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Towards Virtual Reality Stimulation in Force Platform Posturography

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Abstract

We developed a stimulation technique on the basis of virtual reality methods for balance investigation performed in balance laboratories of otorhinolaryngological clinics and institutes of occupational health. Such a stimulation technique is greatly progressive in the sense that by creating virtual moving views and "virtual worlds" inside which the subject is located it is possible to make effective stimuli that would be very difficult or even impossible to set in any real environment. We tested our system on healthy subjects and found out that this kind of virtual reality stimulation system is very useful for balance analysis.

Keywords:

Virtual reality; Signal analysis; Force platform; Human's balance; Otoneurology

Introduction

In investigations of the subspecialty of otology balance tests are performed on patients suffering from otoneurological diseases. A typical symptom of these diseases is vertigo. An important balance test is performed with a force platform that measures the swaying of a subject standing freely on the platform keeping her balance. The physical stability of the subject is slightly affected with appropriate stimuli. Of course, at the same time, any possible fall is prevented. In fact, falling over is an ordinary cause of death, particularly for the elderly. That is why, in addition to otoneurology, balance tests and research are vital to occupational health studies, where safer working environments are developed. For these reasons, the force platform devices and software were designed and built to measure and analyze subjects' balance (Figure 1). An interesting type of stimulus in such a measurement is to affect the subject's visual field when she looks at movements and other physical events in the surroundings. Earlier such stimuli were arranged, e.g., by reflecting lights or corresponding views on a screen in front of the subject who stands on the force platform.

Virtual reality techniques offer an outstanding, completely new means to create many-sided stimuli that can be modified nearly without any limit. Modern computers are fast enough to create natural-like views that are changed in the course of time as it might happen in the real, physical surroundings. It is even possible to take into account the subject's gestures and movements on the platform and let them affect occurrences "in the virtual world", i.e. views seen by the subject.

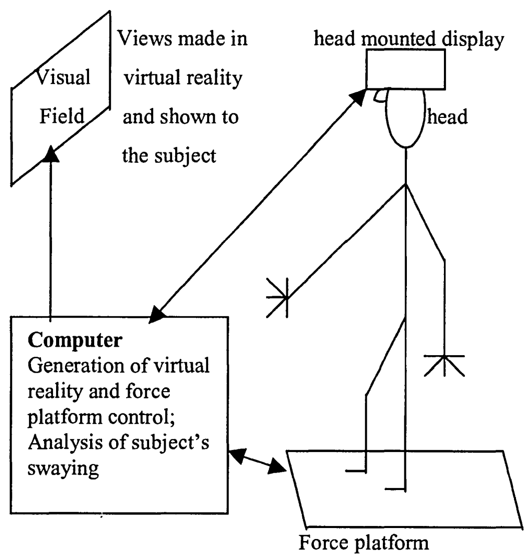

Figure 1. – The subject looks at virtual reality events through the head mounted display. The microcomputer creates the stimulation inside the virtual reality, measures the subject's body swaying and performs signal analysis task on the measurements

We experimented with virtual views shown on the displays of the head mounted display (HMD) worn by a test subject. A few suitable stimulation protocols were designed such as twisting tunnels that created illusion of moving at a high velocity in a tunnel. The force platform then measures the body swaying of the subject standing on the platform. Swaying is measured as movements of the center point of force in the antero-posterior and lateral directions (Figure 1).

In the recent years several virtual reality applications have emerged in medicine like [1-4]. Obviously, in otoneurology no virtual reality application has been designed. Perhaps the only publication is [5] that considered the idea of using virtual reality methods in the rehabilitation of patients suffering from balance disorders - an excellent idea, and also one of our later aims. In any case, this investigation describes the very first trial in order to construct a measurement system combining the force platform with virtual reality stimulation.

As our preliminary experiment we measured a group of healthy subjects. Their balance was clearly affected by the virtual reality stimulation. This is a very promising result, since the group consisted of only young healthy persons. It is also the beginning of collecting normal material. It is quite obvious that for patients the stimuli designed will be able to separate normal cases from those suffering from some vertiginous diseases.

Materials and Methods

We measured the effect of virtual reality visual stimulation on the balance of 30 test subjects. The test group consisted of 4 women and 26 men, aged from 21 to 35 years. The subjects' response to stimulation was measured using a standard force platform [6] commonly used in posturography (the study of balance). In the test the subject stands on a disk-shaped platform, which uses three sensors to determine the center point of force (CPF) exerted by the subject on the platform. Usually, the distance traveled by the center point of force during a certain period of time is used in the analysis. The distance (quantity cm) traveled by the CPF in the course of each measurement was calculated according to the commonly employed way [6] for this purpose:

$$tracelength = \sum_{i=1}^{n} \sqrt{(x_i - x_{i-1})^2 + (y_i - y_{i-1})^2} \qquad (1)$$

In the formula variable x corresponds to the lateral direction and y to the fore-aft direction. When the signals were sampled at the frequency of 50 Hz, and the measurements lasted for 70 seconds, each measurement comprised of n equal to 3500 samples.

Traditional measurements consist of measuring the body swaying of the subject with eyes open and closed and with and without vibratory stimulation of the calf muscles. This is done to measure the dependence of balance on muscular and visual feedback.

The subjects were asked to stand on the platform with their hands crossed on their chest, concentrate on the virtual environment and look forward. During the tests the subjects were shown two different virtual environments: a static environment, in which nothing happens, and a tunnel environment, where the subject travels in a twisting tunnel. The tests lasted 70 seconds per stimulus and the first 10 seconds of the measurements were omitted from the analysis to allow enough time for adaptation to a new environment.

In the test a subject was exposed to an immersive virtual reality environment generated with a microcomputer and displayed using a head mounted display. The latter one comprises a small monitor for each eye and a head orientation tracker. Via the two monitors depth perception is possible and the head orientation tracker provides sensory signals from head movements.

The virtual environments were implemented on an Intergraph workstation equipped with a Virtual Research V8 head mounted display, an Intense3D WildCat 4000 graphics accelerator and an InterSense IS-300 head orientation tracker. The software was implemented in C++ using WorldToolKit from Sense8.

The stimuli were intentionally kept simple. This enabled us to achieve a constant frame rate of 60 frames (images) per second, which is high enough for motion to appear smooth [7]. This was also the maximum frame rate achievable due to hardware limitations on the V8 head mounted display. In some cases plain OpenGL was used to optimize rendering speed. The diagonal viewing angle of the eye monitors was 60° and the monitor resolution 640 times 480 pixels.

The virtual environment in the static stimulus consisted of a world with a floor and two solid cubes in different orientations and different distances from the subject. A frame from the stimulus can be seen in Figure 2. Both of the cubes are in the visual field of the subject and are used for the perception of depth. During the stimulation the world reacts normally to the subject's head movements and no other events occur in the environment during the whole stimulation. This stimulus was also used to adjust the head mounted display settings prior to the measurements.

During the tunnel stimulus the subject is moving inside a twisting tunnel. The tunnel follows a parametric curve, which consists of two summed sine waves in both x and y directions and a linear function in the z direction. The sine waves are not harmonically related, so there is no pattern of movement that could be learned by the subject. The stimulus is shown in Figure 3.

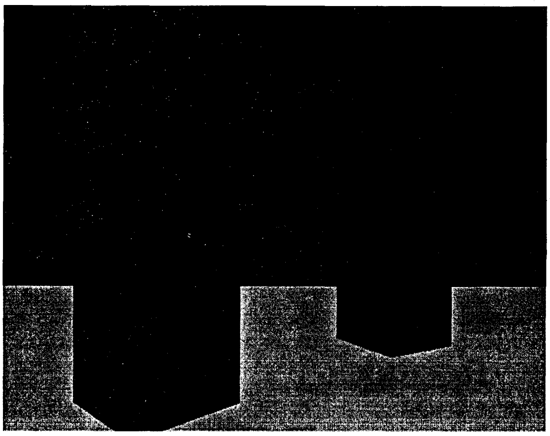

Figure 2. - The static stimulus.

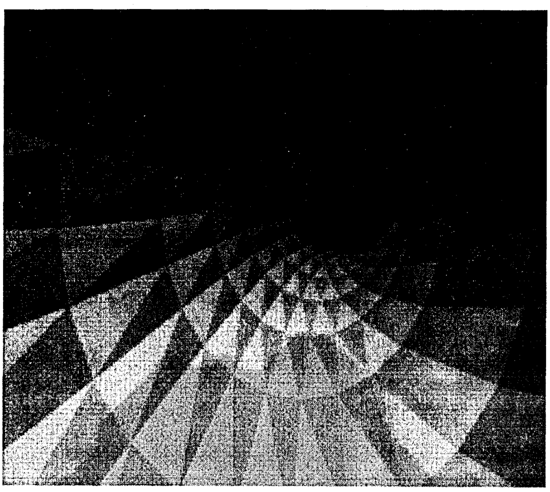

Figure 3. – The tunnel stimulus.

The tunnel was implemented in a time ring, where the sections of the tunnel behind the subject were removed and new sections added before the subject. This way at most one new section had to be generated per frame. A new section was generated by transforming a circular cross-section so that the center of the cross-section is a point on the curve and the normal of the cross-section is parallel to the tangent of the curve at that point. The transformed cross-sections were then joined with polygons.

Results

For the analysis we calculated the length of the trace of the center point of force, which is one of the most commonly used parameters in force platform posturography [6]. A segment of a CPF trace can be seen in Figure 4. Of the 70 s measurements, the segment of the last 60 s was used. The trace length was in the range of 113.2 to 305.3 cm in the case of the static stimulus and 126.8 to 484.1 cm in the case of the tunnel stimulus. The trace lengths measured in this test cannot directly be compared to the normal trace length measurements, since the subjects used a head mounted display, which affects balance (the weight of the head mounted display is 1 kg).

A comparison of trace lengths measured from a subject during the two different stimuli showed that the trace length was 1.34 times longer on the average with a standard deviation of 0.28 in the case of the tunnel stimulus (Table 1). In a few cases where the trace length was shorter while using the tunnel stimulus it is likely that the subjects were not focusing on the stimulus.

Of the 30 measurements 27 were used in this analysis; in one of the three omitted measurements the subject needed support to stay on the platform during the tunnel stimulus and in the other two the subjects adjusted the head mounted display during the tests. In all the omitted tests the trace length more than tripled in the case of the tunnel stimulus.

Table 1 – Trace length measurements (n=27).

Trace length	Mean	St.dev.	Min	Max
Static [cm]	192.1	55.3	113.2	305.3
Tunnel [cm]	258.1	93.8	126.8	484.1
Tunnel/Static	1.34	0.28	0.92	1.95

Visual observation of the subjects during the tests suggests that the control of balance anticipates the movement of the tunnel. The swaying of the subjects was visibly more regular in the case of the tunnel stimulus than in the case of the static stimulus.

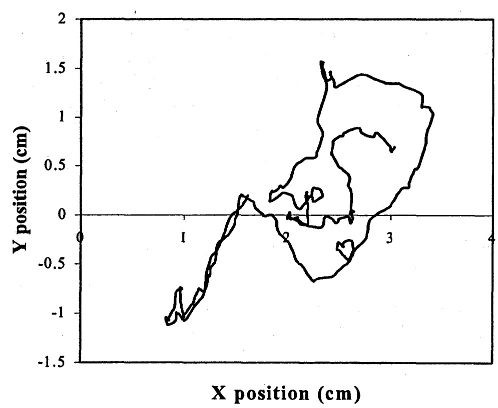

Figure 4. – A segment of a CPF trace.

Discussion and Conclusion

The 60° field of vision achievable using the head mounted display probably affects the results, since the peripheral vision is important in the control of balance. Furthermore, there is no way to reliably determine if the subject is concentrating on the visual stimulation or consciously shutting it out. This might be countered by giving the subject tasks to perform in the virtual environment, but any extra movement will complicate the analysis of the results. Still, our study shows that using the virtual reality stimulation to cause changes in balance is feasible.

In the future we will look into more precise methods of analyzing the measurements, for instance to find out how and why a certain stimulus affects balance. Research into more effective and precise stimuli is also needed. Further tests are also needed to determine that these tests can reliably differentiate between normal subjects and subjects with balance disorders.

We will design our measurement and analysis to also involve head movements. We also have two trackers that can be used to record the movement of the arms. Furthermore, with two datagloves it is possible to register how a subject moves the fingers. One useful possibility, that we are going to explore, is the recording of eye movements with two small video cameras. Perhaps it is even possible to get feedback from these measurements in order to control occurrences in the virtual reality scenery. In any case, there are abundant possibilities to further develop our virtual reality system to create more and more realistic virtual environments appropriate for balance measurements.

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References

[1] Haubner M, Krapichler C, Lösch A, Englmeier K-H, and van Eimeren W. Virtual reality in medicine-computer graphics and interaction techniques. *IEEE Trans Inform Technol Biomed.* 1997: 1(1): 61-71.

[2] Riva G. Virtual environments in neuroscience. *IEEE Trans Inform Technol Biomed.* 1998: 2(4): 275-81.

[3] Krapichler C, Haubner M, Engelbrech R, and Englmeier K-H. VR interaction techniques for medical imaging applications. *Comput Methods Progr Biomed.* 1998: 56: 65-74.

[4] Ramaswamy K and Higgins WE. Interactive dynamic navigation for virtual endoscopy. *Comput Biol Med.* 1999: 29: 303-31.

[5] Viirre E. Virtual reality and the vestibular apparatus. *IEEE Eng Med Biol.* 1996: March/April: 41-3.

[6] Aalto H. *Force Platform Posturography, Methodological Aspects and Practical Applications.* Academic Dissertation, Dept. Physics, Fac. Natural Sci., Univ. Helsinki, Finland. 1997.

[7] Möller T and Haines E. *Real-Time Rendering.* Natick, MA: A. K. Peters, 1999.

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