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

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 Horak3) assesses a person’s ability to select sensory inputs for balance. This test includes 6 conditions: conditions 1, 2, and 3 involve 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.

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-
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 improve the balance attention of stroke patients. Lee et al. 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 Set (SIS) or Fugl-Meyer Sensorimotor Assessment 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 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), TUG time and FAC.

Clinical assessment procedure used to determine the level of recovery of stroke patients by testing muscle tone and voluntary control. 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 stopwatch. 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 required.

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 subjects. 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).

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 intensities. 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 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                     | 0.2:10 3:20:4:22:5:12 |
| Standing balance ordinal score | 1:2:7:3:14:4:20:5:23 |

*: Mean±SD (range) †: n=64 ††: n=61

FAC: Functional Ambulation Category, TUG: Timed up-and-go test, RS: Rydel Seiffer tuning fork
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 sensitivity.23

To investigate standing balance ability, the patients stood on the firm floor (FF) or foam rubber (FR) with their eyes open (EO) or closed (EC) 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.

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 located 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 falls; 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 surfaces; 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 for 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
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 movement; an increase in swaying or falls during standing on a compliant surface suggests dependence on the somatosensory system. 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 systems.

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 standing. 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 conflict.

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

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

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

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

| TUG (< 14.0 s) | FAC (> 4) |
|----------------|-----------|
| Sensitivity | Specificity | Positive predictive value | Negative predictive value | Sensitivity | Specificity | Positive predictive value | Negative 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
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 Test20. 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 stability21. 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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REFERENCES

1) Horak FB, Nashner LM, Diener HC: Postural strategies associated with somatosensory and vestibular loss. Exp Brain Res, 1990, 82: 167–177. [Medline] [CrossRef]
2) Shumway-Cook A, Horak FB: Assessing the influence of sensory interaction of balance. Suggestion from the field. Phys Ther, 1986, 66: 1548–1550. [Medline] [CrossRef]
3) Bonan IV, Colle FM, Guichard JP, et al.: Reliance on visual information after stroke. Part I: Balance on dynamic posturography. Arch Phys Med Rehabil, 2004, 85: 268–273. [Medline] [CrossRef]
4) Bonan IV, Yelnik AP, Colle FM, et al.: Reliance on visual information after stroke. Part II: Effectiveness of a balance rehabilitation program with visual cue deprivation after stroke: a randomized controlled trial. Arch Phys Med Rehabil, 2004, 85: 274–278. [Medline] [CrossRef]
5) Anacker SL, Di Fabio RP: Influence of sensory inputs on standing balance in community-dwelling elders with a recent history of falling. Phys Ther, 1992, 72: 575–581, discussion 581–584. [Medline] [CrossRef]
6) Cohen H, Blatchly CA, Gombush LL: A study of the clinical test of sensory interaction and balance. Phys Ther, 1993, 73: 346–351, discussion 351–354. [Medline] [CrossRef]
7) Wrisley DM, Whitney SL: The effect of foot position on the modified clinical test of sensory interaction and balance. Arch Phys Med Rehabil, 2004, 85: 335–338. [Medline] [CrossRef]
8) Madureira MM, Takayama L, Gallinaro AL, et al.: Balance training program is highly effective in improving functional status and reducing the risk of falls in elderly women with osteoporosis: a randomized controlled trial. Osteoporos Int, 2007, 18: 419–425. [Medline] [CrossRef]
9) Ricci NA, de Faria Figueiredo Gonçalves D, Cunha AM, et al.: Sensory interaction on static balance: a comparison concerning the history of falls of community-dwelling elderly. Geriatr Gerontol Int, 2009, 9: 165–171. [Medline] [CrossRef]
10) van der Linden MH, van der Linden SC, Hendrickx HT, et al.: Postural instability in Charcot-Marie-Tooth type 1A patients is strongly associated with reduced somatosensation. Gait Posture, 2010, 31: 483–488. [Medline] [CrossRef]
11) Yu J, Jung J, Cho K: Changes in postural sway according to surface stability in post-stroke patients. J Phys Ther Sci, 2012, 24: 1183–1186. [CrossRef]
12) Okawara N, Usuda S: Influence of visual and surface conditions on standing postural control in patients with post-stroke hemiplegia. Rigakuryooukou Kagaku, 2014, 29: 33–38 (in Japanese). [CrossRef]
13) Kim D, Ko J, Woo Y: Effects of dual task training with visual restriction and an unstable base on the balance and attention of stroke patients. J Phys Ther Sci, 2013, 25: 1579–1582. [Medline] [CrossRef]
14) Lee YJ, Park J, Lee D, et al.: The effects of exercising on unstable surface on the balance ability of stroke patients. J Phys Ther Sci, 2011, 23: 789–792. [CrossRef]
15) Chino K, Sonoda S, Domen K, et al.: Stroke Impairment Assessment Set (SIAS): a new evaluation instrument for stroke patients. Jpn J Rehabil Med, 1994, 31: 495–495.
16) Fugl-Meyer AR, Jäätiskö L, Leyman I, et al.: The post-stroke hemiplegic patient. 1. a method for evaluation of physical performance. Scand J Rehabil Med, 1975, 7: 13–31. [Medline]
17) Di Fabio RP, Badke MB: Relationship of sensory organization to balance function in patients with hemiplegia. Phys Ther, 1990, 70: 542–548. [Medline] [CrossRef]
18) Brunnstrom S: Movement Therapy in Hemiplegia. Ney York: Harper & Row Publications, 1970, pp 1–30.
19) Podsiałdo D, Richardson S: The timed “Up & Go”: a test of basic functional mobility for frail elderly persons. J Am Geriatr Soc, 1991, 39: 142–148. [Medline]
20) Holden MK, Gill KM, Magliorzi MR: Gait assessment for neurologically impaired patients. Standards for outcome assessment. Phys Ther, 1986, 66: 1530–1539. [Medline]
21) Collins S, Visscher P, De Vet HC, et al.: Reliability of the Semmes Weinstein Monofilaments to measure cutaneous sensibility in the feet of healthy subjects. Disabil Rehabil, 2010, 32: 2019–2027. [Medline] [CrossRef]
22) Martina IS, van Koningsveld R, Schmitz PI, et al.: Measuring vibration threshold with a graduated tuning fork in normal aging and in patients with polyneuropathy. European Inflammatory Neuropathy Cause and Treatment (INCAT) group. J Neurol Neurosurg Psychiatry, 1998, 65: 743–747. [Medline] [CrossRef]
23) Horak FB, Wrisley DM, Frank J: The Balance Evaluation Test (BESTest) to differentiate balance deficits. Phys Ther, 2009, 89: 484–498. [Medline] [CrossRef]
24) Andersson AG, Kamwendo K, Seiger A, et al.: How to identify potential fallers in a stroke unit: validity indexes of 4 test methods. J Rehabil Med, 2006, 38: 186–191. [Medline] [CrossRef]
25) Niam S, Cheung W, Sullivan PE, et al.: Balance and physical impairments after stroke. Arch Phys Med Rehabil, 1999, 80: 1227–1233. [Medline] [CrossRef]
26) Horak FB, Wrisley DM, Frank J: The Balance Evaluation Test (BESTest) to differentiate balance deficits. Phys Ther, 2009, 89: 484–498. [Medline] [CrossRef]
27) Tsang CS, Liao LR, Chung RC, et al.: Psychometric properties of the Mini-Balance Evaluation Systems Test (Mini-BESTest) in community-dwelling individuals with chronic stroke. Phys Ther, 2013, 93: 1102–1115. [Medline] [CrossRef]