Original Article

Effect of home-based oculomotor exercises on postural stability in healthy female adults

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ABSTRACT

Visual information improves postural stability and facilitates stabilization of upright posture. To date, how saccades and smooth pursuit eye movements affect postural control is still a matter of debate. Therefore, the purpose of this study was to investigate the effects of oculo-motor exercises on static postural stability in healthy female adults. Participants (51.6 ± 4.9 years) were randomly allocated to an experimental group (n = 9) that performed 4-week home-based oculomotor exercises (i.e., saccadic eye movement and smooth pursuit) or a control group (n = 9). Pre and post postural stability during quiet standing with eyes open were measured on both groups. Significant 'Time x Group' interaction ($p < .05$) was found for Length Function of Surface, anterior-posterior acceleration, length of the oscillations, rearfoot load and body sway surface. By post hoc analyses, significant differences were found in all stabilometric parameters during quiet standing in the experimental group ($p < .05$). No significant differences were found in postural stability in the control group. Improvements in postural stability after four weeks of two combined oculomotor exercises suggest that this specific type of ocular system exercises may be beneficial for healthy female adults. In addition, the present investigation supports evidence that eye movements interact with the postural control system.
Keywords: Postural control; Proprioceptive; Visual; Saccadic eye movement; Smooth pursuit.

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INTRODUCTION

Vision is an important sensory to process information such as recognition, localization and proprioception (Donaldson, 2000; Irwin, 1991; Lewis, Zee, Gaymard, & Guthrie, 1994). Visual information improves postural stability and facilitates stabilization of upright posture, by enabling detection of self-motion relative to structures in the visual field (Glasauer, Schneider, Jahn, Strupp, & Brandt, 2005; Guerraz & Bronstein, 2008; Laurens et al., 2010; Rodrigues et al., 2015; Schulmann, Godfrey, & Fisher, 1987). In fact, the main afferent sensory systems contributing to postural stability are the visual, vestibular, and somatosensory/proprioceptive systems, reporting every slight change in body position. Re-adjustment of the altered body position into the original one is accomplished by multiple central neural control systems and by the effectors, the skeletal muscles involved in posture control, such as the ankle plantar/dorsal flexors for the anterior-posterior balance and the hip abductors/adductors for the latero-lateral balance (Winter et al., 1996).

There is a close relationship between the ways in which visual and vestibular information about head position are used for postural control (DeAngelis & Angelaki, 2012) and eye movements have been shown to affect posture during standing (Paulus, Straube, & Brandt, 1984). Eye movements are executed by the six extra-ocular muscles (superior, medial, inferior, and lateral rectus muscles; superior and inferior obliques), which are under efferent control from three cranial motor nuclei (abducens nucleus, trochlear nucleus and oculomotor complex). Eye movement kinematics appears to be calculated in the dorsolateral pontine nucleus, which informs the contralateral cerebellum, from where information passes to the vestibular nuclei that coordinate antagonist muscles (Kowler, 2011). During head movements, eye-in-space stabilization is ensured by vestibulo-ocular reflexes (Raphan, Imai, Moore, & Cohen, 2001), vestibulocollic reflexes (Roy & Cullen, 2002), and smooth pursuit eye movements. Compensatory eye movements are a direct response to head movements relative to the fixation point. Therefore, eye movement signals could be used to infer head motion information and contribute to postural stabilization (Glasauer et al., 2005; Guerraz & Bronstein, 2008; Paulus et al., 1984).

The visual tracking of moving targets (smooth pursuits) increased postural sway in adults, in the presence and without of a static visual field (Glasauer et al., 2005; Guerraz & Bronstein, 2008; Laurens et al., 2010). In a previous study, White, Post, and Leibowitz (1980) found that visual influence on posture was suppressed during saccadic eye movements. Stoffregen, Bardy, Bonnet, and Pagulayan (2006) and Rougier and Garin (2007) found that performing saccades toward various targets reduces body sway. Besides to raise the possibility of a functional relation between body sway and eye movements, they interpreted these results as higher allocation of central processing resource in order to support visual performance. However, these results show that saccadic and tracking eye movements have fundamentally different effects on posture. Vision is suppressed during saccades, whereas tracking eye movements participate to the visual control of posture. It must be known that this topic has received little attention in the literature, which is surprising given the prevalence of eye movements in everyday life and their potential link with postural control (Kowler, 2011).

Despite all the importance of saccades, this is not the only important eye motion, since sports and other activities also require eye movements to track (pursuit) objects moving in the environment (Land & Hayhoe, 2001). In addition, Rodrigues et al. (2015) demonstrated that saccades and smooth pursuit eye movements affect body sway equally, reducing the sway magnitude. How these two eye movements affect postural control is still a matter of debate, therefore, the purpose of this study was to investigate the effects of two combined oculomotor exercises (i.e., saccadic eye movement and smooth pursuit) on static postural stability in healthy female adults. It was hypothesized that stabilometric parameters would improve after 4-week home-based intervention.

MATERIALS AND METHODS

Participants

A sample size estimation of n = 16 was calculated a priori on the basis of a statistical power of 80%, at a 5% probability threshold, and a medium 'Time x Group' interaction effect size for the outcome variables. The additional recruitment was accounted for the possibility of dropouts. The experimental protocol was conducted in accordance with the ethical standards of the responsible institutional committee on human experimentation and with the Helsinki Declaration. Eighteen female participants were recruited from a local sport centre and required to meet the following inclusion criteria: all participants had normal vision with or without correction by spectacles or contact lenses and none of them reported history of postural instability and/or vestibular disorders. Participants were informed about the study and gave their written consent. After baseline testing, participants were assigned to an experimental group or a control group using a pre-test matched-pairs approach. Participants were ranked according to their age, paired, and randomly allocated to either the experimental group (n = 9; age: 51.2 ± 1.8 years) or control group (n = 9; age: 52.0 ± 6.9 years). This approach reduces the bias associated with randomization, because it decreases the likelihood of differences between study group at baseline. The experimental group performed oculomotor exercises for four weeks and the control group did not.

Intervention

Two different oculomotor exercises were performed including (1) saccadic eye movement exercises; and (2) smooth pursuit exercises. The saccadic eye movement exercise included moving the eyes horizontally between two stationary targets while keeping the head still. The smooth pursuit exercise included moving the target horizontally and tracking it with the eyes while keeping the head still. During the exercises, subjects were instructed to focus on the target (a letter on a card) held in their hand and to move the target as fast as they could while maintaining clear focus on the target. Participants performed each exercise for 5 min daily for four weeks in the experimental group, and all exercises were performed at home in a stand position (see Figure 1).

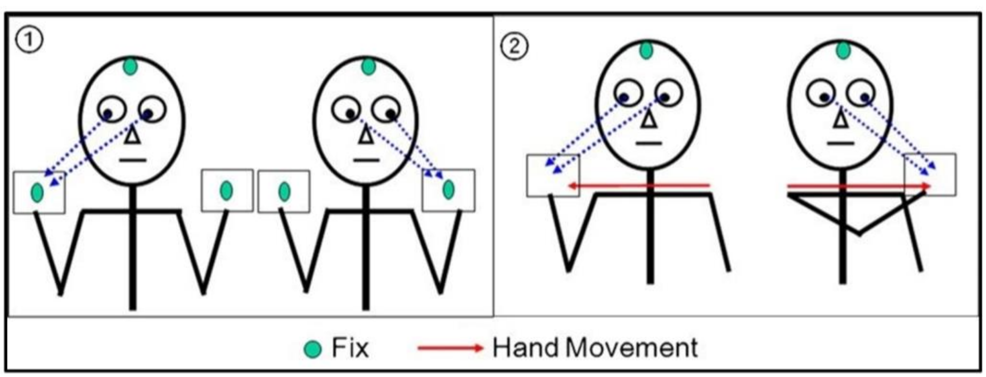

Figure 1. Oculomotor exercises illustrations and descriptions. The target was held in the subjects hand approximately thirty centimetres away from the participants' eyes. Participants performed all exercise in a standing position for 5 min daily for four weeks. Participants were instructed to move the target as fast as they could while maintaining clear focus on the target during the following exercises: (1) saccadic eye movements, (2) smooth pursuit.

Postural stability measurement

At baseline and after four week, posturography recordings were performed using a 10-Hz sampling frequency vertical force platform (Bio Postural System, AXA S.r.l., Vimercate [Mi], Italy) with subjects placed standing in a quiet stance. This platform includes load cells with an internal circuit that changes electrical resistance upon the application of force. Participants were required to remain relaxed but as stable as possible, with eyes open and their arms hanging free beside their trunk and facing the wall (150 cm away). In addition, all subjects were asked to avoid alcohol and heavy exercise during the 24 h before the postural recordings. Each trial lasted 60 seconds (Carpenter, Frank, Winter, & Peysar, 2001) without modification of the position of feet on the platform between tests. Rest periods of 30–60 seconds were provided between trials. Five posturographic parameters were recorded, including:

1) The length function of surface (LFS) provides information about the precision of postural control and the energy used by the participant to stand steady. It is a good yield index for the postural system. Under normal conditions it should be approximately equal to 1.
2) CoP acceleration (mm/s^2) in anterior-posterior (A/P) directions.
3) The length of the oscillations, expressed in mm, showing the total distance covered by the centre of pressure of the subject. It is an index of the energy spent by the equilibrium system.
4) The rearfoot load in percentual (%).
5) The surface of the body sway, expressed in mm^2, showing the confidence ellipse based on 90% of the sample positions. It indicates the precision of the balance control system.

Finally, three trials were taken and the recorded mean value represented the statistical unit.

Statistical analysis

All analyses were performed using SAS JMP® Statistics (Version <14.1>, SAS Institute Inc., Cary, NC, USA, 2018) and the data are presented as group mean values and standard deviations. Normality of all variables was tested using Shapiro-Wilk test procedure. Levene's test was used to determine homogeneity of variance. A multivariate analysis of variance (MANOVA) was used to detect differences between the study groups at baseline. Training-related effects were assessed by 2-way analyses of variance (ANOVA) with repeated measures (group x time). When 'Time x Group' interactions reached the level of significance, group-specific post hoc tests (i.e., paired t-tests) were conducted to identify the significant comparisons and, next, Cohen's *d* effect size was made.

The effect size was identified to provide a more qualitative interpretation of the extent to which changes observed were meaningful. Cohen's *d* was calculated as post-training mean minus pre-training mean divided by pooled SD before and after training, and interpreted as small, moderate, and large effects defined as 0.20, 0.50, and 0.80, respectively (Cohen, 1988). Partial eta squared (η^2_p) was used to estimate the magnitude of the difference within each group and interpreted using the following criteria (Cohen, 1988): small ($\eta^2_p < .06$), medium ($.06 \le \eta^2_p < .14$), large ($\eta^2_p \ge .14$). Percentage changes were calculated as [(post training value – pretraining value)/pretraining value] x 100. A p-value ≤ .05 was considered statistically significant.

RESULTS

There was no significant difference between groups at baseline for all outcome variables ($p > .05$). After 4-weeks, statistical analysis revealed significant differences in stabilometric parameters in the experimental group, whereas no significant differences were found in the control group (Table 1).

Table 1. Changes in the posturographic parameters after 4 weeks. Data are expressed as mean (+SD).

	Experimental group (n = 10)				Control group (n = 10)			
Parameter	**Baseline**	**Post-test**	**Δ%**	**ES**	**Baseline**	**Post-test**	**Δ%**	**ES**
Length in function of surface (LFS)	1.10 (0.13)	0.98 (0.18)*†	-11.0	1.37	1.12 (0.15)	1.11 (0.16)	-0.9	0.07
A/P acceleration (mm/s^2)	234.2 (44.1)	205.5 (32.8)*†	-12.2	1.66	239.5 (40.5)	232.2 (40.0)	-3.0	0.61
Length (mm)	734.1 (106.4)	618.3 (120.9)*†	-15.8	0.98	720.1 (181.9)	716.3 (177.4)	-0.5	0.09
Rearfoot load (%)	85.6 (4.6)	81.0 (4.2)*†	-5.4	3.49	83.3 (12.8)	83.5 (11.5)	0.2	0.05
Surface (mm^2)	23.4 (5.4)	16.3 (6.3)*†	-30.3	1.66	22.5 (24.8)	21.9 (24.3)	-2.7	0.08

*Experimental group: two oculomotor exercises for 4 weeks (5 min daily). Δ%, individual percent change. ES, Cohen's d effect size. *Significantly different from pre-test (p < .05). †Significant 'Time x Group' interaction = significant effect of the oculomotor exercises.*

Statistical analyses revealed no significant main effects of 'Group' for all outcome variables ($p > .05$).

Significant main effects of 'time' were observed for LFS ($F_{1,16} = 5.09$, $p = .038$, $\eta^2_p = .24$), A/P acceleration ($F_{1,16} = 26.69$, $p < .001$, $\eta^2_p = .63$), length of the oscillations ($F_{1,16} = 8.14$, $p = .011$, $\eta^2_p = .34$), rearfoot load ($F_{1,16} = 11.19$, $p = .004$, $\eta^2_p = .41$) and body sway surface ($F_{1,16} = 7.53$, $p = .014$, $\eta^2_p = .32$).

Significant 'Time x Group' interaction was found for LFS ($F_{1,16} = 4.72$, $p = .045$, $\eta^2_p = .23$), A/P acceleration ($F_{1,16} = 9.55$, $p = .007$, $\eta^2_p = .37$), length of the oscillations ($F_{1,16} = 7.12$, $p = .017$, $\eta^2_p = .31$), rearfoot load ($F_{1,16} = 13.25$, $p = .002$, $\eta^2_p = .45$) and body sway surface ($F_{1,16} = 5.24$, $p = .036$, $\eta^2_p = .25$).

The post hoc analysis revealed that the experimental group showed significantly greater improvements in all stabilometric parameters from pre- to post-testing for all outcome variables ($p < .05$) than control group ($p > .05$).

DISCUSSION

We manipulated visual conditions, i.e. saccades and smooth pursuit eye movements, to examine their combined effect on postural stability. We hypothesized that stabilometric parameters would improve after 4-week home-based exercises. The findings of the present study confirmed our hypothesis that combined oculomotor exercises, saccades, and smooth pursuit, improve stabilometric parameters during quiet standing with eyes open in healthy female adults. Parameter values of postural control (LFS), A/P acceleration, length of the oscillations, rearfoot load and surface of the body sway decreased and, therefore, postural stability improved.

These results agree with Rodrigues et al. (2015) that found a reduction of the sway magnitude through saccades and smooth pursuit eye movements. Previous studies indicate that eye movement increases body sway (Glasauer et al., 2005; Jahn et al., 2002; Strupp et al., 2003), but eye movement signals can be used to contribute to postural stabilization (Glasauer et al., 2005; Guerraz & Bronstein, 2008). Although the distinctive properties of saccadic and smooth pursuit eye movements are well known (Laurens et al., 2010; Rashbass, 1961), both eye movements share some neural networks, and, by implication, some similar processing mechanisms (Kowler, 2011). Although some of the previous studies do not agree with our results, they support the functional relation between body sway and eye movements.

Previous findings confirmed the reduction of body sway during saccadic eye movements (Rey, Lê, Bertin, & Kapoula, 2008; Rougier & Garin, 2007; Stoffregen et al., 2006; White et al., 1980), but there are methodological differences between this study and previous studies. In our study, participants performed oculomotor exercises at home and stabilometric parameters were assessed during quiet standing with eyes open, whereas in other studies the participants were assessed in dynamic conditions and with different stimuli frequencies. The novelty brought by our work occurs in the effectiveness of the combined oculomotor exercises, saccades and smooth pursuit, in improving posture stability. The explanation could be that both extraocular afferents (proprioception) and efferent motion perception likely play a significant role in postural control (Guerraz & Bronstein, 2008). In fact, both mechanisms promote visual stabilization of posture (Guerraz, Sakellari, Burchill, & Bronstein, 2000; Jahn et al., 2002; Paulus, Straube, Krafczyk, & Brandt, 1989; Rushton, Brandt, Paulus, & Krafczyk, 1989). In addition, via afferent mechanism, individuals try to minimize the changes of the projected image on the retina in order to keep the relationship between visual information and body posture stable during fixation. Collewijn, Martins, and Steinman (1983) suggested that visual stimulation could improve the function of vestibular system due to a neural adaptation at the vestibular nuclei (Miles & Lisberger, 1981) and cerebellum (Ito, 1972). Therefore, neural adaptation could improve postural stability through oculomotor exercises, as happened in this study. However, even with consistent and relevant results, our findings were limited to females alone. Future studies should extend these observations to males and other age groups.

CONCLUSIONS

The results of this study showed improvements in postural stability of healthy female adults after performing home-based oculomotor exercises (i.e., saccadic eye movement and smooth pursuit) for four weeks. The present investigation supports growing evidence that eye movements interact with the postural control system, which could have important implications for practitioners and researchers working with a variety of populations. Future exercise programs should focus on improving postural control during smooth pursuit eye movements in a variety of conditions. In fact, sports and other activities also require eye movements to track (pursuit) objects moving in the environment (Land & Hayhoe, 2001). It should also be deepened if the oculomotor exercises may improve the cognitive level (sensory integration of visual cues to the postural control system) and the physical functioning level (musculoskeletal responses to maintain upright stability).

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CONFLICT OF INTEREST STATEMENT

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

AUTHORS' CONTRIBUTION

F. Fischetti designed the study, was involved in the interpretation of data and wrote and revised the manuscript. S. Cataldi collected data and was involved in the interpretation of data and writing of the manuscript. A. Giunto designed the study, collected the data, and was involved in the interpretation of data. G. Greco designed the study, carried out the statistical analysis, interpreted the data, wrote and revised the manuscript. All authors contributed intellectually to the manuscript, and all authors have read the manuscript and approved the submission.

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