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Virtual Reality Stimuli for Force Platform Posturography

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Abstract. People relying much on vision in the control of posture are known to have an elevated risk of falling. Dependence on visual control is an important parameter in the diagnosis of balance disorders. We have previously shown that virtual reality methods can be used to produce visual stimuli that affect balance, but suitable stimuli need to be found. In this study the effect of six different virtual reality stimuli on the balance of 22 healthy test subjects was evaluated using force platform posturography. According to the tests two of the stimuli have a significant effect on balance.

1. Introduction

Balance disorders are common especially among the elderly. Different tests of balance are used in the diagnosis of the disorders. Force platform posturography used in this study is a common method used in the evaluation of balance, where the subject stands on platform that measures swaying.

The role of visual control in human posture increases with age. High dependence on vision may indicate abnormal functioning of the postural control system. Therefore the dependence on visual control is an important parameter when evaluating the performance of postural control; the effect of vision on balance has been reported in e.g. [2]. Virtual reality methods are a flexible way of generating different visual stimuli that can be used to measure dependence on vision. We have previously shown that it is possible to use these methods to affect balance [3].

One problem in the use of virtual reality methods in the study of balance is that the number of possible stimuli is practically infinite but technical limitations must be taken into account. For example straightforward replication of mechanical stimulation methods in virtual reality may lead to suboptimal results.

We investigated the use of different virtual reality environments as visual stimuli in force platform posturography with several test subjects. The amount of swaying under stimulation was measured and two of the stimuli were found to have a clear destabilizing effect on the balance of the test subjects. The test setup can be seen in figure 1.

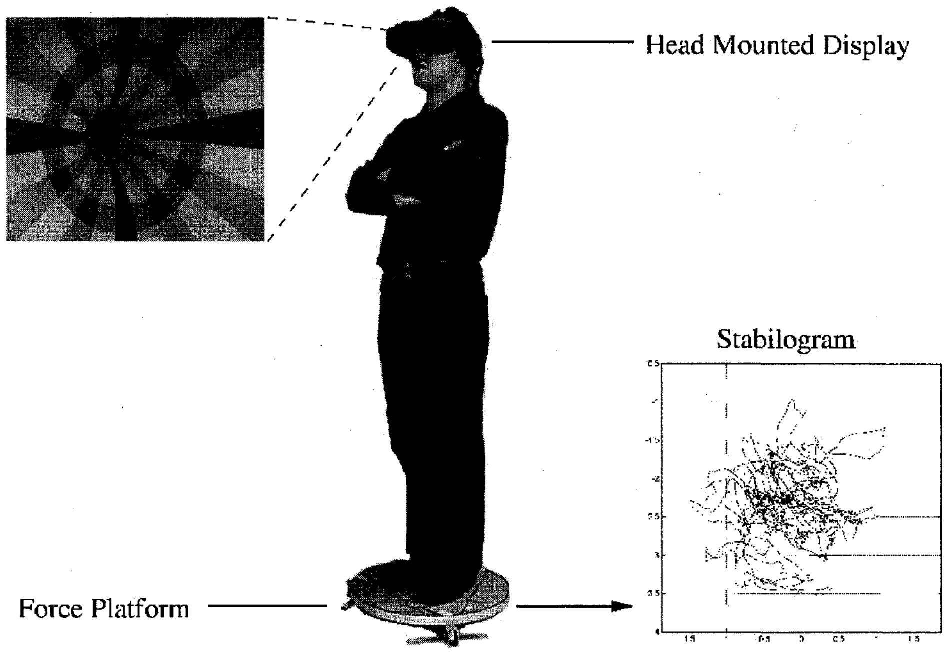

Figure 1: The test setup – the subject is viewing the virtual reality stimulus using the head mounted display and the stabilogram is obtained from the force platform

2. Materials and Methods

We measured the effect of virtual reality stimulation on the balance of 22 test subjects. The subjects' balance was also evaluated without virtual reality stimulation measuring sway with eyes open, eyes closed and wearing the head mounted display without stimulus. The test group consisted of 2 women and 20 men, aged from 22 to 45 years. Most of the test group were between 22 and 30 years and all of them were assumed healthy. None of the subjects had suffered from a diagnosed balance disorder.

Response to stimulation was measured with a standard force platform using three vertical force transducers. In the test a subject stands on the platform in an upright position, with heels together, feet at a small angle and hands locked at the chest.

For the analysis of sway we used the traditional method of computing the center point of force (CPF) exerted by the subject on the platform at each time instant and analyzing its movements. The CPF contains information about the subject's center of gravity and the forces acting on it. The signal consisting of the motion of the CPF is called a *stabilogram* [1].

The data from the platform was sampled with a resolution of 16 bits and sampling rate of 50 Hz. The raw data was filtered with a linear phase FIR filter with a cutoff frequency of 5 Hz to remove noise and then the stabilogram was computed. The motion of the CPF was analyzed using the average CPF velocity v, which can be computed from the sampling rate f_s and the CPF measurements $\mathbf{x}(i)$, $i = 0, \ldots, N-1$ using the formula

$$v = \frac{f_s}{N-1} \sum_{i=1}^{N-1} d(\mathbf{x}(i), \mathbf{x}(i-1)),$$

where d is the Euclidean distance.

The measurements were conducted in about 30 minutes per subject and the stimuli were applied in the same order. There were periods of rest between stimuli to reduce the effect of fatigue. We used six different virtual reality stimuli in our tests: A rotating cylinder, oscillating random dots in space, random dots in space rotating around three different axes and a twisting tunnel. Screenshots of the stimuli can be seen in figure 2. The coordinate system used was arranged so that the subject is looking down the negative z-axis with the positive y-axis pointing up and the positive x-axis to the right.

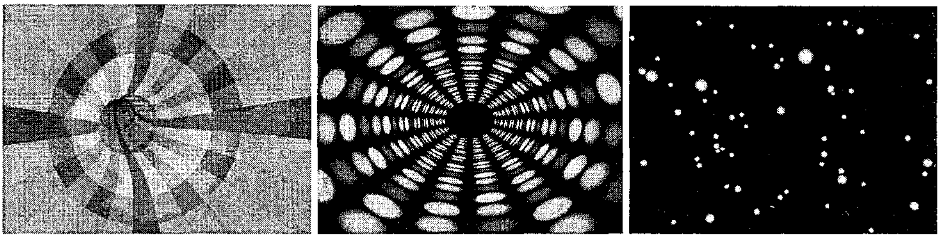

Figure 2: Virtual reality stimuli from left to right: tunnel, cylinder and dots

The virtual reality environments were implemented on an Intergraph PC workstation equipped with a Virtual Research V8 head mounted display (HMD). An Intersense IS-300 head orientation tracker was used to track head movements. All the stimuli were running at a constant frame rate of 60 frames per second (FPS), which is enough for smooth motion.

The rotating cylinder stimulus was inspired by a device found in amusement parks. In the stimulus the person is standing inside a cylinder, which is colored with red, green and blue dots. For the first 10 s the cylinder is immobile, then it starts to rotate counter clockwise accelerating constantly for 15 s, reaches a peak angular velocity of 160°/s and slows down to a halt during the next 15 s. After a pause of 10 s the rotation is repeated in the other direction.

The dots in space environment consists of randomly placed white light dots in space. Four stimuli were implemented using this environment, in three the dots rotated around the x-, y- and z-axes and in one the dots oscillated. The rotation is done similarly to the rolling cylinder stimulus, but in this case the maximum angular velocity is 120°/s. In oscillating dots the rotations around the different axes oscillate in succession during one measurement. The oscillations last 15 s each; the rotation oscillates between 25° and -25° and has a frequency of 0.2 Hz. There is a pause of 5 seconds between the oscillations around different axes.

The tunnel stimulus is a refinement of a similar stimulus used in an earlier study [3]. In the stimulus the subject is moving along a twisting tunnel. In the movement the subject's orientation is matched to the direction of the tunnel, i.e. the subject is always looking directly along the tunnel. The position $\mathbf{p}(t) = (x(t), y(t), z(t))$ of the center of the tunnel at time t (seconds) is given by the equation

$$\begin{cases} x(t) = 5\sin(0.466t + 0.5) + 5\sin(0.674t), \\ y(t) = 6\sin(0.302\,\mathrm{t}) + 6\sin(0.706t + 1.86), \\ z(t) = -10t. \end{cases}$$

Analysis for the stimuli with rotations in different directions was separately performed on the each of the parts and the pauses between the parts were omitted from the analysis. The tunnel stimulus did not have a gradual start, so we omitted the first 10 s from the analysis to allow for adaptation. The measurement without stimulus and eyes closed was also analyzed omitting the first 10 s to allow for adaptation.

3. Results

The results for the mean CPF velocity are presented in table 1. Individual differences, e.g. height, fitness, and weight, can affect the CPF velocity. Therefore we also analyzed each subject separately using the measurement with the subject wearing the HMD without stimulus as a baseline and compared the CPF velocities relative to that measurement (table 2). The missing cases in the results correspond to measurements, where the subject lost balance even after repeated attempts.

It can be seen from the results that the tunnel stimulus was the most effective in the sense of the mean increase of the mean CPF velocity. The rotating cylinder stimulus was also effective. The stimuli based on the dots were less effective and there were no clear differences between rotations around different axes. However, when comparing the tunnel stimulus and the cylinder stimulus it should be noted that in the former only one subject lost balance whereas in the latter four subjects lost balance. The reason for the difference of number of measurements in the case of the cylinder is that one subject lost balance just before the stimulus ended and the first stage was measured completely. It is also interesting to note that two of the persons, who lost balance in the cylinder stimulus also lost balance in the dots rotating around the z-axis stimulus.

Even though the stimuli using the dots environment seemed to be less effective in disturbing balance than the other stimuli, visual observation of the subjects suggests that the stimuli did have an effect on balance. This effect is not evident from the average CPF velocity. For instance, rotation around the x-axis caused the subjects to lean forward and backward during different stages of the stimulus. In the tunnel stimulus the subjects' movements clearly followed the movements of the tunnel and the cylinder stimulus caused leaning to the sides. For quantifying these effects other methods of analysis need to be used.

Statistical evaluation of the stimuli using the Wilcoxon signed ranks test with Bonferroni correction indicated that both the cylinder and the tunnel stimuli had a significantly higher median of mean CPF velocity than the baseline test where the subject was just wearing the HMD ($p = 0.0127$ and $p = 0.01531$ for the cylinder 1 and 2 and $p = 0.00047$ for the tunnel). The statistical analysis included only the 17 test subjects that were able to succesfully maintain balance in all the measurements.

Table 1: Mean CPF velocity (cm/s)

Stimulus	N	mean	median	std dev	min	max
Eyes open	22	1.34	1.32	0.36	0.80	2.36
Eyes closed	22	1.96	1.71	0.83	1.12	4.13
Wearing HMD	22	1.88	1.70	0.65	1.20	3.66
Oscillating Dots	22	2.01	1.85	0.73	1.16	3.88
Rotating dots X 1	22	2.30	1.96	1.10	1.22	5.71
Rotating dots X 2	22	2.32	2.03	1.01	1.18	5.26
Rotating dots Y 1	22	2.24	2.00	0.93	0.97	4.64
Rotating dots Y 2	22	2.16	2.05	0.89	1.03	4.56
Rotating dots Z 1	20	2.47	2.14	1.59	0.97	7.93
Rotating dots Z 2	20	2.44	2.03	1.27	1.11	5.75
Rotating cylinder 1	19	3.07	2.70	1.86	1.02	8.71
Rotating cylinder 2	18	3.20	2.98	2.13	1.07	7.72
Tunnel	21	3.32	2.67	1.96	1.36	10.20

Table 2: Mean CPF velocity / baseline CPF velocity (wearing HMD)

Stimulus	N	mean	median	std dev	min	max
Oscillating Dots	22	1.08	1.08	0.17	0.76	1.46
Rotating dots X 1	22	1.26	1.13	0.56	0.70	3.26
Rotating dots X 2	22	1.31	1.12	0.69	0.80	3.98
Rotating dots Y 1	22	1.20	1.10	0.33	0.72	2.15
Rotating dots Y 2	22	1.17	1.02	0.36	0.62	2.19
Rotating dots Z 1	20	1.29	1.13	0.55	0.72	2.62
Rotating dots Z 2	20	1.29	1.09	0.50	0.80	2.92
Rotating cylinder 1	19	1.64	1.34	0.86	0.83	4.21
Rotating cylinder 2	18	1.72	1.29	1.06	0.78	4.81
Tunnel	21	1.83	1.61	1.06	0.95	5.83

4. Discussion and Conclusion

The tunnel stimulus seems to be the most promising to induce sway. The cylinder stimulus seems to be very effective on certain people, but the reason for this is unclear.

The oscillating dots stimulus was not very effective, but this is most likely due to the implementation details of the stimulus. For instance the oscillating dots stimulus starts the oscillation abruptly instead of gradually fading in. All the stimuli using the dots environment may also suffer from a lack of depth perception; the number of dots was probably too small due to technical limitations, i.e. the frame rate would have dropped below 60 FPS.

It is likely that the most effective stimuli in this study would also be the best in differentiating subjects with balance disorders from healthy subjects, but this needs to be verified using a larger set of test subjects containing both healthy subjects and subjects with balance disorders.

Another topic of future research is to find methods to analyze and quantify the more subtle effects of the virtual reality stimulation and develop methods of analysis suitable for different kinds of stimuli.

5. Acknowledgements

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