CYBERPSYCHOLOGY & BEHAVIOR
Volume 9, Number 2, 2006

Application of Virtual Reality Graphics in Assessment of Concussion

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ABSTRACT

Abnormal balance in individuals suffering from traumatic brain injury (TBI) has been documented in numerous recent studies. However, specific mechanisms causing balance deficits have not been systematically examined. This paper demonstrated the destabilizing effect of visual field motion, induced by virtual reality graphics in concussed individuals but not in normal controls. Fifty five student-athletes at risk for concussion participated in this study prior to injury and 10 of these subjects who suffered MTBI were tested again on day 3, day 10, and day 30 after the incident. Postural responses to visual field motion were recorded using a virtual reality (VR) environment in conjunction with balance (AMTI force plate) and motion tracking (Flock of Birds) technologies. Two experimental conditions were introduced where subjects passively viewed VR scenes or actively manipulated the visual field motion. Long-lasting destabilizing effects of visual field motion were revealed, although subjects were asymptomatic when standard balance tests were introduced. The findings demonstrate that advanced VR technology may detect residual symptoms of concussion at least 30 days post-injury.

INTRODUCTION

A NUMBER OF RECENT STUDIES indicate the presence of both short-term[1] and long lasting[2] residual balance abnormalities in subjects suffering from traumatic brain injury (TBI). The symptoms of abnormal balance in TBI subjects are most evident during dynamic postural tasks when vision is compromised.[3] The destabilizing effect of compromised vision is not surprising since human postural control uses the sense of vision, optic flow and visual field motion.[4]

It is well known since March in 1875,[5] that a moving visual scene may induce a subject's self-motion (i.e., *egomotion*). *Egomotion*, which is actual body motion in response to optic flow, has most recently been defined as "any environmental displacement of the observer" with regard to visual scene motion.[6] *Egomotion* may also be accompanied by subjects' reports of sensations of or illusory effects of postural self-motion induced by a moving background and this is referred to as *vection*.[7] The feasibility of Virtual Reality (VR) to induce *egomotion and vection* during upright stances has been well-documented in a number of studies. Recently, postural responses to visual scene manipulations using (VR) graphics have been reported.[4,8] Exposing subjects to optic flow consistently induces *egomotion*, as evidenced by an increase in postural sway, in both young[9] and elderly[10] subjects. It was hypothesized that conflicting visual field motion induced by VR graphics may trigger postural instability in concussed individuals due to residual perception-action disintegration between sensory modalities and frontal cortex dysfunctions.[11]

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METHODS

Subjects

A total of 55 subjects were recruited for this study. All subjects were Pennsylvania State University athletes at risk for traumatic brain injury (collegiate football, ice hockey and rugby players), male, aged between 18 and 25 years (mean = 19.5 years). None of these subjects had a concussion history at the time of baseline testing. 10 of these subjects suffered mild concussion within six months after baseline testing, as assessed by a team physician. Following injury, these subjects were tested on day 3, day10 and day 30 post-injury. Consent forms approved by the Institutional Review Board of the Pennsylvania State University were obtained from each subject prior to each testing.

FIG. 1. Experimental set-up incorporating VT, force plate and Flock of Birds Motion tracking technologies.

Apparatus

The VR generated 3D stereo visual field consisted of a 6 × 8 foot one wall screen with rear projection, an Electrohome Marquis 8500 projector with full color stereo workstation field (2034 × 768) at 200 Hz, a dual Xenon processor PC with a nVisia Quadro 4900XGl graphics card, and StereoGraphics Inc.glasses. The VR system was synchronized with the AMTI force platform and Flock of Birds Motion analysis system. The subject wore a vest, with five *Flock of Birds* sensors attached, and VR glasses. The *Flock of Birds* sensors were placed on fixed anatomical hallmarks in order to measure the trunk kinematics. An additional *Flock of Birds* sensor was placed on the subject's head in order to interact with VR system. The Visual Field Motion consists of a 3D "virtual room" including the floor, two side-walls, a front-wall and a ceiling. All walls consist of a black and white striped pattern. The specially developed VR software allowed us to animate the "virtual room" as a whole structure, or as separate components of the room in isolation (i.e., front wall only or side walls only). An overview of the experimental set-up incorporating the "virtual room", motion tracking and force platform technologies is shown in Figure 1.

Procedures

In the first experimental condition, the subjects were instructed to stand as still as possible while viewing the computer graphics generated "moving room" visual scenes (30s in duration). There were three testing conditions. The initial condition (0) is the baseline measure with no variation in the visual field. The remaining two conditions are (1) whole-room forward-backward oscillations within 18-cm displacement at 0.3 Hz and (2) whole-room lateral "roll" at 10–30 degrees at 0.3 Hz. Our pilot experiments indicate that these "moving room" conditions maximally induced responsive self-motion in normal controls.

In the second experimental condition, the subjects were requested to produce whole body postural movement in the forward-backward and lateral directions while viewing visual field motion in three randomized tasks.

1. Darkness
2. Moving room matched to a subject's body motion and presented 180 degrees or out of phase, as would occur with natural motion (e.g., complementary visual field motion);
3. Moving room presented 180 degrees in phase so that subjects will be viewing sway responses in the presence of inappropriate visual scene motion (phase = −180, conflicting visual filed motion).

In this condition, subjects actively manipulated the direction and magnitude of the visual scene motion via interactive VR software controlled by Flock of Birds sensor located on a subject head.

Data reduction and analysis

The center of pressure data derived from the force platform were calculated using the following approximations:

$$CPx = (-My+Fx)/Fz \quad (1)$$

$$CPy=(-Mx+Fy)/Fz \quad (2)$$

where Mx and My are the moments about the x and y axes respectively and Fx, Fy, and Fz are the medio-lateral (M-L), anterior-posterior (A-P) and vertical ground reaction forces, respectively. The time series of torso motion along *X* and *Y* axes and coherence values between quantities of moving room and postural responses were assessed using a specially developed m-code in MATLAB 6.5. The auto-spectra for each signal were calculated by using Welsh's averaged periodogram method. Coherence was calculated based on the cross-spectra f_{xy} and auto- spectra f_{xx}, f_{yy} with the spectra estimated from segments of data and the coherence R_{xy} estimated from the combined spectra:

$$R_{xy}(\lambda)|2=|f_{xy}(\lambda)|^2/(f_{xx}(\lambda)f_{yy}(\lambda)) \quad (3)$$

The postural data were subjected to one-way repeated measures ANOVA having the day of testing as a factor. Appropriate post-hoc comparisons (i.e., Tukey HSD) were conducted in the event of significant effects.

RESULTS

Experimental condition 1

The effects of optic flow manipulations on postural response in subjects prior to concussion and consequently on day 3, 10, and 30 after the injury are shown in Table 1.

Prior to concussion, all subjects were able to preserve balance while viewing the virtual room motion. More importantly, as can be seen from Table 1, prior to concussion subjects experienced *egomotion* as reflected in highly significant coherence values between properties of the moving room and their postural responses. Another finding of interest is that only low frequency oscillations of moving room (0.3 Hz) induced the subjects' *egomotion*. None of the subjects were able to preserve balance while viewing the "moving room" on day 3 post-injury. This experimental condition not only induced postural destabilization but also provoked symptoms of TBI, including motion sickness, dizziness and disorientation. A significant drop in coherence was observed on day 10 post-injury ($p < 0.05$). This effect was present up to day 30 post-injury, indicating dynamics of postural responses to visual field motion as a function of time post-injury. Post-hoc comparisons (i.e., Tukey HSD) revealed no differences in the coherence values between pre-injury status and day 30 post-injury ($p > 0.05$).

Experimental condition 2

We examined functional coupling between subjects' postural movement and corresponding motion of the virtual room, as reflected in coherence values similar to *Experimental Condition 1*. There are several findings of interest. First, prior to concussion, all subjects were able to preserve balance and produced coherent oscillatory postural movement matched with the motion of the virtual room (r = ± 0.85). This was the case when both (1) complementary visual field motion (r = ± 0.91) and (2) when phase = −180, conflicting visual filed motion was introduced (r = ± 0.79). Most importantly, subjects prior to concussion were able to adapt to conflicting visual field motion and preserved dynamic postural stability. Subjects' maladaptive responses as reflected in incoherence postural movement were still present at 10 day or even 30 days post-injury.

TABLE 1. EFFECTS OF OPTIC FLOW MANIPULATION

Coupling	*Baseline testing*	*Day 3*	*Day 10*	*Day 30*
(1) Coh VR/CPy	**0.79**[a]	N/A	0.45	**0.75**[a]
(2) Coh VR/CPx	**0.81**[a]	N/A	0.32	0.66
(3) Coh VR/FOB	**0.79**[a]	N/A	0.21	0.65

The magnitude of coherence between (1) virtual room (VR) motion in A-P direction and center of pressure (CPy) motion; (2) virtual room (VR) motion in lateral (roll) direction and center of pressure (CPx) motion; (3) virtual room (VR) motion in A-P direction and body kinematics (flock of birds data).

[a]The significance of coherence was calculated using the test provided by Rosenberg et al.[12] That is, the confidence limit for zero coherence at the α %, and L, which is the number of disjoint segments: $sig(\alpha) = 1-(1-\alpha)^{1/(L-1)}$

CONCLUSION

We designed this study to examine the temporal restoration of the effect of visual field motion on induced by virtual reality graphics on postural responses as a result of traumatic brain injury. Prior to brain injury, all subjects experienced *egomotion*, were able to adapt to confusing visual field motion demonstrating intact perceptual-motion integration in control of balance. This finding is consistent with other studies reporting that an immersive dynamic visual field induces a postural reorganization as reflected in the subjects' head, trunk and ankle responses.[9] Standard balance tests revealed that balance problems are cleared within 10 days post-injury.[1,2] However, more challenging postural tasks such as responses to visual field motion induced postural dysfunctions at least 30 days post-injury. None of the concussed subjects were able to preserve balance while viewing a moving room on day 3 post-injury. This may be attributed to perceptual-motor disintegration induced by conflicting visual field motion in concussed individuals. Overall, the findings suggest the presence of a residual disturbance of the neuronal network that is involved in execution of postural movement and possibly lowering the threshold for brain re/injury. Thus, it is clear that the VR environment can be used to examine the effects of visual field motion on balance in normal controls and especially in individual suffering from traumatic brain injury. The presence of perceptual-motor disintegration, induced by visual field motion could potentially be considered within the scope of existing grading scales of concussion.

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