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Original Article

Effects of eye movement with functional electrical stimulation on balance in stroke patients with neglect syndrome

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Abstract. [Purpose] The aim of the present study was to determine whether eye movement in conjunction with functional electrical stimulation (FES) could improve balance ability in stroke patients with neglect syndrome. [Subjects and Methods] The subjects consisted of 15 stroke patients with neglect syndrome. The intervention was eye movement in conjunction with FES. The program was conducted 5 times per week, for 6 weeks. Static balance (eyes-open and eyes-closed) and dynamic balance were measured before and after testing. [Results] In measurement of static balance, subjects showed significant differences in sway length and sway area when examined in the eyes-open condition, but not the eyes-closed condition. In measurement of dynamic balance, the subjects showed significant differences in limit of stability (forward/backward and left/right). [Conclusion] These results indicate that eye movement in conjunction with FES had a positive effect on the static and dynamic balance in the eyes-open condition, but not in the eyes-closed condition of stroke patients with neglect syndrome. Further studies should therefore investigate various interventions in stroke patients with neglect syndrome.

Key words: Eye movement, Functional electrical stimulation, Neglect syndrome

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INTRODUCTION

Balance disability is common following a stroke, and these patients have greater postural sway than age-matched healthy volunteers[1)]. It is important to maintain balance while performing tasks that require body movement or readjustment due to unexpected external forces[2)]. Neglect is an important predictor of poor outcome following a stroke[3)]. Stroke patients with neglect syndrome showed greater postural instability compared to those without neglect[4)].

The vision, vestibular system, and somatosensory systems are important for postural control[5)]. In the three systems, Grace et al. demonstrated that the visual system is the main sensory system used to maintain a standing posture[6)]. However, stroke patients with neglect syndrome show multiple eye movement impairments, including reduced saccade amplitude and difficulty retaining spatial locations[7)]. This is considered to be a barrier to improvement of functional ability and motor recovery.

Eye movement has been suggested to be an effective method to improve postural control[8)]. Kerkhoff et al. reported eye movement (active smooth pursuit movements) to be a more effective trearment than conventional visual scanning training in neglect patients[9)]. Karnath also reported that eye movement is effective in improving body orientation in spatial neglect patients[10)].

Functional electrical stimulation (FES) is also used to improve balance ability. FES is used for improvement of functional movement in patients who suffer from upper motor neuron diseases such as stroke, multiple sclerosis, and spinal cord injury[11)]. Robertson et al. demonstrated that physical improvements could result from FES treatment of stroke patients[12)].

FES can be used for the restoration of sensory-motor function. Furthermore, FES causes changes in cortical excitabil-

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ity and stimulates cortical reorgnization[13]. Harding and Riddoch reported that FES activates a proprioceptive map, which increases awareness of the contralesional side in neglect patients[14]. However, the effect of application of FES in neglect patients remains unclear. Most previous studies have applied FES to the dorsiflexor muscle. However, in this study, we investigated the effect of applying FES to the neck extensor on the paretic side. Maintenance of balance is influenced by input from the visual senses, vestibular system, and by sensory information from the somatic senses in the neck[15].

Accordingly, the present study assesses the effect of eye movement, in conjunction with FES, on balance in stroke patients with neglect syndrome.

SUBJECTS AND METHODS

The subjects were selected from patients at the Rusk rehabilitation hospital (Seongnam, Republic of Korea), and comprised a total of 15 stroke patients with neglect syndrome. Neglect patients were defined as those scoring 11 or higher, according to the Catherine Bergego Scale (CBS)[16]. The subjects were all paralysed on the left side, because the neglect is more common after a right hemisphere lesion than after a left hemisphere lesion[17].

The subjects had no visual or hearing impairment, and could stand independently for at least 1 min. They were selected from among those who scored at least 24 points on the Korean Mini-Mental State Examination (K-MMSE).

The subjects were volunteers. We explained the purpose and method of the study to the subjects, and only those who consented to participate were included. The study protocol was approved by the Local Ethics Committee of Yongin University (2-1040966-AB-N-01-201503-HSR-025-1). Table 1 shows the general characteristics and CBS values of the subjects.

The intervention was conducted 5 times per week, for a total of 6 weeks. An eye movement program was performed for 10 min, and followed by FES application for 15 min.

The eye movement program was designed according to the method used by Park et al[18]. The program uses a drawing board (Fig. 1). The drawing board was attached to a wall, and the subjects sat 3 m from the board and were asked to conduct the eye movements. The program was composed of 3 steps; saccadic eye movement, pursuit eye movement, and vergence eye movement. For the saccadic eye movement, up-and-down or left-and-right movements of the eyes were performed. For the pursuit eye movement, the subjects performed diagonal movements of the eyes. In the vergence eye movement, the subjects focused on a baton, which was moved slowly from a 10 cm to a 50 cm distance, and vice versa. The subjects performed 2 sets of the program and then a warm-down exercise to alleviate eye fatigue (Table 2). For the warm-down, the therapist rubbed their hands together to generate heat and covered the subject's eyes with their palms lightly for 30 sec. Table 2 shows the eye movement program using the drawing board.

Microstim (Medel GmbH, Germany) FES equipment was used and two electrodes were attached to the paretic splenius capitis muscle (neck extensor), inducing movement of the head. FES was applied for a total of 15 min. The device was programmed to bipolar placement at a pulse rate of 30 Hz, pulse duration of 6 sec, and off-pulse duration of 2 sec. The

Table 1. General characteristics and CBS values of subjects

Gender (male/female)	7/8
Age (years)	56.7 ± 7.76
Time since stroke (months)	28.6 ± 12.1
Stroke type (infarction/hemorrhage)	9/6
Affected side (left/right)	15/0
CBS (scores)	12.7 ± 1.4

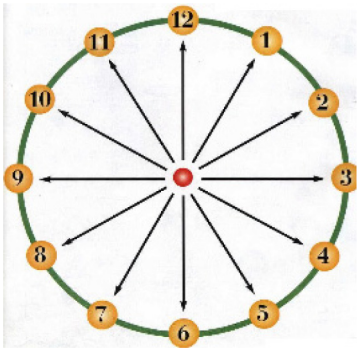

Fig. 1. Drawing board of eye movement

Table 2. Eye movement program

Step	Methods
Saccadic eye movement	Eye up-and-down motion (12↔6 direction) 10 times Eye left-and-right motion (9↔3 direction) 10 times
Pursuit eye movement	Eye right.Up-and-left.Down motion (2↔8 direction) 10 times Eye left.Up-and-right.Down motion (11↔5 direction) 10 times Eye rotational motion 5 times
Vergence eye movement	Moving the target (proximal-distal or distal-proximal) in focus

stimulus strength was less than 15 V; which was sufficient to induce muscular contraction but did not result in discomfort for the subjects.

We used a BioRescue (SyCoMORe, France) to investigate the balance ability of the subjects. The device is comprised of a computer, software, and a platform equipped with sensors to measure the sway length and sway area. In this study, static balance and dynamic balance were measured separately. Static balance was measured with the subject's eyes open, and closed. And dynamic balance was measured with the subject's eyes open. During the test, the subjects stood on the platform with their feet spread at a 30° angle. To measure static balance, the subjects maintained a standing posture for 1 min both with eyes opened and eyes closed, while sway length and sway area were assessed. Dynamic balance was measured as the limit of stability. The subjects shifted their body weight to the maximal extent possible in the four directions shown on the screen, while the therapist measured the distance moved in the forward, backward, left and right direction[19].

Data were analyzed using SPSS for Windows version 20.0 software. The mean and standard deviation of the general characteristics were calculated using descriptive statistics. ANOVA was used to evaluate the changes in balance and head alignment. In all analyses, $p<0.05$ was considered to indicate significance.

RESULTS

This study involved stroke patients with neglect syndrome. The changes in balance are presented in Table 3. The balance ability was divided into static and dynamic balance for this investigation. Lower static balance scores indicated a better level of balance, while higher dynamic balance scores indicated a better level of balance.

For static balance with eyes open, sway length and sway area showed significant differences following the eye movement with FES intervention therapy ($p<0.05$). However, for static balance with eyes closed, sway length and sway area were not significantly. For dynamic balance, the limit of stability in all directions (forward, backward, left and right) showed significant differences following the intervention therapy ($p<0.05$).

DISCUSSION

Balance control is a highly complex function that involves integration of the nervous and musculoskeletal systems. Visual, auditory, vestibular, and proprioceptor sensations, as well as visuospatial perception, stimulate the central nervous system (CNS), allowing it to rapidly, and accurately respond to environmental changes[20]. In postural control, visual input provides information regarding the surrounding environment, postures and head movement[21].

However, stroke patients with neglect syndrome show impaired eye movement due to injury to their neural circuits reauired for attention[7]. As such, improvement of visual attention is important for the treatment of stroke patients with neglect syndrome[22].

The importance of eye and head movements in postural control has been demonstrated, but most previous studied have focused on normal adults[8, 23]. Therefore, in this study, we investigated the effects of head movement induced by eye movement in conjunction with FES on stroke patients with neglect syndrome.

In this study, subjects with eyes open, but not eyes closed, showed a significant difference in static balance. Regarding dynamic balance, there was significant difference before and after the intervention. This indicates that eye movement in conjunction with FES positively affected the balance ability of stroke patients with neglect syndrome when their eyes were open, but did not have positive effects when their vision was blocked.

Koo reported that eye movement induced tonic contraction in the antigravity muscles, and had a positive effect on balance ability by enhancing the sensory function of the CNS[24]. Morimoto et al. noted that eye movement and gaze stability exercise might improve the postural stability of healthy adults. Although based on a different subject group, our findings are consistent with these previous reports, in that reported eye movement had positive effects on postural control[8].

Rushton noted that FES activated motor and sensory nerve fibers and promoted cortical reorganization through sensory

Table 3. Measurement of static and dynamic balance

		Pre-test	Post-test
Static balance	Eyes open		
	Sway length (cm)	37.0 ± 1.8	35.1 ± 1.7*
	Sway area (mm^2)	458.1 ± 28.7	428.9 ± 20.1*
	Eyes closed		
	Sway length (cm)	45.9 ± 2.7	44.9 ± 2.8
	Sway area (mm^2)	547.7 ± 59.7	537.1 ± 41.8
Dynamic balance (Limit of stability)	Forward (mm^2)	287.6 ± 39.8	332.6 ± 48.7*
	Backward (mm^2)	141.0 ± 33.5	150.6 ± 30.9*
	Left (mm^2)	147.1 ± 14.4	160.6 ± 17.1*
	Right (mm^2)	226.9 ± 18.9	238.4 ± 16.8*

*$p<0.05$

stimulation of the paralyzed muscles[25]. Lee et al. reported that balance maintenance is influenced not only by the muscle around the ankle but also by input from the somatic senses in the neck[15]. In this study, FES stimulation of the neck extensor muscles induced muscular contraction, resulting in head movements and activation of the sensory nerve fibers, which exerted a positive effect on the balance ability of stroke patients with neglect syndrome. In addition, previous study reported that FES training influences the plasticity of the cerebral cortex, which improves the postural control of stroke patients with neglect syndrome by enhancing neuroplasticity[26].

Chung et al. reported that enhancement of neuroplasticity leads to functional recovery via improvements in afferent, and efferent neural activities[27]. Correspondingly, in this study, eye movement in conjunction with FES exerted a positive effect on balance ability due to improvements in afferent and efferent neural activities.

However, eye movement in conjunction with FES did not result in significant improvement in balance ability when patients had their eyes closed. This may be because application of eye movement in conjunction with FES had positive effects on the visual ability in postural control but not on the proprioceptive sense. Thus, further studies should assess the effects of other interventions in stroke patients with neglect syndrome, in order to improve balance ability.

The limitations of this study include its small sample size, which lead to difficulty in drawing general conclusions from the results. Moreover, this study was of a single-group pretest-posttest design, not a case-control design. However, in this study, eye movement in conjunction with FES did exert positive effects on the balance ability of stroke patients with neglect syndrome when their eyes were open. Further studies with a larger sample size and analyzing various interventions should be performed to confirm the effects of eye movement, and FES.

REFERENCES

1) Tyson SF, Hanley M, Chillala J, et al.: Balance disability after stroke. Phys Ther, 2006, 86: 30–38. [Medline]
2) Roh H: Change in visual perception and balance caused by different types of hat. J Phys Ther Sci, 2014, 26: 199–201. [Medline] [CrossRef]
3) Stone SP, Wilson B, Wroot A, et al.: The assessment of visuo-spatial neglect after acute stroke. J Neurol Neurosurg Psychiatry, 1991, 54: 345–350. [Medline] [CrossRef]
4) Pérennou DA, Leblond C, Amblard B, et al.: Transcutaneous electric nerve stimulation reduces neglect-related postural instability after stroke. Arch Phys Med Rehabil, 2001, 82: 440–448. [Medline] [CrossRef]
5) Shumway-Cook A, Wallacott M: Motor control; Theory and practical applications, 3rd ed. Maryland: Lippincott Williams & Wilkins, 2007.
6) Grace Gaerlan M, Alpert PT, Cross C, et al.: Postural balance in young adults: the role of visual, vestibular and somatosensory systems. J Am Acad Nurse Pract, 2012, 24: 375–381. [Medline] [CrossRef]
7) Malhotra P, Coulthard E, Husain M: Hemispatial neglect, balance and eye-movement control. Curr Opin Neurol, 2006, 19: 14–20. [Medline] [CrossRef]
8) Morimoto H, Asai Y, Johnson EG, et al.: Effect of oculo-motor and gaze stability exercises on postural stability and dynamic visual acuity in healthy young adults. Gait Posture, 2011, 33: 600–603. [Medline] [CrossRef]
9) Kerkhoff G, Keller I, Ritter V, et al.: Repetitive optokinetic stimulation induces lasting recovery from visual neglect. Restor Neurol Neurosci, 2006, 24: 357–369. [Medline]
10) Karnath HO: Optokinetic stimulation influences the disturbed perception of body orientation in spatial neglect. J Neurol Neurosurg Psychiatry, 1996, 60: 217–220. [Medline] [CrossRef]
11) Ji SG, Cha HG, Kim MK, et al.: The effect of mirror therapy integrating functional electrical stimulation on the gait of stroke patients. J Phys Ther Sci, 2014, 26: 497–499. [Medline] [CrossRef]
12) Robertson JA, Eng JJ, Hung C: The effect of functional electrical stimulation on balance function and balance confidence in community-dwelling individuals with stroke. Physiother Can, 2010, 62: 114–119. [Medline] [CrossRef]
13) Popović DB: Advances in functional electrical stimulation (FES). J Electromyogr Kinesiol, 2014, 24: 795–802. [Medline] [CrossRef]
14) Harding P, Riddoch MJ: Functional electrical stimulation (FES) of the upper limb alleviates unilateral neglect: a case series analysis. Neuropsychol Rehabil, 2009, 19: 41–63. [Medline] [CrossRef]
15) Lee BH, Lee HR, Kim KM, et al.: Effects of spiral taping applied to the neck and ankle on the body balance index. J Phys Ther Sci, 2015, 27: 79–82. [Medline] [CrossRef]
16) Azouvi P, Olivier S, de Montety G, et al.: Behavioral assessment of unilateral neglect: study of the psychometric properties of the Catherine Bergego Scale. Arch Phys Med Rehabil, 2003, 84: 51–57. [Medline] [CrossRef]
17) Chiba Y, Nishihara K, Haga N: Evaluating visual bias and effect of proprioceptive feedback in unilateral neglect. J Clin Neurosci, 2010, 17: 1148–1152. [Medline] [CrossRef]
18) Park GH, Kim YJ, Cho HM, et al.: A study on the change of visual activity and refractive angle through eye exercise. Korean J Phy Edu, 1991, 30: 1117–1127.
19) Kim CS: The effect of proprioception exercise and computerized cognitive therapy in stroke for balance, cognotion and EEG. Daegu University Rehabilitaion Science Graduate School, 2012.
20) Roh H: Effect of visual perceptual disturbance on gait and balance. J Phys Ther Sci, 2015, 27: 3109–3111. [Medline] [CrossRef]
21) Kim JH: Effect of visual feedback training on standing-balance in stroke with neglect and/or sensory deficit. Daegu University Rehabilitaion Science Graduate School, 2007.
22) Han SW, Oh DY, Song SA, et al.: The effect of dynavision rehabilitation on visual attension and unilateral neglect in stroke patients: a single subject research design. J Korean Soc Occup Ther, 2007, 15: 73–82.
23) Meesen R, Levin O, Wenderoth N, et al.: Head movements destabilize cyclical in-phase but not anti-phase homologous limb coordination in humans. Neurosci Lett, 2003, 340: 229–233. [Medline] [CrossRef]

24) Koo BO: The effect of eye movement on balance restoration of adult hemiplegic patient. Daegu University Rehabilitaion Science Graduate School, 2002.
25) Rushton DN: Functional electrical stimulation and rehabilitation—an hypothesis. Med Eng Phys, 2003, 25: 75–78. [Medline] [CrossRef]
26) Wassermann E: Changes in motor representation with recovery of motor function after stroke: combined electrophysiological and imaging studies. EEG Clin Neurophysiol, 1995, 97: 26.
27) Chung E, Park SI, Jang YY, et al.: Effects of brain-computer interface-based functional electrical stimulation on balance and gait function in patients with stroke: preliminary results. J Phys Ther Sci, 2015, 27: 513–516. [Medline] [CrossRef]