Rapid Communication

A Theory for Treating Dizziness Due to Optical Flow (Visual Vertigo)

CHIH-PEI CHANG, Ph.D.^{1,2} and TIMOTHY C. HAIN, M.D.³

ABSTRACT

Virtual reality (VR) training that provides optic flow stimuli and visuo-vestibular conflict has been suggested as a way to treat patients with inappropriate visual dependence (sometimes called visual vertigo even though spinning sensation is often absent). We propose a simple framework based on a hypothesis that the degree of dizziness depends on the offsetting between the destabilizing effect of optical flow and the stabilizing effect provided by stationary objects in the visual field. We define a total destabilizing potential (TDP), which is the ratio of the destabilizing effect over the stabilizing effect. The approach is to gradually increase the person's tolerance of a higher TDP through exercises that may be described as an inverse of the traditional gaze stabilization exercises for vestibular rehabilitation. The theory proposes that an important ingredient in VR training is to incorporate a stationary anchor to help synchronizing the visual sensory to vestibular and somatosensory inputs. The scheme can also be adopted economically with computer-generated imagery or used by individuals in certain everyday environments.

INTRODUCTION

OUR HYPOTHESIS IS DERIVED from a patient's case history. The patient, the first author (CPC), was then a 59-year-old male professor who experienced an attack of benign paroxysmal positional vertigo (BPPV) in October 2004. The BPPV was cured through one session of Canalith repositioning procedure, but visually induced space-motion discomfort^{1,2} continued for 18 months almost without break. The dizziness affected his daily life significantly. He was unable to lecture in front of class or to view slide presentations from close distance. He also had trouble attending meetings, scrolling on computer screens, driving, and inside grocery

stores, buffet restaurants, airport terminals, and rooms with colorful or complex decorations. The discomfort was exacerbated by severe neck and shoulder soreness. Dizziness also often struck when he lowered his head to sign credit cards or looked at a keyboard; when he felt his eyeballs locked to the looking-down position and had to struggle to lift his head back to the normal level.

Starting in March 2005, he kept a daily log of a subjective dizziness index. The highest and lowest daytime values and a usually minimum night value, as well as notes on environments that might affect the dizziness, were recorded. A consistent experience that eventually emerged suggests that when the visual environment was surrounded by large stationary struc-

¹Graduate School of Engineering and Applied Sciences, Naval Postgraduate School Code MR/Cp, Monterey, California.

²Department of Atmospheric Sciences, National Taiwan University, Taipei, Taiwan, Republic of China.

³Departments of Neurology, Otolaryngology, and Physical Therapy and Human Movement Science, Feinberg School of Medicine, Northwestern University, Chicago, Illinois.

FIG. 1. Schematic example to show the contrasts of two background scenarios with the same optical perturbation. The Destabilizing Potential as introduced later in the text is higher for the **left panel** and lower for the **right panel**.

tures such as close-by tall buildings, the discomfort tended to be less than in areas surrounded by lower buildings. This difference became larger when the scene became busier due to the presence of people or objects (Figs. 1 and 2). After the patient participated in a VR experiment directed by Dr. Emily Keshner at the Rehabilitation Institute of Chicago in December

2005, and motivated by the suggestion² that optic flow stimuli and visuo-vestibular conflict may help treatments, he attempted a stimulation exercise entailing trying to watch as long as possible fast-moving trains from the rear seat inside a parked car. He tried to use the sight of the car's stationary front window frame to resist the disturbing sight of the moving train. He

FIG. 2. Another example of high Disturbance Potential (**left**) and low Disturbance Potential (**right**). The complex colors on the table are the source of perturbations.

FIG. 3. Daily dizziness index of the patient, <1.0 indicates mild dizziness, 3.0 indicates severe dizziness including oscillopsia-like vision of jerky moving objects. Thick lines are smoother versions of daily means.

also practiced the train-viewing exercise at subway stations in which the stationary platforms provided the anchoring effect that countered the visual perturbation from the moving train. The dizziness frequency and intensity both subsided by late January 2006 and were practically gone in late March (Fig. 3).

HYPOTHESIS

The history of this case suggested that dizziness due to optical flow may be inversely correlated with the presence of stationary, noncomplex images in the field of view. If we define a destabilizing potential (DP):

$$DP = D/S,$$

where D is the destabilizing effect and S is the stabilizing effect, then a larger DP will be associated with more frequent or intense dizziness. The next task is to define D and S . Figure 4 (left panel) is a schematic diagram depicting an *aiming* area A embedded in a *background* environmental area B , like a picture-in-picture TV. We propose that D and S are functions of both relative visual area of A and B and their velocities. If the aiming area contains optical flow such as that produced by a fast-moving train, an approximation is to let $D = A \times f(V)$ and $S = B$, where V is the velocity of the optical flow. In general, V is a 3D velocity field that may also vary with time, but for the simplest case of linear constant velocity, $f(V)$ will be represented by a constant speed,

FIG. 4. **Left panel:** Parameters determining the Destabilizing Potential. Colored area indicates visual perturbation. **Right panel:** Gaze stabilization for vestibular rehabilitation. Colored area indicates visual perturbation.

$$DP = D/S = A/B \times V.$$

In the examples given in figs. 1 and 2, B is near zero in the left panels and large in the right panels, so even when V is small as is in Fig. 2, the left panel still has a large DP . The velocity V cannot be absolutely zero due to miniature head movements, and the different colors of the objects induce a complex processing that slows down the stabilization of vision leading to continued eye movements.

One may further consider, based on empirical and heuristic logics, that the total effect on a person with optical flow-induced dizziness is DP integrated over the duration of exposure:

$$TDP = \int D/S \, dt = t \times A/B \times V$$

for constant A , B and V .

It is obvious that a person will not suffer visual vertigo if either t or A or V is 0.

To develop a therapy, the practitioner would subject the patient to a lower value of TDP initially, which may be determined subjectively by the tolerance of the patient or by equipment such as dynamic posturography. The TDP can then be increased with the progress of the therapy by increasing either t , A/B , or V . For the train-viewing case, the patient can only control t . In a laboratory or clinic environment, t , A/B , and V can all be controlled. One example is to expand A in Figure 4 (left panel) as the therapy progresses.

This proposed scheme is very different from the gaze stabilization scheme used in the traditional therapy for vestibular rehabilitation.³ In the latter, the aiming area A is a small single object with slow relative motion such that the eyes can be trained to stay focused on the object, while the background environment is typically busy with fast optical flow or complex patterns (Fig. 4 [right panel]). The patient is being trained to stay with A while ignoring B . In the proposed scheme, A is the fast-moving optical flow and B is the stationary and noncomplex background. Not only does the patient not ignore B , he or she uses B as an anchor to overcome the destabilizing effect from the gazing at A .

DISCUSSION

The proposed theoretical framework is based on one case only, but its approach resembles previous studies of optokinetic training⁴ in which patients are exposed to repeated optokinetic stimulation. Our hypothesis differs in that we formally consider both

background and foreground as well as their relative velocities. It can also be compared with the gradual increase of height in VR treatment of people with acrophobia.^{5,6} People with acrophobia experience difficulty as the increased distance from ground causes them to lose reference in space, which is equivalent to a large A/B ratio for those with optical flow-induced dizziness. The gradual increase of height is equivalent to a gradual increase of the area A in Figure 4 (left panel).

Reliably measuring dizziness is a significant problem in diagnosing, monitoring, and treating inappropriate visual dependence due to optical flow. The destabilizing potential DP or TDP proposed here may be used as a parameter to gauge consistently the degree of visual dependence. For example, an image of Figure 4 (left panel) may be incorporated into a posturography system with varying A/B ratio or V velocity to assess the degree of visual dependence quantitatively. This can facilitate monitoring the progress and the effectiveness of treatments.

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Address reprint requests to:
 Dr. Chih-Pei Chang
 Naval Postgraduate School
 Code MR/Cp
 Monterey, CA 93943-5114

E-mail: cpchang@nps.edu