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Case Study

Abnormal bias in subjective vertical perception in a post-stroke astasia patient

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Abstract. [Purpose] Post-stroke astasia is an inability to stand without external support despite having sufficient muscle strength. However, the dysfunction underlying astasia is unclear. We tested the hypothesis that astasia is the result of an abnormal bias in vertical perception, especially subjective postural vertical (SPV), mediated by somatosensory inputs. [Subjects and Methods] A patient with a right posterolateral thalamus hemorrhage had a tendency to fall toward the contralesional side during standing after 8 weeks of treatment. SPV, standing duration, and physical function were evaluated before and after a 1 week standard rehabilitation baseline period, and after a 1 week intervention period, where standing training requiring the patient to control his body orientation in reference to somatosensory inputs from his ipsilateral upper limb was added. [Results] SPV was biased toward the contralesional side before and after the 1 week baseline period. However, SPV improved into the normal range and he could stand for a longer duration after the intervention period. [Conclusion] This case suggests that abnormal SPV is one of the functional mechanisms underlying astasia, and it indicates the effectiveness of standing training with somatosensory information to improve abnormal SPV and postural disorders.

Key words: Post-stroke astasia, Postural disorder, Subjective postural vertical

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INTRODUCTION

Astasia is a clinical postural disorder characterized by the inability to stand without external support despite having sufficient muscle strength. This symptom can be observed in post-stroke patients who have experienced thalamic hemorrhage or ischemia[1–3)], and it is frequently accompanied by falling toward the contralesional side without exhibiting pushing behavior, which is a tendency to actively push away from the ipsilesional side[4)]. It has been reported that symptoms of astasia tend to spontaneously disappear several days after stroke onset[1–3)]. However, little is known about the causal mechanism underlying this postural dysfunction.

It is thought that vertical perception has a pivotal role in maintaining upright posture in humans. One of the important vertical perceptions is subjective postural vertical (SPV), defined as bodily vertical perception mainly derived from somatosensory information[5)]. The authors of previous studies have suggested that the functionality of SPV influences the chance of postural disorders in post-stroke patients[6)]. Indeed, in post-stroke patients, the correlation between the degree of SPV bias

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Table 1. The patient's physical and cognitive function at each phase

	Before the baseline	After the baseline	After the intervention
SIAS-motor (hip/knee/ankle)	4/4/4	4/4/4	4/4/4
Knee extension force (left/right/sum total) (Nm/kg)	0.26/0.38/0.64	Not assessed	0.28/0.36/0.65
SIAS-sensory (upper/lower)	0/0	0/0	1/0
MAS (upper/lower)	1/1	1/1	1/1
SARA (left/right)			
Nose-finger test	0/0	0/0	0/0
Heel-shin slide test	1/0	1/0	1/0
MMSE	20	Not assessed	20
SCP (standing) (section A/B/C)	1/0/0	1/0/0	0.25/0/0
FIM motor total	46	46	48
Bed transfer	4	4	5
Toilet transfer	4	4	5

SIAS: Stroke impairment assessment scale; MAS: Modified ashworth scale; SARA: Scale for assessment and rating of ataxia; MMSE: Mini mental state examination; SCP: Scale of contraversive pushing

and that of falling toward the contralesional side is very strong[6]. Based on these lines of evidence, it was hypothesized that abnormal SPV can be one of the functional mechanisms underlying postural disorders in astasia patients. In the present study, this hypothesis was tested in a single case study of a post-stroke patient with prolonged astasia.

The patient was a 72-year-old man diagnosed with a right thalamic hemorrhage and post-stroke astasia. The patient's SPV and ability to stand were assessed and confirmed an abnormality, especially in SPV. Then, to further elucidate the causal relationship between the abnormal SPV and the postural disorder, a 1 week program of standing training aimed at regulating SPV was applied and its effect on vertical perception and standing ability was evaluated. During this training, the patient was asked to maintain his body orientation vertical in reference to complementary somatosensory inputs arising from the ipsilesional upper limb. Several previous studies demonstrated that somatosensory inputs arising from a hand or finger, by lightly touching it to a stable object, reduce postural sway during standing in healthy subjects[7], as well as in post-stroke patients[8]. These findings seem to imply that somatosensory input from the upper limb can be used as supporting information conveying body orientation[7, 9, 10], which may contribute to regulating somatosensory-dependent vertical perception (i.e., SPV). Therefore, it was expected that this standing training could help the astasia patient regulate abnormal SPV, and thereby lead to an improvement in his postural disorder.

SUBJECTS AND METHODS

A 72-year-old right-handed man diagnosed with right thalamic hemorrhage including the posterolateral nucleus participated in the study. His complication was only a hypertension. The patient started receiving standard physical therapy such as sitting, sit-to-stand, and gait training on the stroke care unit 2 days after stroke onset for about an hour per day. Sixteen days after onset, the patient was transferred to the Recovery Rehabilitation Unit and continued the physical rehabilitation and standard physical therapy for about 3 hours per day. Fifty days after onset, he still had mild hemiplegia and severe somatosensory dysfunction of the upper and lower limbs on the contralesional side (Table 1). In addition, he was not able to stand and gait was not possible without assistance because of a tendency to fall toward the contralesional side despite not having any pusher behavior (his total score on the scale of contraversive pushing was less than the cut off point[11]). It was thought that this was not due to muscle weakness on the contralesional side, because the sum of knee extension force of both sides (0.64 Nm/kg) was higher than the cut-off point for sit-to-stand independence (0.40 Nm/kg)[12]. It was also assumed that the patient's postural disorders were not directly caused by severe somatosensory dysfunction since it has been shown that humans can stand alone with complete somatosensory loss[13]. Accordingly, the patient was diagnosed with post-stroke astasia. The patient and his family gave informed consent to participate in this study.

For measuring SPV, the patient was seated on a tilt table (UA-A501, OG GIKEN, Japan) with his eyes closed. The torso was restrained by two boxes fixed to the tilt table. A physical therapist supported the patient's body with his body from behind, acting like the backrest of a chair without touching the patient with his hands. Another therapist carefully checked the patient's posture from his front in order to keep his torso and head in a straight line. For the assessment, the tilt table was passively tilted either from the right (ipsilesional) toward the left or from the left (contralesional) toward the right with a constant velocity (2.5 degrees/s) in the roll plane. The initial tilting angle was set as either 5 degrees toward the right (5 degree) or left (−5 degree) with respect to the earth vertical. While the table was tilting, the patient was required to verbally indicate the time when he felt his body was vertical. The table's tilting angle (i.e., the angle from the horizontal line) at this time was recorded as the index for SPV. Because of the tendency to feel that the body is vertical when the body was still

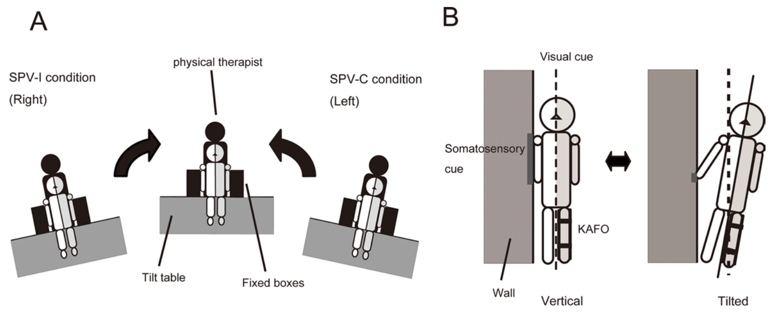

Fig. 1. (A) SPV measurement. The patient was randomly tilted toward either ipsilesional (right) or contralesional (left) side, then the tilt table tilted toward opposite direction until he verbally indicated that his body orientation reached upright.
(B) The body-tilt training (in intervention phase). The subject aligned his body orientation in reference to magnitude of somatosensory inputs from his ipsilesional upper limb. Left: when his body orientation was upright, the magnitude of somatosensory inputs was large, Right; when his body orientation was tilted, the magnitude of those was small.

leaning to the side of the initial tilt[5, 14, 15], ipsilesional (SPV-I) and contralesional tilt conditions (SPV-C) were separately assessed. SPV-I corresponded to the condition in which the table started tilting from the right (ipsilesional) to the left, whereas SPV-C corresponded to the one from the left (contralesional) to the right. Both SPV-I and SPV-C were evaluated five times in a randomized order. The patient was instructed to keep his eyes closed throughout the measurement in order not to receive visual feedback about his position. Since this assessment used different devices from those used in previous studies[6, 14], the intra-rater reliability of this assessment was determined by evaluating intra-class correlation coefficients (ICCs) with eight right-handed healthy subjects (age, 25.5 ± 2.9, mean ± SD). SPV was measured five times per subject and the ICC was calculated using SPSS (version 22, IBM). The ICC value was 0.95 for the condition from the right and 0.85 for the condition from the left, indicating the high reliability of this method of measurement.

Additionally, the duration of standing was measured to assess global postural disorders. The measurement was performed under four different conditions: eyes open or closed with or without holding a side cane. For the measurement with eyes opened, specific visual reference (e.g. a vertical bar) was not presented. Each condition was measured three times and the longest duration was selected for each condition.

First, the 1 week baseline period occurred. In this week, standard physical therapy including sit-stand, standing, transfer, and gait training was provided. During gait training, the patient wore a Knee-Ankle-Foot Orthosis (KAFO) while holding a cane or parallel bars. Occupational therapy, mainly focusing on daily activities such as toilet and dressing training, was also performed each day. The total rehabilitation time was 3 hours per day, 7 days per week. SPV, standing duration, and physical and cognitive function were assessed before the therapy on the first day and after the therapy on the last day.

In the second week (intervention period), standing training (body-tilting training) was added (Fig. 1). The patient stood upright with a KAFO on the contralesional leg beside the wall on his non-paretic ipsilesional side. The patient kept the ipsilesional arm close to his body while extending the elbow. Then, the patient was instructed to keep the forearm, upper-arm, and fingers touching the wall, in order for him to recognize the relationship between the actual vertical in standing with the magnitude of somatosensory inputs from the upper limb. Next, the patient actively tilted his body away from the wall. At this time, he was instructed to keep at least his fingers touching the wall to recognize the relationship between torso listing and reduced haptic inputs from the non-paretic ipsilesional upper limb. This step was repeated 10 times each day for a week. It was expected that, through this training, the patient could recognize his body orientation in reference to the magnitude of somatosensory inputs from the non-paretic ipsilesional upper limb. In the middle of the week, the training setting was changed to reduce the contribution of visual information. During the first 3 days, the patient performed this training about 2 meters ahead of a vertical bar, which could provide the patient with a salient visual vertical reference. Over the next 4 days, the patient was asked to perform the training with his eyes closed and he was given verbal feedback about his body orientation for every trial. During the intervention period, sit-to-stand and standing training were replaced with body-tilt training, but gait training was continued. Thus, total rehabilitation time in this week was comparable to that in the baseline period. SPV, standing duration, physical function, and disability were assessed after the therapy on the last day of the week.

RESULTS

Before the baseline period, both SPV-I and SPV-C were biased toward the ipsilesional and the contralesional side, respectively (Table 2). The absolute value of both SPV conditions was greater than that in the younger healthy subjects measured for the ICC (0.2 ± 0.9 and 0.3 ± 0.9 degrees under the conditions where the table started tilting from the right and left,

Table 2. The patient's SPV and standing duration at each phase

	Before the baseline	After the baseline	After the intervention
SPV-I (degree)	2.7 ± 0.3	−0.3 ± 0.3	0.4 ± 0.8
SPV-C (degree)	−3.0 ± 0.4	−2.7 ± 0.3	−0.8 ± 0.4
Standing duration (sec)			
eyes open (with/without cane)	5/0	20/0	37/34
eyes closed (with/without cane)	0/0	5/0	35/5

Data are presented in the form mean±standard error. For SPV-I and SPV-C, positive value correspond to ipsilesional (right) tilt relative to vertical, and negative value correspond to contralesional (left) tilt relative to vertical.

respectively). At the end of the baseline period, SPV-I showed greater improvement, namely getting closer to zero, and remained close to zero until the end of the intervention period. In contrast, SPV-C was still biased at the end of the baseline period, but finally showed improvement after the intervention period.

The subject was able to keep standing for less than 5 s with his eyes open before the baseline period. After the baseline period, standing duration was slightly increased, especially under conditions with the eyes open. Standing duration under all conditions showed a greater increase after the intervention period. For the assessment of physical functions, Functional Independence Measure (FIM) scores for bed and toilet transfer were improved after the intervention period (from 4 to 5, Table 1).

DISCUSSION

The present study investigated whether postural disorders observed in a post-stroke astasia patient were attributed to abnormal SPV. This abnormality improved through a 1-week period of body-tilting training utilizing complementary somatosensory inputs from the upper limb. In line with this improved SPV, standing duration and activities of daily living (i.e., transferring) showed greater improvement after the 1 week intervention period. These findings suggest that abnormal SPV can be one of the functional mechanisms underlying postural disorders in post-stroke astasia patients, and support the effectiveness of the intervention.

Before the baseline period, both SPV-I and SPV-C were biased more greatly than that of younger healthy subjects. These results support the hypothesis that astasia observed in post-stroke patients is accompanied by abnormal vertical perception, mainly in SPV. In the present study, the body-tilting training was applied to regulate abnormal SPV and investigated its effectiveness for postural disorders, in order to further investigate the causal relationship between them. Interestingly, abnormal SPV-I improved during the week of the baseline period when standard physical treatments were applied, whereas SPV-C remained biased after the baseline period but improved after the week of the intervention period when the body-tilting training was applied. In concordance with the improved SPV-C, standing ability improved more after the intervention period than after the baseline period.

A previous study indicated that post-stroke patients show abnormal vertical perception, especially when their body orientation is tilted toward the contralesional side compared to when it is tilted toward the ipsilesional side[16, 17]. This suggests that the abnormality is more robust in SPV-C than in SPV-I, corresponding to the present results that SPV-C remained biased after application of standard physical therapy.

However, biased SPV-C and postural disorders seem to be effectively improved through body-tilting training with complementary somatosensory inputs from the upper limb. Somesthetic (somatosensory) graviceptive inputs play a crucial role in the perception of body orientation in external space[6, 18, 19]. Light sensory inputs from touching a static object with the upper limb seemed to provide enough additional useful information about body orientation to reduce postural sway during standing[7, 8]. Considering the present post-stroke astasia patient, we speculate that complementary somatosensory inputs from the upper limb could be used as a reference for regulating abnormal perception of body orientation (i.e., abnormal SPV), which resulted in improvements in standing balance, prolonging standing duration and improving transferring ability in daily living. One may claim that vestibular inputs would also change by the training, which might somehow affect SPV and postural control. However, it has been suggested that SPV was mainly derived from bodily somatosensory information, but not vestibular graviceptive information[5, 6]. Thus, we assume that possible changes of vestibular inputs during the training would less effective on improvements of abnormal SPV bias and postural disorder. Moreover, it is possible that improvements in vertical perception and postural disorders are due to spontaneous recovery rather than the effect of body-tilting training. However, we consider that the possibility of spontaneous recovery is less plausible, given the fact that astasia symptoms in the present case had persisted well beyond several days after stroke onset, when most patients show spontaneous recovery from this symptom[1–3], and that his vertical perception and postural disorders were greatly improved after the 1 week intervention period as compared to those after the 1 week baseline period.

The present patient had a lesion in the right thalamus, including the posterolateral nucleus as seen in other post-stroke astasia patients in previous studies[1, 2]. The posterolateral thalamus functions to process both vestibular graviceptive[20] and somesthetic graviceptive information[6]. Thus, the posterolateral thalamus is thought to be a part of a "second graviceptive system," which contributes to controlling body orientation[21]. Therefore, it is highly plausible that post-stroke patients who have posterolateral thalamus lesions frequently present with postural disorders. While it has been reported that symptoms of astasia tend to spontaneously disappear several days after stroke onset[1–3], the present case had symptoms more than 50 days after the stroke. It might be that the present case had severe somatosensory dysfunction in the contralesional side compared with the previous astasia cases, in which somatosensory dysfunction in the contralesional side was absent or mild. As mentioned above, somatosensory inputs are likely to contribute to regulating vertical perception. Therefore, it seems that severe somatosensory dysfunction on one side of the body might delay the improvement of abnormal vertical perception, which might result in prolonged postural disorders, as in the present case.

Our study demonstrated the functional relationship between abnormal SPV and postural disorders in a post-stroke astasia patient. However, it should be noted that the present astasia patient might be a unique case, because symptoms of astasia spontaneously tend to disappear several days after stroke onset[1–3], while the present case had prolonged astasia symptoms more than 50 days after stroke. Thus, it remains unclear whether the abnormal vertical perception found in the present case is a common dysfunction observable in other astasia patients as well. To systematically investigate this relationship and the effectiveness of our standing training, further investigation with a large number of patients is required. Despite this, we believe that the present case report provides useful insights into the clinical condition of post-stroke astasia patients and suggests a possible option to help treat these patients.

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