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Research article

Semi tandem base of support degrades both saccadic gaze control and postural stability particularly in older adults

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ABSTRACT

Differences in the postural stabilization of older and young adults have been shown to be task-dependent on both visual and postural challenges; however, the gaze behavior during such tasks has rarely been examined. This study investigated the effects of horizontal and vertical saccades on gaze control, center of pressure (CoP) and head displacement of young and older adults on different bases of support. Ten young adults (20.7 ± 3.4 years) and ten older adults (71.6 ± 3.1 years) remained in an upright stance on a force platform wearing an eye-head tracker device. The participants performed 30-second trials according to two bases of support (feet apart and semi-tandem) and three gaze behavior (fixation, horizontal and vertical saccades) conditions. Older adults presented greater CoP amplitude ($p < 0.002$) and velocity ($p < 0.001$) (ML axis), and higher head amplitude (ML) ($p < 0.002$) than young adults during the semi tandem base. Head displacement of both groups presented higher velocity (ML axis) during horizontal ($p < 0.001$) and vertical saccades ($p < 0.01$) than the fixation task only on the semi tandem base. There was higher number of fixations ($p < 0.001$) and lower mean fixation duration ($p < 0.001$) on the semi-tandem base ($p < 0.05$). The results showed higher gaze latency variability in vertical saccades for older adults ($p < 0.01$). Challenging postural tasks may alter postural adjustments and gaze control during saccadic tasks. Particularly, the greater postural instability of older adults increased the gaze latency variability during saccadic tasks, suggesting some deterioration in the posture-gaze relation with aging.

1. Introduction

Gaze behavior affects postural stabilization. The magnitude of body sway of young adults is attenuated during continuous saccadic eye movements compared with fixation directed to a target [1–5]. During eye movement tasks, the central nervous system uses additional sensory information from extraocular muscles (efferent perception mechanism) and optical flow characteristics (afferent perception mechanism) to estimate the body position in space, increasing postural stability [6]. A more stable visual scene due to this decreased body sway facilitates more accurate gaze shifts, indicating functional integration of posture and gaze control [2].

Some studies have manipulated bases of support challenges and characteristics of saccadic tasks to examine the posture-gaze relation in young and older adults and have indicated that changes in postural demands may interact with visual task constraints altering the way the posture and gaze control are integrated [5,7]. Rodrigues et al. [5]. examined the effect of different frequencies of horizontal saccades (1.1 Hz and 0.5 Hz) on body sway of young adults during different bases of support demands (wide and narrow stances). Results have shown additional attenuation of trunk sway and head movements in wide stance during the high saccadic frequency condition indicating that the postural control was modulated to facilitate rapid and accurate gaze shifts to the target but only on a less demanding base of support. The authors suggested an adaptive resource-sharing interpretation for these results which states that limited attentional resources are shared according to the demands of each task (i.e. postural and suprapostural tasks) [8].

This interplay between postural demands and saccadic task constraints should be considered when examining the effects of eye movements on postural stabilization of older individuals. It is known that postural control is affected by the aging process [9]; older adults

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present sensory and motor deficits which lead to increased postural instability, mainly during challenging stances [10]. In addition, there are declines in gaze performance; for instance, older adults present longer latencies of voluntary vertical and horizontal saccades to visual targets compared to young adults [11,12]. However, little is known about how these aspects interfere with the postural stabilization of older adults during the performance of saccades.

Aguiar et al. [13], examining the effects of frequency of saccades and bases of support demands in older adults, pointed out that older adults did not show reduced body sway in wide stance during the performance of the more demanding visual task (1.1 Hz), as previously found in young adults [5]. In fact, older adults seem to be more affected by visual task demands since their sway magnitude was not increased in narrow stance (more demanding base of support) compared with wide stance. This suggests that older adults likely adopted a more rigid postural response strategy (i.e. stiffened posture) in narrow stance to stabilize posture in order to facilitate gaze shifts. However, without gaze position measures, it is unclear if older adults successfully achieved gaze performance. Thomas et al. [14], conversely, did not demonstrate the effect of saccades on the postural sway and gaze performance of both young and older females, in narrow stance, through measures of center of pressure displacement (CoP). These results did not corroborate the previous studies [4,5,13] in two respects: reduction in postural sway due to saccades during narrow base of support and effect of aging on gaze performance. The authors suggested that long periods of fixation on the target due to lower saccadic frequency (0.3 Hz) stabilized the sway magnitude, not requiring further postural attenuation. Older adults demonstrated similar gaze errors during the saccadic task compared to young adults.

Despite the contribution of these studies, lack of systematic control over the demands of visual and postural tasks means that there is not yet clarification as to whether greater postural instability affects gaze performance during a more demanding visual task and, in this case, whether there is an interaction between the saccadic task demands and stance difficulty.

In the present study, we examined whether the effects of saccadic eye movements on postural performance might be related to changes in saccadic direction and bases of support demands. Vertical and horizontal saccades, at high saccadic frequency (1.1 Hz), are thought to challenge eye movements in different movement axes. It is known that latency of vertical saccades increases with age [15] and is longer than horizontal saccades [11]. Performing vertical saccades might potentially generate higher attentional demands compared to horizontal saccades, differently influencing postural stability. There is no consensus in the literature regarding the effect of horizontal and vertical saccades on postural sway in different body movement axes (anterior posterior - AP and medial lateral - ML). However, some studies have indicated that changes in postural sway may occur in one specific movement axis depending on the demands of postural and visual tasks [1,2,7,14]. Thus, we examined whether greater mechanical postural instability in the ML axis would affect gaze performance in horizontal and vertical saccadic directions. Body sway and gaze displacement were measured to examine how both systems (balance and oculomotor) deal with the interactions between postural and visual tasks. In addition, we used measures of postural sway based on analysis of both CoP and head displacement in order to provide a more complete description regardingthe effects of saccades on postural stabilization of older adults.

The aim of this study was to investigate the effects of saccadic eye movements in horizontal and vertical gaze directions on the postural control of young and older adults during different bases of support and also to examine whether gaze behavior is affected by demands of both postural and visual tasks. In this context, this is the first study to quantify the effects of eye movement on postural control of older adults in different saccadic directions and base of support demands relating measurements of gaze behavior and balance control. Our hypotheses were: 1) The attenuation effect of horizontal and vertical saccades on sway magnitude would be higher during the semi tandem base of support condition compared to the feet apart base condition. We also expected that standing in semi tandem base, ML sway magnitude would be attenuated by horizontal saccades and AP sway magnitude would be attenuated by vertical saccades; 2) Older individuals would demonstrate decreased performance of saccades (increased gaze latency mean and variability) compared to young adults in horizontal and vertical directions, which would be more pronounced during the semi tandem base of support condition.

2. Materials and methods

2.1. Participants

Ten healthy older adults (71.6, ± 3.1years-old) and ten young adults (20.7, ± 3.4years-old) participated in the study. The participants did not report diagnosed neurological diseases, musculoskeletal disorders, or visual impairments which could compromise performance of the experimental conditions. All participants presented normal or corrected to normal vision by glasses or contact lenses. A written consent was signed by the participants. The experimental procedures were approved by the local University Ethics Committee according to the principles of the Declaration of Helsinki.

2.2. Procedures

Participants were instructed to stand upright, barefoot, on a force plate (AMTI – AccuGait, Boston, MA), as stable as possible; fixating or moving their eyes towards a target that was displayed on a monitor (37.5 cm × 30 cm) positioned 100 cm away from them. The target was a filled circle in red, 2 cm in diameter, on a white background (subtended visual angle of the target was approximately 1.15°) generated by the software Flash Mx (Macromedia) and presented on an LCD monitor.

Twelve 30-second trials were performed in a random order in the following visual conditions: a) Fixation on a stationary target (control condition); b) Horizontal saccades directed to a target; and c) Vertical saccades directed to a target. In the fixation condition, the target was displayed in the center of the monitor throughout the trial. In the horizontal and vertical conditions, participants were required to perform saccades directed to the target appearing on one side of the monitor (e.g., left or upper, respectively), 9.75 cm away from the center, then disappearing and reappearing immediately on the opposite side (e. g. right or lower, respectively). Movements of saccades were performed in response to horizontal or vertical target changes, always at the frequency of 1.1 Hz. Stimuli eccentricities during saccadic conditions involved a visual angle of 11 ° in order to avoid head movements [2,16]. The individuals performed two trials in each visual condition for each base of support: feet apart (parallel feet aligned with the shoulder) and semi tandem (dominant foot aligned ahead and medial to the non-dominant foot).

2.3. Data analysis

From the forces (Fx, Fy and Fz) and moment components (Mx, My and Mz) acquired by the force plate, the CoP displacement was calculated in the AP and ML axes, and provided information about the participant's postural sway. Eye movements and head position were measured by a head mounted eye tracking system (model H6, Applied Science Laboratory, USA) coupled to a sensor of a Flock of Birds magnetic system (Ascension Technology Corporation, Shelburne, VT). The eye-head integration system is able to provide six degrees of freedom with respect to head motion: three-dimensional head position (distance between origins of transmitter and receiver coordinate systems) and orientation (rotation angles of receiver axes with respect to transmitter axes). However, only head position data were analyzed in the present study as head rotations were not expected to play a major role. The system calibration was performed from the fixation of nine points displayed in a 3 by 3 grid and was checked in each trial. The CoP and head displacement data were filtered with a second low-pass Butterworth filter with a 4 Hz cut-off frequency. The sampling frequency was 60 Hz.

From the CoP trajectory data, the following dependent variables were calculated: mean amplitude (i.e. standard deviation of the trajectory after the average position was subtracted from the data points throughout the trial); mean velocity (i.e. trajectory of the total sway divided by the total duration of the trial); and median frequency (i.e., sum of the product of power spectrum and frequency divided by the total sum of the power spectrum which corresponded to 50% of the power spectrum), in the AP and ML directions. The same variables were calculated from the three dimensional head position data.

The parameters calculated for eye movements were: number of fixations; mean fixation duration (i.e. mean of the intervals between the fixation onset and fixation offset throughout each trial); gaze latency mean; and gaze latency variability. The fixation criteria were: fixation onset - occurred when the value of two times point of gaze standard deviation (95% confidence interval) was less than one degree of visual angle in the horizontal axis and one degree of visual angle in the vertical axis over 100 ms (or seven data samples); fixation offset - occurred when six data samples deviated from the initial fixation value by more than one degree of visual angle in the horizontal axis and one degree of visual angle in the vertical axis. The magnitude of gaze latency was defined, for each half of a stimulus cycle, as the time interval between visual target appearance (TA) and the onset of first fixation on the respective target area (OF); its direction is defined by the sign of the difference between TA and OF: positive for “late” gaze arrival (first TA, then OF), negative for “early” gaze arrival (first OF, then TA), and zero for TA and OF time coincidence. Thus, gaze latency mean (i.e. the mean of gaze latency throughout a trial) and gaze latency variability (i.e. the standard deviation of gaze latency mean throughout trial) were also computed (Matlab, 10.0, Mathworks).

2.4. *Statistical analysis*

ANOVAs (2 groups x 2 bases of support x 3 visual tasks) with repeated measures for the last two factors were performed to examine differences between groups (young and older adults) and within-group conditions, separately, for each CoP, head displacement, and gaze dependent variable. Tukey’s post hoc tests, Greenhouse-Geisser degrees of freedom adjustments, and Bonferroni multiple comparisons probability adjustments were carried out for significant main effects when necessary. The effect size (η^2, partial eta-squared) was also measured for each statistical analysis. The significance level was $p < 0.05$ (SPSS, version 17.0). For parsimony purpose, main effects and interactions that did not reach statistical significance were not reported; in addition, significant main effects or lower order interactions were not reported when a (higher order) interaction was significant.

3. Results

3.1. *CoP displacement*

The group by base of support interaction was significant for mean velocity (ML) and mean amplitude (ML) (Table 1); post hoc tests indicated that only in the semi tandem condition, older adults showed higher values for mean velocity ($p < 0.001$) and mean amplitude ($p < 0.002$) in the ML axis compared to young adults.

3.2. *Head displacement*

There was a significant group by base of support interaction (Table 2) and the post hoc analysis revealed, on the semi tandem base, higher mean velocity (AP – $p < 0.002$ and ML - $p < 0.001$), mean amplitude (ML - $p < 0.001$), and median frequency (AP – $p < 0.01$) in

Table 1
Mean (± standard deviation) CoP variables of young and older adults for each experimental condition. AP – anterior posterior; ML – medial lateral. ANOVA results for main effects of Group, Bases of support, and Group and Bases of support interaction. No main effects for visual task or interactions.

Variables of COP	Visual task	Young adults		Older adults		Group effect	Bases of support effect	Group x Bases of support interaction
		Feet apart	Semi tandem	Feet apart	Semi tandem			
Mean velocity of CoP – AP (cm/s)	Fixation	0.53 (± 0.11)	0.98 (± 0.27)	0.65 (± 0.20)	1.25 (± 0.44)	Non-significant	$p < 0.001$	Non-significant
	Horizontal	0.52 (± 0.15)	0.90 (± 0.19)	0.64 (± 0.21)	1.25 (± 0.52)		$F_{1,18} = 48.99$	
	Vertical	0.57 (± 0.18)	0.90 (± 0.25)	0.63 (± 0.22)	1.21 (± 0.46)		$\eta^2 = 0.731$	
Mean velocity of CoP – ML (cm/s)	Fixation	0.38 (± 0.10)	0.93 (± 0.16)	0.41 (± 0.15)	1.51 (± 0.31) *	$p < 0.001$	$p < 0.001$	$p < 0.0001$
	Horizontal	0.36 (± 0.08)	0.91 (± 0.14)	0.42 (± 0.16)	1.57 (± 0.36) *	$F_{1,18} = 24.83$	$F_{1,18} = 205.595$	$F_{1,18} = 27.017$
	Vertical	0.40 (± 0.14)	0.89 (± 0.17)	0.41 (± 0.16)	1.54 (± 0.35) *	$\eta^2 = 0.580$	$\eta^2 = 0.919$	$\eta^2 = 0.600$
Mean amplitude of CoP – AP (cm)	Fixation	0.15 (± 0.03)	0.20 (± 0.04)	0.19 (± 0.06)	0.25 (± 0.06)	Non-significant	$p < 0.001$	Non-significant
	Horizontal	0.16 (± 0.04)	0.19 (± 0.04)	0.19 (± 0.06)	0.26 (± 0.08)		$F_{(1,18)} = 21.362$	
	Vertical	0.17 (± 0.06)	0.20 (± 0.04)	0.19 (± 0.07)	0.25 (± 0.08)		$\eta^2 = 0.543$	
Mean amplitude of CoP – ML (cm)	Fixation	0.10 (± 0.03)	0.23 (± 0.04)	0.13 (± 0.06)	0.34 (± 0.06) *	$p < 0.001$	$p < 0.001$	$p < 0.0001$
	Horizontal	0.09 (± 0.02)	0.25 (± 0.03)	0.14 (± 0.07)	0.36 (± 0.08) *	$F_{1,18} = 15.67$	$F_{1,18} = 220.613$	$F_{1,18} = 12.881$
	Vertical	0.10 (± 0.04)	0.23 (± 0.04)	0.12 (± 0.06)	0.36 (± 0.09) *	$\eta^2 = 0.465$	$\eta^2 = 0.925$	$\eta^2 = 0.417$
Median frequency of CoP – AP (Hz)	Fixation	0.19 (± 0.07)	0.36 (± 0.18)	0.23 (± 0.09)	0.38 (± 0.17)	Non-significant	$p < 0.001$	Non-significant
	Horizontal	0.20 (± 0.06)	0.29 (± 0.11)	0.24 (± 0.09)	0.35 (± 0.19)		$F_{1,18} = 22.434$	
	Vertical	0.23 (± 0.06)	0.32 (± 0.14)	0.21 (± 0.06)	0.43 (± 0.13)		$\eta^2 = 0.555$	
Median frequency of CoP– ML (Hz)	Fixation	0.33 (± 0.18)	0.31 (± 0.09)	0.30 (± 0.13)	0.33 (± 0.13)	Non-significant	Non-significant	Non-significant
	Horizontal	0.30 (± 0.15)	0.26 (± 0.08)	0.36 (± 0.16)	0.36 (± 0.10)			
	Vertical	0.33 (± 0.16)	0.25 (± 0.10)	0.30 (± 0.12)	0.41 (± 0.11)			

* vs young adults within same condition (semi tandem base condition), $p < 0.05$.

Table 2

Mean (± standard deviation) head variables of young and older adults for each experimental condition. AP – anterior posterior; ML – medial lateral. ANOVA results for main effects of Group, Bases of support, Visual task, and interactions (Group and Bases of support, Visual task and bases of support).

Variables of head	Visual task	Young adults		Older adults		Group effect	Bases of support effect	Visual task effect	Group x Bases of support interaction	Visual task x Bases of support interaction
		Feet apart	Semi tandem	Feet apart	Semi tandem					
Mean velocity of head - AP (cm/s)	Fixation	0.302 (± 0.07)$^{\beta,\#}$	0.329 (± 0.09)$^{\beta,\#}$	0.400 (± 0.11)$^{\beta,\#}$	0.513 (± 0.12)$^{*,\beta,\#}$	$p < 0.005$	$p < 0.007$	$p < 0.004$	$p < 0.04$	Non-significant
	Horizontal	0.318 (± 0.06)	0.335 (± 0.09)	0.419 (± 0.14)	0.548 (± 0.16)*	$F_{1,18} = 10.22$	$F_{1,18} = 9.46$	$F_{2,36} = 6.31$	$F_{1,18} = 4.89$	
	Vertical	0.356 (± 0.12)	0.372 (± 0.09)	0.432 (± 0.13)	0.557 (± 0.19)*	$\eta^2 = 0.362$	$\eta^2 = 0.345$	$\eta^2 = 0.260$	$\eta^2 = 0.214$	
Mean velocity of head - ML (cm/s)	Fixation	0.183 (± 0.04)	0.293 (± 0.07)$^{+,\beta,\#}$	0.241 (± 0.08)	0.538 (± 0.15)$^{*,+,\beta,\#}$	$p < 0.001$	$p < 0.0001$	$p < 0.001$	$p < 0.0001$	$p < 0.04$
	Horizontal	0.193 (± 0.03)	0.358 (± 0.09)$^{+}$	0.261 (± 0.10)	0.614 (± 0.17)$^{*,+}$	$F_{1,18} = 18.64$	$F_{1,18} = 100.02$	$F_{2,36} = 15.52$	$F_{1,18} = 16.99$	$F_{2,36} = 3.58$
	Vertical	0.193 (± 0.05)	0.328 (± 0.08)$^{+}$	0.240 (± 0.09)	0.575 (± 0.14)$^{*,+}$	$\eta^2 = 0.509$	$\eta^2 = 0.847$	$\eta^2 = 0.463$	$\eta^2 = 0.486$	$\eta^2 = 0.166$
Mean amplitude of head - AP (cm)	Fixation	0.148 (± 0.04)$^{\beta,\#}$	0.150 (± 0.05)$^{\beta,\#}$	0.201 (± 0.05)$^{\beta,\#}$	0.239 (± 0.06)$^{\beta,\#}$	$p < 0.01$	Non-significant	$p < 0.021$	Non-significant	Non-significant
	Horizontal	0.160 (± 0.03)	0.160 (± 0.05)	0.219 (± 0.08)	0.244 (± 0.06)	$F_{1,18} = 8.81$		$F_{2,36} = 4.33$		
	Vertical	0.172 (± 0.06)	0.183 (± 0.05)	0.223 (± 0.07)	0.243 (± 0.06)	$\eta^2 = 0.329$		$\eta^2 = 0.194$		
Mean amplitude of head - ML(cm)	Fixation	0.070 (± 0.02)$^{\beta,\#}$	0.128 (± 0.04)$^{\beta,\#}$	0.105 (± 0.04)$^{\beta,\#}$	0.242 (± 0.07)$^{*,\beta,\#}$	$p < 0.001$	$p < 0.0001$	$p < 0.001$	$p < 0.001$	Non-significant
	Horizontal	0.078 (± 0.02)	0.172 (± 0.05)	0.122 (± 0.06)	0.289 (± 0.08)*	$F_{1,18} = 20.16$	$F_{1,18} = 103.55$	$F_{2,36} = 14.85$	$F_{1,18} = 11.30$	
	Vertical	0.078 (± 0.03)	0.153 (± 0.04)	0.110 (± 0.05)	0.255 (± 0.06)*	$\eta^2 = 0.528$	$\eta^2 = 0.852$	$\eta^2 = 0.452$	$\eta^2 = 0.386$	
Median frequency of head – AP (Hz)	Fixation	0.138 (± 0.03)$^{\beta,\#}$	0.150 (± 0.02)$^{\beta,\#}$	0.156 (± 0.03)$^{\beta,\#}$	0.188 (± 0.03)$^{*,\beta,\#}$	$p < 0.025$	$p < 0.001$	$p < 0.04$	$p < 0.05$	Non-significant
	Horizontal	0.132 (± 0.02)	0.145 (± 0.03)	0.155 (± 0.04)	0.177 (± 0.04)*	$F_{1,18} = 5.93$	$F_{1,18} = 33.74$	$F_{2,36} = 3.63$	$F_{1,18} = 4.66$	
	Vertical	0.158 (± 0.04)	0.168 (± 0.03)	0.164 (± 0.04)	0.217 (± 0.07)*	$\eta^2 = 0.248$	$\eta^2 = 0.652$	$\eta^2 = 0.168$	$\eta^2 = 0.206$	
Median frequency of head-ML (Hz)	Fixation	0.152 (± 0.05)	0.132 (± 0.02)	0.159 (± 0.03)	0.144 (± 0.02)	Non-significant	Non-significant	Non-significant	Non-significant	Non-significant
	Horizontal	0.141 (± 0.04)	0.150 (± 0.03)	0.175 (± 0.06)	0.174 (± 0.02)					
	Vertical	0.149 (± 0.05)	0.135 (± 0.02)	0.180 (± 0.05)	0.180 (± 0.05)					

[*] vs young adults within same condition (semi tandem base condition).

[+] vs Feet apart.

[β] vs Horizontal saccades.

[#] vs Vertical saccades; $p < 0.05$.

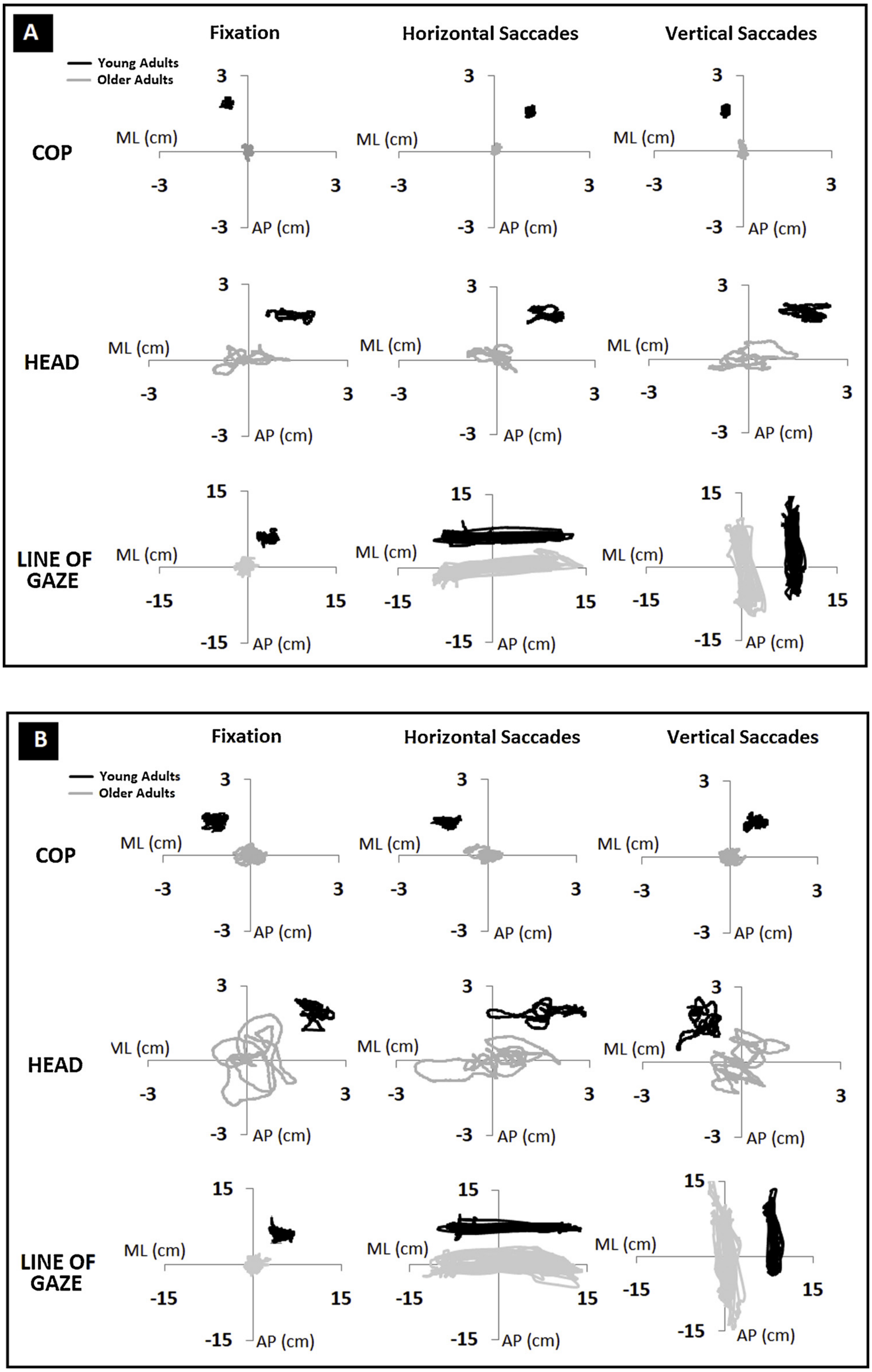

Fig. 1. Representative data from center of pressure (CoP) displacement, head displacement and line of gaze of a young adult (black line) and an older adult (gray line) in the feet apart base condition (A) and semi tandem base condition (B).

older adults compared to young adults. Only older adults presented greater mean velocity (AP - $p < 0.002$) on the semi tandem than feet apart base.

The visual task condition by base of support interaction reached significance for mean velocity in the ML axis. Post hoc tests revealed that both groups presented higher mean velocity on the semi tandem compared to feet apart base in all visual task conditions ($p < 0.001$) and was higher during horizontal ($p < 0.001$) and vertical saccades ($p < 0.01$) than the fixation task only on the semi tandem base.

There were also significant main effects of visual task condition for mean amplitude (AP and ML), mean velocity (AP), and median frequency (AP). Post hoc tests revealed that head displacement was greater ($p < 0.05$) and faster ($p < 0.04$) during vertical saccades than the fixation task ($p < 0.05$) and faster during vertical than horizontal saccades, in the AP axis. In the ML axis, head displacement was greater ($p < 0.001$) during the horizontal saccades than fixation and vertical

Table 3
Mean (± standard deviation) number of fixations and fixation durations of young and older adults for each experimental condition. ANOVA results for main effects of Bases of support and Visual task. No main effects for group.

Variables of gaze	Visual task	Young adults		Older adults		Bases of support effects	Visual task effect
		Feet apart	Semi tandem	Feet apart	Semi tandem		
Number of fixations	Fixation	13.30 (± 8.25) $^{\beta,\#}$	16.90 (± 9.42) $^{+,\beta,\#}$	12.25 (± 12.10) $^{\beta,\#}$	20.60 (± 14.88) $^{+,\beta,\#}$	$p < 0.02$	$p < 0.0001$
	Horizontal	57.55 (± 8.78)	63.00 (± 12.35) $^{+}$	55.40 (± 15.76)	60.15 (± 6.95) $^{+}$	$F_{1,18} = 6.09$	$F_{1,18} = 187.53$
	Vertical	54.30 (± 12.68)	54.25 (± 17.75) $^{+}$	52.35 (± 3.09)	53.85 (± 4.99) $^{+}$	$\eta^2 = 0.253$	$\eta^2 = 0.912$
Fixation Duration (seconds)	Fixation	3.02 (± 1.29) $^{\beta,\#}$	2.57(± 2.03) $^{\beta,\#}$	2.57 (± 2.12) $^{\beta,\#}$	2.31 (± 1.66) $^{\beta,\#}$	Non-significant	$p < 0.0001$
	Horizontal	0.48 (± 0.10)	0.45 (± 0.11)	0.61 (± 0.46)	0.46 (± 0.05)		$F_{1,18} = 31.70$
	Vertical	0.64 (± 0.48)	0.81 (± 1.04)	0.53 (± 0.04)	0.52 (± 0.03)		$\eta^2 = 0.638$

$^{+}$ vs Feet apart.
$^{\beta}$ vs Horizontal saccades.
$^{\#}$ vs Vertical saccades; $p < 0.05$.

saccades (both $p < 0.05$). Fig. 1(a, b and c, respectively) displays an exemplification of CoP and head displacements and gaze behavior of a young adult and an older adult during the experimental conditions.

3.3. Gaze behavior

A significantly higher number of fixations was shown during the semi tandem base than feet apart (Table 3). Both groups presented a significantly higher number of fixations ($p < 0.001$) and lower fixation duration ($p < 0.0001$) in horizontal and vertical saccades compared to the fixation task.

For gaze latency mean, there was a significant base of support by visual task interaction ($F_{1,18} = 5.95$, $p < 0.03$, $\eta^2 = 0.248$). Post hoc tests revealed that for both groups, only on the feet apart base ($p < 0.01$), horizontal saccades presented negative gaze latency mean values and vertical saccades presented positive gaze latency mean values, indicating anticipation and delay to the target, respectively. In the semi tandem base, gaze latency mean values remained around zero for both visual tasks ($p > 0.05$), indicating that the participant's eye movement matched the appearance of the target (Fig. 1d).

For gaze latency variability, the analysis showed a significant group by base of support by visual task interaction ($F_{1,18} = 7.27$, $p < 0.02$, $\eta^2 = 0.288$) (Fig. 1d). Post hoc tests revealed that older adults presented greater gaze latency variability on the semi tandem than feet apart base only during vertical saccades ($p < 0.01$). Gaze latency variability was higher in older than young adults during vertical saccades ($p < 0.001$) on both feet apart ($p < 0.001$) and semi tandem bases ($p < 0.001$). During the horizontal saccades, older adults presented higher gaze latency variability on the feet apart base ($p < 0.02$). (Fig. 2)

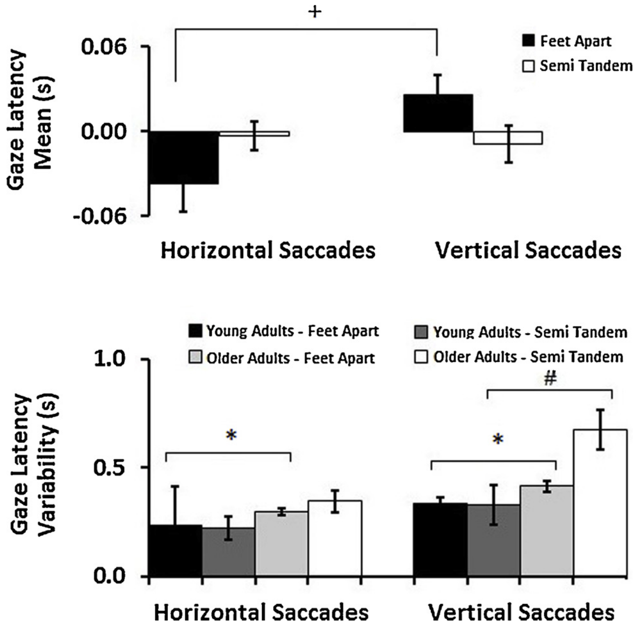

Fig. 2. Mean (± standard deviation) values of gaze latency mean and gaze latency variability of young and older adults in feet apart and semi tandem bases of support during horizontal and vertical saccades conditions. Note: + indicates significant differences between horizontal and vertical saccades during feet apart condition; * indicates significant differences between groups during both horizontal and vertical saccades in feet apart base condition; # indicates significant differences between groups during vertical saccades in semi tandem base condition.

4. Discussion

The present study aimed to investigate the effects of horizontal and vertical saccades on postural stabilization of young and older adults during different bases of support and to examine how gaze performance is affected by postural and visual task demands. Our results revealed that challenging stance condition degraded postural stability, increasing head displacement during the saccadic tasks compared to fixation task. This greater postural instability modified the way the eyes moved toward the target during saccadic tasks, particularly in older adults. In this case, horizontal saccades demonstrated anticipation to the target and vertical saccades delay to the target during the feet apart base condition. However, during the semi tandem base condition, saccadic eye movements matched the appearance of the target. Particularly, greater gaze latency variability was found for older adults, indicating that the posture-eye relation may be affected by declines related to aging. Lastly, there were no changes in CoP displacement during the experimental conditions, indicating that head and CoP displacements were differently affected by the bases of support and saccadic directions. Possible reasons and implications of these results are discussed below.

The increase in head displacement did not corroborate previous findings which indicate attenuation on postural sway during saccadic tasks either in normal or narrow stances [1,2,7,13]. However, our results corroborate other studies showing that there are no changes in the CoP displacement of young [17] and older adults [3,14] during saccadic eye movements. Stoffregen et al. [17] suggested that measurements of body motion (head and trunk) may be a more sensitive way to assess the relation between postural control and supra-postural tasks (p.98). We found that different constraints and contexts imposed by saccadic tasks may differently affect body movements and forces applied to the support surface under challenging stance. Thus might suggest that the central nervous system adopted different postural strategies to compensate the unbalance due to an unstable base of support in an attempt to facilitate the performance of the saccadic task

[2,7,17].

One possible reason for the unexpected increase in head displacement during the saccadic tasks may lie in the fact that the semi tandem base of support added more complexity to the postural task, for instance, compared to the narrow stance employed in other studies [5,13], requiring additional neuromuscular effort of the postural control system to properly stabilize body position. Thus, the mechanical instability generated by this stance condition led to adjustments in the translational head displacement independently of the configuration of trunk and lower extremities [18], the head being referenced to vestibular and visual inputs. However, this strategy did not reduce head displacement during the saccadic tasks, indicating that a combination of greater postural instability with requirements for precise control of eye movements at 1.1 Hz frequency [17] had a negative impact on postural sway. In this case, retinal flow and additional extraocular information (efferent copy) from eye movements [6] were compromised by excessive head displacement, being less effective to provide useful sensory information for postural control.

However, assessment of the position and direction of eye movements during visual tasks allowed us to understand how head stabilization and gaze control were modulated by the stance difficulty. Our results indicated more accurate gaze shifts (i.e. gaze latency mean around zero) during the more demanding stance despite head instability. These results may support the adaptive resource-sharing model in terms of precision requirements and acquisition of information for each task [8]. Thus, reduced attentional resources resulting from the most difficult base of support led to a more constrained pattern of visual coincidence between saccades and stimulus, independently of gaze direction, with latencies around zero.

In this case, head displacement may have been visually anchored on the target position in an attempt to bring the eyes back towards the center of the orbit during the saccadic tasks, facilitating acquisition of the succeeding visual target position [19]. Indeed, our results show that head displacement was adjusted in specific movement axes according to the saccadic directions being faster during horizontal saccades in the ML axis and greater and faster during vertical saccades in the AP axis, which supports the idea of eye-head coupling. It might be assumed that this strategy diminished the efficacy of efferent mechanisms [6] of reducing postural sway.

This sharing of resources was not required during an easier stance (feet apart base) allowing the eyes to be controlled according to the demands of saccadic directions. Studies have reported that vertical latencies are longer than horizontal ones during the lifespan regardless of age [11] and this has been related to the fact that we move our eyes more often in the horizontal direction since many objects in the visual environment are arranged in this plane. In line with previous studies, our results suggest that control of vertical saccades was more challenging for the oculomotor system than horizontal ones [20] which led to a more delayed gaze response. Although eye movements in the vertical direction had no influence on postural sway when the participants were standing on the stable base of support, the axis of gaze movement seemed to alter the attentional engagement throughout the task, measured by mean gaze latency. The reason for these results is unclear. Neural circuitry and respective frames of reference for vertical saccades still need to be identified [21].

Lastly, although no group effect was found in the gaze latency mean, older adults demonstrated greater gaze latency variability during the vertical saccadic task and in unstable stance (semi tandem base). Larger body sway and head displacement, as compared to young adults, seem to have compromised efficient gaze control in older adults. Two aspects might be considered to explain these results. First, additional attentional resources may have been required to maintain the continuous performance of both postural and saccadic tasks, exceeding the limited attentional capabilities of older adults [22]. Second, some brain areas responsible for generating and controlling eye movements may deterioratedduring the aging process [11,12] contributing to more variable gaze behavior in the vertical direction.

In summary, the present study demonstrates that the semi tandem base of support degrades the postural stability of young and older adults by increasing head displacement, instead of decreasing it, under saccadic conditions, compared to fixation. For both young and older adults, gaze performance was modulated according to the postural and visual task demands. However, greater postural instability seems to deteriorate eye movements in the vertical direction, particularly in older adults. Therefore, future studies should control the possible interactions between postural and task demands and examine how these aspects interfere with the effects of eye movements on postural stabilization in more naturalistic situations.

5. Conclusion

The results of the present study contribute to our understanding of the gaze-posture relationship, demonstrating that greater demands for the postural control system from challenging bases of support interfere in how the eyes are controlled during saccadic eye movements. Moreover, the results indicate that the known decline in the postural control system with aging (i.e. greater postural instability) does not seem to affect the accomplishment of saccadic visual tasks in older adults but increases the variability of eye movements, mainly in the vertical direction and in challenging postural tasks, suggesting some deterioration in the posture-gaze relation with aging. Increased gaze latency variability could also be associated with inaccurate acquisition of useful visual information available in the environment, further degrading the balance of these individuals.

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