Immersive Virtual Environment for Visuo-Vestibular Therapy: Preliminary Results

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An Immersive Virtual Environment for Visuo-Vestibular Therapy

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Abstract. The sense of equilibrium aggregates several interacting cues. On patients with vestibular loss, vision plays a major role. In this study, the goal is to propose a new immersive therapy based on 3D opto-kinetic stimulation. We propose to demonstrate that 3D monoscopic optical flows is an efficient tool to stimulate adaptive postural adjustment. We developed an immersive therapeutic platform that enables to tune the difficulty of the balance task by managing optic flow speed and gaze anchoring. **METHODOLOGY**: the immersive sessions proposed to vestibular areflexic patients are composed of a repetition of dynamic optic flows, with varying speed and presence or not of a gaze anchor. The balance adjustments are recorded by a force plate, and quantified by the length of the center of pressure trajectory. **RESULTS**: Preliminary analysis shows that (i) Patients report a strong immersion felling in the motion flow, triggering more intense motor response to fight against fall than in standard opto-kinetic protocols. (ii) An ANOVA factorial design shows a significant effect of flow speed, session number and gaze anchor impact. **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; vestibular areflexy; visual immersion; visual-vestibular interaction; balance control.

1. 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

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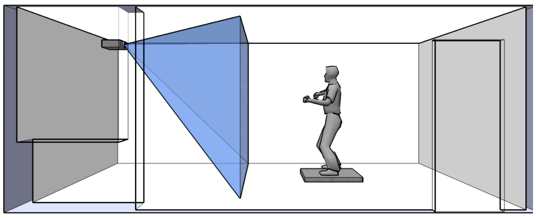

Figure 1. The immersive platform, installed in an available room of the hospital. The large retro projected screen is at 60 cm of the patient, covering most of its visual field. The patient is standing on a force plate, recording CoP.

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.

Using virtual reality (VR), it has been demonstrated that immersion is appropriate to study reactive balance control [2,3] and question visual-vestibular disorders [4,5]. 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.

2. Hypothesis of the Study

The aim of this experiment was to measure the therapeutic effect for vestibular areflexic patients 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.

3. Methods

The platform (Figure 1) is based on a single PC, a video projector and a large retro projection screen ($3\ m \times 2.4\ m$). The system generates smoothly moving stimuli at 120Hz. A *WiiFit balance board* records center of pressure kinematic at foot level (CoP) at 200 Hz, with a precision of $\approx 0.1\ mm$. Data is filtered with a Butterworth low pass filter at 10Hz, from which the length of the CoP trajectory is calculated. We used the *R* statistic software to test the hypothesis that CoP length trajectory is related to the increasing speed of the flow, the session number, and the gaze anchor condition (a visual target visible or not at the screen center).

The factorial design was Speed(6) $\times$ Session(8) $\times$ Anchor(2). Patients participate to ten immersive sessions, four with the anchoring, four without, then two control sessions with and without anchoring. Each session consists of 6 identical

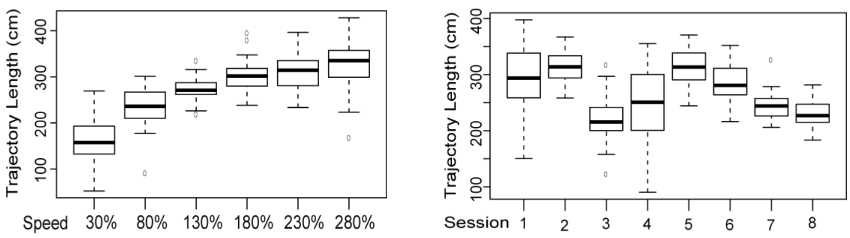

Figure 2. **Left**: Length of the CoP trajectory plotted against speeds, for a representative patient, with all stimuli and sessions. **Right**: Length of the CoP trajectory plotted against sessions. The first four with the visual anchor (fixed target at screen center), the three last without.

blocks with increasing speed. Each block is composed of 8 stimuli always in the same pseudo-random order. Each stimulus lasts 15 s, with 5 s preparatory and 5 s recover periods. A 5 mn resting period is imposed between blocks to alleviate fatigue impact. 16 patients with unilateral vestibular areflexy are included in this clinic study, with a mean age of 51.

4. Results

All patient reported strong motion illusions that generated intense muscular efforts to maintain the upright standing using fight against fall. Most patients consider the stimuli are more involving than traditional opto-kinetic. They explain that by the realistic looking of perspective and parallax in the 3D flow.

The ANOVA analysis of the preliminary data for a representative patient shows a strong increase of the CoP trajectory length correlated to the speed of the optic flow (from 225 cm to 375 cm, $p < 0.001$, see Figure 3 left) and to the removal of the visual anchor (102 cm, $p < 0.001$), but a decrease with session repetition (26 cm, $p < 0.001$, see Figure 3 right). The F-statistic is $F(3, 368) = 105$ (the reference being 1.65 for a 95% confidence interval).

5. 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 patient (H1). Those perturbations are reported stronger than ones experienced in standard opto-kinetic protocols. We also demonstrate a habituation-like process along sessions with significant reduction of the postural adjustments (H2). Moreover, correlation between the optic flow speed and anchor presence to the length of the CoP trajectory demonstrates that difficulty of the exercises can be tuned (H3).

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

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