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Reactive Ocular and Balance Control in Immersive Visual Flows: 2D vs. 3D Virtual Stimuli

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Abstract. The control of gaze and balance strongly depend on the processing of visual cues. The aim of this study is to assess the effects of the dynamic 2D and 3D visual inputs on the oculomotor and balance reactive control. Thirteen subjects were immersed in a virtual environment using 10 different 2D/3D visual flow conditions. Analysis of eye movement and postural adjustments shows that 2D and 3D flows induce specific measurable behavioral responses.

Keywords. Reactive control, oculomotor, balance, virtual immersion, visual flow, performance measurement, adaptation.

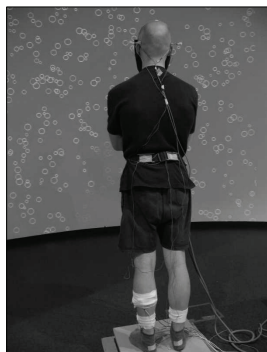
Introduction

The balance adaptation mainly depends on the efficient visual information processing during postural mechanisms. The visuo-postural control quickly integrates dynamic visual cues extracted from images properties to adapt oculomotor and balance commands in order to quickly react to the visual environment. Our previous works have shown the ability to adapt movement and posture to visual changes [1] or visuomotor discordance [2] in virtual visual environments (VEs) with similar neuromotor processes as those use in natural visual environment. However, despite the fact that the automatic oculomotor reaction (*optokinetic nystagmus*) to large 2D visual flow is well established [3], the question about how the automatic ocular and balance strategy use the spatial characteristics of dynamic visual cues is still unclear, mainly concerning the specific effects of moving 2D vs. 3D visual stimuli. The goal of this study is to determine the effects these visual inputs on ocular and balance responses. By analyzing the effects of the moving visual stimulation on motor adjustments, it also questions the sensorimotor flexibility of the initial postural and the online balance adaptation in VEs.

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Methods

Thirteen subjects aged from 22 to 42 participated in the study. The experiment lasted 1 hour per subject. All subjects had normal or corrected vision and were naive to the purpose of the study. Subjects stood within an immersive VE displayed on a 180 degrees curved screen (12x2 meters). They wear stereo-shutter glasses. Virtual visual stimulus consisted in randomly displayed circle-like flow patterns (multi-color patterns on a gray-light background). Ten conditions of stimuli were proposed: right, left, up and down (both in 2D and 3D), forward and backward (in 3D only). Each stimulus was presented during 20 seconds, and was preceded by a preparatory period of 4 seconds without visual stimuli (gray-light full screen). Subject was instructed to keep a comfortable stabilized upright posture during this preparatory period. No instruction was given about the way to behave during the stimulus, except to stand up and keep the arms crossed on the chest. Two randomized sessions of 10 trials per stimulus was



performed, corresponding to 100 trials for each subject. A 10 minutes rest period occurred between sessions. Eye movements was recorded using an electrooculographic system (EOG at 500Hz) to analyze both the horizontal and vertical *optokinetic nystagmus (OKN)* frequency. Postural adjustments was evaluate using a force platform to record (at 500Hz) the ground reaction forces around the medio-lateral (x), antero-posterior (y) and vertical (z) axes at the feet center of pressure. Data processing and analysis focused on the ocular and postural adjustments parameters. A multi-factorial statistical design between *2D/3D* and the visual flow *Directions* conditions was applied to data.

Figure 1. Subject installation in the virtual environment. The subject stands on the force platform in front of the 180° curved full-screen and has to maintain a stabilized balance during the visual flow stimuli.

Results

General comment. No subject mentioned immersive discomfort or motion sickness during or after the experiment. This indicates that neither maladaptive transfer nor after effects was observed despite the one-hour VEs exposure. No unbalance imposing a footstep or to go down from the force platform was observed.

Eye movement. EOG results show that the optokinetic responses to virtual flows are dependent of the visual flow *Direction* in both *2D* and *3D* (figure 2 left). This OKN is automatically triggered from the first flows motions and persists during all the trial. For all *Direction* conditions, the frequency of the ocular responses decreased for *3D*-flow stimulus, and is balanced in forward/backward directions.

Postural adjustment. Force platform results show an initial reactive postural adjustment to counteract the sudden unbalance when the visual flow begins. This starting reaction is followed by on-line postural corrections *Direction*-dependent, to compensate for the balance automatic deviation due to the visual flow. This is clearly visible for antero-posterior postural correction in Up/Down directions in figure 2 (right).

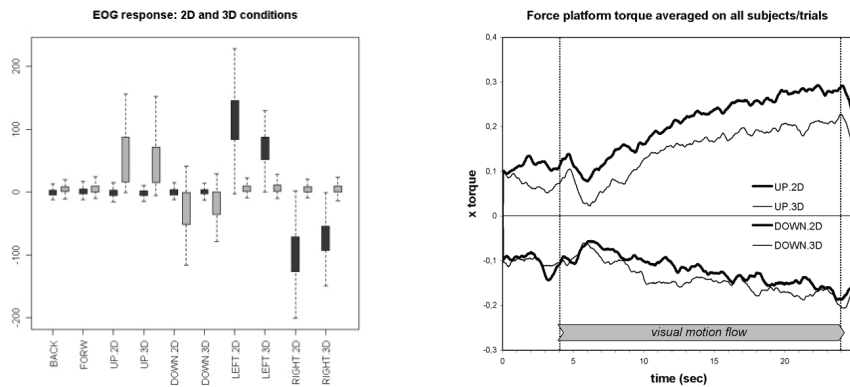


Figure 2. Left: Opto-kinetic nystagmus frequency signed from [left – right] and [up – down] calculation. Boxes represent central quartiles (50%) for horizontal (black) and vertical (grey) visual flows, for 2D and 3D Direction conditions. Right: X-axis torque for Up/Down Directions for 2D/3D flows (in thick and thin line).

Discussion and conclusion

The study shows the oculomotor and balance reactivity to both vertical and horizontal 2D and 3D visual flows. The decrease of optokinetic nystagmus frequency for 3D visual flows could be due to the non-uniform motion and depth-dependant perception for the 3D cues, moving slower for farthest ones. Comparatively, the motion uniformity and the absence of depth ambiguity in 2D visual flows overdrive the optokinetic and visuo-postural behaviors in a more repetitive and predictive way.

For 3D flows, cues velocity is not uniform because of parallax. We suggest that higher complexity of the visual stimuli explain an increased cognitive load and the observed modification of balance control and oculomotor characteristics.

This study proves that 3D flows, closer to natural visual stimulation than 2D ones, induce measurable specific behavioral responses. Finally, we propose that virtual immersion is an appropriate tool for richer immersive protocols in clinical assessment of the visuo-vestibular disorder, and in functional rehabilitation based on visuo-motor and cognitive reactivity.

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