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The effects of the pressure on the coccygeal skin on the perception of backward-leaning sitting positions in stroke patients.

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Abstract

The present study investigated the effects of an additional pressure stimulus on coccygeal skin using an original tool to evaluate the perceptibility of sitting while leaning backward in 13 chronic stroke patients who were able to walk independently and 12 age-matched healthy subjects. Each participant’s perception of the trunk reference angle at which they felt the highest-pressure stimulation of the coccygeal skin while leaning backward from a quiet sitting position was evaluated based on the accuracy of each reproduction under both normal and additional pressure conditions. The absolute error under the pressure condition was significantly smaller than that under the normal condition in the control group, while no marked difference between conditions was found in the stroke group. The relationship between the absolute error under the normal condition and the pressure effect index showed a significant negative correlation in the stroke group. In stroke patients with a high trunk position perceptibility under the normal condition, the additional pressure information may have functioned as a disturbance and reduced the position perceptibility. In contrast, stroke patients with a low perceptibility in the normal condition may have been able to re-weight and prioritize the additional pressure information in the reference frame. In the control group, the added pressure information may have been re-weighted as prior position information in the reference frame.

Keywords: coccyx pressure information; trunk position perception; sitting position; backward leaning; sensory weighting

1. Introduction

One of the purposes of physical therapy in the early stage after the onset of a stroke is to improve the patient's ability to maintain an upright position while sitting as much as possible. The ability to maintain one's balance while sitting in the subacute stage of stroke is an important predictor of the functional recovery of stroke patients [10, 16, 24]. Trunk training exercises improve trunk control and dynamic sitting balance in subacute stroke patients [6]. Appropriate trunk muscle strength and neural control as well as an accurate sense of the trunk position are required to maintain stability in the sitting position [7].

Stroke patients with a history of falling backward from a sitting position showed larger trunk repositioning error during sitting than control subjects [21], a reduced ability to control the trunk and avoid falling backward to the hemiparetic side when their eyes were closed [19], and a greater body fluctuation on the anteroposterior direction while sitting than age-matched normal participants [14]. In terms of clinical intervention, weight-shift training in the sitting position improved the dynamic balance of the trunk as well as the perception of the trunk position in stroke patients [15] and improving perception of the trunk position led to a positive effect on trunk control [18]. Therefore, an accurate perception of the trunk position is related to improved posture control and sitting stability.

In normal subjects, perception of the trunk position while sitting is lower at positions located close to the quiet sitting posture and higher close to the most backward-leaning positions [1]. Similarly, the standing position perceptibility is higher at positions near the most backward leaning position [12]. Large changes in pressure information from the heel while leaning backward in a standing position are considered important clues concerning position [2,13]. It was thus also considered that additional sensory information derived from the skin at the coccyx region to increase the amount of such information available might support perception of the sitting trunk position and thereby improve control and prevent falling backward in stroke patients.

However, the perceptibility of backward leaning while standing did not always improve when the heel pressure information was artificially increased in normal subjects [3]. This result was thought to be due to the existence of individual sensory weighting in the sensory reference frame when interpreting the environmental situation of the body [8,11,20]. In other words, for subjects who weight pressure information from the heel when perceiving the backward leaning position, the additional pressure had a positive effect on their perception, while a significant negative effect was observed in subjects who emphasized other information. Therefore, it is reasonable to consider that, in normal subjects, individual sensory weighting differences may also be observed in the effect of the additional sensory information from the coccyx region on the perception of the sitting trunk position.

The present study examined the effectiveness of an additional pressure stimulus on the coccygeal skin (using a plastic eraser) and differences in its sensory weighting among individuals based on the change in perceptibility of backward trunk leaning while in the sitting position in stroke patients and age-matched normal subjects. In addition, this study clarified the effect of stroke on the characteristics of sensory reweighting for additional information. Our findings may provide scientific evidence supporting an additional stimulus to improve stability in the sitting posture and prevent backward falling among stroke patients.

2. Methods

2.1. Subjects

Thirteen chronic stroke patients (stroke group) (64.8±10.4 years old, 111±92.1 months post-stroke [mean ± standard deviation {SD}]) were recruited from the outpatient clinical services division of Kanazawa Red Cross Hospital. Twelve age-matched healthy (non-neurologically impaired subjects [control group, 63.8±10.8 years old]) were recruited from among residents of the metropolitan area of Kanazawa City. The principal investigator evaluated the medical history and dementia rating (Mini Mental State Examination [MMSE]) and assessed the balance (Berg Balance Scale).

The inclusion criteria for post-stroke participants were the ability to walk independently with or without a T-shaped cane and the ability to stand independently from a chair. The exclusion criteria were as follows: MMSE score < 24 and a history of spasticity treatment and/or surgical treatment of the lower limbs or any other medical or surgical condition affecting locomotion in the six months preceding the evaluation day of this study.

All participants gave their informed consent to participate in this experiment, the protocol of which was approved by the institutional ethics committee of Kanazawa University in accordance with the Declaration of Helsinki (Approval no. 815-1).

2.2. Apparatus

All measurements were taken with the participants seated on a chair with a hard, 50×50 cm seat surface. The participants first sat down on the chair, aligning the front edge of the seat surface with a point 60% along the length of the thigh from the greater trochanter to determine the initial quiet sitting posture.

In this study, the trunk angle was defined as the angle between the goniometer's vertical arm and the longitudinal axis through both the right trochanter and the right acromion. A manual goniometer attached to an inclinometer with a resolution of 0.1° (BM-801; Ito, Miki, Japan) was used to measure the trunk angle [1] (Figure 1A). This goniometer was able to move manually on a horizontal sliding rail set on the right edge of the seat, and the axis of the goniometer was also able to move manually in the vertical direction to precisely match the right trochanter of the participant in the sitting position (Figure 1A–D). The reference point of the goniometer's moving arm was aligned with the right acromion (Figure 1B, D).

A half-cylinder-shaped original tool made from a plastic eraser was designed to increase pressure stimulation to the coccygeal skin while the trunk leaned backward in the sitting position (Figure 2). The shape of this tool was decided after a pilot study. The convex side was adhered to the gluteal cleft using double-sided tape, and the edge of the tool was attached to the skin at the end of the coccyx.

2.3. Procedure

Measurements were performed with the participants wearing short leggings, sitting barefoot, with their eyes closed. The subjects sat keeping both arms crossed on the chest with no support for the trunk or arms. The chair seat height was 1.5 times the subject's lower leg length to allow for free movement of the knee joints and avoid any contact of the feet with the floor.

The participant's perception of the reference angles was evaluated based on the accuracy of each reproduction. The three reference angles were set as follows: 1) trunk angle where the participants felt the highest-pressure stimulation to the coccygeal skin while leaning from the quiet sitting position (x°); 2) x°+5° forward (+5°); and 3) x°+10° forward (+10°). This experiment was conducted under both the normal condition (no pressure) and the pressure condition (pressure with the original tool described above). These reference angles were repeated randomly five times. The experiment consisted of three sets of five random positions, with three minutes of rest time between each set. The order of these conditions was randomly decided for each subject and performed on the same day.

Each reference position was reproduced by the following procedure [1] (Figure 3):

(1) The participant maintained the quiet sitting (QS) posture for 3 s.

(2) The participant voluntarily and slowly (within 10 s) adjusted their sitting position by leaning forward or backward with the hips as pivotal axes until the experimenter gave the verbal instruction "OK" (reference position angle) and then maintained and perceived the

position for 3 s.

(3) Without returning to the QS posture, they stood up for 3 s.

(4) The participant then sat down again, maintaining the QS posture for 3 s.

(5) The participant was asked to reproduce the reference position (reproduced trunk angle). They were instructed to say “yes” when they judged themselves to be sitting in the reference position and maintained this position for 3 s.

In each case, the time elapsed from the initial memorization of the reference position to its reproduction was within 20 s, which is within the limit of short-term memory [22].

2.4. Data analyses

The data analysis mainly focused on x°. The data of other reference positions (+5° and +10°) were included to avoid a learning effect of x°. The perceptibility was evaluated by the measured reproduced absolute error (the absolute error) between the reference angle and the reproduced angle. The absolute error was calculated using the following formula:

Absolute error = | (reproduced trunk angle) – (reference position angle) |

The ratio of the absolute error at x° under the pressure condition to that under the normal condition was defined as the pressure effect index. The absolute error and relationship between the absolute error under the normal condition and pressure effect index under each condition was calculated for each participant group.

2.5. Statistical analyses

The Shapiro–Wilk test confirmed the non-normal distribution of all data. The Mann–Whitney test was used to test x° between the two groups, the reproduction angle at x° between the two conditions for each group, and the absolute error at x° under the normal condition between the two groups. A Friedman repeated measures analysis of variance on ranks was used to study the effect of trial order at x° on the absolute error within each condition in each group and to study the effect of the reference position on the absolute error within each condition in each group. Wilcoxon's signed rank test with Bonferroni correction was used to assess significant differences identified by the Friedman repeated measures analysis of variance on ranks. In each group, the absolute error at x° under the pressure condition was compared to that under the normal condition using Wilcoxon's signed-rank test. Spearman's correlation coefficient was used to evaluate whether or not the pressure effect index at x° was correlated with the absolute error at x° under the normal condition. In the stroke group, Spearman's correlation coefficient was performed to evaluate whether the pressure effect index at x° was correlated with age, post-stroke duration (months) and the BBS score. The alpha level was set to $p<0.05$. All statistical analyses were performed using the SPSS 14.0J software program (SPSS Japan, Tokyo, Japan).

3. Results

3.1. Perceptibility of x° in both groups under normal and pressure conditions

The measured value of x° in the stroke group (-19.5°±6.2°) was significantly different from that in the control group (-25.6°±5.9°) ($U=36.00$, $p<0.05$). In both groups, the reproduction angle at x° under the normal condition was not significantly different from that under the pressure condition (control group: normal condition -25.6°±5.8°, pressure condition -25.7°±6.0°; stroke group: normal condition -20.8°±6.9°, pressure condition -19.9°±7.4°). The trial order at x° had no significant effect on the absolute error under either of the conditions in the two groups (control group: normal condition $\chi^2=2.99$, $p>0.05$; pressure condition $\chi^2=2.92$, $p>0.05$; stroke group: normal condition $\chi^2=6.43$, $p>0.05$; pressure condition $\chi^2=1.44$, $p>0.05$).

In the control group, the reference position had no significant effect on the absolute error under the normal condition but had a significant effect on the absolute error under the pressure condition ($\chi^2=15.17$, $p<0.01$). A statistically significant difference was observed between x° and +5° ($Z=2.43$, $p<0.05$) and between x° and +10° ($Z=2.98$, $p<0.01$) (Figure 4).

In the stroke group, the reference position had a significant effect on the absolute error under the normal condition ($\chi^2=9.49$, $p<0.05$). A statistically significant difference was observed between x° and +5° ($Z=2.12$, $p<0.05$) and between x° and +10° ($Z=2.41$, $p<0.05$). A significant effect was also found for the reference position on the on absolute error under the pressure condition in this group (χ^2=12.46, p<0.05). The difference was observed between x° and +5° (Z=2.22, p<0.05) and between x° and +10° (Z=2.23, p<0.05) (Figure 4).

In the control group, the absolute error at x° under the pressure condition was significant smaller than that under the normal condition (Z=-2.94, p<0.01) (Figure 4). In contrast, in the stroke group, the absolute error at x° under the two conditions did not differ significantly. Similarly, under the normal condition, the absolute error at x° in the two groups was not significant (Figure 4). Hence, under the pressure condition, a significant difference was observed between the two groups in the absolute error at x° (U=26.00, p<0.01) (Figure 4).

3.2. The pressure effect index

In the stroke group, a significant negative correlation was observed between the absolute error at x° under the normal condition and the pressure effect index (r=-0.65, p<0.05) (Figure 5). This correlation was not observed in the control group (r=0.026, p>0.05).

In the stroke group, the pressure effect index showed no significant correlation with age, post-stroke duration, or BBS score (age: r=-0.09, p>0.05; post-stroke duration: r=0.25, p>0.05; the BBS score: r=-0.02, p>0.05).

4. Discussion

In this study, a plastic eraser was attached to the coccyx to increase the pressure information due to contact between the seat surface and the coccyx while leaning backward in the sitting position. The absolute error under the pressure condition was significantly smaller than that under the normal condition in the control group, while no marked difference between conditions was found in the stroke group. The relationship between the absolute error under the normal condition and the pressure effect index showed a significant negative correlation in the stroke group. For stroke patients who normally have a high trunk position perceptibility, the additional pressure information may have functioned as a disturbance, reducing position perceptibility. In contrast, stroke patients with a low perceptibility under normal conditions may have been able to re-weight and prioritize the additional pressure information in the reference frame. In the control group, the added pressure information may have been re-weighted as prior position information in the reference frame.

If the device acted as a stopper of the movement, then the reproduction angle under the pressure condition (with the device) would likely be smaller than that under the normal condition (without the device). However, there was no significant difference in the reproduction angle for x° between the two conditions for the two groups, indicating that this device did not act as a stopper for pelvic retroversion movement. In addition, no significant effect of the trial order of the absolute error at x° was observed under either condition in either of the groups. This result indicates that there was no learning effect in reproducing x° by randomly performing + 5° and + 10° trials in addition to the x° trial.

In the control group, x° was located significantly farther backward than in the stroke group. Messier et al. reported that the upper trunk flexion of stroke patients in the sitting position was executed mostly by flexing the upper trunk [17]. In addition, the trunk of the stroke participants in the upright position was located in a more forward-leaning position than in age-matched healthy subjects, while the pelvic anteversion angle in the trunk forward flexion position while upright was smaller [25]. In this study, the trunk angle was defined as the angle between the vertical line and the longitudinal axis through both the right trochanter and right acromion. Therefore, considering that the trunk angle in the stroke group was the same as that in the control group in the sitting position, the amplitude of upper trunk flexion of the stroke group was larger than that of the control group, while the pelvic retroversion angle of the stroke group may have been larger than that of the control group. In other words, the stroke group had a smaller x°, but the pelvic retroversion angle may have been the same as that of the control group.

The effect of the reference position on the absolute error was not observed under the normal condition in the control group, a finding similar to that in a previous study [9] that investigated the perceptibility of the trunk position while sitting with feet in contact with the floor. In the control group, the absolute error at x° under the pressure condition was significant smaller than that under the normal condition. It was also found that additional pressure on the coccyx significantly reduced the absolute error at x° in comparison to the two other reference positions. Furthermore, the median of the absolute error under the pressure condition was <1°, showing that the trunk position was almost accurately perceived. This result therefore suggests that normal subjects can increase their sensory weighting in the reference frame [8,11,20] for large increases in sensory information provided by the pressure device on the coccyx and thereby increase the role of pressure information in the perception of the trunk position. The fact that the large changes in the sensory information function as trunk position information is consistent with our previous results [1].

However, in the stroke group, a significant effect of the reference position on the absolute error was observed, regardless of the additional pressure on the coccyx. Several participants in the stroke group showed no improvement in their ability to perceive the trunk position by additional pressure on the coccyx. We therefore examined the pressure effect index in the stroke group. The pressure effect index was higher (worse perceptibility) in subjects with a higher perceptibility under normal conditions. This means that the higher the perceptibility in the normal condition, the larger the error in the pressure condition. In addition, the pressure effect index was not significantly correlated with the age, duration of illness, or BBS score, indicating that the pressure effect index was not affected by these factors.

The results regarding the pressure effect index in the stroke group prompted two considerations: 1) for subjects with a large error in the normal condition, a large change in sensory information due to the additional pressure information effectively functions as the trunk position information; and 2) in subjects with high perceptibility of the trunk position (characterized by a small error in the normal condition), a large change in sensory information due to the additional pressure information had a negative effect. In a previous study, a nut was attached to the heel to increase the pressure information from the heel and improve standing position perception during backward leaning [3]. The study concluded that participants with a smaller error and higher perceptibility in the normal condition had a larger error in the pressure condition than others [3]. The results of that previous study were similar to those of the stroke group in the present study. Furthermore, this tendency was newly clarified by studies that added sensory information. Thus, whether or not sensory weighting due to the added sensory information can be increased and/or applied positively to perception is considered the key issue [8]. The subjects from the control and stroke groups whose position perceptibility was increased due to this additional pressure information were probably able to re-weight the added pressure sensation information as position information by incorporating it into the reference frame [23]. This indicates that the stroke group also had the ability to re-weight the additional pressure information in order to perceive the trunk position.

However, in the stroke group, the subjects in whom trunk position perceptibility decreased due to additional pressure information were subjects with a very high position perceptibility under the normal condition. These subjects probably perceived the backward leaning of the trunk position by another specific sensory information channel under the normal condition but were unable to ignore the additional pressure information under the pressure condition. Therefore, this pressure information may have caused confusion in the reference frame, reducing the perceptibility. In other words, it is possible that the additional pressure information functioned as a “disturbance” in the reference frame and reduced trunk position perceptibility [5,23].

In this study, the pelvic retroversion angle, which affects the spinal alignment, was not regulated during the backward movement of the trunk. Therefore, it is possible that the position of each segment of the trunk affects the perception of the trunk position. After this study, the effect of the pelvic tilt angle in the antero-posterior direction on the perception of the trunk position was investigated. It was thus confirmed that the pelvic tilt angle in the antero-posterior direction did not affect the perception of the backward-leaning trunk position (unpublished data). Changes in each segment of the trunk due to changes in the pelvic tilt angle therefore may not have affected the position perception of the entire trunk.

We concluded that there are clear individual differences in the adaptation of additional pressure information from the coccyx in the perception of the trunk position while sitting among stroke patients, which may depend on the previous perceptibility. However, stroke patients who are unable to stand up independently from the sitting position reportedly have a larger pelvic retroversion angle during sitting [4], and additional pressure information from the coccyx may help these stroke patients perceive the backward-leaning trunk position. Furthermore, acute-phase stroke patients with an unstable sitting posture usually show pelvic retroversion while sitting. For such acute stroke patients, additional pressure information from the coccyx may help prevent the trunk from falling backward while in the sitting position.

5. Limitations

We did not examine the superficial sensation of the coccyx of the stroke group in this study. Since it is possible that the sensory condition of this region influenced the results, we would like to increase the number of stroke patients and test superficial sensation of this region as well as examine the effect of the additional pressure information on the perceptibility of the backward trunk position. In addition, the pelvic angle was not measured in this study. It was confirmed that the pelvic tilt angle in the antero-posterior direction did not affect the perception of the backward-leaning trunk position (unpublished data). The pressure intensity to the coccyx may be affected by the pelvic retroversion angle. Therefore, it was necessary to measure and control not only the trunk angle but also the pelvic retroversion angle at X °.

In stroke patients who are unable to stand up independently from the sitting position and those in the acute phase with an unstable sitting posture, the stability of the backward-leaning sitting posture might be improved by additional pressure information from the coccyx.

Further studies will be necessary to confirm the most suitable method for evaluating such subjects. This experiment examined the effect of additional pressure information from only the coccyx on the perception of the trunk leaning position while sitting. The effect of pressure information from other contact sites on the perception of the trunk position while sitting should also be examined.

Author's statement

We guarantee the originality of the manuscript and are responsible for the data and the experimental results of the study.

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Credit authorship contribution statement

Hitoshi Asai: Conceptualization, Methodology, Investigation, Project administration, Resources, Writing – original draft, Writing – review and editing. **Pleiades T. Inaoka:** Investigation, Data curation, Writing – review and editing.

Declaration of Competing Interests

The authors declare no conflicts of interest in association with the present study.

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Figure legends

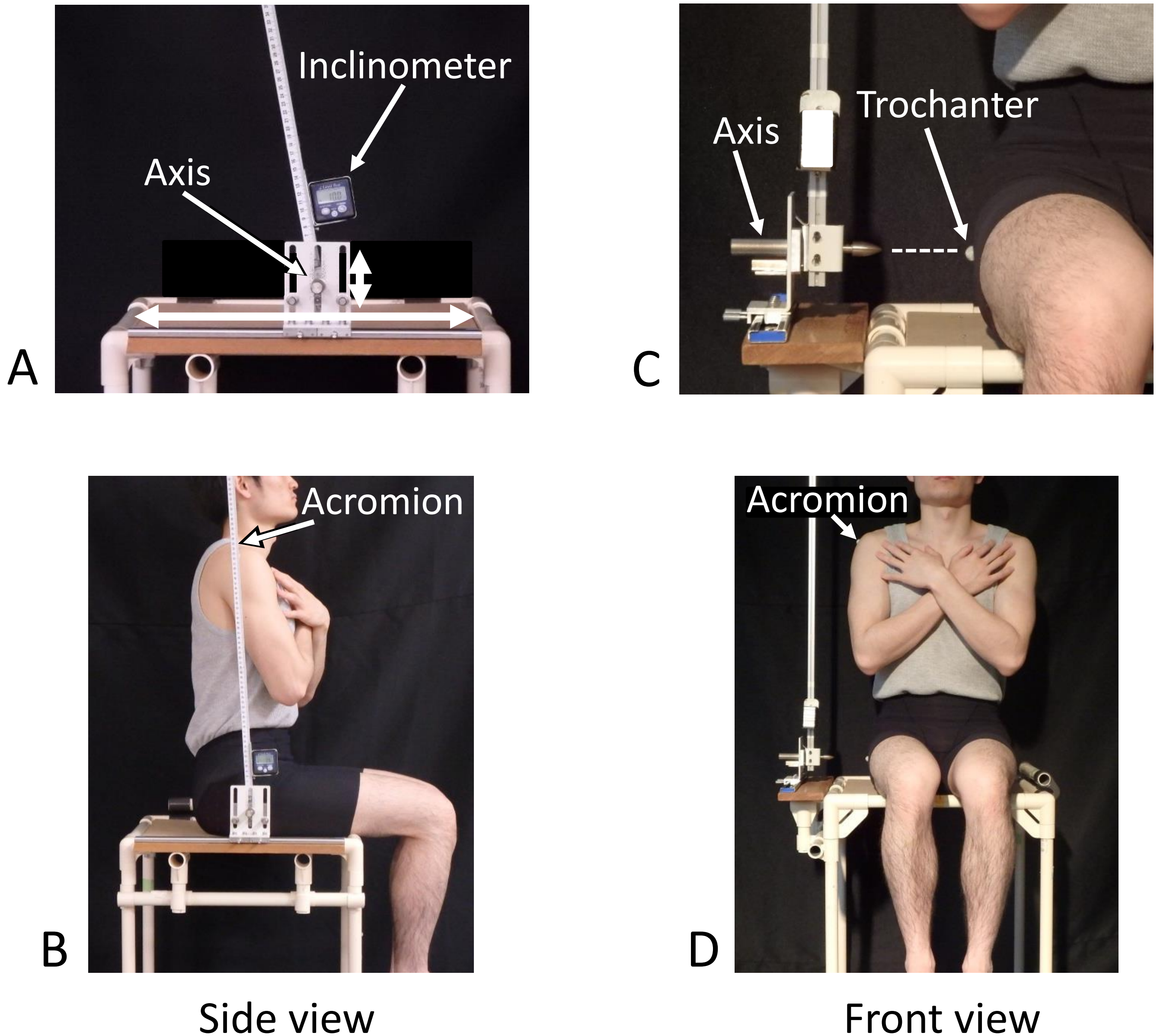
Figure 1. Manual goniometer and set-up. A: Overview of the manual goniometer. B: Side view of the set-up. C: Front view of the set-up in detail. D: Front view of the set-up (Reproduced from Asai et al. [1]).

Figure 2. Size and shape of the half-cylinder-shaped original tool designed to increase pressure stimulation to the coccygeal skin.

Figure 3. Experimental protocol for reproducing reference positions with the eyes closed (Reproduced from Asai et al. [1]).

Figure 4. The sample minimum, lower quartile or first quartile, median, upper quartile or third quartile, and sample maximum of the absolute error of the reproduction for x°, +5°, and +10° under the two conditions in each group. *: Statistically significant difference between the two conditions ($p<0.05$). **: Statistically significant difference between two groups ($p<0.05$). ǂ: Statistically significant difference between x° and + 5°, x° and + 10° under the normal condition. §: Statistically significant difference between x° and + 5°, x° and + 10° under the pressure condition.

Figure 5. The relationship between the absolute error under the normal condition and the pressure effect index of the stroke group. A significant negative correlation was observed ($r=-0.65$, $p<0.05$).


A
Inclinometer
Axis
B
Acromion
Side view
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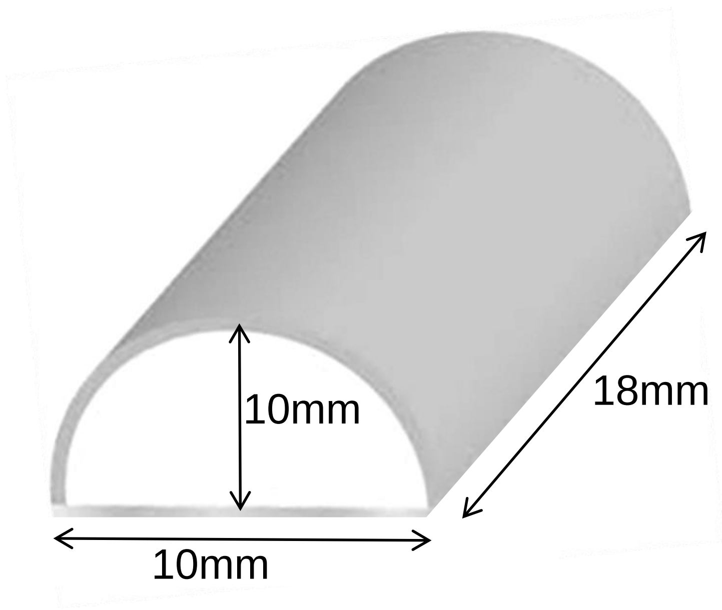
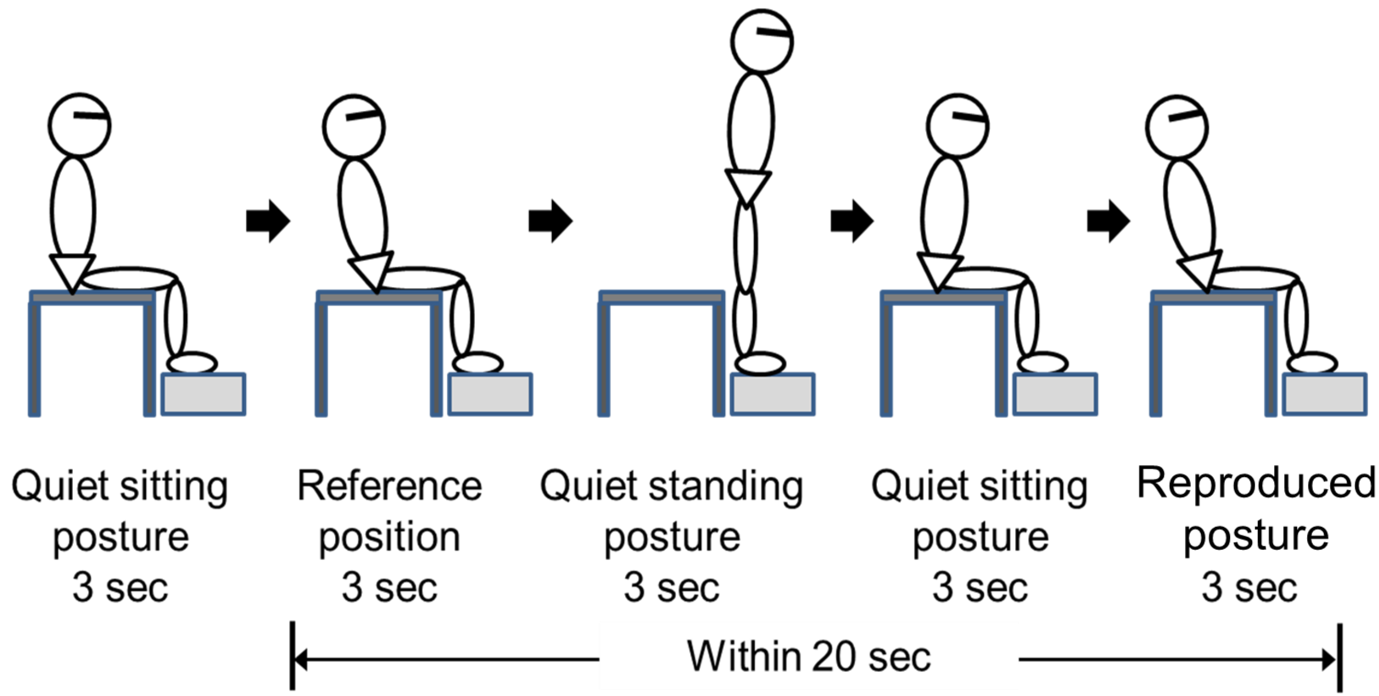
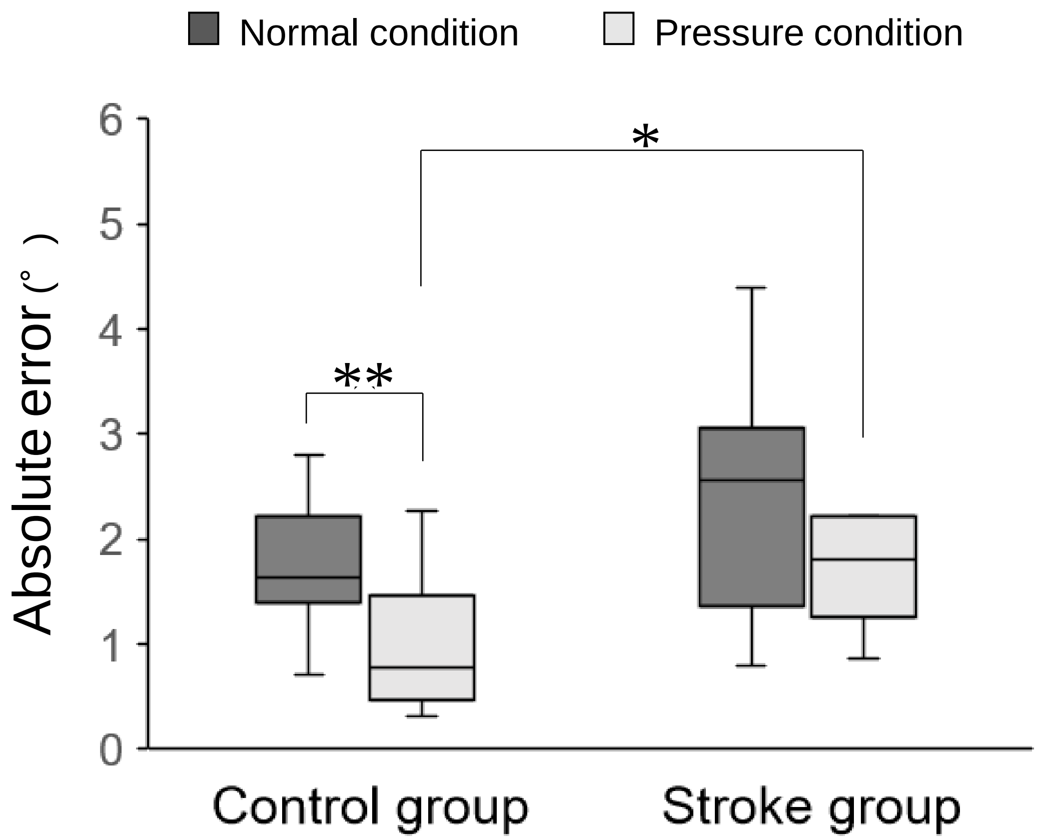
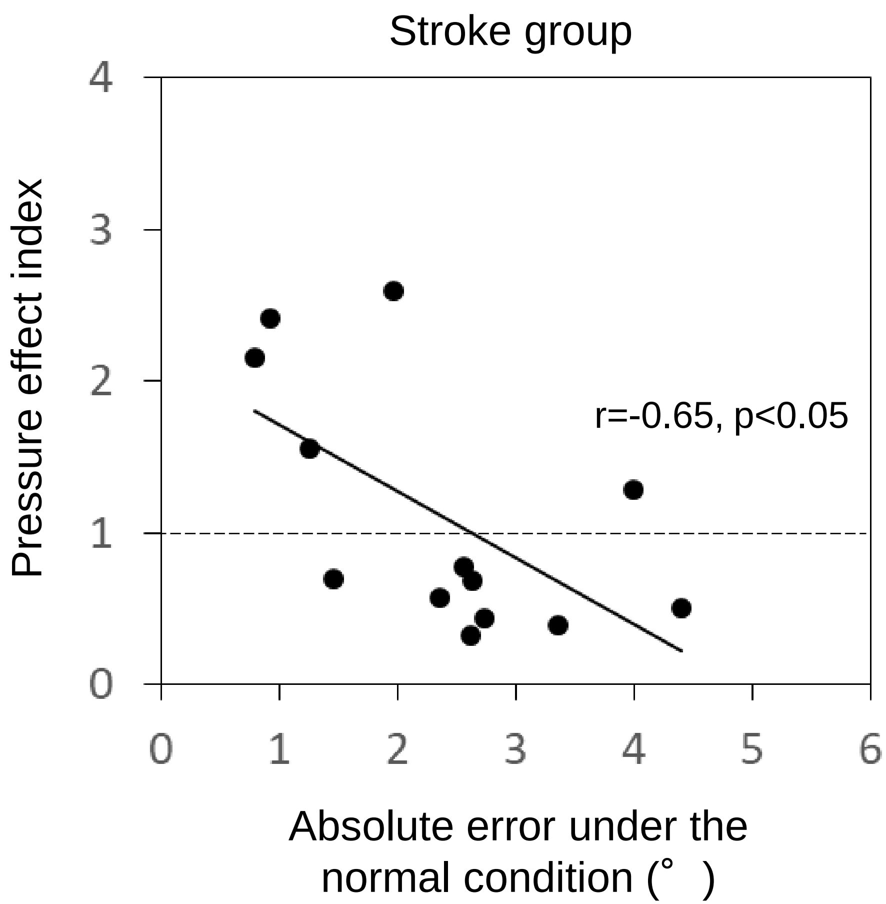
Axis
Trochanter
D
Acromion
Front view


10mm
18mm
10mm


Quiet sitting posture
3 sec
Reference position
3 sec
Quiet standing posture
3 sec
Quiet sitting posture
3 sec
Reproduced posture
3 sec
Within 20 sec



Normal condition
Pressure condition
Absolute error (°)
6
5
4
3
2
1
0
**
*
Control group
Stroke group



Stroke group
Pressure effect index
4
3
2
1
0
r=-0.65, p<0.05
0
1
2
3
4
5
6
Absolute error under the
normal condition (°)