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Real-time visual feedback about postural activity increases postural instability and visually induced motion sickness

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A R T I C L E I N F O

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A B S T R A C T

Background: Several studies have shown that the kinematics of standing body sway can be influenced by the provision of real time feedback about postural activity through visual displays.
Research question: We asked whether real time visual feedback about the position of the body's center of pressure (COP) might affect body sway and the occurrence of visually induced motion sickness.
Methods: Standing participants (women) were exposed to complex visual oscillation in a moving room, a device that nearly filled the field of view. During exposure to complex visual oscillations, we provided real time feedback about displacements of the body's center of pressure through a visual display presented on a tablet computer.
Results: The incidence of motion sickness was greater than in a closely related study that did not provide real time feedback. We monitored the kinematics of the body's center of pressure before and during exposure to visual motion stimuli. Body sway differed between participants who reported motion sickness and those who did not. These differences existed before any participants experienced subjective symptoms of motion sickness.
Significance: Real time visual feedback about COP displacement did not reduce visually induced motion sickness, and may have increased it. We identified postural precursors of motion sickness that may have been exacerbated by the COP display. The results indicate that visual feedback about postural activity can destabilize postural control, leading to negative side effects. We suggest possible alternative types of visual displays that might help to stabilize posture, and reduce motion sickness.

1. Introduction

It is possible to measure precisely the kinematics of postural activity, and to use these data to generate visual displays that provide real-time feedback about postural activity. Several studies have examined the effect of visual displays on the kinematics of standing posture, with mixed results. In some studies, real time visual displays have led to reduction in the spatial magnitude of body sway [1–3]. In other studies, similar displays have had no effect on sway, or have been associated with increases in the spatial magnitude of sway [1,4–9]. We pursued a novel direction. Like previous studies, we examined effects of real time visual feedback upon the kinematics of postural activity. However, we also examined effects of real time visual feedback on visually induced motion sickness. Motion sickness is preceded by distinctive patterns of postural activity: Before the onset of subjective symptoms of motion sickness, postural activity differs between persons who later become sick and those who do not. In this context, we asked whether visual feedback about postural activity might reduce the risk of motion sickness.

1.1. Visually induced motion sickness and its postural precursors

Reports of motion sickness are common among users of many contemporary interactive technologies [10,11]. Video games have been adapted for use in rehabilitation [12], but many video games are known to induce motion sickness [10,13]. Similarly, virtual environments often are used for postural rehabilitation [14,15], but visual simulation of body sway often leads to motion sickness [16,17]. Given these effects, and the finding that real time visual feedback about postural activity sometimes is associated with an *increase* in the spatial magnitude of sway, we might expect that real time visual feedback about a person's own postural activity could give rise to visually induced motion sickness.

The subjective experience of visually induced motion sickness is

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preceded by differences in postural activity between participants who later become motion sick and those who do not. That is, there are postural precursors of motion sickness. Postural precursors have been identified during exposure to nauseogenic visual motion stimuli [17–19]. However, postural precursors of motion sickness also have been identified during unperturbed stance, before participants were exposed to any motion stimuli [17–19].

Postural precursors of visually induced motion sickness have been identified in measures of the spatial magnitude of postural activity, such as the positional variability of the COP [17]. Postural precursors also have been identified in measures that are orthogonal to the spatial magnitude of movement, including the multifractality of COP positions [20–22].

1.2. The present study

The motivation for the present study rests on three effects discussed above. First, visual feedback about postural activity has yielded mixed effects on postural performance. Second, video game and virtual reality technologies similar to those used in physical rehabilitation are associated with the risk of visually induced motion sickness. Third, instability in the control of posture precedes motion sickness.

We presented participants with 2-dimensional, real time visual feedback about COP position during exposure to oscillatory motion of the visual surround. We investigated the incidence and severity of visually induced motion sickness associated with the imposed visual motion stimuli. We compared the incidence of motion sickness in the present study with that reported by Li et al. [22], which was methodologically identical to the present study, with one exception: In [22] during room motion participants were not provided with any feedback about COP position. We predicted that visually induced motion sickness would be preceded by differences in postural activity between participants who (later) reported motion sickness and those who did not, in both the spatial magnitude and the multifractality of sway.

2. Method

2.1. Participants

The participants were 26 healthy females (mean age 22.73 ± 6.77 years), mean weight 69.93 ± 15.65 kg, and mean height 165.10 ± 5.26 cm) with normal or corrected-to-normal vision, who participated in exchange for course credit. Each participant reported that they had no history of dizziness, recurrent falls, or vestibular dysfunction. The research protocol was approved in advance by the University of Minnesota IRB.

2.2. Apparatus

Participants stood on a force plate (AccuSway Plus; AMTI, Watertown, MA). We collected the center of pressure (COP) displacement in the anterior-posterior (AP) and mediolateral (ML) axes at 50 Hz.

Visual stimulus motion was generated using a moving room, which consisted of a cubic frame, 2.44 m on a side, mounted on wheels, and moved along one axis on rails (Fig. 1). The interior surfaces of the walls and ceiling were covered with blue and white marble-patterned adhesive paper. Participants stood on the force plate, which rested on the concrete floor of the laboratory, such that there was no imposed inertial motion. Movement of the room was powered by an electric motor under computer control.

Within the moving room, participants viewed the screen of a tablet computer that was mounted on a stand. The stand rested on the floor of the laboratory, such that it (and the tablet computer) was stationary, relative to the Earth. Real time feedback of COP displacement was provided on the tablet computer. A custom software application took COP data from the force plate and converted it into a 2-dimensional visual display, where the vertical axis of the screen corresponded to displacement of the body in its AP axis, and the horizontal axis of the display corresponded to displacement of the body in its ML axis. The position of the COP was indicated by a circular yellow dot, having diameter 6 mm. There were no axes in the display: Other than the dot, the screen was blank. The COP data were smoothed using 4th order Butterworth low pass filter with a 10 Hz cutoff, using MATLAB^c. The time lag between the acquisition of COP data and their appearance in the display was 0.06 s. The display's scale was 0.6, that is, the magnitude of motion of the dot on the screen was 60% of the corresponding displacement of the body. At the beginning of each trial, the dot was centered on the screen.

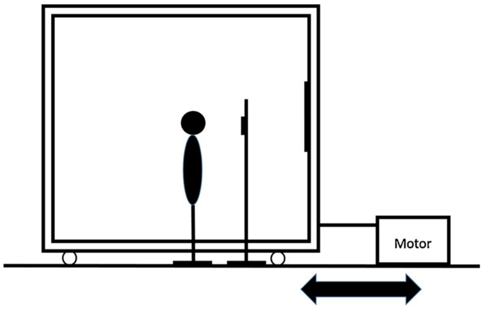

Fig. 1. The moving room.

2.3. Design

For our analysis of the incidence and severity of motion sickness, motion sickness incidence was a dependent variable. That is, we evaluated the number of participants in the Well and Sick groups, and the severity of symptoms for each group. For our analyses of the kinematics of standing body sway, motion sickness incidence was an independent variable, that is, we compared postural activity between the Well and Sick groups.

2.4. Procedure

In terms of independent variables and experimental protocol, our method closely resembled that used in several previous studies [16–18,20,22]. As part of the informed consent process, participants were instructed to discontinue the experiment immediately upon experiencing any motion sickness symptoms, however, mild. After the informed consent process, participants completed the Motion Sickness Susceptibility Questionnaire Short-form, or MSSQ [23] (these data will be reported elsewhere). Participants also completed the Simulator Sickness Questionnaire, or *SSQ* [24], which gave the initial level of symptoms (SSQ-1). Finally, participants answered a forced-choice, yes/no question, *Are you motion sick?* Next, we measured height and weight.

Marked lines on the surface of the force plate were used to constrain stance so that the midlines of the heels were 17 cm apart, and the angle between the feet was 10°. Participants were instructed that, while standing on the force plate, they should refrain from speaking, should not move their feet, and should keep their hands at their sides.

Inside the moving room, the tablet computer was affixed to a stand, which was positioned so that the screen was 1.0 m in front of the participant's heels. The position of the display was adjusted for each participant's eye-height. Postural testing began with two trials, each 60 s in duration, during which the moving room was stationary. In one trial, the tablet computer was blank. In the other trial, the tablet computer presented real time feedback about COP position. Before the COP feedback trial, the visual COP feedback display was briefly turned on and participants were given an opportunity to explore the relation between the display and their own movements.