

Original Article

Perception of trunk inclination during sitting with feet in contact with the floor

SOMA ENDO, RPT^{1, 2)*}, HITOSHI ASAI, RPT, PhD³⁾, TIHARU INAOKA-PLEIADES, RPT, PhD³⁾

¹⁾ Department of Physical Therapy, Graduate Course of Rehabilitation Science, Division of Health Sciences, Graduate School of Medical Sciences, Kanazawa University: 5-11-80 Kodatsuno, Kanazawa City, Ishikawa 920-0942, Japan

²⁾ Department of Rehabilitation, Kanazawa Disabled Children's Hospital, Japan

³⁾ Department of Physical Therapy, Graduate Course of Rehabilitation Science, School of Health Sciences, College of Medical, Pharmaceutical, and Health Sciences, Kanazawa University, Japan

Abstract. [Purpose] To clarify the sitting postural control, the influences of several reference sitting positions on the perception of the trunk position while sitting with the feet in contact with the floor and keeping the eyes closed were investigated. [Participants and Methods] Fifteen young healthy volunteers participated in the present study. The perception of the trunk position was evaluated by calculating the absolute error (error magnitude) and constant error (error direction) between the reference trunk position (which the subjects memorized; the reference position) and the position that they adopted when reproducing the reference position (the reproduced position). Eight reference positions were set at 5° increments (from 15° backward inclination [-] to 20° forward inclination [+]). [Results] The reference positions had a significant effect on the absolute error, and the absolute error values at -15° and -10° were significantly smaller than at 20°. However, the reference positions had no effect on the constant error. [Conclusion] The present study revealed that the perception of the trunk position while sitting with the feet in contact with the floor is better when inclining backward than when inclining forward. The perception of the trunk position may be higher in a low-stability position and lower in a high-stability position.

Key words: Perception of the trunk position, Reference position, Stability of the sitting position

(This article was submitted Sep. 29, 2018, and was accepted Nov. 19, 2018)

INTRODUCTION

The time spent sitting is long in daily life. Bauman et al. reported that the average time spent sitting is 5 to 6 h per day¹⁾. This time may increase in elderly individuals and in patients with locomotion disability. The functional sitting posture is a sitting posture that is adopted to perform sitting activities using the upper limbs²⁾. This posture changes according to the activities being performed, such as writing, reaching for a cup, or other activities of daily living (ADL) while sitting.

Postural control involves various and complex factors (i.e. musculoskeletal components, neuromuscular synergies, sensory strategies and anticipatory and adaptive mechanisms³⁾). These are adopted based on the relationship between the environment and body position. Therefore, it is important to perceive one's own body position accurately. Several reports have examined the perception of the trunk position while sitting, including the subjective postural vertical (SPV)⁴⁻⁶⁾ and trunk position perception^{7, 8)}. The SPV is the perception of body verticality⁴⁻⁶⁾, in which somatosensory information has been suggested to have an important role. The trunk position perception, also known as the "trunk position sense", has been assessed in studies based on the accuracy of the perceived trunk position on the sagittal plane^{7, 8)}. Trunk repositioning error has been used to evaluate the trunk position sense^{7, 8)}. The trunk position sense was evaluated by the magnitude of the absolute error between

*Corresponding author. Soma Endo (E-mail: 11soma08@gmail.com)

©2019 The Society of Physical Therapy Science. Published by IPEC Inc.



This is an open-access article distributed under the terms of the Creative Commons Attribution Non-Commercial No Derivatives (by-nc-nd) License. (CC-BY-NC-ND 4.0: <https://creativecommons.org/licenses/by-nc-nd/4.0/>)

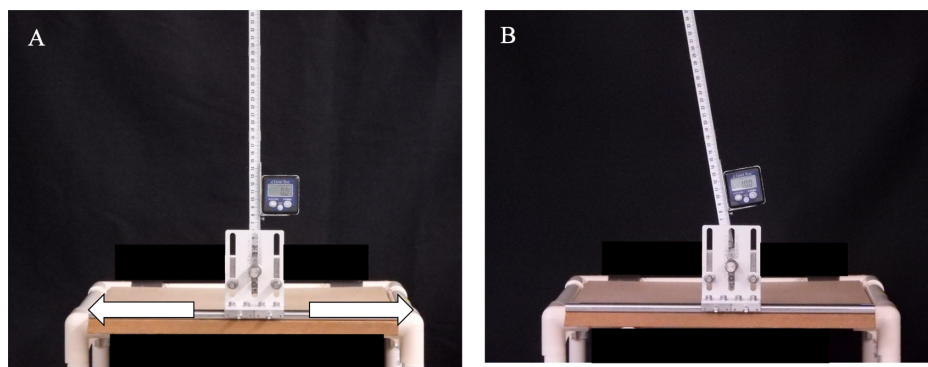


Fig. 1A, B. The original trunk inclinometer. The inclinometer slides in the anterior (right arrow) and posterior (left arrow) direction. The trunk inclinometer rotated 180° on the sagittal plane axis.

the target position and the reproduced position. Patients with stroke hemiparesis are reported to show greater degrees of trunk repositioning error (reproduction error) than age-matched controls⁷⁾, and the sense of the trunk position was associated with the trunk muscle functions during symmetrical trunk movement⁸⁾. As the participants in these reports were stroke patients, the target positions were limited to one forward position in the study by Ryerson et al.⁷⁾ and one forward and one backward position in the study by Liao et al.⁸⁾. Since the accuracy of the perception in the standing position differed according to the position in Fujiwara's study⁹⁾, the accuracy of the perceived trunk position in the sitting position might also differ in various anterior or posterior positions. However, no report has examined how the trunk position perception differs at various trunk positions while sitting with the feet in contact with the floor. Thus, the purpose of this study was to examine the trunk position perception while sitting at various positions during backward and forward inclination.

Various sensations (i.e. visual, vestibular, and somatosensory inputs) are integrated to perceive one's own posture¹⁰⁾. The contribution of each of these sensory systems changes depending on the perturbations that are applied during standing and according to the environmental conditions^{11–13)}; thus, it may be impossible to decide which information is the most important for perceiving the trunk posture. In a previous study on the standing position perception⁹⁾ and the perception of the trunk position when sitting without the feet in contact with the floor¹⁴⁾, the perception of the body position was higher in a low-stability position than in a high-stability position. Thus, in a position in which the trunk is subjected to a high degree of forward or backward inclination, the accuracy of the perceived trunk position may be improved. In contrast, in the sitting positions closest to the rest sitting position, the perceived trunk position would be less accurate.

The present study was conducted based on the following hypothesis: the perception of the trunk position when in the sitting position is lower in the sitting positions close to the rest sitting position and higher when the trunk is subjected to a high degree of forward or backward inclination.

PARTICIPANTS AND METHODS

The participants included 15 healthy young adults (male, n=8; female, n=7; age, 21–25 years) without neurological or orthopedic diseases. Their mean age, height and weight of the participants (mean ± standard deviation) were 22.0 ± 1.0 years, 165.1 ± 9.3 cm and 61.5 ± 9.8 kg, respectively. All participants gave their informed consent to participate in the present study, the protocol of which was approved by the institutional ethics committee of Kanazawa University in accordance with the Declaration of Helsinki (No. 462-2).

The experimental instruments and procedures of our previous study were used¹⁴⁾. The trunk angle was defined as the angle between the line connecting the acromion and the greater trochanter and the perpendicular line. A trunk inclinometer (Fig. 1A), which is an aluminum bar (20 mm × 20 mm × 1,000 mm) with an electronic inclinometer (BM-801, resolution, 0.1°; Ito Co., Ltd., Tokyo, Japan) attached, was used to measure the trunk angle. The trunk inclinometer rotated 180° around the axis on the sagittal plane (Fig. 1B). A 42-cm rail was installed at the right end of the measurement chair, and the trunk inclinometer was set on this rail. The trunk inclinometer was able to move horizontally on this sliding rail, and the rotation axis could also be moved vertically to precisely match the greater trochanter of the participant in each trial. Horizontal and vertical laser beam markers (STS, EXA-YR 21) were used to set the seat height from the right side.

Before the measurement, the seat height was determined as follows: 1) the position of the buttocks was adjusted so that the distance from the greater trochanter to the front end of the measurement chair was 60% of the thigh length (the distance from the greater trochanter to the lateral epicondyle); 2) the seat height was adjusted so that the horizontal laser beam passed over the right greater trochanter and the lateral epicondyle (knee angle, 90°); and 3) the anteroposterior position of the foot was adjusted so that the vertical laser beam passed over the head of the right fibula and the lateral malleolus. At this time, the

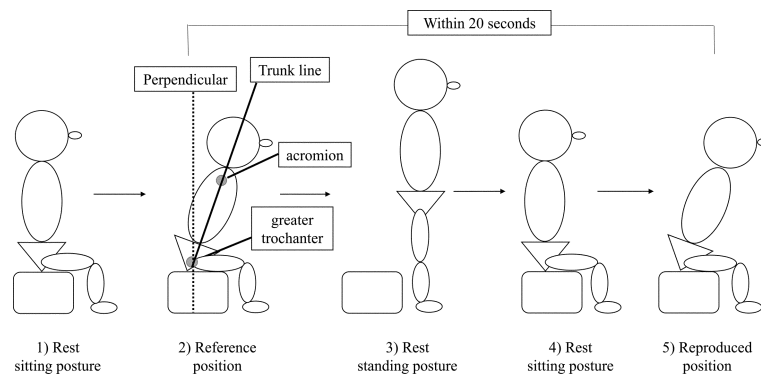


Fig. 2. The method for reproducing the reference positions.

- 1) rest sitting position for 3 seconds; 2) active trunk inclination forward or backward to the reference position for 3 seconds and memorize the position; 3) stand up and maintain a rest standing position for 3 seconds; 4) sit down and maintain a rest sitting position for 3 seconds; 5) instructed to reproduce the reference position.

entire sole of the foot was in contact with the ground, and the ankle joint was at 0° .

All participants wore short leggings made from the same material during all of the trials. The perception of the trunk position was evaluated by the absolute error (AE) and constant error (CE) between the reference trunk angle memorized by the participant (reference position) and the angle reproduced by the participant (reproduced position). The trunk angle when the trunk was in the vertical position was considered to be 0° , with anterior tilt represented by a positive angle and posterior tilt by a negative angle. There were 8 reference positions in total (-15° , -10° , -5° , 0° , 5° , 10° , 15° and 20°), which all participants were able to reach. Five trials were performed (in random order) for each position. During the trials, the participants kept their eyes closed and their arms crossed over their chest. The perception of the trunk position was measured using the following procedure (Fig. 2): 1) The participant maintained a rest sitting position for 3 seconds; 2) the participant actively inclined their trunk forward or backward, to the reference position under verbal instruction with the guidance of the trunk inclinometer; 3) the participants kept their trunk in the reference position for 3 seconds and memorized the position; 4) without returning to the rest sitting position, they stood up and maintained a rest standing position for 3 seconds; 5) they then sat down and maintained a rest sitting position for 3 seconds; 6) they were then asked to reproduce the reference position (as remembered), and the angle that they reproduced was measured. The time elapsed from initially memorizing the reference position to the reproduction of the position was kept to less than 20 seconds, which was within the limits of short-term memory^{9, 14}.

The perception of the trunk position was evaluated with AE and CE. The two errors were calculated using the following equations:

$$AE = |\text{reproduction angle} - \text{reference angle}|$$

$$CE = \text{reproduction angle} - \text{reference angle}$$

AE indicated the magnitude of the error, while CE indicated the direction of the error. A positive CE value indicated that the error was in the forward direction (relative to the reference position), while a negative value indicated that the error was in the backward direction. The average error values from at each reference angles were calculated from five trials; the representative error values at each angle were subjected to a statistical analysis. As normal distribution was observed at all reference angles (Shapiro-Wilks, $p > 0.05$), the absolute error was examined by a one-way repeated-measures analysis of variance (ANOVA) to investigate the influence of reference position. Then, to compare the AE at each reference position, a multiple comparison test using Holm's method was carried out as a post hoc test. The data were not normally distributed at all reference angles (Shapiro-Wilks, $p < 0.05$). The CE was examined using Friedman's test to investigate the influence of the reference positions on the perception of the trunk position. The SPSS Statistics software program (23.0; IBM SPSS, Tokyo, Japan) was used to perform the statistical analyses; the significance level was set to 5%.

RESULTS

The AE and CE values at each reference position are shown in Table 1. The one-way ANOVA revealed that the reference angle had a significant effect on the AE ($F(1, 14) = 2.802$, $p < 0.05$). The multiple comparison test revealed that the AE was significantly smaller at -15° ($t = -3.202$, $p < 0.05$) and -10° ($t = -3.468$, $p < 0.01$) than the reference angle at 20° . In contrast, the reference position had no effect on the CE ($p = 0.832$).

Table 1. The means and standard deviations of the absolute error and the constant error of the reproduced angle for each reference positions

	Reference position (degrees)							
	-15	-10	-5	0	5	10	15	20
Absolute error (degrees)	2.15 ± 1.10*	2.37 ± 0.92†	2.69 ± 1.43	2.76 ± 1.50	2.86 ± 1.36	3.23 ± 1.29	3.13 ± 1.36	3.95 ± 1.68*†
Constant error (degrees)	-0.01 ± 1.27	-0.86 ± 1.58	-1.24 ± 2.17	0.38 ± 2.45	-0.17 ± 2.55	-0.19 ± 2.55	-0.07 ± 3.00	-0.45 ± 3.68

*statistical difference between -15 and 20 angles ($p < 0.01$).

†statistical difference between -10 and 20 angles ($p < 0.05$).

DISCUSSION

In the present study, the perception of the trunk position while sitting with the trunk in various positions in the antero-posterior direction was investigated. It was revealed that the AE at -15° and -10° was significantly smaller than that at 20° ; however, there was no marked difference in the CE. In the point of view of position versus perception, the results showed that the perception of the trunk position at -15° and -10° (in backward inclination) was higher than that at 20° (in forward inclination), which differed from our hypothesis as well as from the perception in the standing position⁹⁾ and the perception of the trunk position in participants sitting without their feet touching the floor¹⁴⁾.

However in the point of view of stability versus perception, the present study had similar findings. The base of support in anterior direction was larger in this study compared to sitting without feet touching the floor. When sitting with the feet in contact with the floor, the front end of the base of support is the toes, while the rear end is the rearmost end of the buttocks where they make contact with the seat. Since the center of gravity of the trunk is located above the buttocks, it is probably closer to the end of the base of support when the trunk is inclined backward than when it is inclined forward. The sitting position with the feet in contact with the floor differs from the standing position and the sitting position without the feet touching the floor; in such a position, it is much easier to lose one's balance while reclining backward than when leaning forward. In other words, the stability when sitting with the feet in contact with the floor is lower when the trunk is inclined backward than forward. Furthermore, it has been confirmed that the perception of the position is lower in high-stability positions and higher in low-stability positions^{9, 14)}. The present study results supported these previous findings. In low-stability positions, the posture may be controlled based on the accurate perception of the trunk position.

The range effect is a psychological effect that causes the participant to overestimate the distance between the starting position and the reference position. The error direction can differ according to the distance from the starting position to the reference position. In this study, the CE did not differ markedly at any reference positions; thus, our method of measurement (in which the participant stood before reproducing the reference position) probably helped avoid the range effect.

Several limitations associated with the present study warrant mention. This study only focused on the influence of the different reference positions on the perception of the trunk position; the muscle activity, the load on the feet, and the pelvic and spinal angles were not measured. In addition, the range of the reference position (-15° to 20°) was set according to the range of positions that all participants could reach. Therefore, the range did not represent the total range of motion of the participants. Thus, the ratio of the reference angle to the total range of motion was probably different for each participant. A method that takes these limitations into account must be adopted in future research.

In conclusion, the present study revealed that the perception of the trunk position while sitting with the feet in contact with the floor is better when inclining backwardly than when inclining forwardly. The perception of the trunk position may be higher in a low-stability position and lower in a high-stability position. Further investigations based on the measurement of muscle activity, the load on the feet, and the pelvic angle are necessary to clarify the mechanisms involved in the perception of the trunk position.

Funding

This work was supported by JSPS KAKENHI, Grant-in-Aid for Scientific Research (C), Grant Number 26350609.

Conflict of interest

None.

REFERENCES

- 1) Bauman A, Ainsworth BE, Sallis JF, et al. IPS Group: The descriptive epidemiology of sitting. A 20-country comparison using the International Physical Activity Questionnaire (IPAQ). *Am J Prev Med*, 2011, 41: 228–235. [[Medline](#)] [[CrossRef](#)]
- 2) Stavness C: The effect of positioning for children with cerebral palsy on upper-extremity function: a review of the evidence. *Phys Occup Ther Pediatr*, 2006, 26: 39–53. [[Medline](#)]
- 3) Shumway-Cook A, Woollacott MH: Motor control: theory and practical applications. Baltimore: Williams & Wilkins, 1995.
- 4) Bisdorff AR, Wolsley CJ, Anastasopoulos D, et al.: The perception of body verticality (subjective postural vertical) in peripheral and central vestibular disorders. *Brain*, 1996, 119: 1523–1534. [[Medline](#)] [[CrossRef](#)]
- 5) Barbieri G, Gissot AS, Pérennou D: Ageing of the postural vertical. *Age (Dordr)*, 2010, 32: 51–60. [[Medline](#)] [[CrossRef](#)]
- 6) Ryerson S, Byl NN, Brown DA, et al.: Altered trunk position sense and its relation to balance functions in people post-stroke. *J Neurol Phys Ther*, 2008, 32: 14–20. [[Medline](#)] [[CrossRef](#)]
- 7) Liao CF, Liaw LJ, Wang RY, et al.: Electromyography of symmetrical trunk movements and trunk position sense in chronic stroke patients. *J Phys Ther Sci*, 2015, 27: 2675–2681. [[Medline](#)] [[CrossRef](#)]
- 8) Fujiwara K, Asai H, Kiyota N, et al.: Relationship between quiet standing position and perceptibility of standing position in the anteroposterior direction. *J Physiol Anthropol*, 2010, 29: 197–203. [[Medline](#)] [[CrossRef](#)]
- 9) Newcomer K, Laskowski ER, Yu B, et al.: Repositioning error in low back pain. Comparing trunk repositioning error in subjects with chronic low back pain and control subjects. *Spine*, 2000, 25: 245–250. [[Medline](#)] [[CrossRef](#)]
- 10) Mittelstaedt H: Origin and processing of postural information. *Neurosci Biobehav Rev*, 1998, 22: 473–478. [[Medline](#)] [[CrossRef](#)]
- 11) Aszländer L, Peterka RJ: Sensory reweighting dynamics in human postural control. *J Neurophysiol*, 2014, 111: 1852–1864. [[Medline](#)] [[CrossRef](#)]
- 12) Carver S, Kiemel T, Jeka JJ: Modeling the dynamics of sensory reweighting. *Biol Cybern*, 2006, 95: 123–134. [[Medline](#)] [[CrossRef](#)]
- 13) Asai H, Endo S, Inaoka PT: Anteroposterior perception of the trunk position while seated without the feet touching the floor. *J Phys Ther Sci*, 2017, 29: 2026–2030. [[Medline](#)] [[CrossRef](#)]
- 14) Weiss B: Movement error, pressure variation, and the range effect. *J Exp Psychol*, 1955, 50: 191–196. [[Medline](#)] [[CrossRef](#)]