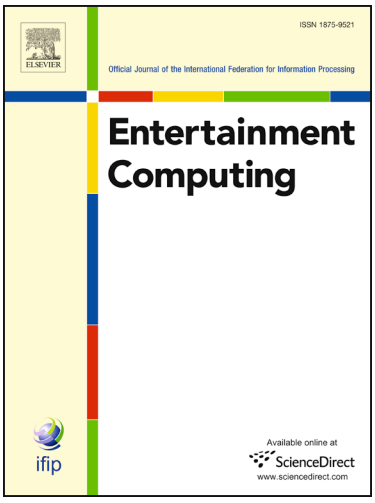

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Depth Gaze and ECG Based Frequency Dynamics during Motion Sickness in Stereoscopic 3D Movie

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Abstract

The simulator sickness questionnaire (SSQ) has been a prevalent method to observe motion sickness in stereoscopic 3D motion picture. However, previous works do not provide adequate comprehension of the relationship between SSQ, depth gaze behavior, and heart rate variability in the stereoscopic 3D motion picture. To fill this research gap, we present a novel investigation of motion sickness in stereoscopic 3D movies using SSQ, electrocardiography (ECG), and 3D gaze tracking. Forty participants ($N = 40$) watched only one of two 3D contents—3D content with a strong or a moderate sensation of vection. We observed that viewers of the 3D content with an intense feeling of vection more frequently reported symptoms of nausea ($p < 0.005$) and disorientation ($p < 0.05$) than their counterpart. SSQ, ECG, and 3D gaze tracking data show that sickness level could be reduced by persistently gazing at a particular point during exposure of 3D contents ($p<0.001$). Additionally, we found that individuals who were prone to motion sickness experienced depth gaze oscillation during several provoking scenes in dynamic 3D contents. Our experimental results may be used as a guideline in the development of a motion sickness predictor for various stereoscopic 3D motion pictures.

Keywords: ECG, heart rate variability, 3D gaze analysis, eye tracking, motion sickness, stereoscopic 3D, user experience.

1. Introduction

During 2007–2012, stereoscopic 3D technology was more readily available to the public. The technology was predicted to be the next trendsetter in the digital media [1]. Various television companies were keeping pace with this emerging technology while introducing their 3D products to their traditional markets [2]. In the consumer electronics business, Nvidia 3D Vision was used in more than 500 video games [3], scientific visualization projects [4], technical workshops [5], and health therapy devices [6]. Even two out of twelve Hollywood's box office movies in 2009-2010 were delivered in both 2D and stereoscopic 3D format [7].

Regardless of enthusiasm in its early launching, stereoscopic 3D technology seems unlikely gaining popularity as it was praised before. Visually induced motion sickness (VIMS) has been the most frequently reported issue among several anecdotal problems behind the decline of stereoscopic 3D technology [8, 9]. During or after exposure of stereoscopic 3D motion pictures, the viewers develop various motion sickness symptoms such as general discomfort, headache, visual fatigue, dizziness, nausea, and increased salivation [10, 11].

One primary cause of motion sickness in stereoscopic 3D contents is a conflict within human sensory systems [12, 13]. A conflict may occur in the visual and vestibular system. When viewers of a stereoscopic 3D content see a dynamic visual stimulus, their visual system senses a vection—a sensation of self-motion—while their vestibular system signals no motion. Another conflict may emerge inside the visual system triggered by a discrepancy between accommodation cues (i.e., visual cues associated with the focus of retinal images) and disparity cues (i.e., visual cues associated with the position of an object on the left and right retinal images). During normal viewing, individuals seeing an object moving closer will defocus their view to adapt accommodation cues. Simultaneously, their gaze will move to adjust left and right retinal images. On the other hand, individuals seeing an object in stereoscopic 3D will typically focus their view on the screen while gazing at different depth positions of the object.

Postural sway has been used as a new approach to observe motion sickness symptoms in virtual environments [14–17]. This method is based on the theory of postural instability during cybersickness. The theory states that sickness level is affected by prior instability in individuals' postural. In this method, postural kinematics were sampled continuously during exposure to potentially nauseogenic motion stimulus. Some metrics used in this technique include the velocity of movement, time to failure in preserving a particular posture, posture breaks, and posi-

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