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Abstract

Despite the recent rise in the popularity of 3D entertainment technology, there is surprisingly little research on the psychophysiological experience of watching 3D movies. Previous studies suggest that exposure to stereoscopic (3D) images in training environments (e.g., flight simulators) can cause discomforts including eyestrain and visually induced motion sickness. However, existing research on 3D entertainment has been mixed and has relied primarily on retrospective, non-experimental research designs, which do not allow us to draw clear causal conclusions. The purpose of this study was to examine the psychological and physiological effects of viewing 3D movies using a controlled, manipulated experiment. Eighty-two participants were randomly assigned to watch a segment of a nature movie in either stereoscopic (3D) or standard (2D) format and were measured on their psychological and physiological experiences. A multivariate analysis of covariance (MANCOVA) revealed statistically significant adverse effects of the 3D movie format. Specifically, watching a movie segment in 3D resulted in significantly more ocular discomfort (e.g., eyestrain) and feelings of disorientation compared to watching the same segment in 2D. Most notably, these results were observed after controlling for an individual's self-reported level of intolerance for physical discomfort and pre-existing attitudes towards 3D movies. Interestingly, although nausea is often reported anecdotally in reaction to 3D movies, we did not find significant effects of the 3D format on feelings of nausea. These results suggest that the direct psychophysiological experience of 3D movies is complex and continued research is necessary to improve the comfort and safety of consumers.

Key Words: stereoscopic images, movies, physical symptoms, anxiety

The Effect of Stereoscopic (3D) Movies on Psychological and Physiological Symptoms

The overall popularity of stereoscopic or three-dimensional (3D) entertainment has increased dramatically in recent years. According to the Motion Picture Association of America, box office sales for 3D movies doubled from $1.1 billion in 2009 to $2.2 billion in 2010 in the United States and Canada. More recently however, *Deadline New York*'s David Lieberman noted that the percentage of box office sales of 3D movies has declined from 43% in 2012 to 33% in 2013(for movies that offer a 3D option). One factor affecting this complex trend may be the adverse effects some viewers experience while watching non-standard video formats such as 3D and point-of-view (e.g., hand-held) movies. For example, in 2003, 36 Japanese junior high school students were transported to the hospital due to severe symptoms of motion sickness, after viewing a 20 minute movie about life at an American junior high school shot with handheld cameras (Ujike, Ukai, & Nihei, 2008). Due to excessive camera motion, the students complained of headache, eye pain, and nausea, with half of the students experiencing physical symptoms (e.g., vomiting). This incident demonstrates how non-standard movie formats may elicit adverse physiological and psychological effects. The current study examined the effect of non-standard (e.g., stereoscopic) movies on viewers reporting adverse psychophysiological symptoms.

Stereoscopic Technology and Techniques

Early stereoscopic (3D) technology utilized anaglyphs. Anaglyphs consist of two slightly different images taken from adjacent cameras. These two images are then presented in contrasting colors, such as red and blue. When wearing special glasses, with one red and one blue lens, the two images are filtered into one 3D image. Each colored lens filters out one image so that the left and right eyes each see a different image (see Figure 1). This technology can be utilized for both still images and movies (Yantis, 2014), but is rarely used today.

Modern stereoscopic (3D) technology uses the polarization of light to produce 3D images rather than the red-blue anaglyphs of the past (Yantis, 2014). This is achieved by filming the same scene with two different cameras that polarize light in different directions. One lens in the glasses allows light from one direction of polarization and the other lens allows light from the other direction (see Figure 2). This allows viewers to see the two slightly different images shot by the two cameras as one image (Yantis, 2014). Both anaglyphs and modern 3D technology rely on presenting two slightly different images to make viewers perceive normally 2D images as 3D.

Movie producers use the lens of the camera to mimic the lens of our eyes. Through the lens of the camera, movie producers imitate important visual cues so movie viewers perceive depth in two-dimensional scenes. The most important visual cue for stereoscopic vision is binocular disparity. In both the anaglyph red-blue glasses and the modern polarized glasses, the viewer's left and right eyes each see a slightly different image. The two images produce binocular disparity. Binocular disparity is present in normal vision because of the slight distance between the eyes (about 63 mm). This cue is integrated with other various visual cues (e.g., changes in size and brightness) in the primary visual cortex to produce stereoscopic (3D) vision (Bando, Iijima & Yano, 2012). Stereoscopic technology imitates these important visual cues to make the brain perceive images that are normally in 2D as 3D images.

Changes in the size of objects and brightness are also involved in the perception of stereoscopic (3D) images. The relative size of an object allows us to judge our distance to that object (Yantis, 2014). When movie producers want viewers to feel like objects are coming towards them, they make the objects appear progressively larger. This can be done by zooming in on the objects or by the objects traveling towards the camera. Additionally, very specific lighting is cast on the scenes of movies to give the perception of depth. The importance of the

use of lighting is exemplified in 2D artwork. Without brightness and shading objects would appear one dimensional and flat (Yantis, 2014). However, changes in size and brightness alone do not produce stereoscopic images, additional visual cues are needed.

Other cues involved in the perception of stereoscopic (3D) images and depth involve physical changes in the eye. The shape of the lens of the eye is an important cue for depth. Accommodation is the process of modifying the shape of the lenses of our eyes to sharply focus images onto the retina (Yantis, 2014). The sensation of this rapid and automatic process provides a cue to the perception of distance and depth. Other rapid and automatic processes, like vergence eye movements (i.e., convergence, divergence), are essential in perceiving how far away an object is (Yantis, 2014). Binocular disparity, changes in size and brightness, accommodation, and vergence eye movements are all visual cues used in our perception of stereoscopic depth. Movie producers use these stereoscopic depth cues in order to increase the overall sensory experience of the movie.

Sensory Experience of Stereoscopic Movies

Viewing stereoscopic (3D) images may be a demanding sensory task due to a phenomenon called binocular rivalry (Frassle, Sommer, Jansen, Naber, & Einhauser, 2014; Schmitzer, Tierney & Toepker, 2009). Binocular rivalry is a phenomenon in which "…two dissimilar stimuli are presented to the eyes, perception alternates between multiple interpretations" (Frassle et al., 2014, p. 1738). The slightly different images imposed on the eyes used to create the 3D quality of images may produce binocular rivalry. This binocular rivalry can occur during 3D movies when the glasses do not carefully align the slightly different images. This was a larger problem in the older technology of red-blue anaglyphs. The images were less integrated through the glasses and produced more rivalry. However, this still may be a cause for

some of the adverse symptoms due to viewing modern stereoscopic technology.

The overall sensory experience differs greatly during standard format (2D) and stereoscopic (3D) movies. The two-dimensional image provided during standard format (2D) movies remains behind the perceived barrier of the screen. This experienced barrier keeps the movie separate from the viewer. In stereoscopic (3D) movies the images move past the barrier of the screen. This removal of a definable barrier between the viewer and the movie provides a sense of immersion that is lacking in standard format (2D) movies. This increased level of immersion is more visually stimulating to the viewer and makes them feel more engaged in the story. Furthermore, viewers have stronger responses, such as emotional responses, when they are more immersed in the movie (Slater & Wilbur, 1997). Viewers' emotional responses might include increased anxiety due to a stressful scene in a movie. Increasing this level of immersion by movie format leads to a more enhanced and demanding sensory experience for the viewer and directly affects the viewers' experience.

Previous Research on Stereoscopic Images

Early investigations of the psychological and physiological symptoms related to viewing stereoscopic (3D) images originated in research on virtual training environments such as flight simulators (Kennedy, Lane, Berbaum & Lilienthal, 1993; Kuze & Ukai, 2008). Initially, the only assessments available for studying the psychophysiological effects of flight simulators were motion sickness questionnaires. Unfortunately, motion sickness questionnaires did not specify symptoms that were experienced in the absence of real (physical) motion, like in a flight simulator or viewing a 3D movie. This lack of focus on stereoscopic (3D) images and simulators made the motion sickness questionnaires inadequate to measure the psychophysiological experiences of 3D simulators.

Kennedy and his colleagues (1993) developed the Simulator Sickness Questionnaire (SSQ) to directly study the symptoms of Simulator Sickness in pilots. Utilizing their new scale, they found that half of the pilots who used the flight simulator reported adverse symptoms such as general discomfort, nausea, headache, eye strain, and difficulty focusing. With the results from the SSQ, Kennedy and colleagues were able to inform pilots on the appropriate time needed between using the simulator and when the flight simulator needed to be recalibrated. Overall, the SSQ increased the safety of pilots and provided a measure of adverse symptoms due to images portraying motion in the absence of real motion. However, due to the differences between simulators and stereoscopic (3D) images in popular settings (e.g., theaters and home entertainment), viewers' experiences may differ. In order to fully understand the effects of stereoscopic (3D) images in popular settings further research is needed.

Researchers have categorized adverse symptoms due to stereoscopic (3D) images into groups such as visually induced motion sickness (VIMS) and visual fatigue (Kennedy, Drexler & Kennedy, 2010; Kuze & Ukai, 2008). Due to the enhanced image depth and motion of stereoscopic (3D) images, Kennedy et al. (2010) found that some individuals report visually induced motion sickness (VIMS). The most commonly reported symptoms of VIMS are nausea, vomiting, sweating, salivation, apathy, fatigue, stomach awareness, disorientation, dizziness, and incapacitation. These symptoms can occur despite the absence of significant physical motion. Visual fatigue or eyestrain can occur due to viewing both stereoscopic (3D) and standard format (2D) movies. Visual fatigue includes symptoms of eye pain, headaches, and tiredness (Kuze & Ukai, 2008). Some symptoms of visual fatigue and VIMS overlap, such as dizziness and eye pain. Although visual fatigue and visually induced motion sickness are two different conditions, they most likely share some biological mechanisms (Wilkins & Evans, 2010) in response to

stereoscopic (3D) viewing. Due to the similarities between visually induced motion sickness and visual fatigue it is difficult to fully attribute specific symptoms to one classification of symptoms.

Individual differences may contribute to the reporting of adverse symptoms due to stereoscopic (3D) images, most notably, abnormal binocular vision. Kim et al. (2013) found that participants with abnormal binocular vision experienced adverse symptoms (e.g., headaches, eye fatigue) after viewing 3D movies. The participants in this study had abnormal binocular vision and some of them had limited ability to view stereoscopic (3D) images. Participants viewed 3D television for 20 minutes and then were given a survey to assess the level of 3D perception and the amount of discomfort felt while viewing television in 3D. The individual's ability to view stereoscopic (3D) images directly affected how many adverse symptoms were reported. Participants with abnormal binocular vision who could not view the stereoscopic (3D) images reported fewer adverse symptoms than participants in the control group with normal vision. Most notably, participants with abnormal binocular vision who could view stereoscopic images (3D) reported more symptoms of visual fatigue than those in the control group with normal vision. This finding identifies abnormal binocular vision as an individual difference which may increase the reporting of adverse symptoms after viewing stereoscopic (3D) images.

Researchers have also found that anxiety may be an individual difference variable that increases the reporting of adverse symptoms after viewing stereoscopic (3D) images (Solimini, 2013; Solimini, Mannocci, Di Thiene, & La Torre, 2012). Solimini and his colleagues used a single self-report question to measure anxiety and retrospective questions regarding the 3D movie experience. Participants were asked about symptoms they felt while watching 3D movies that they had seen up to six months prior. The researchers found that individuals with higher self-

perceived anxiety levels reported more symptoms of VIMS, such as tired eyes and double vision after viewing 3D movies. These findings suggest that certain individuals may be predisposed to having stronger reactions to stereoscopic (3D) images. However, these studies used retrospective non-experimental methodologies (with a 6-month latency period), and psychometrically weak assessments and are thus limited in their ability to draw conclusions about causal effects of the 3D movie experience.

For most viewers, the symptoms related to stereoscopic (3D) images subside when the viewing ends, while for others the symptoms can persist. The existence and persistence of these symptoms may be due to a lack of ideal circumstances while viewing stereoscopic (3D) images. Bando, Iijima and Yano (2012) suggest that in order to prevent adverse symptoms, such as visual fatigue, the left and right eye images need to be carefully aligned, conflict between demands for focusing (e.g., vergence eye movement, lens accommodation) should be avoided, frequency of changes in binocular disparity should be restricted, and the viewer must have appropriate viewing distance. All of these conditions are unlikely to be met in popular 3D movie settings (e.g., movie theaters or home entertainment), suggesting that viewers could have adverse experiences.

The Current Study

In sum, the previous research indicates that stereoscopic (3D) images can have adverse physiological and psychological effects on viewers. However, there are limitations in the existing research. Specifically, the previous studies involving popular movies either focus on specific populations (i.e., participants with abnormal binocular vision) or used retrospective, non-experimental research designs and are limited in their implications for the general population. The existing experimental work has been limited to training environments (e.g., simulators) as

opposed to popular entertainment (e.g., movies). Although the previous experimental research focuses on training environments, the majority of the population views stereoscopic images in a popular movie setting. Further research in stereoscopic movies is needed in order to fully inform movie producers and movie viewers about the potential risks of adverse symptoms.

The current study utilized an experimental research design to directly study the psychophysiological effects of viewing stereoscopic (3D) movies compared to the standard (2D) format. It was predicted that the participants who viewed the movie in 3D would report more physiological symptoms on the Simulator Sickness Questionnaire (SSQ; Kennedy et al., 1993)than participants who viewed the movie in 2D. It was also predicted that the participants who viewed the movie in 3D would report more anxiety symptoms on the Brief State Anxiety Inventory (BSTA; Berg, Shapiro, Chambless & Ahrens, 1998) than participants who viewed the movie in 2D.

Method

Participants

Participants were 82 undergraduate students from a large public university in the Northeastern United States. Of those 82, 79 participants provided usable data. Two participants were excluded due to technical problems (3D glasses malfunctioned) and one participant was excluded because he did not follow directions in the study. The remaining participants ranged in age from 18 to 24 (M=18.74, SD= 1.09). The sample was 72.2% female. The participants' self-reported ethnicity was primarily Caucasian (73.4%). The remaining participants' self-reported ethnicities were Asian (6.3%), Hispanic/Latino (5.1%), African American (8.9%), Middle Eastern (1.3%) and other (5.1%). Participants were granted course credit for their participation in the study.

Design

The current study utilized a between-subjects experimental research design. The independent variable was the format of the movie. Participants viewed a 20-minute film segment in either the stereoscopic (3D) condition or standard (2D) condition. All participants viewed the same movie segment. Participants were randomly assigned to one of these conditions using a block randomization procedure.

Measures

Attitudes/Feelings Towards Stereoscopic (3D) Movies. The Attitudes/Feelings Towards Stereoscopic (3D) Movies (Morse, Sarno, & Horan, 2014) is a 15-item scale measuring attitudes towards stereoscopic (3D) movies. Items are rated on a five point Likert-type scale with anchors ranging from *strongly disagree* to *strongly agree*. Participants were asked to indicate the extent to which they agreed or disagreed with the scale items. The scale included items such as "I enjoy watching 3D movies" and "Watching movies in 3D makes me physically uncomfortable." After reverse scoring, higher scores indicate more favorable attitudes towards stereoscopic movies. In our sample, the Attitudes/Feelings Towards Stereoscopic (3D) Movies exhibited strong internal consistency with Cronbach's alpha = .89. The Attitudes/Feelings Towards Stereoscopic (3D) Movies measure was utilized as a covariate in a primary analysis of the first hypothesis.

Simulator Sickness Questionnaire. The Simulator Sickness Questionnaire (SSQ; Kennedy et al., 1993) is a 16-item scale measuring adverse symptoms while viewing stereoscopic images. Items are rated on a four point Likert-type scale with anchors ranging from *strongly disagree* to *strongly agree*. Participants were asked to indicate how much they experienced the scale items while watching the movie. The scale included items such as "general

discomfort" and "fatigue." Higher scores indicate more adverse symptoms while viewing stereoscopic movies. In our sample, the SSQ exhibited strong internal consistency with Cronbach's alpha = .89. The SSQ was utilized to assess physical symptoms in the primary analysis for the first hypothesis.

Intolerance for Physical Discomfort Questionnaire. The Intolerance for Physical Discomfort Questionnaire (IPDQ; Sirota et al., 2010) is a 14-item scale measuring levels for tolerance for uncomfortable physical sensations. Items are rated on a five point Likert-type scale with anchors ranging from *strongly disagree* to *strongly agree*. Participants were asked to indicate the extent to which they agreed or disagreed with the scale items. The scale included items such as "I can't stand feeling nauseous" and "It really bothers me to feel wet or clammy." Higher scores indicate more intolerance for physical discomfort. In our sample, the IDPQ exhibited strong internal consistency with Cronbach's alpha = .85. The IPDQ was utilized as a covariate in a primary analysis of the first hypothesis.

Anxiety Reactivity Perseveration Scale (part one: reactivity). The Anxiety Reactivity Perseveration Scale (part one: reactivity) (Rudaizky, Page, & MacLeod, 2012) is a 20-item scale measuring anxiety reactivity. Items are rated on a four point Likert-type scale with anchors ranging from *extremely unlikely* to *extremely likely*. Participants were asked to indicate how likely they were to experience the items when exposed to moderately stressful situations. The scale items included items such as "unpleasantness" and "I'm a failure." Higher scores indicate more anxiety reactivity. In our sample, the Anxiety Reactivity Perseveration Scale (part one: reactivity) exhibited strong internal consistency with Cronbach's alpha = .90. Based on previous research this measure was used to assess trait anxiety (Solimini et al., 2012). However, no significant differences were found and this measure was not utilized in the primary analyzes.

Anxiety Reactivity Perseveration Scale (part two: perseveration). The Anxiety Reactivity Perseveration Scale (part two: perseveration) (Rudaizky, Page, & MacLeod, 2012) is a 20-item scale measuring anxiety perseveration. Items are rated on a four point Likert-type scale with anchors ranging from *extremely briefly* to *extremely persistent*. Participants were asked to indicate how likely the items were to persist when exposed to situations that evoked the feelings listed. The scale items included items such as "unpleasantness" and "I'm a failure." Higher scores indicate more anxiety perseveration. In our sample, the Anxiety Reactivity Perseveration Scale (part two: perseveration) exhibited strong internal consistency with Cronbach's alpha = .91. Based on previous research this measure was used to assess trait anxiety (Solimini et al., 2012). However, no significant differences were found and this measure was not utilized in the primary analyzes.

Brief State-Trait Anxiety Inventory. The Brief State-Trait Anxiety Inventory (BSTA; Berg et al., 1998) is a 6-item scale measuring state and trait anxiety.Items are rated on a five point Likert-type scale with anchors ranging from *strongly disagree* to *strongly agree.* Participants were asked to indicate the extent to which they were feeling the items in the moment. The scale items included items such as "I feel relaxed" and "I feel strained." After reverse scoring, higher scores indicate more state anxiety. In our sample, the BSTA exhibited strong internal consistency with Cronbach's alpha = .86. The BSTA was utilized to assess psychological symptoms in the primary analysis for the second hypothesis.

HEXACO Personality Inventory Revised: Extraversion. The HEXACO Personality Inventory Revised: Extraversion (Ashton & Lee, 2009) is a 10-item scale measuring personality characteristic of extraversion. Items are rated on a five point Likert-type scale with anchors ranging from *strongly disagree* to *strongly agree*. Participants were asked to indicate the extent

to which they agreed or disagreed with the scale items. The scale items included items such as "I feel reasonably satisfied with myself overall" and "I rarely express my opinions in group meetings." After reverse scoring, higher scores indicate more extraversion. In our sample, the HEXACO Personality Inventory Revised: Extraversion exhibited strong internal consistency with Cronbach's alpha = .80. Based on a previous, unpublished study, extraversion was found to be related to 3D movie experiences, however it was not utilized in any of the primary analyzes.

HEXACO Personality Inventory Revised: Openness to Experience. The HEXACO Personality Inventory Revised: Openness to Experience (Ashton & Lee, 2009) is a 10-item scale measuring the personality characteristic of openness to experience. Items are rated on a five point Likert-type scale with anchors ranging from *strongly disagree* to *strongly agree*. Participants were asked to indicate the extent to which they agreed or disagreed with the scale items. The scale items included items such as "I would be quite bored by a visit to an art gallery" and "I'm interested in learning about the history and politics of other countries." After reverse scoring, higher scores indicate more openness to experience. In our sample, the HEXACO Personality Inventory Revised: Openness to Experience exhibited strong internal consistency with Cronbach's alpha = .78. Based on a previous, unpublished study, openness to experience was found to be related to 3D movie experiences, however it was not utilized in any of the primary analyzes.

Open-response. Participants were given an open-response space at the end of the questionnaire that stated to "please use this space to explain how you are feeling right now." Participants were able to indicate any symptoms they were feeling, their reactions to the movie, and any other feelings they had before or after the movie.

Procedure

The experiment took place in a small laboratory room with no more than two participants and a lab assistant in the room during a session. Participants were randomly assigned to a condition before they entered the lab. The true nature of the study was intentionally vague to control for demand effects; therefore, participants were told that they would participate in an experiment that would "investigate your preferences and reactions to popular movies." Participants were then administered a questionnaire and asked to fill out the first seven pages that included the Attitudes/Feelings Towards Stereoscopic (3D) Movies, Intolerance for Physical Discomfort Questionnaire, the Anxiety Reactivity Perseveration Scale (part one: reactivity and part two: perseveration), the Brief State-Trait Anxiety Inventory and the HEXACO Personality Inventory Revised for Extraversion and Openness to Experience. At the end of the seven pages they were directed to stop and wait for further instructions.

Following the first half of the questionnaire, the participants were seated approximately 48 inches from the TV as recommended by Samsung, to watch a 20-minute segment of a movie. Participants in the stereoscopic (3D) condition put on 3D glasses prior to the start of the movie. The movie that was chosen for the experiment was *Under the Sea* (Warner Bros., 2009). The movie was selected for its neutral genre and impressive scenes.

Participants watched the movie, uninterrupted, for 20 minutes. At the end of the segment the participants filled out the rest of the questionnaire that included the Simulator Sickness Questionnaire, the Brief State-Trait Anxiety Inventory, demographics, and an open response section. Participants were then debriefed and credited for their participation.

Results

Descriptive Statistics and Correlations

Table 1 outlines the descriptive statistics for the questionnaire items. Of the 79 valid participants, 48 (60.8%) participants indicated they had seen a 3D movie in the past year. This finding was evenly distributed between the two conditions (2D vs. 3D). The average number of 3D movies seen was 2.58 (*SD*=1.98). The average score for items on the Attitudes/Feelings Towards Stereoscopic (3D) Movies Scale was 3.04 (*SD*=0.75), which is slightly above the midpoint of the response scale indicating generally positive overall feelings. The average sum of scores on the Simulators Sickness Questionnaire (SSQ) was 8.38 (*SD*=7.43) indicating most participants reported some level of discomfort while viewing the movie.

Table 2 shows the correlations and reliabilities for the questionnaire items. The Attitudes/Feelings Towards Stereoscopic (3D) Movies scale was strongly correlated with the SSQ, $r(77) = -.28$, $p = .013$, indicating the more favorable attitudes/feelings towards 3D movies the less likely viewers are to report adverse physical symptoms. The Attitudes/Feelings Towards Stereoscopic (3D) Movies scale was also strongly correlated with the number of 3D movies seen, $r(49) = .37$, $p = .008$, and how likely participants were to see a 3D movie in the future, $r(77) = .64$, $p < .001$, indicating that more favorable attitudes/feelings towards 3D movies were associated with higher counts of 3D movies seen and likelihood of seeing a 3D movie in the future.

Figure 3 shows the responses to the Simulator Sickness Questionnaire (SSQ) by condition. The differences in frequency of response for symptoms of general discomfort, headache, eye strain, increased salivation, nausea, fullness of head, blurred vision, dizziness with eyes open, dizziness with eyes closed, vertigo and stomach awareness were all greater in the 3D

condition outside one standard error. There were no significant differences between the groups for symptoms of difficulty focusing and difficulty concentrating.

Figure 4 outlines the open-ended participant responses from the end of the questionnaire. Participants reported common symptoms after viewing the movie. Symptoms of eye issues were reported by 3.8% of the participants in the 2D condition and by 11.39 % of the participants in the 3D condition. Symptoms of headaches were reported by 7.59% of the participants in the 2D condition and by 12.66% of the participants in the 3D condition. Feeling relaxed was reported by 32.9 % of the participants in the 2D condition and by 18.99% of the participants in the 3D condition.

Hypothesis Tests

The first hypothesis predicted that participants who viewed the movie in 3D would report more physiological symptoms on the Simulator Sickness Questionnaire (SSQ) than participants who viewed the movie in 2D. In order to examine the effects of stereoscopic images on physical symptoms, a multivariate analysis of covariance (MANCOVA) was utilized to analyze the effects of movie condition (3D vs. 2D) on the nausea, ocular discomfort, and disorientation dimensions of the SSQ. The three dimensions of the SSQ were used to provide a more in depth analysis of the types of symptoms affected. Participants' self-reported attitudes and experiences with 3D movies and (in)tolerance for physical discomfort were used as covariates. A significant multivariate effect was found for movie condition, $F(3, 73) = 2.79$, $p = .047$, Wilkes' Lambda = .90, as well as both covariates, attitudes and experiences with 3D movies ($F(3, 73) = 2.89$, $p = .041$, Wilkes' Lambda = .90) and (in)tolerance for physical discomfort ($F(3, 73) = 3.06$, $p = .034$, Wilkes' Lambda = .89).

There were significant univariate effects for the ocular discomfort and disorientation dimensions of the SSQ and both covariates were also significant at the univariate analysis. After controlling for attitudes and experiences with 3D movies and intolerance for physical discomfort, there was a significant effect of movie condition on ocular discomfort, $F(1, 75) = 6.55$, $p = .013$, partial $\eta^2 = .08$, such that participants in the 3D condition reported significantly higher levels of ocular discomfort (M=6.82, SD=4.52) than participants in the 2D condition (M=4.60, SD=3.59). Further, after controlling for attitudes and experiences with 3D movies and intolerance for physical discomfort, there was a significant effect of movie condition on disorientation, $F(1, 75) = 7.94$, $p = .006$, partial $\eta^2 = .10$, such that participants in the 3D condition reported significantly higher levels of disorientation (M=4.82, SD=4.54) than participants in the 2D condition (M=2.55, SD=2.94). However, there was no significant effect of movie condition on the nausea dimension, $F(1, 75) = 1.98$, $p = .164$. Overall, these findings support Hypothesis 1.

The second hypothesis predicted that participants who viewed the movie in 3D would report more anxiety symptoms on the Brief State Anxiety Inventory than participants who viewed the movie in 2D. The Brief State-Trait Anxiety measures were used to examine the relationship between anxiety and viewing stereoscopic images. The Brief State-Trait Anxiety pre measure was used to measure trait anxiety, whereas the Brief State-Trait Anxiety post measure was used to measure state anxiety. There were no significant relationships between trait anxiety, the film condition or the SSQ. Additionally, there were no significant differences on the Brief State Anxiety post measure between the 3D condition (M=2.09, SD=0.77) and the 2D condition (M=1.91,SD=0.76); $t(77) = 1.08$, p =285. However, the Brief State Anxiety post measure was strongly correlated with the SSQ, $r(77) = .50$, $p < .001$, indicating the more state anxiety

participants reported the more physical symptoms they reported. Since there were no significant differences between the 3D and 2D conditions these findings only partially support Hypothesis 2.

Discussion

The purpose of the current study was to examine the psychological and physiological symptoms of viewing stereoscopic (3D) movies. Overall, the results supported the hypothesis that participants who viewed the film in the stereoscopic (3D) condition would report more physiological symptoms than participants who viewed the same film in the standard (2D) format. Additionally, the results partially supported the hypothesis that participants who viewed the film in the stereoscopic (3D) condition would report more psychological symptoms than participants who viewed the same film in the standard (2D) format.

The results from this study support the first hypothesis by demonstrating that movie condition (3D vs. 2D) has a significant effect on the amount of physiological symptoms (i.e., ocular discomfort, disorientation) reported after viewing a 20 minute segment of a movie. Originally, Kennedy et al. (1993) established that stereoscopic (3D) images in training environments can cause adverse physical symptoms, such as general discomfort, nausea, headache, eye strain, and difficulty focusing. The major difference between Kennedy et al.'s findings and the findings of the present study was the dimensions (i.e., nausea, ocular discomfort and disorientation) of symptoms reported. Kennedy et al. found that participants significantly reported symptoms in all three dimensions of the Simulator Sickness Questionnaire in response to stereoscopic (3D) images in training environments. However, the present study found that participants only reported significantly more symptoms in the ocular discomfort and disorientation dimensions of the Simulator Sickness Questionnaire after viewing the stereoscopic movie but not the nausea dimension. The symptoms of the ocular discomfort and disorientation

dimensions were still reported significantly more in the 3D condition than the 2D condition even after controlling for (in)tolerance for physical discomfort and attitudes and experiences with 3D movies. These results indicate that even the most resilient movie watchers who love the 3D movie experience will still report significantly more adverse physical symptoms after viewing a movie in 3D rather than in 2D. This finding demonstrates the profound physical effects that stereoscopic (3D) images may have on movie viewers. It is interesting to note that the participants in the 3D condition did not report more symptoms of the nausea dimension than participants in the 2D condition, suggesting 3D movies do not affect feelings related to nausea. This difference highlights the importance of examining stereoscopic images in different settings (i.e., training environments, popular settings). In all, these results suggest that viewing a movie in 3D accounts for a significant amount of the variability in feelings of ocular discomfort and disorientation, even after controlling for individual differences in attitudes and experiences with 3D movies and self-reported intolerance for physical discomfort.

The present study also provided further insight into the reporting of psychological symptoms after viewing stereoscopic (3D) images. Although Solimini et al. (2013) used a non-experimental research design, they indicated that trait anxiety may be an individual difference that affects the reporting of symptoms while viewing stereoscopic images. Utilizing a single self-report question, they found that individuals with higher self-perceived anxiety levels report more symptoms of visually induced motion sickness (VIMS) after viewing 3D movies. The present study utilized the 6-item Brief State-Trait Anxiety (BSTA) scale for a pre (trait) and post (state) measure of anxiety. The results partially supported the hypothesis that participants who view the movie in the 3D condition would report more psychological symptoms than participants who view the same film the 2D condition. The post BSTA was significantly correlated with the

Simulator Sickness Questionnaire (SSQ), indicating the more state anxiety reported after viewing the movie, the more adverse physical symptoms were reported. However, there was no relationship between the SSQ and state or trait-level anxiety measured prior to the manipulation. This lack of a relationship prior to manipulation followed by a significant relationship after manipulation suggests trait anxiety does not predispose people to adverse 3D movie effects but is actually an effect of watching the movie itself. It is difficult to draw causal conclusions from this result, as state anxiety may lead to more physical symptoms, physical symptoms may lead to more state anxiety, or there could be a third variable affecting both. Therefore, the relationship between anxiety and adverse physical symptoms after viewing stereoscopic images should be further explored.

Future studies should utilize a physical measure of anxiety in order to ascertain an additional measure of state anxiety. The current study only utilized a brief self-report measure of state anxiety. A physical measure of anxiety may demonstrate a more accurate report of the participant's state anxiety while viewing the movie. This type of measure may show an effect that the present study missed. A possible reason for increased anxiety during stereoscopic movies may be the increased level of immersion. Slater & Wilbur (1997) suggested that the level of immersion of movies may cause viewers to have stronger emotional responses (e.g., anxiety). Due to the possible effect of stereoscopic images on anxiety, other psychological symptoms should be further explored such as executive functioning.

Limitations

The current study only utilized participants who were students at a large university. Future studies should attempt to obtain data from participants from the general population. There may be a potential age effect which would be interesting to study. Based on an earlier,

unpublished pilot study, Morse, Sarno, and Horan (2014) found that age acted as an entry barrier to viewing 3D movies, but once older individuals had seen at least one 3D movie, age was no longer related to the likelihood of seeing another 3D movie or preferences for 3D movies. However, other age effects for 3D movies may be uncovered due to age-related changes in visual acuity. Using more diverse age samples will demonstrate greater external validity and generalize better to the population. Other limitations of this study include the length of the movie segment viewed and the screen size of the television. Participants only viewed a 20 minute segment of the movie on a relatively small television screen (32-inch). The full effect of stereoscopic images on psychophysiological symptoms may be underestimated by only viewing a short segment of the movie on a smaller screen. Using longer movie segments on larger televisions screens and/or in a movie theater may show a larger effect than the present study.

Future Directions

Based on the differences between the present study and Kennedy et al., further research should also explore other types of stereoscopic images in different popular settings. We found that there are differences in the reporting of symptoms between simulators and popular movies, therefore there may be differences between popular movies viewed on T.V. compared the big screen or other technologies such as video games. The viewer's experience while watching movies in the theater instead of at home at are extremely different (i.e., noise level, size of screen) and lead to higher levels of immersion. The same is true for video games, the viewers are able to manipulate the stereoscopic (3D) images they are viewing therefore they have higher levels of immersion. Varying movie genres should also be used in future research studies. It is possible that certain genres will elicit more or less adverse symptoms than others. In the present study we only looked at a nature movie, future research should examine other genres such as

action, comedy and children's movies. Exploring different stereoscopic (3D) images settings will help to further explain the relationship between stereoscopic (3D) images and the reporting of adverse symptoms.

Conclusion

Adverse symptoms (i.e., ocular discomfort, disorientation) are reported by many viewers watching non-standard forms of movies (Ujike, Ukai, & Nihei, 2008). However, previous research has been limited to training environments, individual differences and non-experimental research designs (Kennedy et al., 1993; Kim et al., 2013; Solimini et al., 2012). The current study utilized an experimental research design to examine the effect stereoscopic (3D) movies on the adverse psychophysiological symptoms reported by viewers. The results of the study demonstrated that stereoscopic movies cause significantly more adverse physical symptoms than the standard movie format. Furthermore, the results established that the stereoscopic movie viewers only reported significantly more symptoms of ocular discomfort and disorientation, but no nausea. It is important to note that participants in training environments report symptoms of ocular discomfort, disorientation and nausea. This finding highlights the importance of studying stereoscopic images in different settings. In conclusion, the current study represents the first attempt to manipulate the effects of 3D movies in an experimental setting, and the results provided ample opportunities for further research in the field.

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Table 1
Study 1. Descriptive Statistics

Variable	*N*	Mean	*SD*	Median	Possible Range	Actual Range	Skewness
3D movies seen total	51	2.58	1.98	2.00	0.00 - ∞	1.0-13.00	2.77
Likelihood of seeing a 3D movie in the near future	79	1.75	1.08	2.00	0.00-4.00	0.00-4.00	0.40
Attitudes/Feelings Towards Stereoscopic (3D) Movies	79	3.04	0.75	3.00	1.00-5.00	1.40-4.80	-0.01
Simulator Sickness Questionnaire	79	8.38	7.43	6.00	0.00-48.00	0.00-32.0	1.54
Intolerance for Physical Discomfort Questionnaire	79	3.767	0.61	3.86	1.00-5.00	2.00-4.86	-0.41
Anxiety Reactivity Perseveration Scale (part 1: reactivity)	79	2.42	0.48	2.4	1.00-4.00	1.15-3.90	0.27
Anxiety Reactivity Perseveration Scale (part 2: perseveration)	79	2.02	0.52	2.10	1.00-4.00	1.00-3.65	0.39
Brief State –Trait Anxiety Inventory (pre)	79	2.10	0.71	2.00	1.00-5.00	1.00-4.33	0.85
Brief State –Trait Anxiety Inventory (post)	79	2.00	0.76	2.00	1.00-5.00	1.00-3.83	0.52
Extraversion	79	3.51	0.61	3.50	1.50-5.00	1.50-4.70	-0.41
Openness to Experience	79	3.14	0.67	3.00	1.80-5.00	1.80-4.70	0.47

Table 2
Study 1. Correlations and Reliabilities

Variable	1	2	3	4	5	6	7	8	9	10	11
1. 3D movies seen total	--										
2. Likelihood of seeing a 3D movie in the near future	.22	--									
3. Attitudes/Feelings Towards Stereoscopic (3D) Movies	.37**	.64**	.89								
4. Simulator Sickness Questionnaire	.28*	-.35**	-.28*	.89							
5. Intolerance for Physical Discomfort Questionnaire	.06	.02	.01	.28*	.85						
6. Anxiety Reactivity Perseveration Scale (part 1: reactivity)	.10	.10	.04	.19	.42**	.90					
7. Anxiety Reactivity Perseveration Scale (part 2: perseveration)	.04	-.01	-.03	.13	.26*	.76**	.91				
8. Brief State –Trait Anxiety Inventory (pre)	-.08	-.16	-.22	.18	.17	.36**	.33**	.78		.	
9. Brief State –Trait Anxiety Inventory (post)	.13	-.26*	-.12	.50**	.19	.18	.23*	.35**	.86		
10. Extraversion	.01	.20	.16	-.14	-.23*	-.48**	-.47**	-.32**	-.12	.80	
11. Openness to Experience	.15	-.07	-.13	-.10	-.12	-.13	-.08	.10	.04	-.08	.78

Note. Values in the diagonal are Cronbach's Alpha (reliability) for the scales

*$p < .05$; ** $p < .01$

Figure 1. *Avatar* (Twentieth Century Fox Film Corporation, 2009) (Anaglyph)

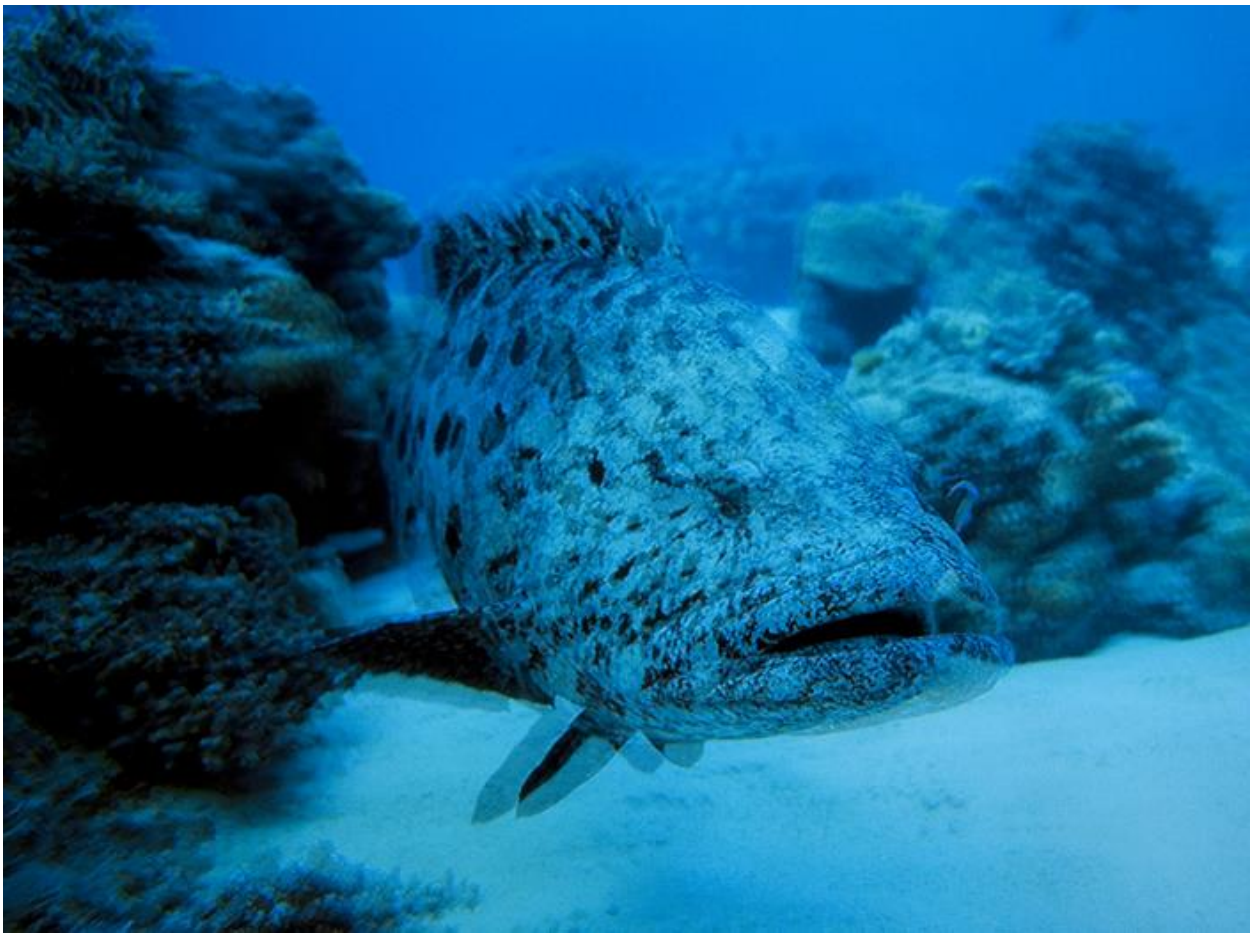

*Figure 2***.** *Under the Sea* (Warner Bros., 2009) (Polarized)

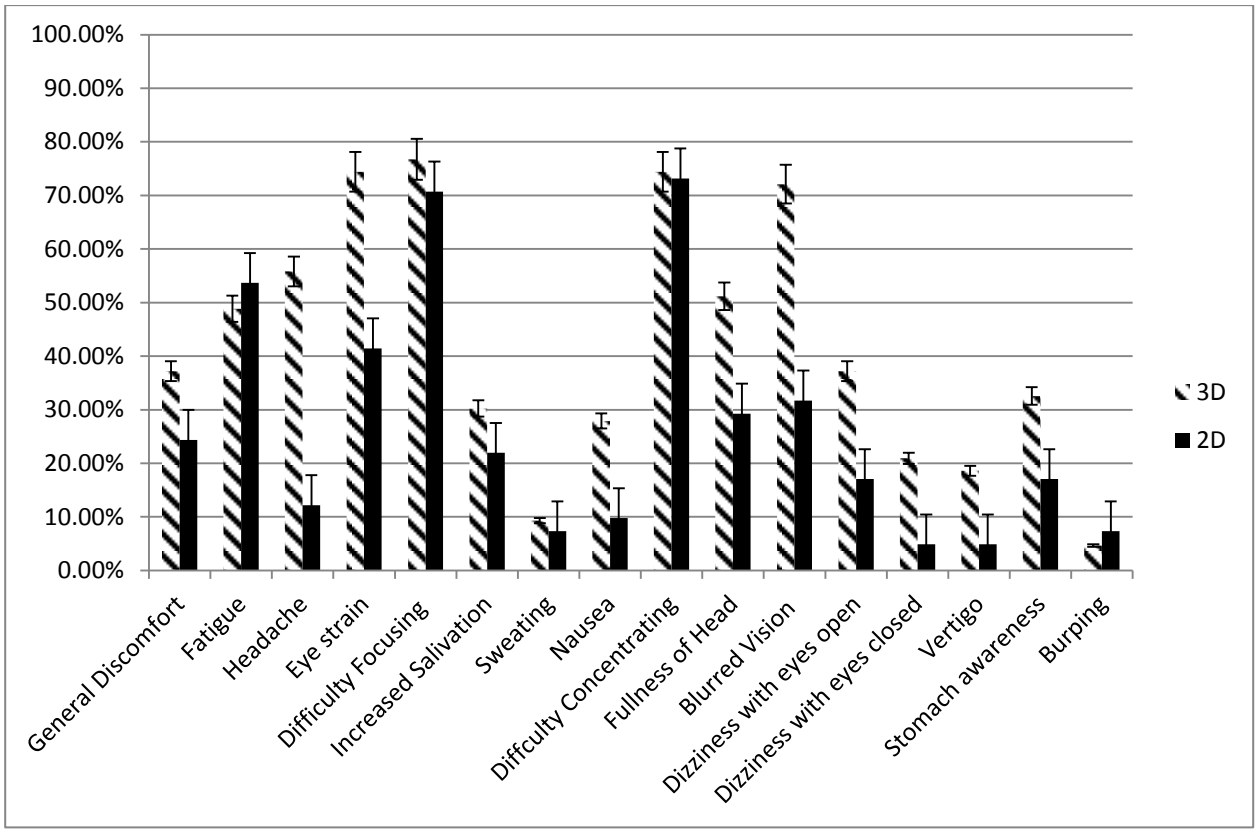

*Figure 3***.** Simulator Sickness Questionnaire Responses

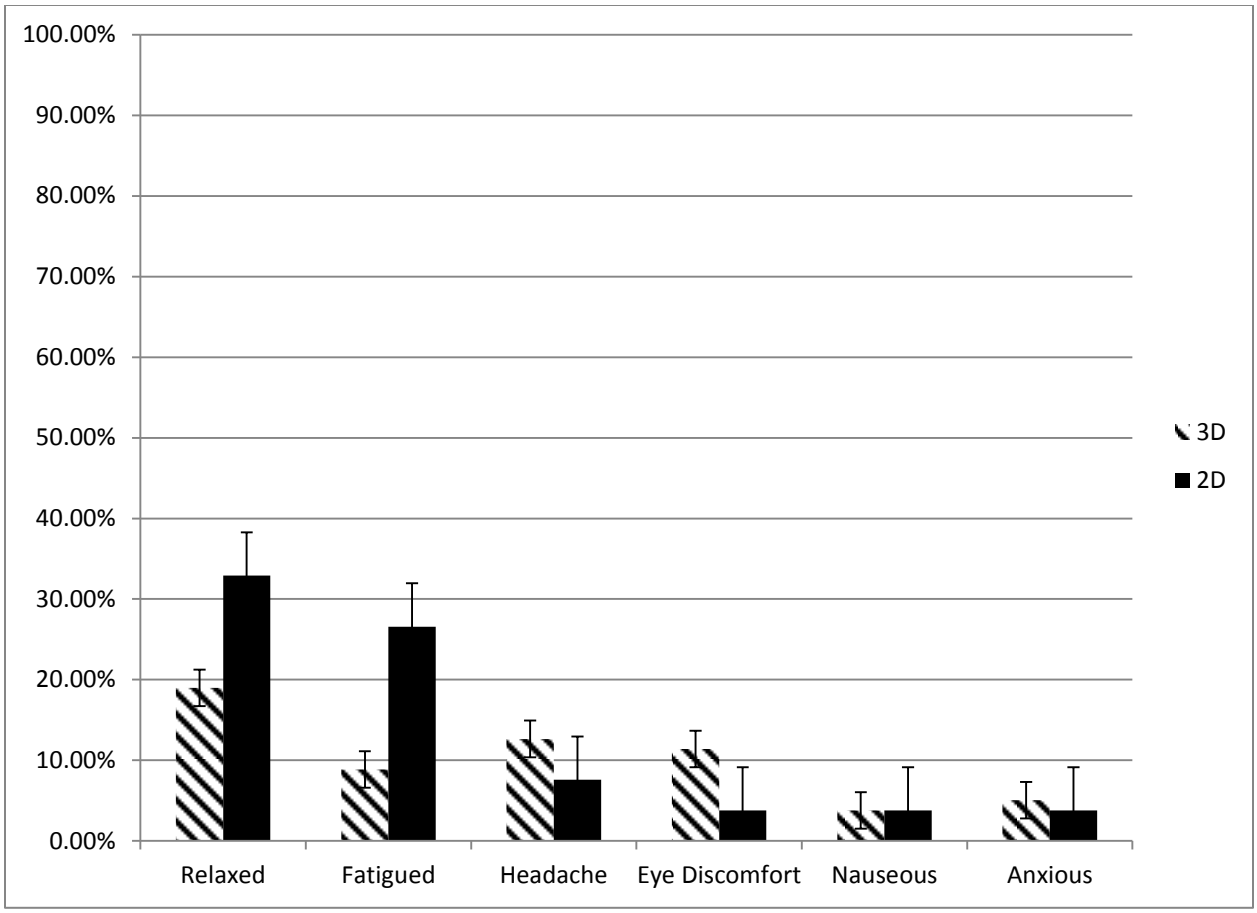

Figure 4. Open-Ended Participant Responses