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Saccadic Eye Movement Improves Plantar Sensation and Postural Balance in Elderly Women

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Vision, proprioception and plantar sensation contribute to the control of postural balance (PB). Reduced plantar sensation alters postural response and is at an increased risk of fall, and eye movements reduce the postural sway. Therefore, the aim of this study was to study the improvement of plantar sensation and PB after saccadic eye movement (SEM) and pursuit eye movement (PEM) in community-dwelling elderly women. Participants (104 females; 75.11 ± 6.25 years) were randomly allocated into the SEM group (n = 52) and PEM groups (n = 52). The SEM group performed eye fixation and SEM for 5 minutes, and the PEM group performed eye fixation and PEM for 5 minutes. The plantar sensation was measured according to the plantar surface area of the feet in contact with the floor surface before and after the intervention. Before and after SEM and PEM with the eyes open and closed, PB was measured as the area (mm^2), length (cm), and velocity (cm/s) of the fluctuation of the center of pressure (COP). The plantar sensation of both feet improved in both groups ($p < 0.01$). Significant decreases in the area, length, and velocity of the COP were observed in the eye open and close in both groups ($p < 0.01$). The length and velocity of the COP significantly decreased in the SEM group compared to the PEM group ($p < 0.05$). In conclusion, SEM and PEM are effective interventions for improving plantar sensation and PB in elderly women, with greater PB improvement after SEM.

Keywords: elderly women; plantar sensation; postural balance; pursuit eye movement; saccadic eye movement
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Introduction

Postural regulation is a multi-step process; moreover, postural stability is modulated and determined by various factors such as age and the availability of sensory information (Woollacott and Shumway-Cook 2002). Balance in a standing position is controlled by the integration of various sensory systems, including vision (Paulus et al. 1984), the vestibular system (Day et al. 1997), information from sole mechanoreceptors (Kavounoudias et al. 2001), and proprioception of the ankle (Kavounoudias et al. 1999).

As the ability to control posture decreases through the aging process, postural sway in the standing position is increased in the elderly. Tactile stimulation, such as plantar cutaneous information from the foot, induces strong postural regulation, and cutaneous afferent messages from the supporting zones of the feet have sufficient spatial relevance to inform the central nervous system about the body's position with respect to the vertical reference, which consequently induces adapted regulative postural responses (Kavounoudias et al. 1998, 2001). However, the accuracy of sensory receptors in the plantar surface and leg decreases in the elderly (Skinner et al. 1984; Stelmach and Worringham 1985). Therefore, the elderly may experience balance problems (Ricci et al. 2009), and vision plays a dominant role during postural maintenance (Lord and Menz 2000).

Vision is an important factor for balance control and mobility. In the elderly, visual function is associated with the ability to maintain postural balance and perform daily activities (Aartolahti et al. 2013). Voluntary and involuntary eye movements are induced to assess the surroundings and respond to visual stimuli. Primates and many other vertebrates use voluntary eye movements such as pursuit eye movement (PEM) and saccadic eye movement (SEM) to track moving objects (Krauzlis 2005). PEM allows the eyes to follow a moving object, whereas SEM refers to simultaneous movement of both eyes between two points fixated in the same direction (Rashbass 1961).

Recent studies have demonstrated that eye movement influences postural control. Stoffregen et al. (2006) found that head and trunk sway changes while performing saccades and visual fixation with the eyes closed and open. In particular, body sway is more reduced during SEM than gaze fixation, and the amplitude of postural sway is reduced in both young adults and the elderly during SEM (Aguiar et

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al. 2015). These findings suggest that elderly individuals depend on vision to control postural balance.

Considering the findings of previous studies (Stoffregen et al. 2006; Aguiar et al. 2015; Rodrigues et al. 2015), the aim of the present study was to evaluate the improvement in postural balance and the plantar surface area (PSA) of the feet in contact with the floor surface when SEM and PEM were performed in community dwelling older adults who maintained postural balance with their eyes open and closed. The following was our research hypothesis: SEM and PEM will both improve information provided by plantar sensation (PS) and postural balance, but SEM will improve postural balance to a greater extent.

Subjects and Methods

This study was designed as a single blind, randomized trial. In total, 104 elderly participants who could walk unaided were screened. In previous studies (Aguiar et al. 2015; Rodrigues et al. 2015), the subjects were young adults and elderly individuals, but the sex was not disclosed. More than 80% of the subjects who wished to participate in this study were women. Therefore, the subjects of this study were limited to community-dwelling elderly women. The subjects were recruited through various means of community center advertisement such as poster.

Participants were selected using the following inclusion and exclusion criteria. Inclusion criteria were female elderly individuals aged over 65 years who could walk and stand unaided, and who were without any history of a fall or episode of dizziness, and were able to perform the eye movement program for over 5 minutes. Exclusion criteria were history of surgery in the lower limbs, previous balance and neurologic or vestibular impairment, and a contraindication to any of the measurement procedures. Participants provided signed written consent, which was approved by the local ethics committee.

All participants were informed about the SEM and PEM program prior to the experiment, and they were randomly allocated into the SEM group (n = 52) and PEM group (n = 52). The PS was measured before and after the SEM program and PEM program, and postural balance was measured before and after the interventions while participants had their eyes open and close. The SEM program and PEM program were performed for 5 minutes, which according to a pilot study conducted on 10 participants was found to be the optimal duration that does not cause any dizziness or discomfort.

Interventions

Participants stood on the BioRescue (RM Ingenierie, Rodez, France) platform, i.e., they stood with both feet in a neutral position with the eyes open (the feet were at a 30° angle with 9 cm between the heels). The arms were placed in a relaxed position parallel to the trunk. A monitor was placed 1 m away from the participant's eyes. The participant was asked to follow the target on the monitor only with her eyes, without moving her trunk or head. The target was a red dot on a white background with a diameter of 2 cm, which was produced by Adobe Flash software on an LCD monitor (27.5 cm × 30 cm, LT24E395KD, Samsung, Korea).

The SEM program was performed under the following experimental procedure: 1) The eye was fixed on the target, with the target immobile in the middle of the monitor for 2 minutes. 2) The eye was then closed for 30 seconds. 3) Eye saccades were performed that were directed to a target appearing on one side of monitor, then disappearing and reappearing on the opposite side of the monitor with a frequency of 0.5 Hz. 4) The eye was then closed for 30 seconds.

The PEM program was performed under the following experimental procedure: 1) The eye was fixed on the target. 2) The eye was then closed for 30 seconds. 3) The eye pursued a target moving in a lateral or vertical direction irregularly from one side to the other side of the monitor with a frequency of 0.5 Hz. 4) The eye was then closed for 30 seconds. The target's moving frequency was set at 0.5 Hz based on Aguiar et al. (2015).

The target was then set to reappear randomly in a horizontal or vertical location in SEM and PEM program. To minimize head movement during the interventions, the total distance of the monitor was set to only allow an 11º field of vision (Stoffregen et al. 2006; Rodrigues et al. 2015).

Measurements

Because cutaneous afferents are associated with plantar information from feet in contact with the floor surface (Inglis et al. 2002), the PS was measured by using the PSA of feet in contact with the floor surface.

BioRescue balance measuring equipment was used to measure the PSA of the feet and postural balance before and after SEM and PEM. The BioRescue system is composed of a platform, software, and monitor. The platform (610 mm × 580 mm × 10 mm) is very thin, and is equipped with approximately 1,600 pressure sensors. The platform safely and accurately measures the length and area of the center of pressure (COP) in both feet of an individual and then transmits the measured data to the computer software. The data measured from the platform are visualized as a COP trajectory and displayed on the monitor. The COP trajectory measures the area (mm^2), length (cm), and velocity (cm/s) while the subject maintains postural balance. COP is most commonly defined as the point of application of ground reaction under the feet (Winter 1995), and is the outcome of the inertial forces of the body and restoring equilibrium forces of the postural control system. COP fluctuation is used to make inferences about biomechanical mechanisms of postural control. The area and length were defined as the total area of the COP and the distance that it moved during the measurement period. The mean velocity was defined as the speed at which the COP fluctuated during the measurement period. Larger values indicated poor postural balance.

The PSA of the feet was measured before and after SEM and PEM were performed. Postural balance was measured as the area, length, and velocity of the COP fluctuation before and after SEM and PEM programs with the eyes open and closed. The mean values for measurements were used.

Statistical analysis

All statistical analyses were conducted using SPSS, version 21.0 (IBM Corp., Korea). Descriptive statistics were used to describe participants' general characteristics. The paired-samples t-test was used to compare the PAS and area, length, and average speed of COP fluctuation as dependent variables within the groups. The independent-samples t-test was conducted to compare the outcome between groups. Outcome variables are shown as the mean ± standard error (SE) of the mean. The significance level was set at $p < 0.05$.

Results

The average age of participants was 75.11 years (range

65-86 years), and their general characteristics are described in Table 1.

The measured values of the PSA of the feet before and after the interventions, which were used to evaluate the change in the PS occurring after the interventions, are shown in Table 2. The PSA for both the left and right feet significantly increased after the interventions in both the SEM and PEM groups ($p < 0.01$).

Postural balance, measured as the area, length, and velocity of the COP, significantly decreased ($p < 0.01$) for both the SEM and PEM groups with open eyes. The length and mean velocity showed a significantly greater decrease in the SEM group than in the PEM group ($p < 0.05$) (Table 3). The values of all variables significantly decreased in the SEM group in the eye closed ($p < 0.01$); similarly, in the PEM group, the area, velocity ($p < 0.01$), and length ($p < 0.05$) of the COP significantly decreased. The SEM group had a significantly greater decrease in the length and velocity of the COP compared to the PEM group ($p < 0.05$) (Table 4).

Discussion

These present study demonstrates that SEM and PEM significantly improve postural balance and PS information. In addition, SEM improved postural balance to a significantly extent than PEM with eyes both open and closed. Thus, these findings support our research hypothesis.

Some ocular movements can modify postural control in the maintenance of upright standing position in humans (Rougier and Garin 2007). When mechanical vibration sufficient to activate large I_a afferent fibers of muscles or tendons is applied to various peripheral points of extraocular muscles, extraocular perception, which is an important factor in postural control, is generated by extraocular signals (Roll and Roll 1988; Guerraz and Bronstein 2008). The area, length, and velocity of the COP fluctuation significantly decreased after the SEM and PEM interventions with eyes open and closed in the current study. These results prove that both SEM and PEM activate the extraocular muscles, and thus positively influence postural balance.

Rodrigues et al. (2015) reported that saccades or smooth PEM decrease the body sway compared to visual fixation. In addition, in this study, the area, length, and velocity of COP fluctuation significantly decreased in both the SEM and PEM groups; thus, this study further confirmed that both SEM and PEM exert positive influences on the postural control of women elderly individuals. Although SEM and PEM have different characteristics (Rashbass 1961), both eye movements share the same neural network and have similar processing mechanisms (Kowler 2011). Therefore, it is suggested that both SEM and PEM improves postural control through similar processing mechanisms.

The present study was performed in the standing position. Even if a simple postural task is performed, a quiet standing position requires more attention than a sitting posi-

Table 1. Baseline characteristics of the participants.

	SEM (n = 52)	PEM (n = 52)	Total (n = 104)
Age (year)	75.33 ± 5.36	74.91 ± 7.04	75.11 ± 6.25
Height (cm)	153.73 ± 5.16	151.35 ± 8.01	152.93 ± 7.10
Weight (kg)	59.75 ± 7.11	58.51 ± 9.36	59.10 ± 3.12

Values are presented as Means ± SD.
SEM, saccadic eye movement group; PEM, pursuit eye movement group.

Table 2. Comparisons of plantar surface area of feet between before and after intervention.

	SEM (n = 52)		PEM (n = 52)	
	Left foot	Right foot	Left foot	Right foot
BI	103.78 ± 1.99	106.31 ± 2.18	113.11 ± 2.20	115.50 ± 2.07
AI	122.71 ± 2.64	127.29 ± 2.05	132.06 ± 2.06	133.83 ± 2.03
change	18.94 ±1.61	20.97 ± 1.48	18.94 ± 1.25	18.32 ± 1.28
p	.000	.000	.000	.000

Values are presented as Means ± SE (mm^2).
BI, before intervention; AI, after intervention.

Table 3. Comparisons of postural balance during eye open between before and after intervention.

		SEM (n = 52)	PEM (n = 52)	p
COP area (mm^2)	BI	48.88 ± 3.25	42.98 ± 3.09	
	AI	28.47 ± 3.02	29.85 ± 3.18	
	change	-20.41 ± 2.74	-13.13 ± 3.22	.091
	p	.000	.000	
COP length (cm)	BI	15.18 ± 1.10	11.91 ± 0.57	
	AI	10.15 ± 1.71	8.78 ± 0.66	
	change	-4.97 ± 1.54	-3.14 ± 0.41	.030
	p	.000	.000	
COP velocity (cm/sec)	BI	0.50 ± 0.04	0.44 ± 0.02	
	AI	0.34 ± 0.03	0.37 ± 0.02	
	change	-0.17 ± 0.03	-0.09 ± 0.02	.045
	p	.000	.001	

Values are presented as Means ± SE.

Table 4. Comparisons of postural balance during eye closed between before and after intervention.

		SEM (n = 52)	PEM (n = 52)	p
COP area (mm^2)	BI	56.04 ± 4.66	54.54 ± 4.36	
	AI	36.16 ± 3.66	45.13 ± 3.77	
	change	-19.88 ± 4.96	-9.40 ± 3.29	.082
	p	.000	.006	
COP length (cm)	BI	16.50 ± 1.50	13.16 ± 0.77	
	AI	11.81 ± 0.92	11.24 ± 0.88	
	change	-4.69 ± 0.72	-1.93 ± 0.76	.010
	p	.000	.014	
COP velocity (cm/sec)	BI	0.53 ± 0.04	0.44 ± 0.02	
	AI	0.37 ± 0.02	0.37 ± 0.02	
	change	-0.16 ± 0.03	-0.07 ± 0.02	.011
	p	.000	.002	

Values are presented as Means ± SE.

tion (Lajoie et al. 1993). Hyndman and Ashburn (2003) reported that visual attention of stroke patients is related to the functional impairment of balance and falling; hence, visual attention is a crucial factor of postural balance. In particular, visual attention is an important mechanism used to produce voluntary SEM (Hoffman and Subramaniam 1995). To evaluate SEM in our study, the target appeared on one side of the monitor and immediately disappeared, and then the target immediately reappeared in a different location; because such saccadic tasks require more spatial accuracy than pursuit tasks, SEM requires more attention to the target's movement than PEM. The SEM group showed a significant decrease in the length and velocity of COP fluctuation compared to the PEM group. SEM has been reported to reduce the amplitude of body sway (Stoffregen et al. 2006; Rougier and Garin 2007), and horizontal and vertical SEMs have been reported to decrease body sway more than visual fixation conditions (Rey et al. 2008). Moreover, during saccade conditions, afferent and efferent mechanisms are in effect that allow saccade conditions to reduce body sway more effectively than fixation conditions (Guerraz and Bronstein 2008). As suggested by previous studies, it is possible to conclude that SEM more significantly improves postural control than PEM. However, SEM and PEM have been reported to be similar in reducing body sway (Rodrigues et al. 2015), and studies that have assessed PEM are lacking; therefore, further research on this subject is warranted.

Age correlates with impaired control of postural sway (Lord et al. 1991; Duncan et al. 1992), and the loss of cutaneous sensation is pervasive (Kenshalo 1986). Previous studies have supported that the cutaneous sensation of the plantar surface important for controlling balance (Perry and Maki 1996; Wu and Chiang 1997). Moreover, cutaneous sensation of the plantar surface has been reported to play an important role in balance control in standing positions (Wu and Chiang 1997; Maki et al. 1999; Meyer et al. 2004). A decrease in foot sole sensitivity occurs with aging, and this decrease in sensitivity is associated with poorer postural control and an increased risk of falls in the older population (Maki et al. 1999; Wells et al. 2003; Perry 2006). In elderly and healthy young adults, information from the plantar of the feet and from the leg muscles significantly contributes to upright standing (Fitzpatrick and McCloskey 1994). Therefore, PS of the feet is an important factor that influences balance control. The PSA of the feet in contact with the floor is directly proportional to the input of cutaneous sensation; thus, it exerts positive influences on balance control in the elderly. In the current study, the PSA of the feet significantly increased during SEM and PEM. Plantar cutaneous afferents produce torque in the ankles and legs, and they provide valuable feedback to the balance control system (Morasso and Schieppati 1999). Such findings suggest that SEM and PEM activate the propriocetion of extraocular muscles is generated by extraocular signals; as a result, improves the postural balance. Postural balance is contributes plantar cutaneous and proprioception of the ankle. Therefore, authors argue that SEM and PEM improves plantar cutaneous input for maintain postural balance. Moreover, our findings also suggest that plantar cutaneous input is crucial for postural balance in the standing position.

In the current study, the area, length, and velocity of the COP fluctuation in the eye closed condition after SEM and PEM significantly decreased. This result contradicts the findings reported by Stoffregen et al. (2006), who indicated that body sway during SEM decreased in the eye open but not in the eye close. The PS and proprioception of the feet are important for maintaining normal standing balance with the eyes closed (Shumway-Cook and Woollacott 2001); because the body relies more on PS to maintain postural balance when the eyes closed, the PSA would consequently increase. Therefore, increased postural balance affect information from PS, and it provide valuable feedback to the balance control system.

As mentioned above, SEM and PEM improve postural balance and PS in woman elderly individuals during stance postural maintenance; therefore, SEM and PEM are effective intervention to improve postural balance. Furthermore, postural balance was found to improve more during saccade conditions. This result, which was derived from SEM and PEM conducted at a frequency of 0.5 Hz, differs from the findings of previous studies that reported improvements in postural balance from saccades conducted at a higher frequency of 1.1 Hz (Stoffregen et al. 2007; Rodrigues et al. 2013). Further research is required to explain this difference.

There are limitations to this study. Because our experiment was conducted over a short time period (5 minutes), the results could only indicate short-term effects; thus, the long-term effects of SEM and PEM remain unclear. Additionally, the mechanism underlying the observed decrease in the area, length, and velocity of the COP fluctuation and the increase in the PSA of the feet is unclear. Further studies should be conducted to evaluate the effects of SEM and PEM in other conditions such as in male elderly individuals and young adults, or in individuals with decreased balance and motor function. To maintain postural balance in the standing position, the ankle muscle also has to be activated along with the PS of the foot (Morasso and Schieppati 1999; Kavounoudias et al. 2001). Therefore, we plan to evaluate the relationship between changes in balance control and muscle activity of the lower extremities, such as the ankle, by assessing SEM and PEM in the elderly.

Conflict of Interest

The author declares no conflict of interest.

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