Immersive Virtual Environment for Visuo-Vestibular Therapy: Preliminary Results

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Abstract. The sense of equilibrium aggregates several interacting cues. On vestibular areflexic patients, vision plays a major role. We developed an immersive therapeutic platform, based on 3D opto-kinetic stimulation that enables to tune the difficulty of the balance task by managing the type of optic flow and its speed. The balance adjustments are recorded by a force plate, quantified by the length of the center of pressure trajectory and detection of disequilibrium corrections (leans, compensation step). Preliminary analysis shows that (i) patients report a strong immersion feeling in the motion flow, triggering intense motor response to "fight against fall"; (ii) the ANOVA factorial design shows a significant effect of flow speed, session number and gaze anchor impact. In conclusion, this study shows that 3D immersive stimulation removes essential limits of traditional opto-kinetic stimulators (limited 2D motions and remaining fixed background cues). Moreover, the immersive optic flow stimulation is an efficient tool to induce balance adaptive reactions in vestibular patients. Hence, such a platform appears to be a powerful therapeutic tool for training and relearning of balance control processes.

Keywords. Virtual reality; clinical study; vestibular areflexy; visual immersion; visual-vestibular interaction; balance control.

Introduction

The human balance control system uses several aggregated sensory information (vision, vestibular, proprioception and somatosensory). It is well known [1] that among these sensory interactions, the visual-vestibular one plays a major role on the postural adjustment to visual disturbance. Patients with vestibular deficits show defective balance mechanism, leading to equilibrium troubles, up to fall. The classical therapy involves opto-kinetic stimulation technique that immerses the patient into a visual moving scene, made of a dense field of projected sparkling dots. The projected motion (essentially 2D) is far from the real characteristics of the natural optic flow used by the visual system to control equilibrium.

It has been demonstrated that immersive virtual reality is appropriate to study reactive balance control [2, 3] to question visual-vestibular disorders [4, 5], or as a therapy for balance disorders [6, 7, 8, 9]. We have demonstrated [3] that virtual optic flow using perspective and parallax effects enable to immerse healthy subjects into 3D scenes and provide stronger stimulation of functional visuo-vestibular regulation for balance control than regular 2D projections.

1. Hypothesis of the Study

The aim of the complete study is to measure, for vestibular areflexic patients, the therapeutic effect of the visual optics flows on the postural reaction to stabilize the standing posture. We postulate that virtual optic flow drives visuo-postural adaptation and stimulate the relearning of balance control strategies for vestibular patients. We hypothesize that: (H1) our visual flows do trigger strong adaptive postural adjustments; (H2) those adjustments do interfere with balance control, and impose patients to develop alternative sensory-motor strategies; (H3) varying flow speed and gaze anchoring does change the balance task difficulty.

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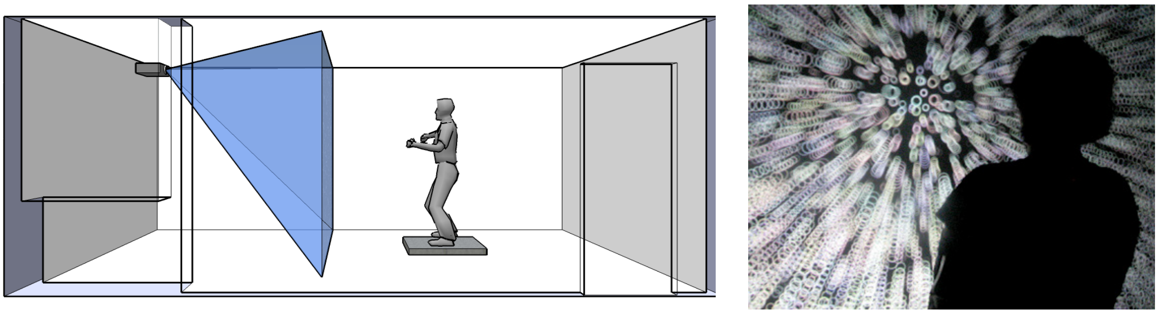

Figure 1. Left: Drawing of the *PIVViiT* immersive platform, set up in an available room of the hospital. The large retro projected screen is at 60 cm of the patient, covering most of his visual field. The patient is standing on a force plate, recording center of pressure trajectories. **Right**: Photo of a patient viewing the forward-moving stimulus.

2. Methodology

The present paper is the result of collaboration between specialists of computer graphics from the *INRIA Grenobles-Alpes* research center, of vestibular disorders from the *Grenoble University Hospital ENT Clinic* and of cognitive neurosciences from the *GIPSA-Lab*.

2.1. Experimental setup

The platform (Figure 1 left) is based on a single PC, a video projector and a large retro projection screen (*3 m × 2.4 m*). The system generates smoothly moving stimuli at 120Hz. A *WiiFit balance board* records the *center of pressure* trajectory (CoP) at foot level at 100 Hz, with a precision > *0.1 mm*. For security, we added lateral supports to lean in case of disequilibrium.

2.2. Subjects

Nine volunteer patients (aged from 44 to 61, mean 52, 3 males and 6 females) participated in the clinical study. All of them are impaired by unilateral vestibular areflexia (consequences of peripheral vestibular disorders: e.g. neurinoma or vestibular neurectomy), and where screened by the *dizziness handicap inventory* test (DHI-test) [10]. The protocol was approved by the French ethical medical research committee (CPP). This paper presents preliminary results.

2.3. Protocol

Subjects stand upright, on the balance recording force-plate, in front of a large immersive screen (see Figure 1). Moving visual flows are projected, and the subjects have to stabilize their balance, in reaction to the visual perturbation.

The complete study consists of ten immersive sessions: the first four with a visual anchoring target (a visual target visible or not at the screen center), the last four without. Each session consists of 6 identical blocks of trials with increasing speed of the visual flow. Each block is composed of 8 stimuli (upon the five: up-, down-, clock-, counter-clock- and forward-moving) in random order, lasting 15 sec, with 5 sec preparatory and 5 sec recovery periods. A 5 minutes resting period is imposed between blocks to alleviate fatigue impact. The factorial design is Anchor(2)×Session(4)×Speed(6)×Stimuli(5). Qualitative results were obtained by questionnaires.

2.4. Data Analysis

To compute the CoP trajectories, we use the four weight sensors at the corners of the force-plate that give the barycentric coordinates of the CoP. Force-plate data is filtered with a Butterworth low pass filter, with a cut-off frequency of 10Hz. To detect subject disequilibrium, we quantify lateral leans or compensatory step by computing the integral of body weight losses ratio (when greater than 5%). We used the *R* statistic software to test the hypothesis that CoP trajectory's length and disequilibrium indicator are related to the increasing speed of the flow, the session number, and the gaze anchor condition.

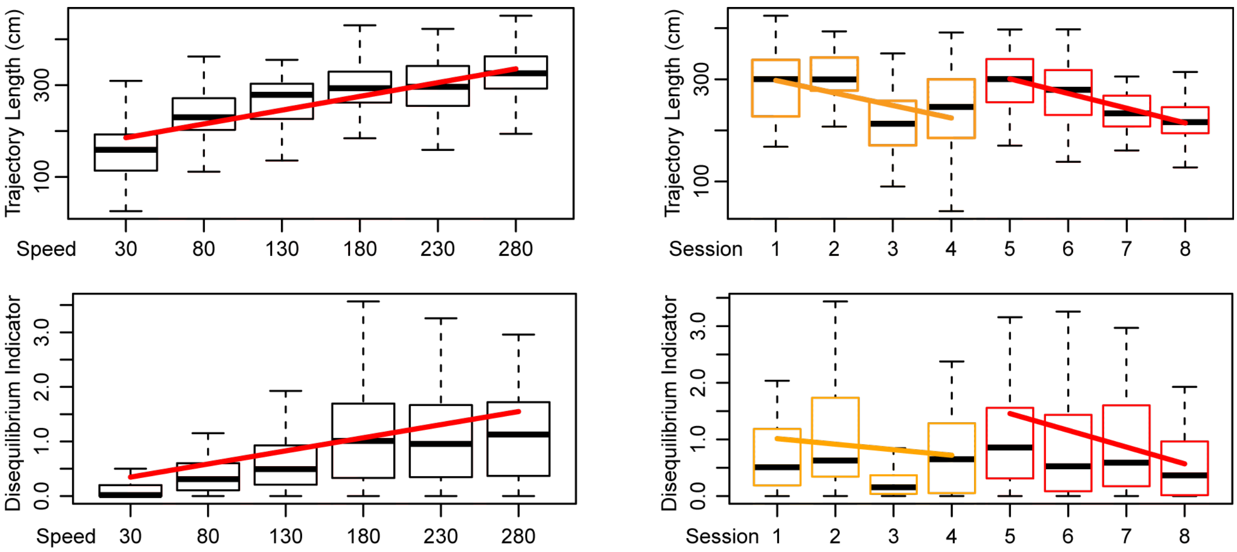

Figure 2. Results for a representative patient. **Top**: length of the center of pressure trajectory. **Bottom**: disequilibrium indicator, measured as weight losses ratio (due to lean on lateral supports or compensatory steps off the platform) integrated over time. **Left**: plotted against speeds. **Right**: plotted against sessions. The first four with the visual anchor (fixed target at screen center), the last four without. Boxes show medians, first and third quartiles, the whiskers represent 5% and 95% percentiles.

3. Results

Both qualitative and quantitative results demonstrated a real functional effect of the virtual immersion on balance control and self-confidence.

3.1. Qualitative results

All patient reported strong motion illusions that generated intense muscular efforts to maintain the upright standing position using “fight against fall”. Most patients consider the 3D stimuli are more involving than traditional opto-kinetic, which could be explained by perspective and parallax [3]. Most patients also reported a self-confidence gain from the first sessions, up to resuming balance-dependent everyday life activities (gardening, housekeeping or cycling).

3.2. Length of the center-of-pressure trajectory

The ANOVA of CoP trajectory for a representative patient demonstrates that the three factors have significant effects. The increasing *speed of the optic flow* increases the CoP trajectory length from 185 cm to 336 cm, ($F(1,369)=258.2$, $p<0.001$), see Figure 2 top-left. *Repeating sessions* decrease CoP trajectory length by 73 cm for 4 sessions with visual anchor ($F(1,187)=27.7$, $p<0.001$), and by 86 cm for the 4 sessions without visual anchor ($F(1,180)=76.7$, $p < 0.001$), see Figure 2 top-right. The removal of the *visual anchor* adds an additional gap to the CoP trajectory length of 107 cm.

3.3. Disequilibrium indicator

The ANOVA of our disequilibrium indicator shows similar correlations to the same three factors. Increasing *speed of the visual flow* from 30 to 280 increases the disequilibrium indicator from 0.145 to 0.453 ($F(1,456)=9.5$, $p=0.002$), see Figure 2 bottom-left. *Repeating sessions* with visual anchor decrease the indicator by 0.171 ($F(1,223)=9.2$, $p=0.003$), by 0.162 for the 4 sessions without anchoring ($F(1,231)=11.2$, $p < 0.001$), with an additional gap of 0.307 added by *anchorage* removal, see Figure 2 bottom-right.

4. Conclusions

In this study, we demonstrated the efficiency of our virtual immersive platform to trig balance perturbations using virtual optic flow which impose postural reactions to vestibular patients (H1). Patients reported that those perturbations have similar effects than those experienced in standard opto-kinetic protocols. We also demonstrate a habituation-like process along sessions with significant reduction of the postural adjustments (H2). Moreover, correlations demonstrate that difficulty of the exercises can be tuned (H3): Both the optic flow speed and the visual anchor presence do have a significant effect on postural reactions, as measured by the decrease of the length of the CoP trajectory and of the disequilibrium indicator.

Finally, this study shows that virtual 3D immersive systems are a valuable improvement to standard projection systems for opto-kinetic therapy. Moreover, recording patient's scores along sessions provides an objective measure of reduction of balance disorder and of strategies' effectiveness developed by the patient to evaluate and circumvent its visuo-vestibular disability.

Acknowledgments

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