I. Introduction

Individuals with cerebral palsy (CP) usually experience disabilities in postural control, such as direction-specific patterns of adjustments and center of mass stability [1]. Therefore, many such individuals require support to maintain balance while sitting and are limited in the performance of upper-limb tasks that move the center of gravity. Individuals with postural issues require extrinsic support to perform activities of daily living with unobstructed voluntary movement. Seat cushion adjustment in wheelchairs is one approach for providing postural support. Previous studies show that seat surface inclination can affect sitting posture and upper-extremity function in children with CP. A more vertical trunk position is associated with more efficient performance [2–4], and the use of an anterior inclined seat is related to initial head position [5]. However, such an anterior inclination could cause forward slippage or burden the lower limbs if used during activities of daily living. The use of seat cushions may help avoid the risks of seat surface inclination. Many seat cushions have been developed to disperse pressure for individuals with CP. However, soft seat cushions and materials that avoid high pressure have some problems concerning instability during movements [6]. As individuals with severe motor disability spend much of their life sitting, it is necessary to investigate seat cushions appropriate for dynamic tasks. Therefore, we developed a seat cushion that aims to facilitate movement for individuals with cerebral palsy who have postural control disabilities.

We previously measured the effect of this silicone seat cushion in terms of the displacement of center of pressure (COP) during a dynamic task. The COP, which is calculated by the dispersion of pressure and an area added to the seat surface, is an index of body disturbance that is closely associated with body sway [7–9]. We observed no difference in COP displacement between seat cushions of different materials in healthy...
adults; however, the silicone seat cushion was associated with decreased COP displacement in individuals with CP [10]. However, the effects of the silicone seat cushion on the timing of movement onset during a reaching task in individuals with CP were not thoroughly investigated. The onset of trunk motion related to movement stability occurs significantly earlier than the onset of peripheral motion related to manipulation during a dynamic task that requires trunk movement [11]. Thus, when evaluating stability, it is necessary to evaluate not only COP displacement but also the timing of movement onset in the peripheral limb and trunk to establish the efficiency of the new silicone seat cushion. Therefore, this study examined COP displacement and the timing of movement onset during a reaching task using three different cushions including a new design made with silicone materials and two others made with conventional urethane materials.

II. Methods

1) Subjects

The study group consisted of 10 healthy adults and three individuals with CP. The healthy adults (all males, mean age 22.9 ± 2.5 years, height 172.5 ± 5.0 cm, weight 64.5 ± 6.4 kg, body mass index [BMI] 21.7 ± 1.7 kg/m², and arm length 72.0 ± 2.4 cm) had no physiological impairments. Individuals with CP (1 male and 2 females, mean age 45.7 ± 4.2 years, height 154.2 ± 6.9 cm, weight 54.2 ± 7.3 kg, BMI 22.9 ± 4.0, arm length 51.6 ± 3.0 cm) were able to maintain an independent sitting position and follow oral instructions (Table 1). Two subjects with CP had level III disability, and one had level IV disability according to the Gross Motor Function Classification System (GMFCS) [12]. They had low muscle tone in the trunk, indicating the absence of postural stability. Two subjects had instability but a low magnitude of body sway and no involuntary movement in activities of daily living. The other subject had both instability and involuntary movement, and sometimes fell during walking. In addition, all of them had functions of reach for the objects during sitting, however limitations manipulating objects of varying quality and quantity. All subjects signed informed consent forms approved by the Ethics Committee of Sapporo Medical University. In addition, this study was performed in compliance with the Declaration of Helsinki and placed careful attention on protecting the privacy and human rights of the subjects. And the authors have no conflicts of interest directly relevant to the content of this article.

2) Instrumentation

During the reaching task, the pressure distribution at the body–seat interface was recorded at 10 Hz using a FSA mat (Vista Medical, Canada), which consists of 225 force sensors organized on a flexible mat in a 15 × 15 grid. The FSA mat was calibrated up to its maximum pressure of 520 mmHg. A web camera (BWC-130MS03A, Buffalo, Japan) was connected to the FSA.

Movements were recorded kinematically with a Locus 3D MA-3000 video monitoring system (Anima Corp, Japan) using a six-camera configuration at a sampling frequency of 100 Hz. Reflective markers were placed on the side of the body corresponding to the dominant hand on the following landmarks: (1) processus spinosus at C7, (2) processus spinosus at T10, (3) processus spinosus at L5, (4) right acromion, (5) left acromion, (6) olecranon of the dominant hand, and (7) styloid process of the ulna of the dominant hand (Fig. 1).

3) Reaching task

The distance between the popliteal fossae and front edge of the seat was adjusted to 5 cm. Subjects were seated on a stool with their hips and knees both bent at 90°, feet hanging free, and without back, leg rest, or arm support. Arm length was measured using a measuring tape from the acromion process to the tip of the third finger while the subject sat in a seated position with the upper limb extended in the horizontal plane and pointing in a forward direction. A small 1 × 1-cm yellow switch was used as a target and set at a distance of 120% of the arm length, level with shoulder height. The task used in

<table>
<thead>
<tr>
<th>Gender</th>
<th>Age</th>
<th>Height</th>
<th>Weight</th>
<th>BMI</th>
<th>Arm Length</th>
<th>Type</th>
<th>GMFCS</th>
<th>Fine motor skill</th>
<th>Trunk tone</th>
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<tbody>
<tr>
<td>cp1</td>
<td>F</td>
<td>49</td>
<td>149.0</td>
<td>61.0</td>
<td>27.5</td>
<td>49.6</td>
<td>SQ</td>
<td>III  severe</td>
<td>Low</td>
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<tr>
<td>cp2</td>
<td>M</td>
<td>47</td>
<td>151.7</td>
<td>46.5</td>
<td>20.2</td>
<td>50.2</td>
<td>SQ</td>
<td>IV   severe</td>
<td>Low</td>
</tr>
<tr>
<td>cp3</td>
<td>F</td>
<td>41</td>
<td>162.0</td>
<td>55.0</td>
<td>21.0</td>
<td>55.0</td>
<td>SD + Ath</td>
<td>III  severe</td>
<td>Low</td>
</tr>
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</table>

Note. M = male. F = female. SQ = spastic quadriplegia. SD = spastic diplegia. Ath = Athetosis

GMFCS = Gross Motor Function Classification System. (Palisono et al., 1997).

Fine motor skill: severe = The performance is slow and achieved with limited success regarding quality and quantity.

modulate = Handles most objects but somewhat reduced quality and speed of achievement.

mild = At most, limitations in the ease of performing manual tasks requiring speed and accuracy.
this study involved reaching for the target repeatedly. The subject started with his or her hand resting on the ipsilateral thigh for the initial position. During reaching, the unused hand was placed on the contralateral thigh to ensure stability.

Subjects performed the reaching task for 60 seconds using the following three seat cushions in random order: a low-rebounding urethane cushion (cushion A, density 55 ± 5 kg/m^3, impact resilience > 15%), a high-rebounding urethane cushion (cushion B, density 40 ± 2 kg/m^3, impact resilience > 30%), and the new silicone seat cushion (cushion C). The silicone cushion consisted of 12 × 12 columns (height 5 cm, diameter 3 cm) with individual columns separated by 5 mm. The hardness of the silicone, determined by a durometer (TECLOCK, Japan), was A15.

The pace of the reaching task for healthy adults was modulated with a metronome (46 beats/min). No instructions on movement speed were given to individuals with CP. They were instead instructed to perform the reaching movement as many times as possible without losing their postural balance. The subjects practiced the task three times before measurement.

4) Analysis

Movement time (MT) was defined as the duration between the beginning of one reaching movement and the next in healthy adults. Mean MT was calculated over 20 trials for each seat cushions as the achievement of task. We set the target of analysis 20 times after the start in order to clarify the effect of the movement by the seat material. For subjects with CP, the number of successful reaches was assumed the achievement of task for each seat cushions.

The pressure exceeding 20 mmHg measured by the FSA was analyzed as COP displacement. The straight rate (SR) was calculated as the total hand path from beginning the reaching movement to touching the target divided by the difference between the target and starting position. SR represents the straightness of the hand trajectory [13] and has an ideal value of 1; the smaller the SR, the straighter the hand trajectory and more efficient the movement. In addition to SR, displacement in the anterior/posterior (AP) and medial/lateral (ML) directions was also calculated. The mean values ± 2SD of the SR, AP, and ML in healthy adults were considered the standard values in this study.

Statistical analyses were performed using SPSS version 21 (SPSS Inc., USA). Repeated-measures ANOVA was used to examine the effects of seat cushions on SR, AP, and ML. The threshold for statistical significance was \( p < 0.05 \).

The marker on the styloid process of the ulna of the dominant hand was defined as the hand marker. The movement trajectory of the hand marker in the horizontal and sagittal planes was calculated. In addition, the maximum velocity of each joint marker was calculated during the reaching task, and movement onset was defined as the continuous change in hand velocity exceeding 5% peak velocity. The timing of movement onset was calculated in terms of the difference in movement onset of each joint marker from that of the hand marker.
III. Results

1) Healthy adults

(1) MT

All healthy adults successfully performed the repeated reaching task. The means MT for seat cushions A, B, and C were 2.61 ± 0.02, 2.62 ± 0.05, and 2.62 ± 0.02 s, respectively. There were no significant differences between seat cushions ($F_{2,18} = 0.114, p = 0.894$).

(2) Measurement of body pressure

Figure 2 presents the means of COP for healthy adults. No significant differences in SR, AP, or ML were observed among cushions. Therefore, the standard values in this study were SR, 1.60; AP, 12.45; and ML, 1.49.

Fig. 2. Mean SR, AP, and ML displacements of COP in healthy adults.

(a) Mean SR, (b) Mean AP displacements, (c) Mean ML displacements

No significant differences were observed between the cushions.
※ SR: straight rate, AP: anterior/posterior, ML: medial/lateral, COP: center of pressure
※ seat cushion; A: low urethane, B: high urethane, C: silicone

(3) Trajectory of the hand marker

Subjects were consistently able to reach straightly to the target from the initial position (Fig. 3). No difference was observed among seat cushions.

Fig. 3. The trajectory of the wrist joint motion in healthy adults.

Upper graph showed the horizontal plane. Lower graph showed the sagittal plane.
Left graph is seat cushion A, Center graph is seat cushion B, Right graph is seat cushion C.
In each trace, the left side is the start of movement, and the right side is the completion of the reach.
The trajectory of the reach motion from completion of one reaching movement back to the start position was excluded.
Each curve represents a trace from a single trial, and each graph contains all trial.
※ seat cushion; A: low urethane, B: high urethane, C: silicone

(4) Movement onset of each joint

Figure 4 shows the timing of the movement onset in each joint. The graph depicts the start time lag (s) of
other markers with respect to the hand marker when the movement onset of the hand marker was set to 0. In all cushions, all markers on the trunk started movement earlier than the hand marker.

2) Individuals with CP
(1) Number of reaches
Subjects with CP were able to reach the target 10 or more times using seat cushion C. By contrast, they were unable to reach the target 10 times using the two urethane seat cushions (Fig. 5). In particular, the fewest reaches were observed using the high-rebounding cushion (cushion B).

(2) Pressure (Fig. 6)
The SR of seat cushion C was almost 1 or smaller than the standard value. The mean AP was smaller than the standard value in every seat cushion. ML was greater than the standard values in all subjects regardless of the seat cushion used. CP1 and CP3 subjects demonstrated the smallest disturbance in ML on seat cushion C.

(3) Trajectory of the hand marker
Figure 7 illustrates the trajectories of movement. Traces were more linear and consistent with seat cushion C than the other seat cushions.

(4) Movement onset of each joint
Figure 8 shows the timing of movement onset in each joint. Using seat cushions, A and B, almost all trunk markers started moving after the hand marker. By contrast, in the seat cushion C, trunk markers, in particular the acromion, started moving earlier than hand marker.

IV. Discussion

1) Effects of seat cushions in healthy adults
Healthy adults were able to perform the task at the prescribed pace and number of times. The speed control of arm motion varies when the movement speed slows down [14]; therefore, the task was designed with a constant rhythm. As a result, there was no difference in movement velocity among the seat cushions. In addition, the SR, AP, and ML values of the COP were not significantly different among seat cushions. The healthy subjects’ proficient posture adjustability can be considered a factor in their high performance regardless of the seat cushion material used as a base of support.

Movement analysis supported this hypothesis, indicating the right acromion began moving earliest with all cushions and that the trunk moved prior to peripheral parts. This timing is due to anticipatory postural adjustment (APA) [15, 16]. APA is a postural adjustment function that stabilizes posture during disturbance caused by voluntary movement and is largely related to developmental processes [2, 17]. Various investigations into APA have been conducted since it was first reported in 1967 by Belen’kii [18]; however, in healthy adults with mature motor function, APA is thought to function by increasing the efficiency of a movement. In other words, by stabilizing the trunk, the center of the body, during a movement and reducing shaking, APA helps exercise the pectoral girdle, a moving segment, more efficiently and improves the accuracy of a movement [14].
As the reaching task was designed to require a reach longer than arm length, forward movement of the trunk was required, and movement of the center preceded that of the periphery for more efficient movements. Previous studies also reported that the center begins moving earlier than the arm and suggest a connection between the movements of the center and arm [11]. Therefore, it can be presumed that healthy adults use this strategy for efficient movement wherein they stabilize their center to move closer to an object.
2) Effects of seat cushions in individuals with CP

According to a previous report, in a reaching task requiring greater posture adjustment such as circumnutation of the trunk, CP patients prioritized the stability of the center rather than the motion efficiency of the periphery; thus, the movement of the peripheral controlling part tended to be unstable [13]. The results of the present study also demonstrate that the motion trajectory of the wrist joint was extended on a more unstable seat cushion, requiring posture stabilization. By contrast, all subjects had a stable motion trajectory, and their motion start time was similar to the motion pattern of healthy adults on the silicone seat surface. Therefore, we hypothesize that the improvement of trunk support enabled the forward movement of the trunk, leading to improvements in task performance and stability of the motion trajectory compared to those on the urethane seat surface.

The cause of the improvement in trunk support with the silicone seat cushion might be the sensory feedback exerted from each silicone tube, supplying the posture control mechanism of the trunk with more information. CP patients cannot gain adequate sensory feedback because of somatosensory system dysfunction and may have difficulty controlling their posture [7, 19], which can result in increased shaking during balancing in the standing position [7]. As this study confirms the effects of the silicone seat cushion specifically in subjects whose trunks were hypotonic, it demonstrates the possibility that the postural control of such subjects can be
promoted by environmental factors such as seat surface material to help them exercise more efficiently.

V. Conclusion

The findings of this study indicate that the use of a silicone seat cushion increases the number of reaches, efficiency of COP displacement, and stability of the trajectory of peripheral movement in individuals with CP who have hypotonic trunk muscles. Therefore, seat cushion design may improve movement in individuals with cerebral palsy who have postural control disabilities. However, further larger studies considering multiple clinical conditions are needed. In addition to the current reaching task, the use of a silicone cushion should be investigated in many reaching and manipulation tasks resembling activities of daily living.

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References