Displays 44 (2016) 5–14

Contents lists available at ScienceDirect

Displays

journal homepage: www.elsevier.com/locate/displa

Brightness and contrast do not affect visually induced motion sickness in a passively-flown fixed-base flight simulator ☆

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ARTICLE INFO

Article history:
Received 8 February 2016
Received in revised form 8 May 2016
Accepted 26 May 2016
Available online 30 May 2016

Keywords:
Motion sickness
SSQ
FMS
VIMS
Brightness
Contrast
Postural sway

ABSTRACT

Background: Visually Induced Motion Sickness (VIMS) or simulator sickness is often elicited by a visual stimulus that lacks the appropriate vestibular or proprioceptive feedback. In this study, we chose to investigate the effects of brightness and contrast of the visual scene on VIMS.
Hypothesis: We hypothesized that visual environments differing in brightness or contrast would differentially induce VIMS. The symptoms of VIMS should be most severe for the combination of high brightness and high contrast and conversely lowest for the low brightness and low contrast condition.
Methods: 33 healthy subjects were tested in a fixed-base flight simulator. Each subject flew in four consecutive but counterbalanced conditions during one large experimental session. The four conditions consisted of identical recorded flight paths, differing only in brightness and contrast in a fully crossed design. VIMS was assessed with the Simulator Sickness Questionnaire and the Fast Motion Sickness scale administered during and after each condition. Postural Sway (PS) was measured after each condition.
Results: All four brightness and contrast conditions were found to be effective in that they increased PS and elicited moderate VIMS. However, there were no main or interaction effects for brightness or contrast.
Conclusions: Our findings suggest that brightness and contrast do not modulate the induction of VIMS. This conclusion may be limited to moderately provocative stimuli.

1. Introduction

Ever-evolving virtual environments are part of modern life, from entertainment to professional purposes. One example of such a virtual environment is a flight simulator. Used today both for entertainment and training purposes, flight simulators offer realistic environments to the extent that flight training hours can be replaced by corresponding simulator hours [12]. In a significant number of subjects, the use of virtual environments is hampered by the occurrence of Visually Induced Motion Sickness (VIMS), a phenomenon commonly experienced in highly immersive environments. Various definitions of VIMS have been proposed. We adopt the position that any deviation from normal well-being induced by a mismatch between physical movement and perceived motion is an expression of VIMS.

1.1. Motion sickness theories

Although many different theories have been advanced to explain and predict VIMS, no unified theory exists that accounts for the elicitation and all aspects of this disorder. For a comprehensive overview, please refer to Keshavarz et al. [21].

Arguably the most cited theory of Motion Sickness (MS) is the sensory conflict theory by Reason and Brand [29]. It states that "motion sickness is a self-inflicted maladaptation phenomenon [...], which occurs at the onset and cessation of conditions of sensory rearrangement when the pattern of inputs from the vestibular system, other proprioceptors and vision is at variance with the stored patterns derived from recent transactions with the spatial environment". Thus, according to the sensory conflict theory, the interactions of the visual, vestibular and proprioceptive systems are the basis of the genesis of MS.

VIMS may be construed as an instance of a sensory conflict in which the visual system perceives self-movement while the vestibular and proprioceptive systems perceive a stationary environment. VIMS is also known as "cyber-sickness", "virtual reality sickness", "gaming sickness", "cinerama sickness", or

☆ This paper was recommended for publication by Richard H.Y. So.

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http://dx.doi.org/10.1016/j.displa.2016.05.007
0141-9382/

"simulator sickness". The illusory impression of ego-movement in the absence of physical motion is called vection. The perceived visual movement accompanied by a lack of a correspondent physical acceleration causes a discrepancy of visual-vestibular information (i.e. a sensory conflict) which in turn results in VIMS [3,14]. It is nevertheless important to note that the exact correlation between vection and VIMS is the issue of extensive debate [23].

Reason [28] introduced the neural store into his view of sensory conflict theory, accommodating the role of past motion experience. When a movement is planned or registered by the sensory organs, it is compared to similar stored movements from the past. In the case that the newly sensed pattern of movement fails to fit a previously stored movement, it may provoke MS. Following Reason [28], Keshavarz et al. [21] have argued that MS cannot solely be explained by a concurrent sensory mismatch. Afferent sensory information can be stored, altered, even anticipated—and thus influence the evaluation of the current afferent information.

The ecological theory of motion sickness and postural instability [32] is another attempt at providing an etiologic explanation for the genesis of MS. This theory builds on the ecological theory of orientation perception, which postulates that the perception of upright stance is not determined by the acting gravitational forces [40]. The authors argue that concordance of sensory information is not required or expected. Instead, MS should occur when an individual is unable to use or has not yet learned the appropriate strategies necessary to maintain a stable posture. On several occasions, Stoffregen and others found that no MS was elicited even though a sensory conflict was present (e.g. [8,31,41]). Postural instability is hypothesized to precede the onset of MS symptoms and to be a prerequisite for all other symptoms. According to Riccio and Stoffregen [32], motion sickness is preceded by significant increases in several indices of Postural Sway (PS). Stoffregen and Smart [41] also showed that PS preceded the subjective symptoms of MS. They went on to show that a correlation exists between the pre-exposure postural sway of a subject and his or her vulnerability to MS. Subjects with high pre-exposure PS showed significantly higher MS values than those with lower pre-exposure PS.

While some studies support this theory, numerous findings cannot be reconciled with this hypothesis [5,21,26]. According to Bos [5] the unresolved issues include, but are not limited to, the fact that people without functioning organs of balance do not get sick from motion; negative correlations that have been found between VIMS symptoms over time and postural instability; and medical conditions, such as Ménière's disease, where patients experience symptoms of MS while lying in bed. Bos [5] concluded that while MS and PS may be linked by a shared mechanism, the co-occurrence of these two phenomena does not establish causality.

1.2. Visual perception of light

A visual stimulus can be described using various parameters (e.g. sharpness, saturation, hue, etc.), which affect the way we perceive the stimulus [46]. As much as we know about these parameters, their effect on the elicitation of VIMS has not yet been investigated. Thus, we have focused on two of the most prominent features of the visual stimulus, its brightness and contrast.

It is beyond the scope of this article to give an in-depth account of theories on brightness and contrast and their role in human visual perception. Basically, **brightness** is the amount of light originating from a specific target or a scene [2]. It is also referred to as luminance. **Contrast** is the difference between maximum and minimum intensities of a pattern or a scene, relative to the overall intensity [6].

Whereas brightness is the physical dimension of the amount of light emitted or reflected from the scene, **lightness** refers to the subjective light intensity perceived by the viewer [1]. Although not the subject of this study, it is nevertheless of importance to differentiate between brightness and lightness in the following discussions.

1.3. Vision at high and low intensities

Following the separate definitions of brightness and contrast, a closer account of their possible interaction is given in the following. Visual acuity and visual sensitivity vary with luminance [46]. While the cones in the human eye allow for high acuity in well-lit environments, the rods optimize sensitivity in low brightness, at the account of acuity [6]. As both contrast and luminance may weaken the stimulus with respect to its ability to induce VIMS, it is of interest to explore the role of brightness *and* contrast as well as their possible interaction.

1.4. Brightness & contrast in flight

Both brightness and contrast vary extensively within different flight conditions, such as night flight or flight in different weather conditions.

1.4.1. Brightness in flight

Changes in ambient lightness have crucial effects on man's perception of his environment. One does not have to be a pilot to be able to appreciate the fundamental differences between day and nighttime flight. Night vision sensors have been developed in order to overcome the limitations on performance posed by darkness. These technologies employ various methods (e.g. infrared imaging and residual light amplification) in order to enable the human eye to perceive the environment beyond its normal brightness envelope. In terms of ambient brightness, we therefore suggest that flight can nowadays be divided into three types of brightness levels: daytime flight, nighttime flight, and aided nighttime flight.

1.4.2. Contrast in flight

Wright [46] has referred to changes in contrast as crucial when describing the effects of fog. Visual stimuli during flight in clear weather are experientially different from those in flight in fog or haze. Although the term "contrast" is not used in the aviation jargon, it is our contention that, following Wright's observation, contrast is the salient variable associated with changes caused by fog.

1.5. Brightness, contrast and VIMS

As previously discussed, both brightness and contrast play a significant role in providing visual information of the perceived environment. Based on the theories of sensory conflict [29] and neural storage [28], changes in the visual stimulus could induce different degrees of sensory conflict between modalities, which could, in turn, evoke different levels of VIMS.

Changes in brightness and contrast are inherent in everyday flight conditions. Based on previous MS research and on the changing characteristics of flight environments, both real and simulated, we set out to explore the effects of visual aspects of the simulated outside world on the viewer's well-being in terms of VIMS. While this connection between the environment's visual characteristics and the corresponding VIMS is plausible, it has yet to be investigated.