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Effect of Visual and Somatosensory Information Inputs on Postural Sway in Patients With Stroke Using Tri-Axial Accelerometer Measurement

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Abstract

Background: Posture balance control is the ability to maintain the body's center of gravity in the minimal postural sway state on a supportive surface. This ability is obtained through a complicated process of sensing the movements of the human body through sensory organs and then integrating the information into the central nervous system and reacting to the musculoskeletal system and the support action of the musculoskeletal system. Motor function, including coordination, motor, and vision, vestibular sense, and sensory function, including proprioception, should act in an integrated way. However, more than half of stroke patients have motor, sensory, cognitive, and emotional disorders for a long time. Motor and sensory disorders cause the greatest difficulty in postural control among stroke patients.

Objects: The purpose of this study is to determine the effect of visual and somatosensory information on postural sway in stroke patients and carrying out a kinematic analysis using a tri-axial accelerometer and a quantitative assessment.

Methods: Thirty-four subjects posed four stance condition was accepted various sensory information for counterbalance. This experiment referred to the computerized dynamic posturography assessments and was redesigned four condition blocking visual and somatosensory information. To measure the postural sway of the subjects' trunk, a wireless tri-axial accelerometer was used by signal vector magnitude value. Ony-way measure analysis of variance was performed among four condition.

Results: There were significant differences when somatosensory information input blocked ($p<.05$).

Conclusion: The sensory significantly affecting the balance ability of stroke patients is somatosensory, and the amount of actual movement of the trunk could be objectively compared and analyzed through quantitative figures using a tri-axial accelerometer for balance ability.

Key Words: Balance; Postural sway; Sensory information; Stroke; Tri-axial accelerometer.

Introduction

Balance is a generic term describing the dynamics of body posture to prevent falling. It is related to the inertial forces acting on the body and the inertial characteristics of body segments. In addition, balance can be said to involve complex motor skills resulting from the interactions of many senses, including motor and cognitive responses, rather than the product of righting, equilibrium reflection, or one system (Matsumura and Ambrose, 2006). Therefore, the ability to control balance is the complex result of sensory ability and motor ability and is an integral element in the human body, enabling us to perform activities of daily living and to walk independently (Laufer et al, 2003). Balance control requires the interaction of various organs, such as vision, hearing, the vestibular organ, proprioceptive sensibility, sense of position, muscle strength, and cognitive function (Geiger et al, 2001; Jang et al, 1999). Among them, the activities of the sensory system for balance require visual, vestibular, and somatosensory in-

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formation; therefore, their harmony is required (Brauer et al, 2000). That motion, termed postural sway, produces a flow of information across the sensory system and may be used to maintain postural stability (McCollum et al, 1996; Riccio and Stoffregen, 1991).

Balance disorder, common among stroke patients, has a negative effect on activities of daily living and functional independence level (Benaim et al, 1999; Liaw et al, 2008). Therefore, it is very important to diagnose the severity of the disorder or predict the functional results with the choice of an appropriate rehabilitation treatment (Wang et al, 2004). The major causes of balance disorders of hemiplegic patients are diverse, such as joint range limit, muscular weakness, changes in muscle tension, sensory deficit, abnormal postural response, cognitive deterioration. However, central integration capability, the deterioration of vision and vestibular sense, and somatesthesia can be discussed among them (Horak, 1997). As shown above, balance disability among stroke patients is the main cause of the lowering of walking ability (Tyson et al, 2006), and it increases the risk of falling and reduces moving ability and activities of daily living (Kwakkel et al, 1996). Therefore, the focus of the rehabilitation treatment of early stroke patients should involve an understanding of balance problems and various strategies for balance recovery, and quality of life should be improved, such as independent daily living and walking (Moon et al, 2012).

Computerized dynamic posturography (CDP) is a test method that can analyze the sensory and motor system individually or collectively by combining afferent stimulation, such as vision, the vestibular system, somatosenses, somatesthesia. Moreover, CDP can quantify the degree of the disorder and can identify a disorder of vestibular spinal reflection (Jacobson et al, 1993). As stated above, an CDP assessment has the advantages of demonstrating concurrent validity (ICC=.48~.72) and test-retest reliability (ICC=.98) (Liston and Brouwer, 1996), as well as assessing quantitative and objective balance ability by processing balance ability through expensive high-end equipment with the computer program (Allum et al, 1998).

An accelerometer is a device for measuring the speed variation of a vehicle, and studies on various human activities, such as moving route, range of activities, postural changes are underway using the acceleration scale. In particular, since the 1990s, many studies have been actively carried out in the field of medicine due to the performance improvement and miniaturization of a sensor and the monitoring of patients' human activities using an acceleration sensor, and studies on falling are actively in progress (Mathie et al, 2004a). Besides, it has been widely used as equipment for measuring balance in many studies (Kamen et al, 1998; Mayagoitia et al, 2002; O'Sullivan et al, 2009; Whitney et al, 2011).

Thus, this study aims to identify the effect of visual and somatosensory information inputs on the balance ability of stroke patients using a tri-axial accelerometer, a quantitative measurement equipment, and to represent balance ability objectively through a kinematic analysis. We hypothesized that somatosensory information input would decrease the postural sway more than visual information input.

Methods

Subjects

We explained the purpose of the study is to target patients diagnosed as having had a stroke and receiving occupational treatment in one rehabilitation hospital in Gyeonggi-do, and we asked for consent to perform the research. We also, selected a person can stand independently for more than 1 minute, hasn't complained of dizziness for last three months in the medical records or during the interviews. The subjects who met these selection criteria totaled 34 people, and general characteristics are shown in Table 1. The subjects of this study consisted of 25 males (73.5%) and nine females (26.5%), and regard-

Table 1. General characteristics of subjects (N=34)

Variables		n (%)	Mean	Standard deviation
Gender	Male	25 (73.5)		
	Female	9 (26.5)		
Affected side	Right	16 (47.0)		
	Left	16 (47.0)		
	Both	2 (6.0)		
Age (year)			49.7	16.8
Disease duration (month)			16.5	13.5
BBS[a]			40.0	12.6

[a] Berg balance scale.

ing hemiside, 16 were affected on the right side (47.0%), 16 on the left side (47.0%), and two on both sides (6.0%). The average age was 49.7 years (standard deviation 16.8), and the average time since stroke was 16.5 months (standard deviation 13.5). The mean score of berg balance scale was 40.0 points (standard deviation 12.6).

Procedures

All subjects posed four stance condition was accepted various sensory information for counterbalance (Table 2). This experiment referred to the CDP assessments and was redesigned using a sleep shade for visual blocking in the condition with eyes closed and using 50×41×6 ㎝ balance pads (CH-5643, Airex AG, Sin, Switzerland) for somatosensory information blocking. For the experiment process and measurement method, each conditions were conducted for 30 seconds, and were repeatedly measured three times. Experiments were carried out randomly from condition 1 to condition 4. When the postural sway measurement experiments for each condition was over, the subjects took a rest on the chair prepared in the back. And, for the safety of the subjects, the experiment was stopped immediately if falling occurred, and the experiment was carried out again after having a break.

Table 2. Four stance conditions

Conditions	Eyes	Support surface	Sensory input
1 (reference)	Open	Floor	Visual Somatosensory
2	Closed	Floor	Somatosensory
3	Open	Balance pad	Visual
4	Closed	Balance pad	-

Instrumentation

To measure the postural sway of the subjects' trunk under four stance conditions, a wireless tri-axial accelerometer was used. The measuring device is a Trigno™ Wireless EMG System (Delsys Inc., Boston, MA, USA) and it consists of an accelerometer sensor and receiver. This measuring device can sensitively sense the acceleration of the tri-axial (X axis, Y axis, Z axis) direction and measure from a minimum -9 g to a maximum +9 g. Signals sensed in the accelerometer sensor are collected in the EMG works program (Delsys Inc., Boston, MA, USA) via a receiver connected to the computer and they can be monitored in realtime. The accelerometer sensor attached to the trunk prints (L3 level) out the movement of the trunk according to the tri-axial acceleration data of the X-axis (up and down), Y-axis (left and right), and Z-axis (forward and backward). The value of acquired acceleration was converted to signal vector magnitude (SVM) values (Figure 1). The instantaneous resultants SVM was derived by combining accelerations measured in the vertical and medio-lateral, and anterior-posterior planes. In short,

$$\mathrm{SVM} = \sqrt{x_i^2 + y_i^2 + z_i^2}$$

Figure 1. Signal vector magnitude.

we can estimate the motion of postural sway by the acceleration vector of SVM value.

Statistical analysis

The data collected through this experiment process were analyzed using the SPSS statistical software package ver. 18.0 (SPSS Inc., Chicago, IL, USA). The general characteristics and balance ability of the subjects were expressed descriptive statistics as a frequency analysis, mean and standard deviation. One-way measure analysis of variance was performed to determine the effect of visual information and somatosensory information inputs on postural sway (condition 1~4). Bonferroni correction as post-hoc analysis was used to determine differences among each conditions. The significance level of all statistical analyses was selected as $p<.05$.

Results

The effect of visual and somatosensory information inputs on postural sway in stroke patients was examined according to the SVM value of acceleration. There were significant differences among their conditions ($p<.05$) (Table 3).

On a firm surface, eyes open and eyes closed conditions were 1.078 g and 1.080 g respectively, and there were no significant differences by post-hoc analysis. Also, on the foam surface, the eyes open and eyes closed conditions were 1.108 g and 1.123 g, respectively, and there were no significant differences by post-hoc analysis. In short, acceleration doesn't increase when visual information input removed.

In the eyes open condition, standing on a firm surface and a foam surface were 1.078 g and 1.108 g respectively, and there were no significant differences by post-hoc analysis. But, in the eyes closed condition, standing on a firm surface and a foam surface were 1.080 g and 1.123 g respectively and there were significant differences by post-hoc analysis ($p<.05$). In short, acceleration increase when somatosensory information input removed.

Lastly, standing condition with eyes open on a firm surface and eyes close on a foam surface were 1.078 g and 1.123 g respectively and there were significant differences by post-hoc analysis ($p<.05$). In brief, acceleration increase when visual and somatosensory information input removed.

Discussion

Postural sway is believed to play an important role in the control of standing balance, and many indicators of body sway have been suggested. Most commonly, these are based on the excursions of the body center of mass or the center of pressure, the latter being the point location of the vertical ground reaction force vector. The purpose of this study is to carry out a kinematic analysis using a tri-axial accelerometer to determine the effect of visual and somatosensory information on balance ability targeting stroke patients. The results showed that postural sway increased if removing somatosensory information, not

Table 3. Results of the effects of visual and somatosensory information input on the postural sway (Unit: g)

	Eyes open, firm surface (condition 1)	Eyes closed, firm surface (condition 2)	Eyes open, form surface (condition 3)	Eyes closed, form surface (condition 4)
Acceleration (SVM[a])	1.078±.066[b]	1.080±.071	1.108±.133	1.123±.146[*†]

[a]signal vector magnitude, [b]mean±standard deviation, [*]significant difference compared eyes open, firm surface (condition 1) (p=.006), [†] significant difference compared to eyes closed, firm surface (condition 2) (p=.006).

visual information.

This is consistent with the results of research that postural sway of 17 older patients increased significantly when somatosensory blocked (O'Sullivan et al, 2009). This means that vision is not necessary for static standing control and proper speaking. Vision can be seen to contribute to balance control during static standing, although many studies that investigated the effect of vision during static standing examined the sway amplitude when opening and closing eyes, and it was found that sway increases greatly when closing eyes (Edwards, 1946; Lee and Lishman, 1975; Paulus et al, 1984). Another study demonstrated the information provided by the various senses is partially redundant, and healthy subjects are able to compensate for the loss of somatosensory input with visual input (Horak et al, 1989; Woollacott and Shumway-Cook, 1990). Moreover, another study reported that neurological disease patients rely more on visual information in the beginning of the recovery process due to damage to the sensory system. Therefore, training using somatosensory and vestibular sensory information while blocking visual information is more effective than training that allows visual information, and when motor skills including postural control are re-acquired through this, patients are less dependent on vision and use somatosensory information more often (Mulder et al, 1993).

The methods of assessing balance ability include the clinical measure and the laboratory measure. The laboratory measure can measure balance delicately and quantitatively, but it has drawbacks in that it is expensive and not universal, while the clinical measure measures simply and is less expensive, but it has drawbacks in that it is difficult to assess balance delicately and quantitatively. The ideal assessment method should provide objective, quantitative measurements that could be easily translated into simple and useful information. Advances in computerized technology have made objective assessments of balance more and more practical for clinical environments (Mancini and Horak, 2010). Therefore, both clinical measure and laboratory measure should be considered together for an ideal balance assessment (Bogle Thorbahn and Newton, 1996).

Accelerometers are usually displayed in multiples of gravity based on the amount of change of speed over time while moving and provide indicators on motor because the degree of acceleration includes the speed in the distance traveled. An accelerometer is one of tools which are widely used because it can be used to measure and assess physical activities in the freely living state and can be used irrespective of the wearing position such as the wrist, ankle, pocket, bag, waist of the subjects. In addition, due to their advantages that they are relatively easy to operate compared to other activity monitors (Initialization to record data and download data) and non-invasive to subjects because of small size and long-term data can be collected, these accelerometers are often utilized by physical activity-related researchers. Choosing a reference point over the lumbar spine as an indicator of center of mass during standing and walking is a possible alternative that is easy to administer and that facilitates testing in environments other than a laboratory (Warren et al, 1986). Accelerometers have been proposed as a quantitative measure of balance during standing and walking, and is a reliable method with hight absolute test-retest reliability for the measurement of balance. Also accelerometers offer a practical and low cost alternative (Moe-Nilssen, 1998; Mathie et al, 2004b).

Thus, the purpose of this study is to present quantitatively the effect of various sensory inputs on balance maintenance using an accelerometer. However, postural sway using an accelerometer was analyzed, but research comparing and analyzing the kinetic balance assessment, another objective assessment, should be conducted in the future. Also we would need the study compared with normal adult and stroke patients for the postural sway by tri-axial accelerometer.

Conclusion

The significance of this study was to determine the effect of visual and somatosensory information inputs on postural sway in stroke patients and carry out a kinematic analysis using a tri-axial accelerometer, a quantitative measurement equipment. Through this, we revealed the fact that various sensory information inputs play an important role in the balance ability of stroke patients, and we found that somatosensory information is more important than visual information to reduce postural sway in stroke patients. In view of these things, it can be seen that visual information plays an important role in maintaining balance, but not an absolute role. Above all, the necessity and utilization of a quantitative balance assessment were presented as commonly used in clinical trials and balance assessments using an accelerometer.

References

Allum JH, Bloem BR, Carpenter MG, et al. Proprioceptive control of posture: A review of new concepts. Gait Posture. 1998;8(3):214-242.

Benaim C, Pérennou DA, Villy J, et al. Validation of a standardized assessment of postural control in stroke patients: The Postural Assessment Scale for Stroke Patients (PASS). Stroke. 1999;30(9):1862-1868.

Bogle Thorbahn LD, Newton RA. Use of the Berg Balance Test to predict falls in elderly persons. Phys Ther. 1996;76(6):576-583.

Brauer SG, Burns YR, Galley P. A prospective study of laboratory and clinical measures of postural stability to predict community-dwelling fallers. J Gerontol A Biol Sci Med Sci. 2000;55(8):M469-M476.

Edwards AS. Body sway and vision. J Exp Psychol. 1946;36(6):526-535.

Geiger RA, Allen JB, O'Keefe J, et al. Balance and mobility following stroke: Effects of physical therapy interventions with and without biofeedback/forceplate training. Phys Ther. 2001;81(4):995-1005.

Horak FB. Clinical assessment of balance disorders. Gait Posture. 1997;6(1):76-84.

Horak FB, Shupert CL, Mirka A. Components of postural dyscontrol in the elderly: A review. Neurobiol Aging. 1989;10(6):727-738.

Jacobson GP, Newman CW, Kartush JM. Handbook of Balance Function Testing. 1st ed. St Louis, Mosby Year Book, 1993: 308-334.

Jang ES, Yang WH, Kim KY. The effects of balance training using balance system in the hemiplegic patients. J Korean Acad Rehabil Med. 1999;23(5):899-904.

Kamen G, Patten C, Du CD, et al. An accelerometry-based system for the assessment of balance and postural sway. Gerontology. 1998;44(1):40-45.

Kwakkel G, Wagenaar RC, Kollen BJ, et al. Predicting disability in stroke--A critical review of the literature. Age Ageing. 1996;25(6):479-489.

Laufer Y, Sivan D, Schwarzmann R, et al. Standing balance and functional recovery of patients with right and left hemiparesis in the early stages of rehabilitation. Neurorehabil Neural Repair. 2003;17(4):207-213.

Lee DN, Lishman JR. Visual proprioceptive control of stance. Journal of Human Movement Studies. 1975;1(2):87-95.

Liaw LJ, Hsieh CL, Lo SK, et al. The relative and absolute reliability of two balance performance measures in chronic stroke patients. Disabil Rehabil. 2008;30(9):656-661.

Liston RA, Brouwer BJ. Reliability and validity of measures obtained from stroke patients using the balance master. Arch Phys Med Rehabil. 1996;77(5):425-430.

Mancini M, Horak FB. The relevance of clinical balance assessment tools to differentiate balance deficits. Eur J Phys Rehabil Med. 2010;46(2):239-248.

Mathie MJ, Celler BG, Lovell NH, et al. Classification of basic daily movements using a triaxial accelerometer. Med Biol Eng Comput. 2004a:42(5):679-687.

Mathie MJ, Coster AC, Lovell NH, et al. Accelerometry: Providing an integrated, practical method for long-term, ambulatory monitoring of human movement. Physiol Meas. 2004b:25(2): R1-R20.

Matsumura BA, Ambrose AF. Balance in the elderly. Clin Geriatr Med. 2006;22(2):395-412.

Mayagoitia RE, Lötters JC, Veltink PH, et al. Standing balance evaluation using a triaxial accelerometer. Gait Posture. 2002;16(1):55-59.

McCollum G, Shupert CL, Nashner LM. Organizing sensory information for postural control in altered sensory environments. J Theor Biol. 1996; 180(3):257-270.

Moe-Nilssen R. Test-retest reliability of trunk accelerometry during standing and walking. Arch Phys Med Rehabil. 1998;79(11):1377-1385.

Moon SJ, Kim YW, Kim TH. The effects of balance training with visual cue deprivation on gait function in patients with stroke. J Korean Soc Phys Med. 2012;7(4):411-421.

Mulder T, Berndt H, Pauwels J, et al. Sensorimotor adaptability in the elderly and disabled. In: Stelmach GE, Hömberg V eds. Sensorimotor Impairment in the Elderly. 1st ed. Dordrecht, Springer Netherlands, 1993.

O'Sullivan M, Blake C, Cunningham C, et al. Correlation of accelerometry with clinical balance tests in older fallers and non-fallers. Age Ageing. 2009;38(3):308-313. http://dx.doi.org/10.1093/ageing/afp009

Paulus WM, Straube A, Brandt T. Visual stabilization of posture. Physiological stimulus characteristics and clinical aspects. Brain. 1984;107(Pt 4): 1143-1163.

Riccio GE, Stoffregen TA. An ecological theory of motion sickness and postural instability. Ecol Psychol. 1991;3(3):195-240.

Tyson SF, Hanley M, Chillala J, et al. Balance disability after stroke. Phys Ther. 2006;86(1):30-38.

Wang CH, Hsueh IP, Sheu CF, et al. Psychometric properties of 2 simplified 3-level balance scales used for patients with stroke. Phys Ther. 2004; 84(5):430-438.

Warren WH Jr, Young DS, Lee DN. Visual control of step length during running over irregular terrain. J Exp Psychol Hum Percept Perform. 1986;12(3):259-266.

Whitney SL, Roche JL, Marchetti GF, et al. A comparison of accelerometry and center of pressure measures during computerized dynamic posturography: A measure of balance. Gait Posture. 2011; 33(4):594-599. http://dx.doi.org/10.1016/j.gaitpost.2011.01.015

Woollacott MH, Shumway-Cook A. Changes in posture control across the life span--A systems approach. Phys Ther. 1990;70(12):799-807.

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