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Equally moved and not really sick from viewing 2D and 3D motion stimuli on a TV screen

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ABSTRACT

Objective: Visually induced motion sickness (VIMS) and increased postural sway are two adverse side effects that may occur when viewing motion stimuli. However, whether these effects are elevated to a greater extent when viewing stereoscopic 3D motion stimuli, compared to 2D stimuli on a TV screen, has not been investigated under controlled circumstances. Therefore this study aimed at investigating VIMS and postural sway before, during, and directly after viewing 2D and 3D motion stimuli, on a commonly available TV screen.

Method: 16 Participants were exposed to an aviation documentary shown in 2D and in 3D on separate occasions. Before, during, and after exposure, VIMS and postural sway were measured. VIMS was quantified by a rating scale giving a single number, and by a multi-symptom questionnaire that assessed multiple VIMS symptoms separately. Sway path length, standard deviations and short-range and long-range scaling components of the center of pressure were calculated as measures of postural sway.

Results: VIMS symptom severity, as obtained with the single rating scale, did not show a significant increase to either 2D or 3D exposure. The multi-symptom questionnaire did reveal significant increases in VIMS symptom severity to both 2D and 3D exposure. However, VIMS was not significantly more increased in case of 3D exposure compared to 2D exposure. All postural sway measures (sway path length, standard deviation in mediolateral and anteroposterior direction, as well as the short-range scaling components) increased significantly as a result of exposure. None of the postural sway measures was differentially affected to 3D as compared to 2D exposure.

Conclusion: Viewing 3D motion stimuli did not cause more serious VIMS symptoms, compared to viewing motion stimuli in 2D. We attribute this lack of difference to the fact that the 3D effects in this documentary were optimized for viewing in a cinema, the projection on the TV-screen thus causing quarantining of the visual input. The increase in postural sway, irrespective of image type, may reflect exploratory behavior, allowing the participant to gain more information about self-orientation with respect to the virtual environment.

1. Introduction

Nowadays, thanks to spectacular technological improvements, 3D stereoscopic technology is implemented on a regular basis, and has entered the living room with the introduction of commercially available 3D TVs. However, with these developments the concern over possible adverse effects due to prolonged exposure to 3D motion stimuli has increased. This study aims at jointly investigating two possible adverse effects of viewing 3D, compared to viewing 2D, on a common TV screen.

Exposure to motion stimuli, either in 2D or 3D, can cause symptoms similar to those associated with motion sickness, also called visually induced motion sickness (VIMS) [1–6]. VIMS is a condition in which viewers experience oculomotor, disorienting and especially nauseating symptoms due to exposure to certain visual patterns, while being physically stationary [1–4]. In addition to VIMS symptoms, viewing motion stimuli can also affect postural control, defined as "the act of maintaining, achieving or restoring a state of balance during any posture or activity" [7]. In particular it has been shown that postural sway increases due to viewing 2D [8–11] and 3D motion stimuli [12].

An influential theory explaining the origin of VIMS is the sensory conflict theory [13–15]. According to this theory, VIMS symptoms arise when there is a mismatch between sensory signals from

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the visual, vestibular and somatosensory senses and the expected sensory signals [13–15]. In daily life the signals from these senses correspond with each other, and are also congruent with the expected sensory signals based on an internal model. However, when viewing 2D or 3D motion stimuli whilst sitting or standing still, the visual cues do not coincide with the vestibular cues and are also not in line with the expected sensory signals. This conflict between the sensory signals and expected sensory signals is proposed to cause VIMS. It has been suggested already that especially visual motion indicating a change in the Earth-vertical is necessary to cause VIMS [15–17]. Next to such visual motion, in this paper we propose that viewing 3D motion stimuli exacerbates VIMS compared to viewing visual motion stimuli in 2D.

3D motion stimuli contain, compared to 2D motion stimuli, stereoscopic information which is proposed to be the additional provocative factor with respect to VIMS symptoms (see e.g. [18–20]). The stereoscopic information is known to add to the naturalness of the 3D motion stimuli [21,22]. Because 3D motion stimuli appear more natural, a larger conflict between the sensed and expected sensory signals is suggested (see also [23]), therefore causing more severe VIMS symptoms as compared to 2D. Several earlier studies have investigated the effect of viewing stereoscopic 3D stimuli, compared to viewing 2D stimuli. In these studies participants were exposed to computer generated stimuli or a movie, that was shown in 2D and 3D on either a projection screen, at the cinema or on a TV-screen [2,24–27]. Despite the large differences in stimuli and displaying techniques, in all studies participants experienced significantly more severe VIMS symptoms after viewing 3D motion stimuli compared to 2D motion stimuli [2,24–27].

VIMS and postural sway have been jointly studied, mainly using 2D stimuli. The majority of these studies reported a significant rise in VIMS symptoms as well as increased postural sway (e.g. [8–11]). To the best of our knowledge only Bos et al. [12] studied VIMS and postural sway characteristics prior to, and after viewing 3D motion stimuli. They found that, after viewing a 3D documentary in a cinema, VIMS and postural sway were significantly increased compared to before viewing. Unfortunately, Bos et al. [12] were not able to make a comparison with 2D presentation, impeding a direct comparison of potential adverse effects of 3D viewing to 2D viewing on both VIMS and postural sway.

In summary, exposure to both 2D and 3D motion stimuli are able to cause VIMS symptoms and increase postural sway. However, an experiment comparing VIMS, as well as postural sway induced by viewing 2D and 3D motion stimuli is still lacking. To address this gap in the literature, in this paper we investigate subjective reports of VIMS symptoms and postural sway in one group of participants, who are exposed to the same motion stimuli shown in 2D and 3D on a commonly available TV-screen. Based on the existing literature, we hypothesize that prolonged exposure to both 2D and 3D motion stimuli will increase symptoms of VIMS, and we predict 3D to cause more VIMS related symptoms in comparison to 2D exposure. We also expect postural sway to significantly increase when viewing both 2D and 3D. However, whether postural sway will also increase more when viewing 3D compared to viewing 2D remains to be seen.

2. Methods

2.1. Participants

Sixteen healthy young adults ($N = 16$) of the Faculty of Human Movement Sciences of the VU University Amsterdam participated in this study. Participants were 5 males and 11 females with a mean age of 21.5 ($SD = 1.32$) years. All participants signed an informed consent form before participation. The ethics committee of this same faculty approved the study in accordance with the Declaration of Helsinki.

2.2. Stimuli

Participants watched the aviation documentary 'Legends of Flight', with ample scene motion in all degrees of freedom, previously shown to cause VIMS in an unselected sample of cinema goers [12]. The documentary lasts 45 min, and in the current experiment it was viewed in two separate sessions, once in 2D and once in 3D, using a commonly available 55-in. TV-screen (LG 55LA8609). 3D was realized using (light-weight) passive circular polarized glasses as provided by the manufacturer. Participants were seated at a distance of 1.34 m from the screen, yielding a field of view of 48 by 28° (horizontal × vertical). To minimize the differences between sessions, we originally aimed at using the glasses also in the 2D session (possibly using equal glasses for both eyes). This, however caused a grid of thin lines to become visible, which was not present in 3D. We therefore chose to use no glasses at all in the 2D session.

2.3. Measurements

2.3.1. Subjective misery

Three sickness measurements were included. First, the motion sickness susceptibility questionnaire (MSSQ) was filled out prior to the experiment, in order to assess a potential history of motion sickness over the lifetime. The MSSQ assesses previous occurrences of motion sickness in cars, buses, trains, aircrafts, boats, swings, roundabouts and theme park rides up to the age of 12 and for the last 12 years. The MSSQ score has a minimum of 0, implying no problems whatsoever, and a maximum of 222, implying severe problems in all above situations. The 50th percentile of a normal population corresponds to a MSSQ score of 37 [28,29].

Second, before and right after the experiment, VIMS was assessed using the simulator sickness questionnaire (SSQ) [3]. With the SSQ, the severity of 16 sickness symptoms is rated on a 4-point scale ranging from 0 to 3 (none, slight, moderate, severe). Outcome measures of the SSQ are expressed in three subscales, representing distinct symptom clusters of simulator sickness (nausea, oculomotor and disorientation), and a total score (TS) that represents overall discomfort.

Third, misery scale (MISC) [29] rates were obtained before, during and right after the experiment. In this case, participants were asked to report their symptoms on an 11-point scale, ranging from 0 to 10. A score of 0 represents absence of symptoms, a score from 1 to 5 represents with increasing severity any symptom except nausea; a score of 6 or higher represents an increasing severity of nausea with 10 when vomiting. The MISC makes use of the observation that sickness symptoms other than nausea may vary largely between participants, and if present, generally precede nausea [29]. The advantage of the MISC over the SSQ is that it is scored using one value only, and hence can be administered within a short period of time.

2.3.2. Postural sway

Postural sway was quantified by measuring excursions of the center of pressure (CoP). A custom made 1 × 1 m strain gauge force plate (resolution: 0.28 N/bit) was used to collect 60 s CoP time series at 100 Hz. Participants were instructed to stand still with their arms hanging alongside their torso, head upright, and eyes closed. Feet were positioned at an angle of 30° with the heels together as depicted on the force plate.

All postural sway measures were calculated using Matlab R2014a. Onset-effects were ignored by excluding the first 5 s of each CoP time series. From these time series, a number of global,