of activities of daily living. From these studies, we believe that intervention in the sitting posture of disabled persons and elderly people who are the target of rehabilitation is especially important from the viewpoint of life support.

The authors are developing a seating surface that can support trunk function even during movement as an intervention in the sitting posture of the subject. Previous studies on reach movements in the sitting posture [4, 5] found that in reach movements exceeding the upper limb length, it was necessary to reach while tilting forward and flexing the trunk and hip joints, and there is a possibility that the seat structure that assumes only static posture maintenance is not sufficient. We are developing a seat surface to assist the original trunk and pelvic movements that occur during the forward reach.
The feature of this seat surface is that it tilts forward, and can be moved forward to assist the reach movement without changing the positional relationship between the pelvis and the trunk. This seat surface is designed to move forward with weight load to the front and return backward while tilting backward owing to the weight load to the rear. This seat surface may assist in the movement of the upper limb. This is because it tilts forward to assist the tilting movements of the pelvis and lower parts of the trunk. It also moves forward to help the trunk tilt forward and rotate.

In a co-author’s study using this movable seat surface for healthy adults [6], it was possible to perform forward reach with less anterior tilts and rotation of the trunk than the normal seat surface. In addition, it was clarified that the muscle activity of the external oblique muscle in the first half of the reach and that of the external oblique muscle in the latter half of the reach were less than those of the normal seating surface. Due to such characteristics of muscle activity, this seat surface may be effective for subjects with weakened trunk function. However, since this study focused on the total amount of muscle activity after the start of reach movement, it was not sufficient to evaluate the postural control required for the sitting-reach movement.

Sufficient postural control ability is indispensable for the performance of voluntary movements [7, 8], and the strategy including anticipatory postural adjustments (APA) that act functionally prior to movement is important. It is said that this APA has a role of minimizing the sway of the center of gravity caused by movements [9], and in the temporal phase, it is often divided from 200 msec before the start of movement to 50 msec after the start of movement [10]. Shimura et al. [11] investigated the relationship between exercise speed and APA appearance time in healthy adults. As a result, when the weight is attached to the upper limb in the standing position and the upper limb is lifted, the movement speed of the upper limb decreases, and the start time of biceps femoris activity is delayed relative to the deltoid muscle, which is the main muscle of movement. In addition, Sadeghi et al. [12] verified the APA of the trunk and lower limbs in patients with and without chronic LBP. The task was to raise the upper limbs in the standing position. As a result, APA of the transversus abdominis muscle and oblique abdominal muscle was confirmed in those without back pain, and the gastrocnemius muscle was confirmed in patients with back pain. It is possible that the difference in the exercise strategy when raising the arms between the two groups may have an effect.

Thus, it has been reported that APA that precedes the activity of the main muscle movement is confirmed in voluntary movements such as reach movements of the upper limbs, and its appearance is influenced by the movement speed and individual movement strategies. However, these have been studied in a standing position in which body sway due to movement is likely to occur. The movable seat surface we made this time has a backrest, and the specifications are such that the movement starts from the state where the back of the subject is attached to the backrest. Therefore, it is expected that the posture using this movable seat surface will not collapse, but studies to examine the timing of muscle activity start in the reach task in such a sitting posture have not been sufficiently conducted. The purpose of this study is to clarify the effectiveness of the movable seat surface from the viewpoint of the timing of the start of muscle activity, including APA.

Method

1. Subjects

The subjects were 15 healthy adults in their 18 to 30s. The average age, height, weight, BMI, upper limb length, and leg length of the subjects were: 22.5 ± 2.7 years old, 171.9 ± 5.2 cm, 60.4 ± 9.0 kg, 20.4 ± 2.5, 73.5 ± 3.2 cm, and 44.9 ± 3.1 cm, respectively. All the subjects were right-handed, so the right side was the reach side. We included participants with a standardized BMI (18.5–25) and no orthopedic, ophthalmologic, otolaryngologic, or neurological history. Excluded were those with: BMI exceeding the standard value, back pain, musculoskeletal disease that impaired reach movement, and those who were unable to follow the explanation.

2. Experimental preparation and equipment

2-1. Surface EMG

EMG was measured using TELEMYO DTS EM-801 (Noraxon), a transmitter (EMG probe) was attached to the derived muscle, and the sampling frequency was set to 1000 Hz and the filter characteristic was set to 15 to 500 Hz. The electrodes were made of silver, and the distance between the electrodes was 2 cm. The measurement region of muscle activity was disinfected with alcohol, skin resistance was reduced with a skin pretreatment agent, and the electrode was attached to the body with a seal. The lead-out muscles are the: anterior deltoid fibers on the reach side, which act as the main muscles of the reach movement, external oblique muscles that are the trunk flexors, lumbar spine erectors that are the trunk extensors, and thigh straight muscles that are the hip flexors. The left and right muscles were measured except for the deltoid muscle. The electrode attachment region of the deltoid muscle was placed on the line connecting the acromion and thumb, one lateral finger distal from the anterior acromion, referring to a
previous study [13]. Similarly, the erector of the lumbar spinal column is located 2–3 cm outside the spinous process along the fiber run in the abdominal muscle. The external oblique muscle is located below the outer side of the 8th rib, along the run of the muscle fiber, and the rectus femoris was placed 10% proximal from the center of the line connecting the anterior iliac spine and the upper part of the patella.

2-2. Movement task

The movement task was a forward-reach task. Figure 1 shows the experimental environment and the arrangement of the measuring instruments. The starting posture and the method of performing the reach movement were based on previous research [14]. Specifically, the starting limb position was seated with the back resting on the back, the foot was grounded on the floor with ankle dorsiflexion of 0°, and the hand on the reach side was held on the thigh. Reaching was performed by the subject's dominant hand, and the upper limbs on the opposite side of the reach were kept in a comfortable position on the body side so as not to affect the sitting posture. The subject reached a switch connected to a sensor light at the level of the acromion at 130% of the length of the upper limb and reached a free speed to return to the starting posture. After sufficient practice, the reach movement was performed 5 times in this trial, but to clarify the breaks for each trial, after returning to the starting posture, resting for 3 seconds was followed by the next trial. Afterwards, the seat surface condition was changed, and the task was repeated.

2-3. Seat surface and experimental conditions

In this study, we used a seat made by the co-author (Fig. 2). The size of the seat surface is 40 cm in width × 41 cm in depth, and the seat back angle is 95°, which is the same as that of a general wheelchair. It has a spring structure under the chair, and when the user moves his/her weight backward while sitting down, the spring contracts, the seat surface tilts up to 4° and stops. When the weight is moved from the buttocks to the feet, the elastic force of the spring works, the seat surface leans forward up to 8.7°, its midpoint moves forward by 6.5 cm and moves upward by 3.5 cm. Previous studies [15] reported that tilting the chair forward by 10° or more has little benefit to subjective sitting comfort and spinal muscle activity, especially in the elderly. As we expected that the seating surface we created in this study will be used by elderly people in the future, we set the forward tilt angle to 10° or less. The spring under the chair has a hydraulic damper mechanism; therefore, the moving speed of the seat surface is almost constant both forward and backward.

The experimental conditions were fixed and movable. The seat surface angle at the beginning of the experiment was 4° backward tilt, which is the angle used in general wheelchairs in both conditions. The seat height was adjusted to 4 cm below the length of the lower leg [16]. Under the fixed backward tilt condition, it does not move as it is, and under the movable condi-
tion, the seat tilts forward and moves forward within the above range.

3. Data analysis

Three trials between the 1st and 5th trials were adopted as trials for data analysis. We measured the timing of the muscle activity start and reach time when the subject underwent a reach task under fixed and movable conditions. In this study, we analyzed data from the start of the operation to touching the target. The start point of the reach movement was the timing when the activity of the anterior deltoid muscle fiber was observed. Moreover, the timing of touching the target object was judged from the blinking of the sensor light on the WEB camera that was shooting the sagittal plane. From these times, the reach time for each subject was analyzed.

Data analysis of muscle activity was performed using Myo Muscle Master (Noraxon). The analysis was performed after rectifying all the waveforms to be analyzed, referring to a previous study [17]. The definition of the onset of muscle activity refers to the method of Dean et al. [16]; use the average amplitude when resting for 10 seconds as the baseline, and when muscle activity was over 3SD of baseline and continued 25 ms or more. Using the obtained activity start time of each muscle, other muscle activity start times were calculated when the activity start time of the right deltoid anterior fiber, which is the main motion muscle, was set to 0 s.

4. Statistics

Comparing the reach time and the start time of muscle activity in the reach task obtained under fixed and movable conditions. As for the statistical processing method, we performed a paired t-test for the difference in reach time between conditions and the difference in activity start time for each muscle, and if normality is not recognized, the Wilcoxon signed-rank test was performed. A one-way ANOVA was performed to determine the difference in muscle activity start time between conditions, and a post-hoc test was performed by the Sidak method when a significant main effect was observed. Friedman’s test was used for non-normal distribution, and a post-hoc test was performed using the Wilcoxon signed-rank test when a significant main effect was observed. However, the significance level was modified by Bonferroni correction. The significance level was set at 0.05. IBM SPSS Statistics 25 was used for analysis.
5. Ethics
This study was carried out with the approval of the Sapporo Medical University Ethics Committee (approval number 24-2-33).

Result

1. Reach time
Figure 3 shows the reach time from the start of the deltoid muscle activity until the sensor light is touched. It was 1.57 ± 0.42 seconds under fixed conditions and 1.64 ± 0.40 seconds under movable conditions. As a result of statistical processing, no significant difference was found.

2. Start time of muscle activity
Figure 4 shows the other muscle activity start times (s) when the deltoid muscle activity start time is 0 s, in order from the earliest activity start time. Under fixed conditions, in order from the earliest, start time was 0.14 ± 0.24 for the right external oblique muscle, 0.36 ± 0.64 for the left external oblique muscle, 0.58 ± 0.39 for the right spinal erector, 0.58 ± 0.43 for the left erector, 0.30 ± 0.41 for the right rectus femoris, and 0.26 ± 0.21 for the left rectus femoris. As a result of statistical processing, no significant difference was found in the muscle activity start time within the conditions. No APA was confirmed to appear between 200 ms before the start of exercise and 50 ms after the start.

Similarly, under the movable condition, in order from the earliest, the start time (sec) of muscle activation was 0.22 ± 0.36 for the right external oblique muscle, 0.21 ± 0.14 for the left external oblique muscle, 0.79 ± 0.49 for the right spinal erector, 0.89 ± 0.52 for the left spinal muscle, 0.17 ± 0.22 for the right rectus femoris, and 0.39 ± 0.20 for the left rectus femoris. As a result of statistical processing, a significant difference...
was found within the conditions ($F_{5,48} = 2.439, p < 0.05$). As a result of the analysis of variance, the erection of the right spinal column was significantly later than that of the right external oblique muscle and the right rectus femoris ($p < 0.05, p < 0.01$, respectively). In addition, the erectors of the left spinal column had a significantly later onset time than the right external oblique, left external oblique, and right rectus femoris muscles ($p < 0.01, p < 0.05, p < 0.01$, respectively). No APA was confirmed to appear between 200 ms before the start of exercise and 50 ms after the start.

Furthermore, when the same muscles were compared between the fixed and movable conditions, a significant difference was observed only in the left erector spinae muscle, and a delay in the activity start time was confirmed under the movable conditions ($p < 0.05$).

Discussion

In this study, we examined the effectiveness of the movable seat surface from the reach time and the start time of muscle activity in healthy adults. As a result, there was no significant difference in reach time between the fixed seat surface and the movable seat surface. Analysis of the muscle activity start time showed that there was no significant difference in the activity start time of each muscle on the fixed seat surface, and the activity was started from the right external oblique muscle. On the movable seat surface, it was confirmed that the activity of the left and right erector spinae muscles was delayed compared to the abdominal oblique muscle and the rectus femoris muscle, and the activity was started from the right rectus femoris muscle. From these results, it was shown that there is no difference in the time required to perform the reach task, but the movement strategies may differ between the two seat surfaces.

1. Appearance of APA

Among the muscle activities involved in postural control, the comparison of the start time of other muscle activities with respect to the main motion muscle revealed a difference in the movement strategy between fixed and movable conditions. That is, under the fixed condition, the activity was started from the external oblique muscle on the reach side, and under the movable condition, the activity was started from the rectus femoris muscle on the reach side. In the movable condition, the left and right erector spinae muscles were activated later than the external oblique and rectus femoris muscles. It is considered that this is because the movable seat surface supports the movement of the trunk in the reach task. Kamisaki et al. [5] performed a forward reach task at a distance that can be reached only by the upper limbs, a distance that can be reached using the trunk and upper limbs, and a distance of 33% and 66% between those distances. As a result, hip flexion was hardly seen at the upper limb length, but at all distances beyond the upper limb length, the hip flexion angle increased with increasing reach distance and the anterior tilt of the trunk increased. In addition, in a study by Nakaya et al. [6], a collaborative researcher who performed muscle activity and motion analysis using the same seat surface as in this study, the movable seat surface has less activity in the external oblique muscles at the beginning of movement in the first half of the reach than the fixed seat surface, and less forward tilting and rotation of the trunk. As described above, the movable seat surface used mainly assisted the anterior tilting of
the trunk necessary for the forward reach movement and could contribute to the reduction of the muscle activity amount and the movable range at that time. Furthermore, this time, from the timing of muscle activity start, in the reach task, as shown in the fixed condition, the trunk is flexed by the activity of the external oblique muscle, the erector spine erector, which is an antagonist muscle, works almost simultaneously with the flexion of the trunk and hip joints, and the simultaneous contraction of the trunk is maintained. On the other hand, by using the movable seat surface, it assists the anterior movement of the trunk to increase the stability at the beginning of movement of the trunk. Spine upright muscle activity may have been delayed relative to the oblique and rectus femoris muscles. The same reason is considered that only the contralateral erector spinea muscle was significantly delayed in the comparison between the conditions. In addition, six subjects were asked about the ease of movement under each condition in five stages of “very easy to move, easy to move, neither, hard to move, and very difficult to move.” All respondents answered, “easy to move” on the movable seat surface, but under fixed conditions, 1 responded “difficult to move” and 5 responded “neither.” From this, the movable seat surface is a seat surface that subjectively feels easy to move, and there is a possibility that it is a seat surface that is easy to reach in terms of muscle activity, start time of muscle activity, and movement strategy as seen from motion analysis. Under the movable conditions, while the stability of the trunk was maintained, it was necessary to load the seat forward while keeping the sole and buttocks in contact with the ground to operate the seat surface. Therefore, it is possible that the rectus femoris muscle acted first and prioritized the flexion of the hip joint. It is necessary to verify how much muscle activity is required to operate the movable seat surface in the future.

In addition, the delay in the onset time of erector spinea muscle activity, which was shown this time, is an important finding when considering adaptation to the elderly and persons with disabilities who have an imbalance in muscle tone. Yokoyama et al. [20] investigated the sagittal plane angle of the spine with age, and the thoracic spine entrance angle, thoracic kyphosis, and C2–C7 sagittal vertical axis increased and the round spine posture increased with age from late middle age. It is known that such spinal deformity leads to deterioration of ADL ability and motor function, and shortens the functional reach distance [21]. In the case of such a subject, it may be difficult to make the trunk extension motion under fixed conditions confirmed this time. In addition, in subjects with central nervous system disorders such as cerebral palsy, it is often clinically experienced that trunk extension activity easily affects the whole-body extension pattern due to abnormal muscle tone. That is, for such a subject, the movable seat surface that may delay the extension activity of the spinal column may support movement while avoiding excessive effort and posture collapse at the start of the reach movement.

**Conclusion**

In this research, we showed the effectiveness of the movable seat surface for healthy adults and the future clinical application from the difference in start time of muscle activity. Since support for the trunk function of the subject is often static, we consider that the effect of dynamic support, including wheelchairs and seating system devices that match body movements is a necessary research theme. To verify the effect of the movable seat surface prepared this time, it is necessary to clarify not only the reach task but also the daily activities such as eating and writing on the subject. In addition because the movable seat surface used this time was designed so that it moves due to body weight movement, it is necessary for the subject to have a certain level of motor function. Therefore, we would like to study the mechanism, direction, and degree of seat movement in the future.

**Conflicts of interest statement**

The authors have no conflicts of interest relevant to this article.

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