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Angle of gaze and optic flow direction modulate body sway

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ABSTRACT

Optic flow is a crucial signal in maintaining postural stability. We sought to investigate whether the activity of postural muscles and body sway was modulated by eye position during the view of radial optic flow stimuli. We manipulated the spatial distribution of dot speed and the fixation point position to simulate specific heading directions combined with different gaze positions. The experiments were performed using stabilometry and surface electromyography (EMG) on 24 right-handed young, healthy volunteers. Center of pressure (COP) signals were analyzed considering antero-posterior and medio-lateral oscillation, COP speed, COP area, and the prevalent direction of oscillation of body sway. We found a significant main effect of body side in all COP parameters, with the right body side showing greater oscillations. The different combinations of optic flow and eye position evoked a non-uniform direction of oscillations in females. The EMG analysis showed a significant main effect for muscle and body side. The results showed that the eye position modulated body sway without changing the activity of principal leg postural muscles, suggesting that the extraretinal input regarding the eye position is a crucial signal that needs to be integrated with perceptual optic flow processing in order to control body sway.

1. Introduction

The optic flow is the visual stimulus provided to the retinae of an observer during self motion (Gibson, 1950). When the observer moves forward fixating his/her final destination, retinal images diverge radially from a single central point, the focus of expansion (FOE), but when the observer directs the gaze outside his/her path the changing image structure caused by the eye movement produces an asymmetrical flow that has been defined as retinal flow (Cutting, 1986; Cutting et al., 1992; Warren and Hannon, 1990).

During locomotion, an observer tends to fixate the FOE of the optic flow field; however, he/she is able to maintain correct heading perception when looking elsewhere. Indeed, the eyes contribute to processing the visual judgments via the orientation of the ground plane (Schreiber et al., 2008) and perceived distance (Harris et al., 2015). Information concerning eye position is therefore crucial in creating the interior representation of extrapersonal space (Guerraz and Bronstein, 2008). The integration of multiple sensory inputs is crucial to perceive both self-motion and motion of a dynamic environment when maintaining body balance. It has been shown that the detection of body sway by means of somatosensory input channels plays a predominant role during quiet stance (Fitzpatrick and McCloskey, 1994). In addition to other mechanisms, eye position depends on the perception that the brain has about the body posture and the head relative to the body. The close relationship between visual system and postural control has been emphasized by Roll and coworkers (Roll et al., 1991; Velay et al., 1994) who showed that the vibratory stimulation of the extraocular muscles corresponded to a precise postural change.

In everyday life, during self-motion, an observer does not always fixate his/her final destination, however he/she is perfectly able to maintain the correct heading but the mechanisms which allow postural adaptation in relation to eye position changes are still to be elucidated. Thus, we sought to investigate whether and how postural stability is influenced by an angle of gaze shift while looking at an optic flow field. Furthermore, in previous studies, we showed that women and men have a different postural control in response to visual stimuli, so we also examined the gender effect (Persiani et al., 2015; Raffi et al., 2014). To study the postural effect of optic flow direction and eye position, we performed an experiment in which we varied the retinal optic flow component on the basis of different eye positions (Regan and Beverley, 1982). Surface EMG and stabilometric responses showed that the integration of eye position signal and optic flow processing contribute to postural balance maintenance.

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2. Methods

Experiments were performed in 24 healthy volunteers, 12 females and 12 males. The females' age ranged from 21 to 27 years (average 22.8), and average height and weight including standard deviation were 166.8 ± 5.7 cm and 57.8 ± 5 kg, respectively. The males' age ranged from 20 to 29 years (average 22.3), and average height and weight were 177.3 ± 5.4 cm and 79.1 ± 11 kg, respectively. All subjects had normal vision. The hand and foot laterality of each subject was assessed by a laterality questionnaire (Elias et al., 1998; Levin et al., 1989) before the beginning of the experiment using the following formula:

$$[(\text{right preference} - \text{left preference})/(\text{right preference} + \text{left preference})] \times 100$$

A positive laterality index was indicative of a right dominance, while a negative index was indicative of a left dominance.

Written informed consent to participate in the study was signed before the beginning of recordings. The experimental protocol was approved by the Institutional Ethic Committee of the University of Bologna. The experiments were performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki.

2.1. Optic flow stimuli

Given that in a previous study we did not find a significant modulatory effect of optic flow direction on muscle activity (Raffi et al., 2014), in the present experiment we only used expanding optic flow. Stimuli were comprised of white dots ($1.3\ \text{cd/m}^2$, size 0.4°) presented full field on a translucent screen that covered $135 \times 107°$ of the visual field. The experiments were performed in the dark. To study the influence of gaze direction during optic flow stimulation, we changed the fixation point (FP) position (size 0.6°) and the speed of the dot pattern. Specifically, the FP was presented in one of three positions along the horizontal axis (in the center, 15° to the left, or 15° to the right) and always concentric with the FOE. The dot speed was accelerated to the left or to the right hemifield to simulate different headings at different angles of gaze (Regan and Beverley, 1982): FP to the left and dots accelerated to the right simulated heading direction to the right while fixation to the left (DirR-FixL, Fig. 1A); FP to the left and dots accelerated to the left simulated both heading and fixation to the left (DirL-FixL, Fig. 1B); FP to the center and dots accelerated to the right simulated heading direction to the right while fixation straight ahead (DirR-FixC, Fig. 1C); FP to the center and dots accelerated to the left simulated heading direction to the left while fixation straight ahead (DirL-FixC, Fig. 1D); FP to the right and dots accelerated to the right simulated heading direction to the right while fixation to the right (DirR-FixR, Fig. 1E); FP to the right and dots accelerated to the left simulated heading direction to the left while fixation to the right (DirL-FixR, Fig. 1F); radial expansion concentric with the FP simulated heading direction and fixation straight ahead (DirC-FixC, Fig. 1G). Random dot motion (Random, Fig. 1H) and static random dots (R_Dot, Fig. 1I) were used as control stimuli, and fixation on a dark screen was used as baseline condition (Baseline, Fig. 1J). Optic flow stimuli were made using Matlab psychophysical toolbox (The Mathworks Inc.).

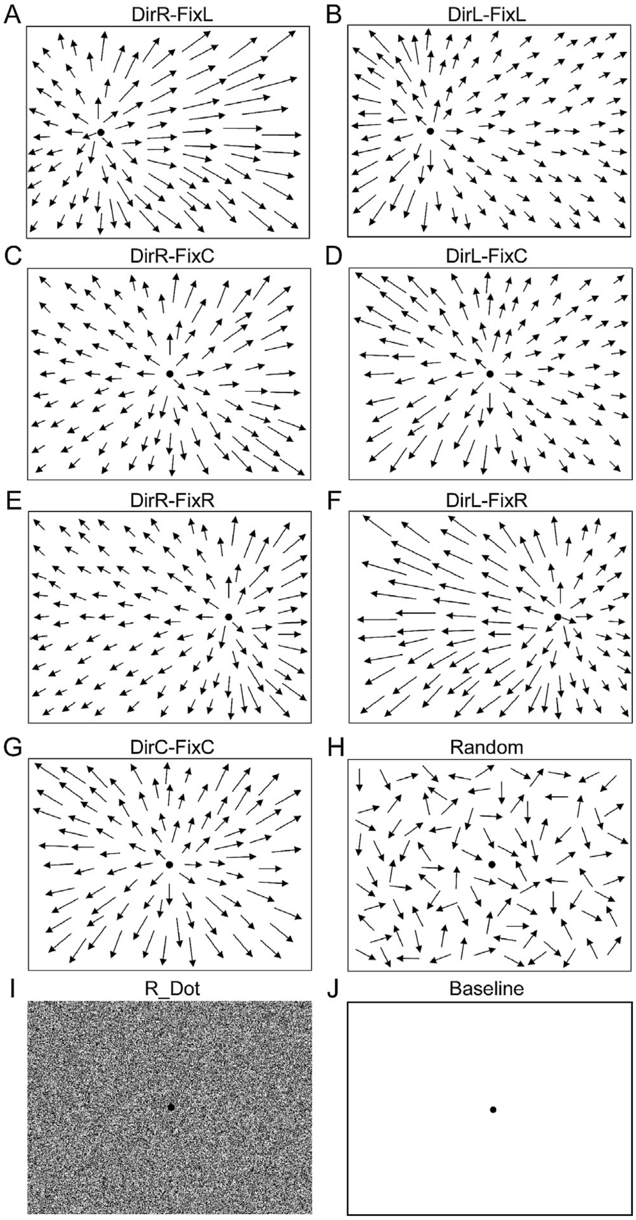

Fig. 1. Stimuli. Arrows represent the velocity vectors of moving dots. A. Fixation point (FP) to the left and dots accelerated to the right (DirR-FixL). B. FP to the left and dots accelerated to the left (DirL-FixL). C. FP to the center and dots accelerated to the right (DirR-FixC). D. FP to the center and dots accelerated to the left (DirL-FixC, D). E. FP to the right and dots accelerated to the right (DirR-FixR). F. FP to the right and dots accelerated to the left (DirL-FixR). G. Radial expansion concentric with the FP (DirC-FixC). H. Random dot motion (Random). I. Static random dots (R_Dot). J. Baseline condition.

2.2. Recordings

The skin of each subject was shaved and cleaned with ethanol before placing the Ag/AgCl disposable electrodes 32×32 mm (RAM apparecchi medicali s.r.l.) used in a bipolar configuration. Electrodes were positioned on the muscular belly of the right tibialis anterior (RTA), left tibialis anterior (LTA), right soleus (RSOL), left soleus (LSOL), right vastus medialis (RVM), left vastus medialis (LVM), right biceps femoris (RBF), left biceps femoris (LBF), right rectus femoris (RRF), left rectus femoris (LRF), right erector spinae (RERS), and left erector spinae (LERS). The reference electrode was placed on the malleolus bone. EMG data were acquired at 1000 Hz by a Pocket EMG (BTS Bioengineering Inc.). We acquired the maximum voluntary contraction (MVC) of each muscle using isometric machines. The peak of the MCV has been used for the normalization of EMG activity.

Stabilometric data were acquired at a sampling rate of 1000 Hz using two Kistler force platforms (Kistler Instrument). Before recordings, the subjects were asked to place a foot on each platform. The FP position on the center of the screen was adjusted