The Impacts of Animated-Virtual Actors’ Visual Complexity and Simulator Sickness in Virtual Reality Applications

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Abstract—This article discusses the effects of Animated Virtual Actors’ (AVAs) visual complexity on Simulator Sickness (SS) in Virtual Reality (VR) applications. SS is one of the major disadvantages of VR simulations. Previous research has shown that visual complexity correlates with SS. Yet complex AVAs are increasingly used along with real-time graphics. Minimising SS for a VR application is thus beneficial. A series of VR simulations were created to teach second-year psychology students about the navigational capabilities of desert ants with various levels of AVAs’ visual complexity: flat, cartoon, or life-like. We predicted that more complex AVAs would induce more SS. The results contradicted the predictions, with no significant differences in SS between groups as a function of the AVAs’ visual complexity. Moreover, our methods succeeded in lowering overall levels of SS in all the simulations. Possible explanations and our future research directions are discussed.

Keywords—virtual actors; virtual reality; visual complexity; simulation sickness; visualisation

I. INTRODUCTION

One of the main goals of in graphics technology and Virtual Reality (VR), is the availability of tools to create low-cost [1], [2], or even free [3], [4] complex Animated Virtual Actors (AVAs). This was nearly impossible for low-budget industries in the early 1980, but is now readily available. The applications of AVAs for learning in VR extend from medical education [5] to Risk Assessment Training for customs officers [6]. Despite the educational benefits of VR, the designer must be concerned with the question: “Will it make people sick?” One major disadvantage of VR applications is that they can cause Cybersickness or Simulator Sickness [7, SS]. The visual complexity of a VR scene is known to induce SS. Therefore, the impact of an AVA’s complexity on SS must be examined to be beneficial for educational purposes.

In an attempt to minimise the effect of an AVA’s complexity on SS, this study employed a recently developed non-interactive VR learning material that was integrated into the curriculum of second-year psychology students at Macquarie University. This learning material took the students through a 3D North African saltpan to learn about the navigational capabilities of Cataglyphis ants [8]. Depending on the group, they learned with flat, cartoon, or life-like AVAs (Table I). We used standardised the Simulator Sickness Questionnaire [7, SSQ] to measure students level of SS. AVAs are not limited to humans. The Cataglyphis ants provide complex shapes and tripod-gait information, which is more complex than a human-shaped AVA. This article defines an AVA’s visual complexity as the amount of visual information or elements in depicting an entity.

A. Simulator Sickness (SS)

Motion sickness is widely accepted as a form of sickness according to the Sensory Rearrangement Theory as proposed by Reason and Brand [10] and Reason [11]. Sensory Rearrangement Theory suggests that symptoms of motion sickness occur when two or more sensory cues disagree, or do not match with the expected experience. Motion sickness often arises from visually-induced self-motion orvection [12], [13]. The symptoms of motion sickness include vertigo, dizziness, stomach discomfort and even vomiting [7]. The effect of motion-sickness can be devastating, leading possibly to performance interruption and termination of task [14], [15].

In VR applications, it is commonly called Cybersickness or Simulator Sickness (SS). In VR, the reason for SS lies in the sensory stimuli rather than sensory conflicts (e.g., [16, [17]) as originally proposed by Sensory Rearrangement Theory. So et al. [12] argue that sensory conflicts cannot be measured directly but sensory stimuli can be measured readily. The new trend in the study of SS investigates various sensory stimuli. The primary stimulus, which is the main theme of VR applications, is the visual depiction of the scene [12]. Most VR simulations involve the movement of the virtual camera, while the user is mostly stationary. This sense of visual self-motion contradicts vestibular stimuli and triggers symptoms of SS. Various factors affect the degree

1 Visual complexity has various dimensions, such as unintelligibility, disorganisation, amount, heterogeneity, symmetries, colour variety, and three-dimensionality of elements [9].
of visual stimulus in VR that contribute to SS, including field of view [18], display size and movement [19], length of exposure [20], [21], movement speed [22], and the visual complexity of the scene [23], [22], [17], [12].

B. AVA’s Level of Visual Complexity

How does an AVA’s level of complexity affect SS? Commonly in VR applications, the camera is fixed on the stationary AVA (e.g., [5], [6]). In science learning, however, the camera must often follow on AVA to observe a particular behaviour. Nowadays, creating even more complex AVAs is not difficult with the availability of 3D modelling and painting tools, along with faster computers and graphic cards [6], [24].

Studies indicate that the complexity of visual stimuli in a scene, arising from scenes with many elements, increases SS [23], [22], [17], [12]. Kavakli et al. [17] showed that a complex scene with objects, which contain extraneous details, such as windows, doors, cracks, and signs of surface imperfections, induces more SS than a simple black and white scene. In an attempt to quantify visual complexity, So et al. [12] showed that complex scenes with detailed textures and additional objects increase SS rating. Similarly, Moutant and Thattacherry [23] and Mourtant et al. [22] showed that adding details such as urban buildings in the scene increases SS. The increase of SS is expected because higher complexity increases the amount of optic flow, creating stronger vection [22]. In light of these studies, our initial hypothesis is that the AVA’s visual complexity will also increase overall complexity of the scene, which in turn increases vection and produces stronger SS. The simulation, which was created for Psychology students, contains three different types of AVAs (Table I). We predicted that the SS ratings will follow the order of AVA complexity.

II. METHODS

A. Participant and Design

The participants were 200 second year psychology students at Macquarie University (59 males and 141 females) with median age of 20.55 (IQR = 20 - 22). No extra credit was given as the session was part of the course. A prac group of 4 to 25 students participated in the experiment in the VR lab at the same time. Each prac group as a whole was randomly assigned to one of 3 conditions differing in the AVA’s complexity (Table I), 60 participants learnt with flat AVAs, 63 participants learnt with cartoon AVAs, and 77 participants learnt with life-like AVAs.

B. Material and Apparatus

The Simulator Sickness Questionnaire [7, SSQ] was employed to assess the degree of severity in the simulation. The SSQ was administered before and after the exposure to the VR presentation. The SSQ required the participants to give a scale from 0 to 3 on each of 16 symptoms listed: General discomfort, Fatigue, Headache, Eyestrain, Difficulty focusing, Increased salivation, Sweating, Nausea, Difficulty concentrating, Fullness of head, Blurred vision, Dizzy (eyes open), Dizzy (eyes closed), Vertigo, Stomach awareness, and Burping. Questions were summed to obtain three sub-scores of SS: Nausea, Disorientation and Oculomotor, which can be added for a total severity score [17]. The VR simulation was run on an immersive semi-cylindrical (6m-wide) projection system, which allowed a 160° field of view (FOV). The VR simulation was designed to teach students about the navigational capabilities of Cataglyphis ants on a featureless saltpan [8]. The VR simulation was developed from actual experiments and observations conducted by Wehner [8], Zollikofer [25] and Wittlinger et al. [26]. It was organized into five continuous scenes: 1 - introduction; 2 - overview of path integration; 3 - skylight compass; 4 - step counting behaviour; and 5 - summary. The length of the simulation was 8 minutes and the camera moved slowly from one location to another. The virtual actors were visible only in scene 1, scene 2, scene 3, and scene 5. We used Blender [3] for 3D modelling, and animation; Vue [27], GIMP [28] and Inkscape [29] for texturing the virtual world. The VR simulation ran smoothly at maximum frame-rate. The virtual scene was projected onto the semi-cylindrical screen by using Vizard [30] at 3027 x 1024 pixels resolution. The scene was composed of AVAs, plain sand throughout, a clear blue sky, simulated polarisation patterns in the sky, food items and three test-channels. Throughout the experiment, the scenario, the scene, screen resolution, screen colour, camera’s movement and the narration were the same. The only independent variable is the type of AVA, which was altered for each group. None of the students had attended the simulation before. Since there was no interactivity within the VR simulation, everyone received an equal visual exposure.

Table I summarises the different viewing conditions with three types of AVA and Figure 1 shows the AVAs on the semi-cylindrical canvas in our VR Lab. The life-like AVA was the complex AVA. It was modelled and animated after the real Cataglyphis ant. The cartoon AVA was a simplified model of life-like AVA and composed of fewer polygons, joints and simpler animations. The flat AVA was modelled after an extreme simplification of a Cataglyphis ant. The flat AVA did not have any 3D shape, only a 2D plane with no animated joints, and it took less than 2 minutes to create it.

C. Procedure

Upon the arrival in the VR lab, a group of students was asked to fill in the consent form and randomly assigned to one of three AVA conditions. The students were then reminded about SS and the procedure to follow if they feel sick in the simulation. SSQ values were collected before and after viewing the simulation. Finally, once the students completed the questionnaires, they were thanked for the participation.
Table I

<table>
<thead>
<tr>
<th>Type</th>
<th>Visual</th>
<th>Polygons</th>
<th>Shape</th>
<th>Joints</th>
<th>Animation</th>
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<tbody>
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<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Cartoon</td>
<td></td>
<td>1755</td>
<td>Cartoon</td>
<td>18</td>
<td>Human gait</td>
</tr>
<tr>
<td>Life-like</td>
<td></td>
<td>2415</td>
<td>Life-like</td>
<td>25</td>
<td>Tripod gait</td>
</tr>
</tbody>
</table>

III. RESULTS

Initial assessment using the Shapiro-Wilk normality test and the Levene test for unequal variances found violations for assumptions needed for parametric statistical tests. Non-parametric tests were thus used in this study. Cliff’s d values were calculated to indicate the effect size [31], [32], [33]. All statistical analysis methods were performed by using R [34]. Table II shows the medians (Mdn) and the interquartile range (IQR) of three sub-dependent measures and the total SSQ score for each group: nausea, disorientation, oculomotor and total severity score.

Does the increase of SS follow the order of AVA’s visual complexity? To answer this question, a Kruskal-Wallis nonparametric ANOVA test was performed with AVA’s visual complexity as the factor, and the difference in total SS severity scores (post-exposure score minus pre-exposure score), as the dependent variable. The test did not reveal any significant differences between the groups, $\chi^2(2, N = 200) = 0.55$, $p = 0.76$. The results did not support the proposed prediction and showed no differences between flat, cartoon and life-like AVA in causing SS.

A. Other Results

Additionally, Wilcoxon signed rank test between post and pre total severity scores in each group revealed a significant decrease of total severity score in all conditions (flat: $V = 827.5$, $p = 0.03$, $d = 0.12$; cartoon: $V = 887.5$, $p = 0.02$, $d = 0.18$; and life-like AVA: $V = 1449.5$, $p = 0.00$, $d = 0.15$).
Furthermore, this study discovered gender effects of SS. The Wilcoxon rank sum test was performed, using gender as the factor, and the differences between post and pre total severity scores as the dependent variable. The analysis revealed that female participants felt less SS after viewing the VR simulation than male participants, $W = 3262.5$, $p = 0.02$, $d = 0.22$. There was also a significant gender difference in the SSQ sub-score: oculomotor, $W = 3395$, $p = 0.04$, $d = -0.18$. However, there was no significant gender difference in disorientation, $W = 3558.8$, $p = 0.09$, $d = -0.14$, or Nausea, $W = 3688.5$, $p = 0.19$, $d = -0.11$.

IV. DISCUSSION

Recent technologies in computer graphics enable artists and designers to create complex Animated Virtual Actors (AVAs). The availability of the technology enables institutions to create AVAs for education and research purposes.

On the negative side, VR is known for inducing SS and one of the main factors of SS is the visual complexity of the scene. Previous studies indicate that the complexity of a scene in VR applications induce SS, which detracts from the advantages of the latest technology in creating complex AVAs. Three different types of AVAs were made available for the latest VR learning experience at Macquarie University. The simulation taught students the navigational capabilities of Cataglyphis ants. The study investigated the effects of visual complexity of AVAs in causing SS.

In contrast to the previous studies [23], [12], [22], [17], our findings do not indicate any increase in SS with increasing AVA visual complexity. If anything, subjects reported less SS after viewing the animated scene. We can think of several explanations for our results. Firstly, the results from previous studies in visual complexity and SS are based on the visual complexity of the virtual environment itself. Kavakli et al. [17] added visual details in the buildings, So et al. [12] added detailed textures and objects, and Mourant et al. [23], [22] added urban buildings in a driving simulator, and all showed that scene complexity led to higher SS. These virtual environments had complex backgrounds that stood still and did not move along with the camera. In our experiment, however, the AVAs portrayed in the simulation served as both foreground and background objects. Secondly, the speed and the path of the virtual camera were slower and different from the previous studies of SS in VR simulations. We deliberately slowed the camera movements in an attempt to minimise possible SS in the students. This factor deserves to be further tested. Thirdly, the amount of visual complexity of our AVAs might not be sufficient to induce SS. The AVA’s complexity in this study is small in comparison to the visual complexity of AVAs in Kavakli et al.’s study [17].

A fourth possible explanation is that the AVAs do not appear in every scene, and they were sometimes very small because the camera was far away.

V. CONCLUSION

In sum, this study assessed the impact of the AVA’s visual complexity on simulator sickness. Results showed that the visual complexity of AVAs did not affect SS, and that the VR simulation on the whole produced very little SS. We have made a safe VR presentation for future educational use. The results also have important implications for artists and designers. If the AVA’s complexity does not affect SS, artists and designers can unleash their creativity by using affordable and readily available modelling packages, such as; Quidam [2], Daz3D [1], Makehuman [4] and Blender [3], in creating visually complex AVAs, as long as measures are taken, as we have done, to minimise overall SS. To confirm the findings of this study, another simulation is underway to train fire-fighters in VR.
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