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Utilization of Virtual Moving Surround on Static Balance in the Patients With Balance Dysfunction

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Abstract

The purpose of this study was to investigate the possibility of virtual moving surround (VMS) on static balance in the patients with balance dysfunction. Eighty three subjects who were admitted or treated as an outpatient, or a family member, at the department of rehabilitation unit of university hospital were recruited to participate. Subjects were three groups based on their overall medical status: healthy, diabetic neuropathy and stroke. Each group was tested for static balance with a forceplate during static standing with VMS. The virtual movement was simulated with a head mounted display. The parameters for static balance were total sway path. In this study, the parameters of postural control for patients with diabetic neuropathy and stroke subjects were significantly increased in conditions elicited with the VMS. In the healthy elderly participants, the total sway path was not significantly different under virtual movement conditions. Therefore, VMS could be used in the evaluation and treatment of the patients with balance dysfunction.

Key Words: Balance; Postural Control; Virtual moving surround; Vision.

Introduction

The continuous use of the information from somatosensory, proprioceptive, visual, and vestibular sources is critical for maintaining postural control in humans. This information is analyzed and integrated in the central nervous system, which then sends efferent signals to activate appropriate postural muscles (Nashner and Peters, 1990). In the presence of disease or dysfunction in the relevant parts of the nervous and musculoskeletal system the ability to control balance may be impaired (Maki and McIlroy, 1996). In patients undergoing rehabilitation, a prominent symptom of a balance disorder is the increased dependency on vision for postural control (Tossavainen et al, 2003).

Visual function is commonly weakened with aging and this affects postural stability, often causing reduced ability to perform activities of daily of living and independent mobility (Lord and Menz, 2000). There are few reports in the medical literature that report on the role of vision as an important component for postural control in the elderly (Hytonen et al, 1993; Ring et al, 1988; Stribley et al, 1974). In the study of Peterka and Black (1990), visual dependency

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is increased with aging and postural sway is increased with age, generally greater than 55. Vision provides the information that alerts to risk from environmental factors, the distance from objects as well as the contextual and surface information. With the information obtained through perception of the environment and then integration into central nervous system processing, humans are able to adapt and correct posture to maintain stability (Galley and Forster, 1985).

The visual system also synapses with the vestibular and proprioceptive system, which adds to determination of the center of gravity and support systems controlling postural stability (Umphred, 2001). Many studies have been reported on age-related physiologic decline in multiple balance-associated systems; this leads to significant balance and functional impairments in older adults (Bergin et al, 1995; Grimston et al, 1993; Rosenhall and Rubin, 1975). In addition, researches have also reported results on comparisons in decreased ability of postural control between patients, normal subjects or young people and the elderly (Laughton et al, 2003; Tinetti et al, 1988).

Currently, most evaluations for balance are done using vision with eyes opened and closed (Hageman et al, 1995; Peterka and Black, 1990). However recently, virtual reality technology has been utilized in the rehabilitation setting for evaluation and treatment. It has been shown to provide stimulation that affects balance ability (Christiansen et al, 1998; Grealy et al, 1999; Rose et al, 1999). Virtual movement can affect the vestibular system for integrated balance ability by providing visual stimulation (Tossavainen et al, 2003). In the vestibular system, receptor cells are stimulated by endolymph movement during body motion. Therefore, the semicircular canal detects the rotational acceleration and the otholith perceives the linear acceleration (Lundy-Ekman, 2002). Gourlay et al (2000) reported that simulation of the environmental factors for activities of daily life by visual perception is an advantage for performing the real task. In addition, few researches reported that virtual reality could be applicable to physically disabled people, especially in the rehabilitation setting during treatment sessions (Greenleaf and Tovar, 1994; Kuhlen and Dohle, 1995; Sveistrup et al, 2003; Zhang et al, 2003). One of the beneficial aspects of virtual reality is the ability to present an infinite variety of stimuli. Using a simulation technique, creating virtual moving views on the basis of virtual reality methods for balance investigation, it is possible to make effective stimuli that would be very difficult or impossible to set in the real environment (Tossavainen et al, 2001a).

There are a variety of balance tests that can be used to assess balance performance. Accepted clinical balance tests include: the Tinetti Performance-Oriented Assessment of Mobility, the Get Up and Go Test, the Berg Balance Scale and the Functional Reach Test. Forceplate posturography is one of the most commonly used tests for balance assessment. The posturography technique of sway measurement is a sensitive and reliable measure, particularly when used with normal stance (Cobb and Nichols, 1998). During this test, the swaying of a subject standing on a force-sensitive platform is measured and analyzed. Forceplate posturography takes advantage of consistency in data collection and analysis. Virtual reality simulation system and the posturography technique of sway measurement are also useful for balance assessment and analysis.

However, few studies have investigated the correlation between the virtual reality technique and postural control. Therefore, we investigated the possibility that virtual moving surround could affect static balance.

Methods

Subjects

Eighty three subjects were recruited for this study (Table 1). All subjects who were admitted or treated as an outpatient, or a family member, at the department of rehabilitation unit of university hospital, were asked to participate; the study was approved by the Institutional Review Board. Subjects were divided into three groups as follows: normal, diabetic neuropathy and stroke. Normal subjects were subsequently excluded for any of the following reasons: they had a medical or neurologic disorder which could cause severe muscular weakness, visual disturbance and vestibular dysfunction by examination, history, or medical record review; they underwent medical treatment for osteoarthritis or trauma of a lower extremity during last 3 months. Patients with diabetic neuropathy were diagnosed with nerve conduction tests. Subjects with stroke history were able to maintain an independent unsupported stance and had a unilateral hemiparesis as a result of the stroke as part of the inclusion criteria and reported no cardiac, respiratory, or neuromuscular problems (e.g., impairment of vestibular system, peripheral neuropathy, ankle sprain, shoulder tendinitis) that would interfere with the testing protocol. Subjects were assessed with the Berg balance scale.

Measures

Static balance assessment is the forceplate measure of postural control in the quiet stance (in between feet distance was 20 ㎝) was recorded for 20 seconds. To measure the change of center of pressure (COP) in the movement of body mass, we made one custom forceplate (60 ㎝ x 40 ㎝ sized) with 4 load cells (CBES 200 ㎏ type) in the corners of the plate. COP analog signals from the load cells were amplified, filtered and converted to a digital signal with a 12-bit, 8-channel A/D converter. The subjects were asked to stand on a forceplate with eyes opened and closed. The Virtual Moving Surround (VMS) conditions were delivered using a head-mounted display (HMD)[1], device with different moving patterns (left-right tilting, superior-inferior tilting, close-far and horizontal rotation) (Figure 1).

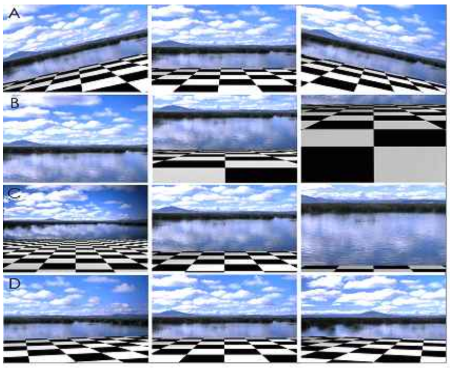

Figure 1. (A) Right-left tilting, (B) Superior-inferior tilting, (C) Close-far (D) Horizontal rotation

Table 1. Demographic data of study subjects (N=83)

Group of subjects		Normal (n_1=13)	Diabetic neuropathy (n_2=29)	Stroke (n_3=41)
Age (yrs)		58.9±2.8[a]	58.3±9.2	53.4±16.3
Height (㎝)		157.8±4.9	162.8±7.0	165.2±11.0
Weight (㎏)		58.5±6.4	61.4±9.2	63.3±12.5
Days post onset (m)			153.9±106.0	13.8±15.7
Berg balance scale			54.5±1.9	37.3±11.0
Gender	Male	4	15	26
	Female	9	14	15
Side of hemiplegia	Right			20
	Left			21

[a] Mean±SD

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1) Olympus Optical Co., Japan.

Each VMS was 5 cycles during the test session. The COP was obtained in each VMS condition. Obtained data were analyzed using Lab View analysis software. COP parameters were the total path distance as a summation of total sway from the initial to the final positions and the COP weight spectrum measured by the most frequent COP positions within the anterior-posterior and medial-lateral components of sway. The VMS stimuli were applied in random order.

Data Analysis

Statistical analysis was performed using Windows SPSS version 13.0. Demographic data of subjects according to groups (normal, diabetic neuropathy and stroke) were summarized using descriptive analysis. An analysis of variance was used for comparing the balance ability among the subjects; analysis of variance for repeated measures within subject's factor (6 testing sessions) was performed for each parameter. Post hoc multiple paired-sample t tests were used to determine differences between testing sessions. For all analyses, a significance level with an alpha less than .05 was adopted.

Results

1. Comparisons of balance ability measurements among the groups

For the posturography, the results of mean sway path of groups were showed in Table 2. The post hoc test revealed a significant difference for all conditions between normal and stroke groups. However, there was no significant difference between normal and diabetic neuropathy groups in all conditions. In addition, there was no significant difference, for all conditions, between diabetic neuropathy and stroke groups.

2. Comparisons of sway path in VMS conditions

For the normal subjects, there was a significant difference between eyes open and close. And, there was a no significant difference between eyes open and VMS conditions. In addition, there were no significant difference between eyes close and VMS B (superior-inferior tilting) and C (close-far). However, there were significant difference between eyes close and VMS A (left-right tilting) and D (horizontal rotation) (Table 3).

For the diabetic neuropathy subjects, there was a significant difference between eyes open and close. And, there were no significant difference between eyes open and VMS A (left-right tilting) and D (horizontal rotation). In addition, there were no significant differences between eyes close and VMS B

Table 2. Mean sway path of the groups (N=83)

Condition		Normal (n_1=13)	Diabetic Neuropathy (n_2=29)	Stroke* (n_3=41)
Eyes	Open	9.90±1.70[a]	12.53±4.23	14.47±5.54
	Close	13.34±1.84	17.08±5.84	22.36±13.06
Virtual moving surround	Right-left tilting	10.66±1.53	14.22±5.35	17.54±7.96
	Superior-inferior tilting	11.14±2.18	15.57±5.92	19.71±12.86
	Close-far	10.64±1.74	15.34±5.77	20.86±12.41
	Horizontal rotation	10.84±1.73	14.87±6.22	18.83±10.26

[a] Mean±SD

*Significant difference in all conditions between normal and stroke groups based on post-hoc multiple comparison tests.

Table 3. Comparison of sway path during VMS and eyes open and close in normal subjects (n=13)

Conditions		Eyes		Virtual moving surround		
		Open	Close	A	B	C
Eyes	Close	.007				
Virtual moving surround	A	1.000	.024			
	B	1.000	.370	1.000		
	C	1.000	.092	1.000	1.000	
	D	1.000	.028	1.000	1.000	1.000

Values mean the probability value after post hoc multiple comparison tests in the one way repeated analysis variance.
A: Right-left tilting, B: Superior-inferior tilting, C: Close-far, D: Horizontal rotation

Table 4. Comparison of sway path during VMS and eyes open and close in iabetic neuropathy subjects (n=29)

Conditions		Eyes		Virtual moving surround		
		Open	Close	A	B	C
Eyes	Close	.000				
Virtual moving surround	A	.211	.031			
	B	.000	1.000	.338		
	C	.002	.954	.727	1.000	
	D	.058	.377	1.000	1.000	1.000

Values mean the probability value after post hoc multiple comparison tests in the one way repeated analysis variance.
A: Right-left tilting, B: Superior-inferior tilting, C: Close-far, D: Horizontal rotation

Table 5. Comparison of sway path during VMS and eyes open and close in stroke subjects (n=41)

Conditions		Eyes		Virtual moving surround		
		Open	Close	A	B	C
Eyes	Close	.000				
Virtual moving surround	A	.010	.020			
	B	.015	.824	1.000		
	C	.001	1.000	.059	1.000	
	D	.002	.340	1.000	1.000	.270

Values mean the probability value after post hoc multiple comparison tests in the one way repeated analysis variance.
A: Right-left tilting, B: Superior-inferior tilting, C: Close-far, D: Horizontal rotation

(superior-inferior tilting), C (close-far), and D (horizontal rotation) (Table 4).

For the stroke subjects, there was a significant difference between eyes open and close. And, there were significant differences between eyes open and VMS conditions. However, there were no significant differences between eyes close and VMS B (superior-inferior tilting), C (close-far), and D (horizontal rotation) (Table 5).

Discussion

Understanding the mechanisms involving balance impairment in the rehabilitation population and conducting accurate assessments of problems with balance may lead to improvements in treatment and outcome in the rehabilitation population. The ability to balance requires that the body's center of gravity or mass lie over the base of support (Nashner, 1989).

When evaluating postural control, dependence on vision is an important parameter. The importance of the effect of vision on balance has been reported in many studies. Traditionally, balance ability has been assessed using a Get-up and go test (Mathias et al, 1986), Berg balance scale (Berg et al, 1995) and Functional reach test (Duncan et al, 1990); however, all of these tests have a limitation in quantitative assessment. The forceplate is one of the objective balance measures in the clinical balance test. Generally, for the forceplate measurement, the center of pressure of the ground reaction force is obtained using parameters of sway speed, trace and sway area when eyes are open and when they are closed (Goldie et al, 1989; Hageman et al, 1995; Peterka and Black, 1990). We also used the forceplate for quantitative assessment using parameters of sway path. Our testing conditions were different from other investigations mentioned earlier. The use of VMS as a stimulus, for static balance control, provides stimulation of the visual system. This stimulus technique is based on virtual reality technology and is effective in the rehabilitation population. In our study, VMS methods safely generate a variety of visual stimuli that can affect the postural control.

In more traditional approaches, visual stimulation has been generated mostly based on mechanical systems such as the tilting room and by the comparison of the eyes open and closed in the experimental groups (Dornan et al, 1978). Tossavainen et al (2003) evaluated the effect of six different virtual reality stimuli, such as a rotating cylinder, oscillating random dots in space, random dots in space rotating around three different axes and a twisting tunnel, on the balance of healthy test subjects using forceplate posturography. We used the virtual visual stimulations such as right-left tilting, superior-inferior tilting, close-far and horizontal rotation with .25 ㎐ (1 cycle per 4 seconds in each moving surround). During the moving surround, there were angular and linear acceleration or deceleration virtually that could affect the semicircular canals and otholith in the vestibular system (Lundy-Ekman, 2002). For our subjects, there are significant increase the postural sway during static standing using VMS; these results suggest that vision plays an important role to compensate for a loss of proprioception in postural control for subjects with diabetic neuropathy and stroke. Researchers have suggested that visual information can compensate for sensorimotor loss during postural control (Mulder and Hulstyn, 1984).

Therefore these findings suggest that VMS could be used during the treatment sessions and evaluation of the postural control. In the study by Tossavainen et al (2001b) a small group of healthy subjects were recruited to investigate the effect of alcohol and virtual reality stimulus on the subjects′ balance; the testing results showed an increased lateral body sway. In our study, for all conditions evaluated there was not a significant effect on postural control. Thus, design of virtual reality stimuli to cause different effects on the postural control is possible. In addition, the development of balance evaluation or testing using a virtual reality or moving surround, although promising, is still rare.

The findings from this study suggest that virtual technology in rehabilitation setting may provide a new way to create a variety of exercise or evaluation environments. Effective virtual-based rehabilitation requires a three-dimensional stimulus and must be easily adapted for the patient to real environment ADLs. Our VMS still needs additional research for postural control with dynamic context. In addition, there is motion sickness when the patient wears the head mounted display for a long time. Therefore, modifications are required and further study needed.

Conclusion

Our study demonstrates the possibility of using VMS for postural control in the patients with balance dysfunction. Study results showed that postural sway increased with VMS in individuals with balance dysfunction such as diabetic neuropathy and stroke. Therefore, VMS could be used in the rehabilitation setting for postural control assessment and treatment. Further study in this field is needed to determine the best systems and techniques for VMS application.

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