CYBER (MOTION) SICKNESS IN ACTIVE STEREOSCOPIC 3D GAMING

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ABSTRACT

Mass-market stereoscopic 3D gaming has recently become a reality on both gaming consoles and PCs. At the same time the success of devices such as the Nintendo Wii, Nintendo Wii Balance Board, Sony Move and Microsoft Kinect have made active movement of the head, limbs and body a key means of interaction in many games. We hypothesized that players may be more prone to cybersickness symptoms in stereoscopic 3D games based on active movement compared to similar games played with controllers or other devices, which do not require physical movement of the body with the exception of the hands and fingers. Two experimental games were developed to test this hypothesis while keeping other parameters as constant as possible. For the disorientation and oculomotor cybersickness subscales and the overall score of the Simulator Sickness Questionnaire, a significant interaction between display mode (S3D versus non-stereoscopic) and motion sickness susceptibility was found. However, contrary to our hypothesis, there was no indication that participants were particularly susceptible to cybersickness in S3D motion controller games.

Index Terms— Stereoscopic 3D, computer games, cybersickness, simulator sickness, motion parallax.

1. INTRODUCTION

Active movement tracking and control (using the Microsoft Kinect or Nintendo Wii for example) is an increasingly popular interaction paradigm for computer gaming. At the same time there has been increasing opportunity for and use of stereoscopic 3D (S3D) display in games. Stereoscopic 3D computer games rely on technology to present different image sequences to the left and right eyes of the viewer. This binocular presentation enables game designers to enhance the sense of depth and space in their virtual worlds through binocular stereopsis. Both active gaming and stereoscopic display promise to provide a more compelling, immersive or natural gaming experience. We hypothesized while active motion control in stereoscopic gaming may increase the sense of self-motion and agency in the game, it may at the same time also increase the effects of discrepancy between physical motion and simulated motion. Discrepancy between physical and simulated motion has been linked with increasing sensitivity to vertigo, oscillopsia [1] (a visual disturbance in which objects in the visual field appear to move or oscillate) and cyber or simulator sickness [2], [3].

In typical games based on motion sensing, players move their limbs, head and/or body to make gestures to control the game. These gestures are often linked to the movements the players intend their avatar to perform. For instance in Wii Sports (Nintendo Corp. 2006), one of the earliest popular motion-based games, one can swing the Wii-mote to have the avatar swing the bat in baseball. Devices that enable or require vigorous or full body motion such as the Kinect or the Wii balance board are often associated with considerable head movement during the game play. Unlike head-tracked immersive virtual reality [4], the head is typically not precisely tracked and thus the rendered view is not closely linked to the head position or orientation.

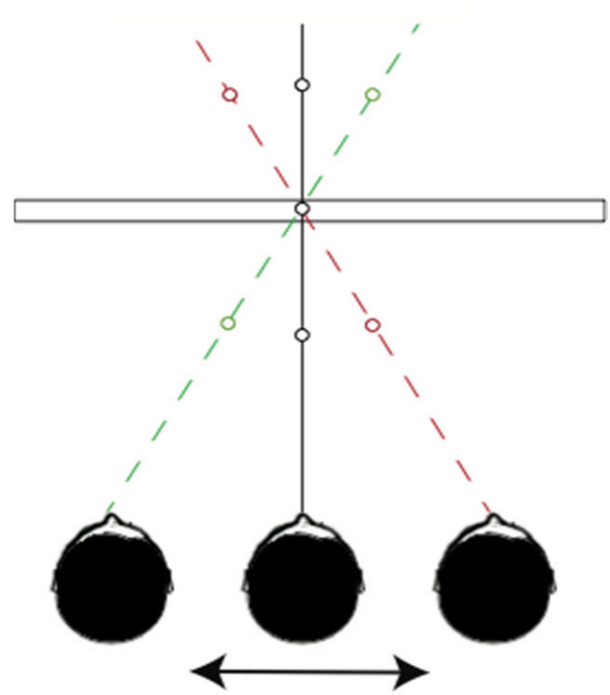

Fig. *1* Illusory motion parallax produced when the head moves relative to a non-head-tracked stereoscopic display.

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It is well known that movement of an observer's head relative to a stereoscopic 3D (S3D) display produces illusory motion parallax. This parallax is often experienced as distorted, shearing or rubbery scenes. This perception can be understood by noting that, when the observer's head is not tracked to produce the vantage point for the virtual camera then the head movement is not accompanied by the change in parallax that is normally associated with a change in vantage point; the brain interprets this lack of parallax as motion in the scene. For example, consider stereoscopic display of three objects aligned in a central view as represented by the black circles in Fig *1*. As these objects are lying in the same direction, the average of the left and right views of all the objects have the same horizontal pixel coordinate (or a direction corresponding to the black line). If the head moves to the left or right, then since the pixel positions do not change, the objects should still appear to lie in the same direction relative to the head. Thus the positions of the objects should appear to shear in space (red and green circles for right and left head positions, respectively). We hypothesized that this non-rigid shearing of the world may be disturbing and result in increased cybersickness.

In this paper we seek to assess 1) whether players are more susceptible to simulator sickness in S3D versus non-stereoscopic 3D games and 2) whether active motion exacerbates cybersickness (versus passive seating) more in S3D viewing than in 2D.

2. METHODS

We compared the effects of S3D viewing on motion sickness for passive (gamepad) and active motion game control (Kinect). The hypothesis was that persons playing an S3D game would be more susceptible to motion sickness when using motion-based control compared to traditional game controller interaction.

2.1. Game Scenario

Two experimental games were designed using Unreal development kit (UDK, Epic Games Inc., http://www.unrealengine.com/udk/). The gameplay was simple but the games included scenes of modest complexity, and rendering and interaction quality were typical of commercial games. The Stereoscopic 3D rendering was produced by TriDef 3D software (http://www.tridef.com/).

Table *1* Controls for the games *Rocks* and *Forward*. The shooting action in the game *Rocks* as well as the acceleration action in the game *Forward* were controlled using the gamepad even when played with Kinect.

Body Movements	Gamepad controls	Vehicle Action
Jump	Button 1	Jumps
Translate/ lean left	Arrow left	Moves left
Translate or lean right	Arrow right	Moves right

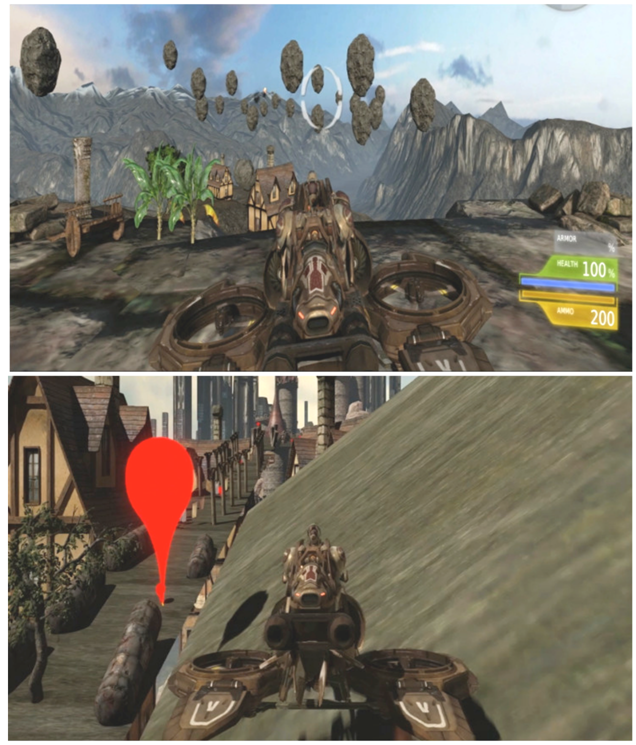


Fig. *2* Screenshots of the *Rocks* (top) and *Forward* (bottom) games used in this study.

The first game (the *Rocks* Game) was a shooting game, where players had to hit static targets using a weapon fixed to their combat vehicle (see Fig *2*a). The vehicle could move laterally (left/right), jump and shoot straight-ahead.

The second game (the *Forward* game) was a variation of a racing game, where players had to drive a vehicle along a rough elevated track avoiding obstacles and obtaining goals by intercepting them with the vehicle. To succeed they had to avoid obstacles, stay on the track and collect red targets (see Fig *2*b).

In both games vehicle orientation was fixed because it is known that fast camera rotation in gaming can generate motion sickness [5] and we wished to control and eliminate this factor.

Shooting and forward travel actions were triggered by pressing a gamepad button in all cases. The experimental manipulation was to vary the means of controlling the lateral and up-down motion of the vehicle (Table *1*). For both the *Rocks* and the *Forward* games the player controlled the vehicle motion using either:

1. Active motion. Using the Kinect, the players performed three body movements to play. Moving the head Left/Right moved the vehicle laterally in the respective direction and jumping made the vehicle go up. The vehicle returned to the ground by simulated gravity.

2. Gamepad control. In the gamepad condition these actions were assigned to specific gamepad axes/buttons.

2.2. Apparatus

The games were played on a Panasonic VT25 HD3D TV connected to a PC (equipped with two Nvidia GeForce GTX560 in SLI) that provided for a high-performance S3D gaming platform (relative to the current state-of-the-art at the time).

In all cases subjects viewed the television from a distance of approximately 2 m through the Panasonic 3D glasses provided with the television. In some cases the rendering was not stereoscopic (see Procedure) but in all cases the glasses were used. In non-stereoscopic presentations identical images were presented to both the left and right eyes.

In some conditions, the player's body was tracked in real time using a Microsoft Kinect motion tracker (http://www.microsoft.com/en-us/kinectforwindows/). The subject was positioned at the appropriate distance and gesture data from the Kinect was converted to actions in the game using the Flexible Action and Articulated Skeleton Toolkit (FAAST) (http://projects.ict.usc.edu/mxr/faast/). For each of the two games, we defined several body movements that were equivalent to the gamepad button hits (see Table 1). Two actions were triggered using a gamepad even when a Kinect was in use, those are: shooting in the "Rocks" game and acceleration in the "Forward" game. We opted for this strategy in order to avoid body movement combinations (for example: Translating left to move the vehicle and leaning forward to accelerate) that were complex to manage with our participants.

In addition to what the Kinect can offer in terms of body control of the game, it also has a considerable latency (approximately 90 ms according to Microsoft) that may influence the study results. In our case, we consider the latency time as part of the Kinect and present our results specifically for this hardware.

Symptoms	Rating			
	None	Slight	Moderate	Severe
S1. General Discomfort	0	1	2	3
S2. Fatigue	0	1	2	3
S3. Headache	0	1	2	3
S4. Eyestrain	0	1	2	3
S5. Difficulty focusing	0	1	2	3
S6. Increased Salivation	0	1	2	3
S7. Sweating	0	1	2	3
S8. Nausea	0	1	2	3
S9. Difficulty concentrating	0	1	2	3
S10. Fullness of head	0	1	2	3
S11. Blurred vision	0	1	2	3
S12. Dizziness (eye open)	0	1	2	3
S13. Dizziness (eye closed)	0	1	2	3
S14. Vertigo	0	1	2	3
S15. Stomach awareness	0	1	2	3
S16.Burping	0	1	2	3

Fig. *3* Simulator Sickness Questionnaire (SSQ).

The players used a Logitech WingMan Cordless gamepad to control the forward speed, shoot and in some cases steer the vehicle.

2.3. Procedure

Half of the players were assigned to play the game with Microsoft Kinect while the other half played with a game pad.

All participants played both the *Rocks* and *Forward* games with the order randomized for each player. Each game was played for a timed 15-min period with levels advanced or the game restarted if a level was completed before 15 minutes.

The experiment involved 4 conditions and the participants were randomly assigned to participate in one of these four groups:

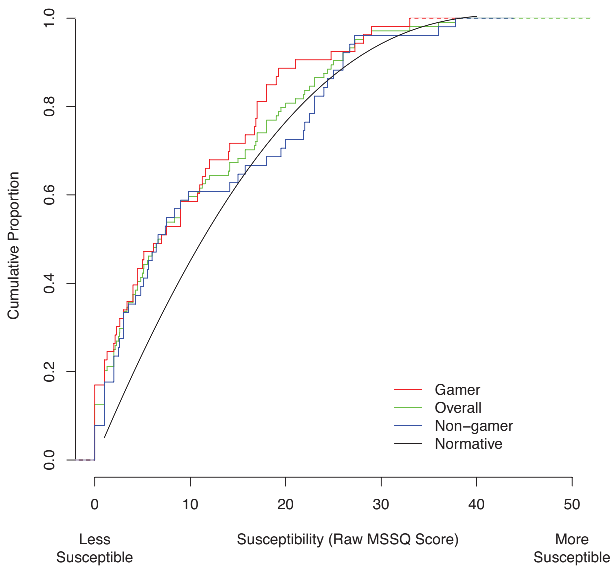
1. **Kinect S3D:** Participants played the 2 games in S3D using Kinect in a standing position.
2. **Kinect 2D:** Participants played the 2 games in non-stereoscopic mode using Kinect in a standing position.
3. **Gamepad S3D:** Participants played the 2 games in S3D using a gamepad in a sitting position.
4. **Gamepad 2D:** Participants played the 2 games in non-stereoscopic mode using a gamepad in a sitting position.

Participants were asked to fill out the Simulator Sickness Questionnaire [6] three times, once before starting play, again after the first game, and finally after the second game. The Questionnaire included 16 symptoms as shown in Fig. *3*. The participants reported the degree to which they experienced each of the symptoms, they scored the symptoms as 0 for no effect, 1 for slight effect, 2 for moderate effect and 3 for severe effect.

These weighted SSQ questionnaire scores were combined into Nausea (N), Oculomotor (O) and Disorientation (D) factor scores [6]. Each of these sub-scores was calculate as a sum of responses to selected questions related to the particular factor. These factors were in turn combined into a total weighted SSQ scores (TSC).

Subjects self-reported whether they considered themselves gamers. Before playing the game subjects also completed a short questionnaire that queried their susceptibility to motion sickness known as the short version Motion Sickness Susceptibility Questionnaire (MSSQ-Short) [7], [8] as well another short questionnaire querying the amount of habitual computer, mobile and gaming use; preferred game genres; level of skill in computer games; and experience with 3D movies.

The MSSQ-Short asks about experience with motion sickness in various scenarios both as children and as adults (Cars; Buses or Coaches; Trains; Aircraft; Small Boats;



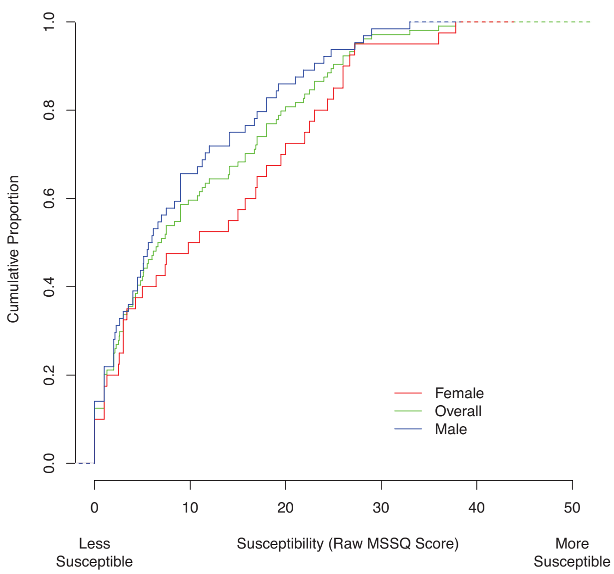


Fig. *4* Cumulative distribution of MSSQ-Short scores. Top panel shows data for gamers and non-gamers along with the total participant pool and normative data from Golding, 2006 [8]. Bottom panel shows data for male and female participants along with the total participant pool.

Ships; Swings in Playgrounds; Roundabouts in Playgrounds; and Rollercoasters/ Amusement Park Rides). The responses were weighted as 0, 1, 2, and 3 for never felt sick, rarely felt sick, sometimes felt sick and frequently felt sick, respectively, summed to obtain a raw MSSQ-Short (susceptibility) score with correction for scenarios not experienced, and converted to a percentile MSSQ-Short score using a polynomial model of the normative data [8].

2.4. Participants

Subjects were recruited using advertisements or the Undergraduate Research Participant Pool of York University. The total number of tested participants was 104 (40 female). As we had four groups this resulted in 26 players assigned to each group (with half in each group playing *Rocks* first and the other half playing *Forward* first). Subjects were all university students and ranged in age from 17 to 50 with a mean age (± SD) of 23±4.5, 24±6.1, 26±8.6, 23±5.5 in the Kinect-3D, Kinect-2D, Gamepad-3D and Gamepad-2D groups, respectively. The study was conducted under a human participants ethics protocol approved by York University.

3. RESULTS

3.1. Survey results

The four test groups were fairly similar in terms of media experience and gaming interest and experience. There were 14 players (of 26) who considered themselves as gamers in the Kinect-3D, Gamepad-3D and Gamepad-2D groups and 11 self-identified gamers in the Kinect-2D group. Only a few (2-4) participants in each group concerned themselves expert gamers. Participants preferred a range of gaming genres with first-person shooters, role-playing, action and racing games most popular. A preference for motion gaming was not typical and less than 1/3 of players reported playing motion-based games on the Nintendo Wii, Sony Move, or Microsoft Kinect. Experience with S3D movies was modest with all participants but one reporting watching 3D movies at most a few times and 33% had never seen a 3D movie.

Fig. *4* shows the distribution of motion sickness susceptibility (MSSQ-Short) scores across our participant pool. The top graph shows that our participants on average had lower motion sickness susceptibility reports than the normative data of [8] which is reflected in the shifts of the curves to the left (lower MSSQ-Short). Also plotted, as red and blue respectively, are the gamer and non-gamer sub-populations. There was a tendency for our gamers to be less susceptible to motion sickness (as reflected in the MSSQ-Short) than the non-gamers.

Similarly the bottom graph shows MSSQ-Short score distribution for men and women in our sample and our data are consistent with previous reports that women are more susceptible to motion sickness than men [9]. Interestingly we found that male gamers tended to be *more* susceptible to motion sickness than non-gamers while, in contrast, female gamers were *less* susceptible to motion sickness than non-gamers. It would be interesting to follow this observation up with a larger sample of male and female gamers and non-gamers. Mean average MSSQ-Short converted to normative percentiles were 32.5, 42.7, 47.4 and 37.8, for the Kinect-2D, Kinect-3D, Gamepad-2D and Gamepad-3D conditions respectively. As MSSQ-Short score varied between

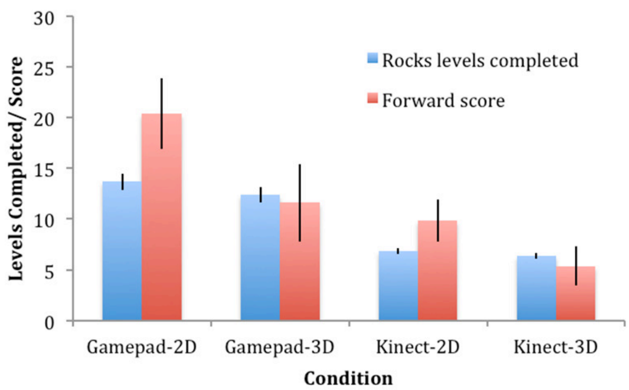


Fig. *5* Performance comparison between the different conditions.

individuals and groups it was included as a covariate in the analysis of the cybersickness (SSQ) data in the experiments.

3.2. Game performance

Game performance was assessed to compare the difficult of the conditions. For the *Forward* game players got rewarded for completing a level and penalized for falling off of the path and having to restart. The players were awarded 20 points for each level they reached and penalized 1 point for falling off of the road. Note that negative scores are possible especially if a level was not completed. For the *Rocks* game players were awarded a point for every level they completed (range 3 to 22). Game performance in the *Rocks* game was similar for S3D and non-stereoscopic display and was slightly poorer in the Kinect compared to the gamepad conditions. For the *Forward* game players seemed to find the S3D conditions more difficult than the non-stereoscopic conditions and the Kinect control more difficult than the gamepad (Fig. *5*).

3.3. SSQ Responses

Using the data from the Simulator Sickness Questionnaire, we calculated the scale scores for Nausea (N), Oculomotor (O) and Disorientation (D) factors as well as the weighted SSQ scores (TSC). Details of these calculations are provided in the Appendix. Prior to testing, most subjects reported very weak cybersickness ratings as expected but note that even prior to testing SSQ ratings were not zero. Scores generally increased during the testing but cybersickness symptoms were typically mild when reported with no or mild symptoms reported throughout the testing and with more intense symptoms reported occasionally. The scores in the first and second games were highly correlated as shown in Fig. *6* for the TSC score. Correlations between the scores after the first and second game were 0.72, 0.82, 0.80 and 0.85 for the N, O, D and TSC scores (all significantly different from zero). There were also smaller but typically significant correlations between scores prior to testing and after the first and second games (correlations ranged from 0.04 to 0.29). Correlations between motion sickness susceptibility (MSSQ-Short) and the cybersickness (SSQ) responses were moderate, ranging from 0.19 to 0.23, but significant so the MSSQ-Short was included as a covariate in the statistical analysis.

Fig. *7* shows the SSQ sub-scores and TSC after playing the first and second games for each of the four main conditions. SSQ scores increased from baseline to after the first game and on average increased further between the first and second games.

Analysis of variance modeling found a significant main effect of the within-subject variable of testing interval (after first or second game) for TSC and all three sub-scores ($F_{1,97}$ = 12.19, 4.71, 16.92 and 5.48 for the TSC, N, O and D scores, respectively; $p < 0.05$). This reflected the increase in SSQ ratings from the first to second game.

For the TSC score, the Disorientation and Oculomotor subscales, a significant effect of raw MSSQ (marginally for D; $F_{1,97}$ =5.48, 5.16 and 3.72; p = 0.021, 0.027 and 0.057, respectively for TSC, O and D scales), and a significant interaction between display mode (S3D versus non-stereoscopic) and MSSQ ($F_{1,97}$ =6.25, 6.06 and 8.54; p = 0.014, 0.016 and 0.004, respectively for TSC, O and D scales) was also found. MSSQ and SSQ were positively correlated so SSQ scores were larger for subjects with higher MSSQ. The interaction between stereo condition and MSSQ was such that the influence of MSSQ was greater under stereo conditions. The main effects of stereo and control mode and their interaction were not significant and no clear pattern of effects for these variables could be identified.

For the Nausea subscale there were significant effects of time and raw MSSQ (latter $F(1,97) = 5.05$, $p = 0.027$) that were similar those found for the other SSQ measures but also a significant main effect of control mode (Kinect versus gamepad) with Nausea scores higher in the Kinect mode.

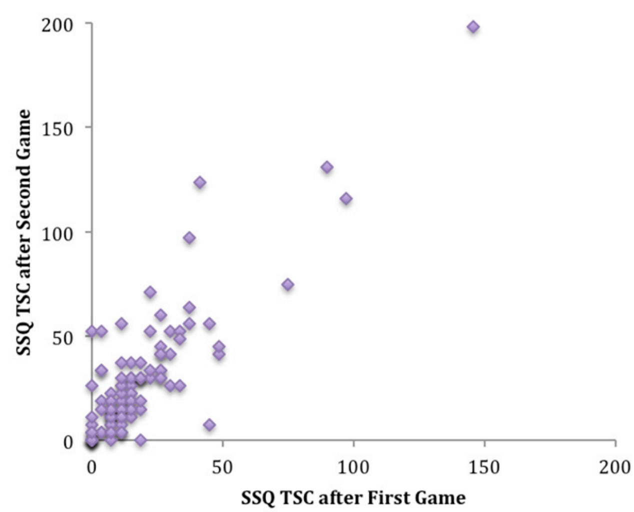


Fig. *6* Correlation between cybersickness (TSC score of the SSQ) scores after first and second games.

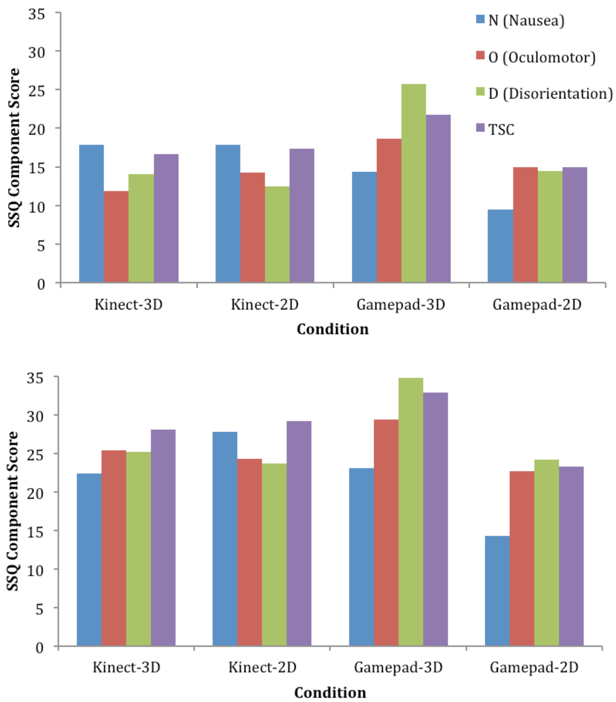


Fig. *7* **SSQ results after the first 15 minutes of play (top) and second 15 minutes of play (bottom).**

Contrary to our hypothesis we did not find that participants who played Kinect in S3D experienced more Nausea compared to those who played Kinect in non-stereoscopic mode ($F(1,97) = 0.454$, $p = 0.502$). Although the main effect of stereoscopic mode was not significant we noticed that TSC, O and D subscale scores were higher when players used gamepad in 3D compared to 2D at both time periods.

4. DISCUSSION

As computer games become more interactive and immersive they increase the likelihood of negative aftereffects reported for virtual reality such as cybersickness [10]. Cybersickness is a negative response to immersive media and has much in common with motion sickness, computer vision syndrome, and aesthenopia (eye strain normally from reading or work requiring near vision). It is characterized by a range of negative effects including headaches, eyestrain, dry eyes, disorientation, vertigo, dizziness, discomfort and nausea. A precise definition is difficult to agree upon as the symptoms are varied and there are multiple causes [2]. Early work on the related phenomena of simulator sickness suggests that the technical features of the immersive display play a major role in the occurrence of symptoms and that 'bad simulators' can have disproportionate levels of side-effects [2]. Cybersickness symptoms and computer vision syndrome symptoms are not uncommon in gaming (e.g. headaches, nausea, vertigo; [11]).

We found that susceptibility to other types of motion sickness was a useful predictor of cybersickness experiences in our games. Correlations between MSSQ-Short and SSQ scores in the experiment were significantly positive although only around 0.2. Thus susceptibility is a useful indicator but not all participants who were susceptible to motion sickness became cybersick (or vice versa). We used the MSSQ-Short which is a recently modified [8] variant of the original MSSQ [12]. The MSSQ-Short is convenient but also more appropriate for study of cybersickness since it eliminates questions about vomiting (emesis) from the longer survey. This change is desirable for cybersickness studies since cybersickness (unlike sea sickness and other motion sicknesses) rarely produces severe symptoms and emesis.

How do we expect the move to stereoscopic displays and active motion to affect the prevalence of cybersickness occurrence in gaming? Misalignments, mismatches, distortions, and inconsistencies between the images delivered to each of the eyes in a stereoscopic head mounted display can produce eyestrain and poor visual quality [13]. For imagery presented in the near space, even perfect monocular images can cause visual stress due to the discrepancy between accommodation and vergence [14], [15]. Crosstalk [16] in the display can reduce performance and degrade depth. Many of these undesirable phenomena have impacts on space perception and visual comfort and have recently been linked to cinema sickness [17]. In accordance with this we found an interaction between MSSQ and stereoscopic display mode on the Oculomotor and Disorientation sub-scores of the SSQ responses following the games.

What about the effects of moving in S3D worlds? Deficiencies in the virtual environment have been implicated in cybersickness. For example, unlike traditional games, VR systems are typically head tracked and update the display to correspond to where the user has directed their gaze. There is always a delay between the tracking measurement and the corresponding display update. This end-to-end system latency is a major determinant of perceived stability of the world [18] as well as performance and presence in virtual environments.

We had predicted that the illusory motion parallax produced while moving the head during a stereoscopic game would be a similar discrepancy and produce increased cybersickness symptoms. However, we did not find strong evidence for this hypothesis and in fact while Nausea scores were higher in Kinect play, they were not higher in 3D Kinect play compared to 2D Kinect play as we had predicted.

Besides this finding we did not find that Kinect gaming produced significantly more cybersickness than game pad gaming. Active gaming is intended to increase the interactivity of the experience. The lack of cybersickness in the Kinect condition may be attributed to the control/non-control effect [19]. In the motion sickness literature, active control is known to reduce symptoms [19] as reflected in the truism that the driver rarely gets carsick. Motion sensing based games rely on naturalistic active head motion and this may tend to reduce cybersickness effects particularly if the active control is well matched to the task [20].

Motion sickness has been linked to cue discrepancies between the visual, vestibular and other sensory systems [21] and this is likely true for the motion-sickness components of cybersickness. We hypothesize that this conflict will become more provocative as the fidelity of sensory information increases based on evidence that cybersickness increases with level of immersion (e.g. [22]). Current motion sensing based interaction, including that used in this study, is still abstract and very different from natural motion in the simulated scenario. This lack of fidelity may explain why the illusory motion parallax with active head motion did not produce many ill effects. As the congruence between reality and the simulation increases we hypothesize subjects may become more sensitive to the discrepancies that remain.

5. ACKNOWLEDGMENTS

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APPENDIX: SSQ SCORING

SSQ component scores were computed as described in [6]. These scores are based on sums of the symptom scores reported (weighted from 0 to 3 as shown in Fig. 3).

$$N = 9.54(S1+S6+S7+S8+S9+S15+S16)$$

$$O = 7.58(S1+S2+S3+S4+S5+S9+S11)$$

$$D = 13.92(S5+S8+S10+S11+S12+S13+S14)$$

$$TSC = 3.74(N + D + O)$$