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COMPARING STANDING BALANCE AT REAL AND VIRTUAL ELEVATED ENVIRONMENTS

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The study evaluated the efficacy of a surround-screen virtual reality (SSVR) system in simulating heights for studying human postural balance at elevation. Twenty four subjects performed standing tasks at 9-m elevation and ground level, on firm and deformable surfaces, in a real environment (RE) and a comparable virtual environment (VE). The RE was the interior of the high-bay laboratory at the National Institute for Occupational Safety and Health (NIOSH) in Morgantown, West Virginia; the VE simulated this environment in the SSVR system. Medial-lateral and anterior-posterior body sways and mean velocity of the human center-of-pressure displacement were collected using a force platform. The results indicated that the sway parameters were similar in VE and RE at elevation on both firm and deformable surfaces. At ground level, the sway parameters were significantly increased in the VE compared to the RE on a deformable surface, but not on a firm surface. It appears that visual simulation of elevated environments within a SSVR is adequate for studying the risk factors leading to losing balance and fall incidents.

INTRODUCTION

Work performed at heights is associated with great risk of losing balance and falling, which can result in serious injury and death. Experimental studies to identify causes of falls from elevations are difficult to conduct, due to the high risk of injury to subjects. The technology of virtual reality provides an opportunity to safely conduct such research. Human subject tests can be performed at simulated heights in computer-generated elevated work environments. A key to the successful application of this technology to fall research is the evaluation of its efficacy in reproducing the postural instability that is induced by a real exposure to elevation.

Posture control is maintained through integration of sensory information from the visual, vestibular, and somatosensory systems. For stable and familiar standing postures the balance-control system relies mainly on somatosensory information. When balance is challenged, e.g., for unstable conditions or in attention-demanding visual tasks (Paulus et al., 1984, Stoffregen et al., 2000a) the posture control system relies heavily on visual information for stabilization. Previous research has shown that exposure to height can affect a person's balance due to degraded visual stabilization (Brandt et al., 1980, Bles et al., 1980). At elevation, when a standing observer is facing an open space, his field of view is often deficient in close visual structures. In such conditions, distant (>5 m) visual scenes are not effective for postural stabilization, and body sway increases (Lee and Lishman 1975, Paulus et al., 1984). In addition, previous research demonstrated that the destabilizing effect of height is significantly amplified under deformable support conditions (Simeonov and Hsiao, 2001).

This study compares postural-stability effects induced by exposure to a real, elevated environment at firm and deformable surfaces with the effects induced by exposure to a virtual reality model of the same environment.

METHOD

Subjects

A sample of twenty four volunteers from the general population in the local area (12 male and 12 female) having an average age of 23.6 years (range

19-37 years; median 22 years) was used. The requirements for study participation were: normal or corrected vision in both eyes, free of balance problems, not fearful of heights, no medication use, no alcohol consumption, and 18 years or older. All participants gave informed consent prior to the study and were compensated for their time.

Independent Variables

Visual environment. This variable had two levels, real environment (RE) and virtual environment (VE). The RE was the interior of the "High-bay" laboratory and the VE was created in the NIOSH Virtual Reality laboratory, Morgantown, West Virginia. The existing visual structures of the High-bay lab were simulated in the Virtual Reality lab with reasonable detail. The test subjects wore shutter glasses required for the virtual reality system during all tests. They used the same glasses to maintain a comparable visual field (120° horizontal by 60° vertical angle) during the RE tests.

Height. This variable had two levels, ground and height. At the ground level, the test subjects were standing in front of a poster with random contrasts at a distance of 100 cm. This setup provides a standardized condition with close visual structures which are normally available at the ground, and is comparable to the baseline conditions of previous studies (Paulus et al., 1984, Straube et al., 1994). The tests at height were conducted at a 9-m-high balcony in the lab. At the balcony the closest visual structures were at distance >5 m; the shutter glasses prevented subjects from seeing the protective railing, floor edges and ceiling. The balcony was equipped with a metal protective railing which minimized subjects' psycho-physiological stress related to elevation exposure in this study.

Surface Firmness. Two levels of surface firmness were evaluated: (1) a firm and stable work surface, and (2) a deformable support simulating unstable work surface. The force platform positioned on the High-bay and SSVR floor was used to mimic a firm and stable work surface. A foam pad with a thickness of 10 cm and density 0.080 g/cm^3 was placed on the top of the force platform to simulate unstable surface conditions.

Dependent Variables

The dependent variables were the root mean square (RMS) of the center-of-pressure (CP) displacement in the medial-lateral direction (ML sway) and anterior-posterior direction (AP sway), and mean velocity of CP displacement (sway velocity). RMS of CP represents a suitable measure for average body sway over a certain period and allows an easy comparison to be made between the effects of different experimental conditions (Bles et al., 1980). Sway velocity is considered to be a valid measure of postural stability which correlates well with risk of falling (Fernie et al., 1982).

Equipment

Force platform. The system for registering the center-of-pressure includes an Accusway™ portable strain-gage-type force platform and Swaywin™ software to calculate the dependent variables (Advanced Mechanical Technologies, Inc. Watertown, MA, USA), and a portable personal computer.

Virtual Reality System. A projection-based surround-screen virtual reality (SSVR) system was used for the study. The SSVR consists of three 4m by 3.5m walls and a 4m by 4m floor. An SGI Onyx with two Infinite Reality graphics pipelines, each split into two channels, controlled the projected images. The viewer wore a pair of liquid crystal shutter glasses that separated the left- and the right-eye images that were being projected, making the images appear three-dimensional. A position tracking system tracked the movement of the head of the subject and the image generator continuously updated the environment to give the subject the right perspective. During the tests the subjects were standing in the center of the SSVR system, 2.7 m from the front screen.

Procedure

The test procedure included eight standing tasks performed at height and at ground level, on firm and deformable surfaces, in real and virtual environment. The subjects stood on a force platform with feet at 30 degrees and heels together, and looking straight forward. Three consecutive standing trials were completed for each experimental condition, and data was collected for 30 seconds in each trial. Between experimental conditions the subjects had a seated rest period of 3 minutes to reduce the possibility of fatigue. Prior to each test in the VE the subjects were given time to familiarize with the environment. After the VE test session, subjects' balance performance was checked for any adverse effects. During the tests the subjects were wearing safety shoes provided by the lab.

Statistical analysis

The study used a balanced repeated measures design. Analysis of variance (ANOVA) was used to determine differences between the experimental conditions. The analysis was performed with the general linear model (GLM) procedure in SAS software (SAS Institute Inc., Cary, NC). Dependent variables were assessed assuming within-subject variation as a random effect. Post hoc comparisons were performed using the appropriate error term under the assumptions described above.

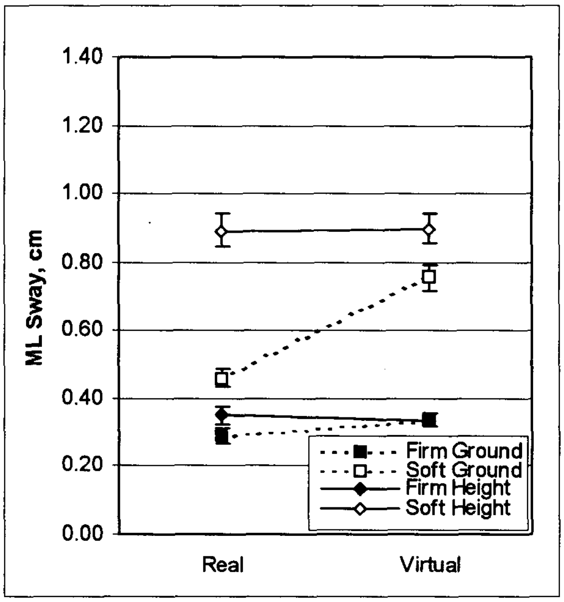
RESULTS

ML and AP Sway

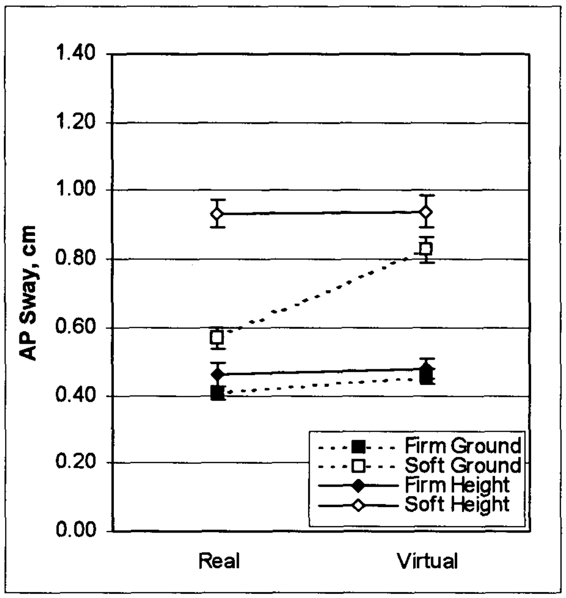
ML sway analysis indicated a significant three-way interaction of visual environment, height, and surface firmness ($F_{1,23}$=20.92, p<0.001). ML sway was significantly increased in the VE compared to the RE at ground level on deformable support surface. No significant differences existed between ML measurements in the RE and the VE at elevation, both on firm and deformable support (**Figure 1a**). AP sway analysis also demonstrated a significant three-way interaction of visual environment, height, and surface firmness ($F_{1,23}$=15.21, p<0.001). The results for AP sway were similar to those of ML sway (**Figure 1b**).

Sway Velocity

Analysis of sway velocity also showed a significant three-way interaction of visual environment, height, and surface firmness ($F_{1,23}$=22.49, p<0.001). Sway velocity was



a)



b)

Figure 1. Significant three-way interactions of visual environment type, height, and surface firmness on ML sway (a) and AP sway (b), presented in means and standard errors.

significantly increased in the VE compared to the RE at the ground level, and this difference was larger on deformable compared to firm support. Sway velocity was increased in the VE compared to the RE at elevation only on deformable support (**Figure 2**).

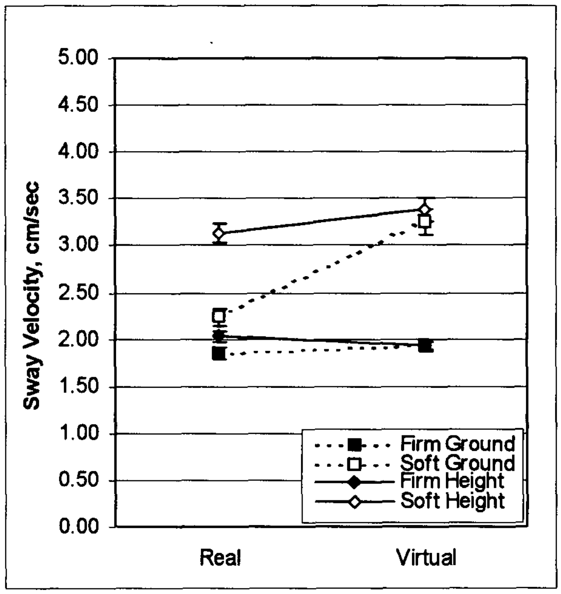


Figure 2. Significant three-way interaction of visual environment type, height, and surface firmness on Sway velocity, presented in means and standard errors.

DISCUSSION

The study results indicate that exposure to a real height environment and to a virtual height environment induced similar instability measured as sway amplitude and sway velocity on firm support, and sway amplitude under deformable support conditions. Postural instability at the real and at the virtual height environments reflects reduced visual stabilization, which is best demonstrated under conditions of unreliable somatosensory inputs i.e., on deformable support. The level of visual stabilization in the real environment depends on the distance from the observer to a visual target. In this study, postural stability at height was degraded as a result of viewing distant scenes, which is consistent with previous research on the effects of vision on postural stability (Lee and Lishman 1975, Paulus et al 1984) and the mechanism of physiological height vertigo (Bles et al 1980).

The postural stability effects of a visual environment in a SSVR are affected by multiple factors including the distance from the observer to the screens and to a visual target in the virtual scene, and by the quality of the interactive virtual images. Factors such as low image resolution, time lag, tracking inaccuracies, etc. have been associated with motion sickness (Kolasinski 1995), which is possibly preceded and caused by prolonged postural instability (Riccio and Stoffregen 1991, Stoffregen and Smart 1998, Stoffregen et al., 2000b). Consistently, the results from this study indicate that the subjects experienced increased postural instability at ground level in the virtual environment.

CONCLUSION

The study results demonstrate that the SSVR system is adequate for generating simulations of elevated work environments with destabilizing effect on standing balance. These simulations will be useful in evaluation of risk factors for loss of balance and fall initiation events.

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