

Influences of visual and supporting surface conditions on standing postural control and correlation with walking ability in patients with post-stroke hemiplegia

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Abstract. [Purpose] To quantify the influence of visual and under-foot-surface conditions on standing balance in patients with post stroke hemiplegia and examine associations of this ordinal score with somatosensory disturbance and walking ability. [Subjects] Sixty-six patients with post-stroke hemiplegia. [Methods] Standing balance was tested in 4 conditions (firm floor or foam rubber surface with eyes open or eyes closed) for 30 s per condition and scored using a 5-category ordinal scale. The accuracy of the standing balance score to distinguish patients above/below cut-offs for the timed up-and-go test (14 s) and functional ambulation category (4) was determined. [Results] Standing balance score was correlated with sensory impairments (tactile and vibration perception) and walking ability (up-and-go and functional ambulation category). The standing balance score distinguished patients with up-and-go times ≤ 14 and >14 s with moderate sensitivity and specificity, and distinguished patients with functional ambulation category <4 and ≥ 4 with high sensitivity and specificity. [Conclusion] Patients with post-stroke hemiplegia may be unable to adapt to changing visual or surface conditions. Therapists should perform comprehensive balance tests. The standing balance ordinal scale score was moderately correlate with walking ability, distinguishing patients according to walking ability. This scale's validity and reliability must be assessed in clinical settings.

Key words: Stroke, Standing balance, Walking ability

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INTRODUCTION

Sensory information for postural control comes from at least 3 sources: the somatosensory, vestibular, and visual systems. Information from these sources appears to be at least partially redundant, as sway increases only minimally with eyes closed and many patients with a loss of somatosensory or visual function are capable of independent stance and gait¹⁾.

In patients with neurologic problems, instability can result from inappropriate interaction among the 3 sensory inputs that provide orientation information for the postural control system. A patient may depend inappropriately on one sense in certain situations, causing intersensory conflict²⁾.

The Clinical Test of Sensory Interaction in Balance (CTSIB) developed by Shumway-Cook and Horak²⁾ assesses a person's ability to select sensory inputs for balance. This test includes 6 conditions: conditions 1, 2, and 3 in-

volve standing on a firm floor with eyes open, eyes closed, and wearing a visual-conflict dome for 30 s per condition, respectively; conditions 4, 5, and 6 involve standing on foam rubber in the same respective conditions. Postural instability with eyes closed suggests abnormal reliance on vision for postural control, and excessive reliance on visual input may be a natural compensatory strategy for coping with poor balance³⁾. However, many patients with post-stroke hemiplegia seem to rely on visual input^{3, 4)}. The modified CTSIB excludes the 2 conditions that involve wearing a visual conflict dome, and is thus more practical and easy to implement^{6, 7)}. The CTSIB or modified CTSIB has been used to determine fall risk^{8, 9)} or the influence of somatosensory impairment on balance¹⁰⁾.

To investigate the changes in postural sway according to surface stability, Yu et al.¹¹⁾ measured postural sway velocity, area, and distance under the unstable and stable conditions. They identified significant differences under the unstable conditions and conclude the results may be useful in balance training to prevent future falls after stroke¹¹⁾. Meanwhile, we previously investigated the influence of visual and supporting surface conditions on standing postural control in patients with post-stroke hemiplegia by measuring postural sway; furthermore, we examined the associations of postural sway under these conditions with somatosensory impairments, clinical standing balance measures, and walk-

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ing ability¹²). Postural sway, i.e., the swaying of the center of pressure was significantly greater in the eyes-closed and foam rubber conditions than the eyes open and firm floor condition. In almost all conditions, sway length was significantly correlated with standing balance score, walking ability, and superficial sensory disturbance of the paretic side. Therefore, we concluded that patients with hemiplegia have a reduced ability to select or compensate for appropriate sensory information when there are changes in various conditions and that they require environmental exercises¹²).

The effects of balance training for rehabilitation on an unstable surface (i.e., foam rubber) in stroke patients have recently been investigated. The effects of visual restriction and unstable base dual-task training effectively in improve the balance attention of stroke patients¹³). Lee et al.¹⁴) compared the effects of balance exercises performed on unstable and stable surface on the balance ability of stroke patients. In the unstable surface group, the velocity moment, a parameter of postural sway, decreased. In that study, an AIREX® balance-pad, which is commonly used in the fields of rehabilitation or sports, was used as the unstable surface.

Many patients with post-stroke hemiplegia have sensory disturbance; the degree of residual sensation may influence their static balance. The Stroke Impairment Assessment Set¹⁵) or Fugl-Meyer Sensorimotor Assessment^{16, 17}) are frequently used sensory assessment tools for patients with post-stroke hemiplegia, but both have limitations regarding the assessment of standing postural control. Therefore, a quantitative tool for sensory assessment is required to elucidate the relationship between sensory disturbance and standing balance.

This study aimed to quantify the influence of visual and supporting surface conditions on standing balance using a 5-category ordinal scale in patients with post-stroke hemiplegia and examine the correlations of the ordinal score with somatosensory disturbance and walking ability.

SUBJECTS AND METHODS

This study involves 66 patients (45 men and 21 women) with post-stroke hemiplegia. The mean age of participants was 69.4 years and the disease duration ranged from 13–7,600 days (Table 1).

The patients were screened to ensure medical stability and their ability were to stand independently with no assistive device for 15 s. Patients were excluded if they were unable to understand verbal instructions or provide consent.

The purposes and procedure of this study were explained to the participants and written consent was obtained from all patients prior to participation. This study was approved by the Ethics Committee of Hidaka Hospital (acceptance numbers 16 and 32).

Clinical assessments of motor function and walking ability were performed by one researcher. All measurements were taken on a single occasion. The following data were recorded; gender, age, disease, disease duration, the Brunnstrom Recovery Stage (BRS)¹⁸), TUG time¹⁹) and FAC²⁰); the latter 2 were evaluated as indices of balance and walking ability, respectively. BRS is an assessment procedure used to determine the level of recovery of stroke

Table 1. Characteristics of patients with post-stroke hemiplegia (N = 66)

Characteristic	Values
Gender	male: 45 female: 21
Age (years)*	69.4 ± 11.2 (38–91)
Damage hemisphere	left: 36, right: 30
Disease duration (days)**	1,408.6 ± 1,834.3 (13–7,600)
Tactile perception: SWM (g)*	
non-paretic side	11.1 ± 28.6 (0.2–190.5)
paretic side	39.1 ± 70.8 (0.5–302)
Vibration perception: RS*	
non-paretic side	5.2 ± 1.8 (1–8)
paretic side	4.3 ± 2.1 (0–8)
TUG (s) **††	30.8 ± 43.6 (6.3–204)
FAC	0:2 2:10 3:20 4:22 5:12
Standing balance ordinal score	1:2 2:7 3:14 4:20 5:23

*: Mean±SD (range) †: n=64 ††: n=61

TUG: Timed up-and-go test, FAC: functional ambulation category, SWM: Semmes-Weinstein monofilaments, RS: Rydel Seiffer tuning fork

patients by testing muscle tone and voluntary control¹⁸). In the TUG test, the participant stood up from a chair, walked 3 m, turned at a designated spot, returned to the chair, and sat down. The time taken perform the test was recorded using a stopwatch¹⁹). The FAC is functional walking test that evaluates walking ability. The patient was classified according to their most independent level of function with regard to the supervision or physical required²⁰).

The tactile perception threshold was measured with Semmes Weinstein Monofilaments (SWM; North Coast Medical, Inc., Morgan Hill, CA, USA). Four SWM testing areas were selected on the plantar side of the foot. The test locations were the hallux, thenar pad, digital pad and heel avoiding horny substances or calluses; the locations were tested on both feet. The monofilaments were applied starting with the filaments 3.22–4.08, which is the normal tactile perception threshold of healthy subjects²¹). Patients were instructed to close their eyes during the test. A monofilament was applied to a test location for 3.0 s and the patients were instructed to identify the test location where they felt the monofilament. If a monofilament was perceived and located correctly, the filament representing the force was noted as the patient's sensory score. If a monofilament was not detected, the researcher tested the next monofilament in rank order. The results were converted into grams and the mean sensory score from the 4 areas was used for further analysis. The SWM has high test-retest reliability (intraclass correlation coefficient = 0.78)²¹).

The vibration detection threshold was measured using a 128 Hz Rydel-Seiffer tuning fork (RS; BONIMED), which is a graduated fork that can be used to quantify subjects' ability to perceive various vibration intensities²²). A triangle and an arbitrary scale from 0 (minimum score) to 8 (maximum score) are imprinted on the weights to assess vibration threshold. Once the arms of the fork are swinging, the fork

Table 2. Four conditions of the standing balance test

	Surface condition	Visual condition
FF-EO	Firm floor	Eyes open
FF-EC	Firm floor	Eyes closed
FR-EO	Foam rubber (AIREX)	Eyes open
FR-EC	Foam rubber (AIREX)	Eyes closed

The patients stood on the firm floor or foam rubber with their eyes open or closed with no assistive device for up to 30 s. The 4 conditions were tested in the following order: FF-EO, FF-EC, FR-EO, and FR-EC.

vibrates at 128 Hz and the triangles on the weights appear double. The intersection of these 2 virtual triangles moves from 0–8 in an exponential manner with decreasing vibration amplitude of the arms. Vibration threshold was measured at the medial malleolus of each ankle. The tuning fork was applied as perpendicular as possible resting on its own weight with the arms of the fork swinging maximally. The vibration threshold was measured 3 times and the average value was calculated for each ankle. This method for evaluating vibration threshold has high inter-rater and test-retest reliability as well as high sensitivity²³.

To investigate standing balance ability, the patients stood on the firm floor (FF) or foam rubber (FR) with their eyes open (EO) or eyes closed (EC) with no assistive device for up to 30 s (Table 2). The AIREX[®] Balance-pad plus (AIREX AG, 25% compression resistance, 20 kPa; apparent density 55 kg/m³; tensile strength 260 kPa; 410 × 500 × 60 mm) was used for the FR conditions. The 4 conditions were tested in the following order: FF-EO, FF-EC, FR-EO, and FR-EC. If patient failed to stand for 30 s without losing balance in an EO condition, the measurement was terminated. If the patient failed to stand for 30 s without losing balance in the FF-EC condition, the measurement continued to the FR-EO condition.

The standing balance test was performed with the patient's feet at a comfortable width; the stance width was kept as constant as possible among conditions. The test was performed barefoot or with the brace used on a daily basis if applicable. The patient was instructed to, "stand upright and look straight ahead with your arms alongside your body." During the EO conditions, the patient was looked at a stationary target at eye level on a wall approximately 3 m in front of them. The researcher used a stopwatch to measure the amount of time the patient was able to stand in each condition. The time ended when the patient either: (1) moved his/her upper limbs, (2) moved his/her lower limbs, or (3) opened his/her eyes during EC conditions. The patient was allowed to sit down and take a longer rest in between conditions if they were tired.

We rated the results of the standing balance test using a 5-category ordinal scale. The scale scores are assigned on the basis of the testing conditions of testing and the duration of stance maintenance (<30 s or 30 s). The score ranges from 1–5 as follows: 1, unable to stand without assistance for 30 s in the FF-EO condition; 2, able to stand independently for 30 s only in the FF-EO condition; 3, able to stand independently for 30 s in both FF conditions; 4, able to stand

independently for 30 s in the FR-EO condition but not the FR-EC condition; and 5, able to stand independently for 30 s in all 4 conditions.

Statistical analysis was performed using IBM SPSS version 21. The level of statistical significance was set at $p < 0.05$. Spearman's rank correlation coefficients were used to evaluate the correlations between the standing balance ordinal scale score and each clinical assessment. To investigate the accuracy of the ordinal score for fall prediction and walking ability, the sensitivity and specificity with which the ordinal score distinguished patients with a TUG time ≤ 14.0 s vs > 14 s (fall prediction) and FAC < 4 vs ≥ 4 (walking ability) were calculated, along with positive and negative predictive values. Patients who take longer than 14.0 s to complete the TUG have a high risk of falls²⁴; therefore, 14.0 s was adopted as the cut-off for the TUG. An FAC of 4 means that the patient can ambulate independently on level surfaces but requires supervision or physical assistance to negotiate stairs, inclines, or non-level surfaces²⁰, therefore this category was adopted as the cut-off for the FAC.

RESULTS

The characteristics of patients with post-stroke hemiplegia are summarized in Table 1. Motor function (BRS), somatosensory disturbance (tactile and vibration threshold) and walking ability (TUG time and FAC) exhibited large inter-individual variability.

Two patients were not able to stand independently 30 s in FF-EO condition and achieved a score of 1 on the standing balance ordinal scale and 23 patients were able to stand for 30 s in all 4 conditions, thus achieving a score of 5. Patients who were unable to stand independently for 30 s in the FF-EO condition likewise failed to stand for 30 s in the FR-EO condition.

The correlations of standing balance ordinal scores with clinical parameters are summarized in Table 3. The standing balance score was positively correlated with tactile perception (SWM) on both the paretic and the non-paretic sides and was moderately correlated with vibration perception (RS), BRS and FAC. In contrast, standing balance score was negatively correlated with TUG time.

A standing balance ordinal scale score of 5 distinguished patients between TUG time ≤ 14 s and > 14 s with moderate sensitivity and specificity. Meanwhile, a standing balance ordinal scale score of 4 distinguished between patients with an FAC < 4 and ≥ 4 with high sensitivity and specificity (Table 4). The standing balance ordinal score had high negative predictive value and a low positive predictive value for distinguishing between a TUG time ≤ 14 s and > 14 s and an FAC < 4 and ≥ 4 .

DISCUSSION

As mentioned above, this study aimed to determine the influences of visual and supporting surface conditions on standing balance using a 5-category ordinal scale in patients with post-stroke hemiplegia as well as examine the correlations of the ordinal score with somatosensory disturbance and walking ability. Moreover, we investigated the accuracy

Table 3. Correlations between standing balance ordinal scale score and clinical assessments

	BRS	SWM		RS		TUG	FAC
		non-paretic side	paretic side	non-paretic side	paretic side		
Balance score	0.590**	-0.339*	-0.350*	0.382**	0.465**	-0.632**	0.726**

Values are Spearman's correlation coefficients *: $p < 0.05$, **: $p < 0.01$

BRS: Brunnstrom recovery stage, TUG: Timed up-and-go test, FAC: functional ambulation category, SWM: Semmes-Weinstein monofilaments, RS: Rydel Seiffer tuning fork

Table 4. Accuracie of fall risk prediction and walking ability (%)

	TUG (< 14.0 s)				FAC (> 4)			
	Sensitivity	Specificity	Positive	Negative	Sensitivity	Specificity	Positive	Negative
			predictive value	predictive value			predictive value	predictive value
Score 1 (n = 2)	100	0	28.6	0	100	0	51.5	0
Score 2 (n=7)	100	6.7	30.5	100	100	6.3	53.1	100
Score 3 (n = 14)	100	20.0	33.9	100	100	31.5	59.6	100
Score 4 (n = 20)	94.4	46.7	41.5	95.5	91.1	62.5	72.1	87.0
Score 5 (n = 23)	72.2	77.8	56.5	87.5	58.8	68.8	87.0	67.4

TUG: Timed up-and-go test, FAC: functional ambulation category

of the standing balance ordinal scale score for distinguishing patients with TUG time and FAC above and below specified cut-offs.

Only 23 of 66 patients who were able to stand for 30 s independently in all 4 conditions (score 5). In the EC or FR conditions there may be a lack of reliable visual and somatosensory information, indicating that patients who achieved a score 4 or 5 have good standing postural control ability. In the FR conditions, during stance on a compliant surface, the change in ankle position may no longer correlate with center of gravity movement⁵); an increase in swaying or falls during standing on a compliant surface suggests dependence on the somatosensory system^{2, 5}). Furthermore, standing time in each condition, or the related ordinal score used in the current study reflects the ability of patients to adapt and maintain postural stability in a variety of situations requiring information from all 3 sensory systems²).

Patients with post-stroke hemiplegia usually present with abnormal muscle tone, abnormal movement control, discoordination within motor strategies, loss of anticipatory postural control, reduced cutaneous sensation, distorted lower limbs proprioception, impaired visual mechanisms and abnormal vestibular mechanisms all of which may affect their ability to maintain standing¹⁹). The sensory system used for postural control is typically determined by the sensory characteristics of the perturbation, but many patients with hemiplegia overly rely on visual input. The lack of ability to analyze, compare, and select the pertinent sensory information cause instability in EC or FR conditions. The balance test used in the present study can be used to determine which sense a patient is most dependent on for sway orientation information and how well a patient can adapt to reliance on the various senses in situations with intersensory conflict²).

The patients had a wide range of clinical impairments and walking abilities. However, standing balance ordinal score was positively correlated with tactile and vibration percep-

tion thresholds. This indicates patients who have a sensory disturbance, i.e., disturbed tactile or vibration perception, are unable to maintain stable standing balance in the absence of accurate visual or somatosensory information. In real-life settings, this may mean such patients are unable to adapt to changing visual or surface conditions. This impaired adaptive ability may increase the risk of falls at night or when transitioning from one surface to another, for example, when moving to soft carpet from a hard floor. The standing balance ordinal scale score was moderately correlated with walking ability, which is concordant with the results of previous studies^{4, 25, 27}).

Standing balance ordinal scale score of 4 distinguished between patients with an FAC < 4 and ≥ 4 with high sensitivity and specificity. Also, the standing balance ordinal score had a high negative predictive value and a low positive predictive value for distinguishing between patients with TUG times ≤ 14 and > 14 s, and FAC < 4 and ≥ 4 . Therefore, we conclude that it is possible to accurately distinguish patients according to walking ability by using the standing balance ordinal score.

The low positive predictive value of the standing balance ordinal score for distinguishing TUG time ≤ 14 s from > 14 s is because of the differences of the standing balance test and TUG. The standing balance test measures static balance, whereas the TUG test requires dynamic balance and walking¹⁷). Some patients who had a TUG time > 14 s had a high score on the standing balance test. Balance incorporates many systems including stability limits, postural responses, sensory organization, and gait stability²⁶); thus, therapists need to be able to differentiate the contribution of the different underlying systems to balance problems and fall risk. Hence, therapists need to perform a comprehensive balance test for all post-stroke patients.

The limitations of this study are that the balance test used measures only static standing balance and is therefore

insufficient to inform clinical decision-making. Patients with post-stroke hemiplegia have multiple motor or sensory impairments; therefore balance impairments should be assessed using a comprehensive tool such as the Balance Evaluation System Test²⁶). Likewise, a computerized force platform is commonly used to measure standing balance¹⁹); however, this equipment is expensive and not readily available in clinics. However, the static standing balance test used in the present study involves standing with eyes closed or open on a firm surface or foam rubber, is easy and safe to use and does not require any special or expensive equipment. As our results indicate standing balance ordinal score is correlated with sensory disturbance and walking ability, analysis of the pattern of instability among the 4 conditions provides therapists insight regarding which sense a person is dependent on to maintain stability²). A follow-up intervention study assessing the validity and reliability of this ordinal score system in clinical settings as well as efficacy as an outcome measurement for evaluating patients' performance should be performed.

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