Associations between Simulator Sickness and Visual Complexity of a Virtual Scene

Iwan Kelaiah[*1], Manolya Kavakli[2], Ken Cheng[3]

[1]Australian Centre of Field Robotics, The University of Sydney, NSW 2006, Australia
[2]Department of Computing, Macquarie University, NSW 2109, Australia
[3]Department of Biological Sciences, Macquarie University, NSW 2109, Australia

[*1]i.kelaiah@acfr.usyd.edu.au; [2]manolya.kavakli@mq.edu.au; [3]ken.cheng@mq.edu.au

Abstract- **This study examined the effects of simulator sickness (SS) as a function of the visual complexity of animated virtual actors (AVAs) and the virtual environment (VE) in a virtual scene. Visually complex stimuli may be attractive; however, studies on SS indicate the possibility of significant health risks outweighing the expected benefit in virtual reality (VR) simulations. This study used a series of simulations to teach the basic skills required for village fire fighting to manage fires caused by car accidents. The participants learnt in one of 4 experimental conditions; simple (simple AVAs and simple VE), simple world (lifelike AVAs and simple VE), simple AVAs (simple AVAs and lifelike VE) and lifelike (lifelike AVAs and lifelike VE). We predicted that: (1) SS ratings would increase with the scenes' visual complexity and (2) simpler VEs would compensate for the effects of visually complex AVAs. Surprisingly, the results contradicted our predictions, with no effect of either variable. We discuss possible explanations for these results, and suggest future research directions to design safe VR simulations.**

Keywords- Animated-Virtual Actors; Virtual Environment; Simulator Sickness; Virtual Reality; Virtual Scene; Visual Complexity; Visualisation; Vection

LIST OF ABBREVIATIONS

3D	three-dimensional
ANOVA	analysis of variance
ANTECATALYST	animated Cataglyphis ants
AVA	Animated virtual actors
FOV	field of view
GIF	Graphic Interchange Format
IQR	interquartile range
JPEG	Joint Photographic Expert Group
SS	simulator sickness
SSQ	simulator sickness questionnaire
VE	virtual environment
VEAF	vehicle accident and fire
VR	virtual reality

I. INTRODUCTION

Developing visually complex scenes in virtual reality (VR) applications is becoming easier with advanced three dimensional (3D) modelling tools [1] and the latest 3D engines [2, 3] many of which are freely available. The application of digital content — animated virtual actors (AVAs) and the virtual environment (VE) — is often technologically driven or market-driven. In most cases, the technology is used as a showcase [4, 5]. In the domain of education and training with multimedia systems using VR simulations [6], there are two conflicting hypotheses: media-affect-learning and method-affect-learning. The media-affect-learning hypothesis states that using better technology when delivering learning content promotes learning. In contrast, the method-affect-learning hypothesis argues that, as long as the methods promote cognitive learning, the medium does not matter [7].

In examining both the media-affect-learning and method-affect-learning hypotheses, Moreno and Mayer [6] compared the influence of different levels of immersion in VR devices and personalised narration. The experimental results with college students indicated that there were no differences in learning outcomes between the use of a standard desktop and a head mounted display; however, those who learnt with personalised narration performed better than those who learnt with non-personalised narration. Moreno and Mayer [8] analysed the effects of different levels of immersion in various VR devices, and as well as the method of delivery. The experimental results with college students revealed that those who learnt with head mounted displays were more motivated to learn, yet they did not learn better. However, students performed better when they learnt with narration rather than on-screen text. From these empirical results, Moreno and Mayer [6] concluded that, as long as the learning material promotes cognitive processing, the medium of delivery does not seem to matter.

Mayer [9], and Schnotz and Bannert [10] added that research on comparing media is largely fruitless because methods to promote cognitive processing from one medium can be applied to another. There are only a few studies in literature focusing on the characteristics of the digital content on their impact on learning. Choi and Clark [11] argued that AVAs as a medium of delivering information can be replaced by other means. Although AVAs can be replaced with text or narration on screen, in some circumstances the presence of AVAs is necessary in certain scenarios for learning to occur (for example, in the interpersonal skills education of a medical student, from observing the behavioural cues of virtual patients [12]).

VR simulations offer advantages that would be difficult to duplicate using traditional teaching methods or media, including presenting phenomena that are not readily observable or are too dangerous in real life. The studies agree that an effective VR simulation for learning must facilitate memorisation and, more importantly, problem solving or transfer of knowledge to another scenario [7, 13]. Learning outcomes cannot be achieved when the medium promotes SS. Although the authors — as VR-based education and training developers — incline towards the method-affect-learning hypothesis, the visual complexity in VR simulations is known to induce simulator sickness (SS) [14-16]. Therefore, the effect of the AVAs' visual complexity and the VE's must be examined.

In the attempt to examine the impact of digital contents' visual complexity on SS, this study employed a recently built VR simulation called `VEAF' (vehicle accident and fire) as shown in Fig. 1, and a standardised SS questionnaire [17] to obtain the subjective rating of SS. The four experimental conditions were set out as (A) simple, (B) simple world, (C) simple AVAs and (D) lifelike.

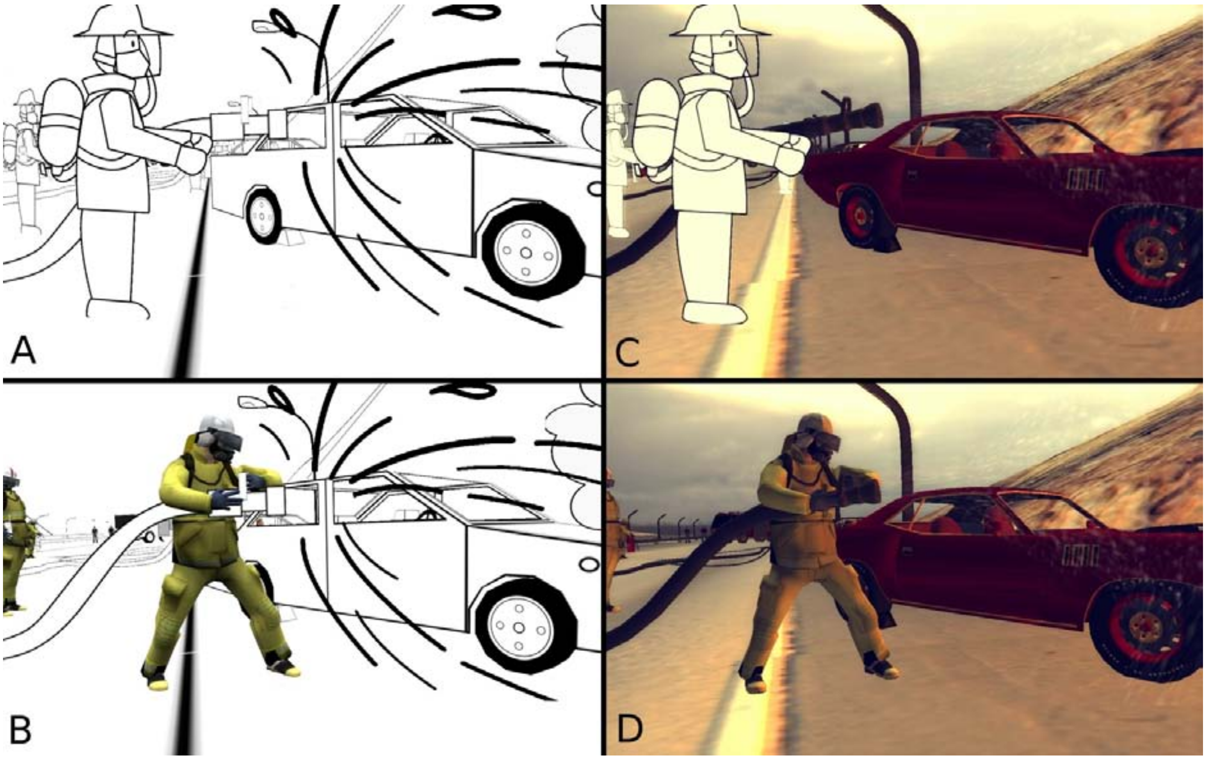

Fig. 1 The four experimental conditions of VEAF: (A) simple, (B) simple world, (C) simple AVAs and (D) lifelike

A. Discomfort in a Virtual Simulator

Humans derive a sense of position by integrating various spatial cues in an environment [18], including visual motion cues, such as those found in a VR simulation. Visually more complex scenes can increase optic flow and heighten the visual perception of self-motion [19]. The continuous stream of visual stimuli in VR applications creates vection or self-induced motion, which can lead to SS [14]. In most VR applications, the user is stationary and the illusion of movement is caused by the movement of the virtual camera. When the brain perceives the inconsistency between the sense of self-motion derived from visual stimuli and the lack of self-motion derived from the body senses (vestibular, proprioceptive and kinaesthetic stimuli), this can trigger the symptoms of SS. Similar to real-world motion sickness, SS has harmful effects, such as nausea, headache and vomiting [14].

Kavakli et al. [15] examined the effect of a VE's contents on SS in a Virtual Roller Coaster. The participants were exposed to a realistic scene versus a number of versions with varying levels of complexity. The realistic scene included myriad elements, such as signs, windows, surface imperfections and detailed roads. The participants experienced greater discomfort than did the group who were exposed to an environment with black and white colours. The path of the roller coaster ride was otherwise equivalent in all experimental condition groups. Similarly, So et al. [16] examined the effect of spatial velocity and visual complexity by varying both factors. The results showed that scenes with textures and additional objects increased discomfort ratings. Kartiko et al. [14] also investigated the relationship between visual complexity and SS and found contrasting results. Their participants were subjected to cartoon and lifelike AVAs in a simulation (ANTECATALYST) that taught the navigational behaviour of Cataglyphis ants. The results showed that the AVAs' visual complexity did not contribute to SS. Kartiko et al. argued that this negative outcome might be due to the lack of AVAs' presence in some scenes, and the insufficient level of visual complexity in the AVAs and VE.

In light of these studies, one can easily predict that an increase in the visual complexity of AVAs and VEs will increase the overall complexity of the scene, which will subsequently increase vection and produce stronger ratings of discomfort. Thus, it is important to ask: does the use of lifelike objects increase visual complexity? To establish if this is the case, the analysis requires a measure of visual complexity to demonstrate whether there is actually a significant difference between simple and complex scenes. Given edge detection and information content theories suggesting that the simple image may actually be the most complex [20, 21], it is possible that the 'simple' scenes in the studies by Kavakli et al. [15] and Kartiko et al. [14] were not actually simple at all, but were outlined images with a lot of details. The complex visual conditions could have been perceived as simpler because added colour and shading might actually obliterate some of the details of line drawings. These factors may explain why Kartiko et al. [14] found no effects on SS.

B. Visual Complexity of Veaf

Before framing our predictions concerning SS and visual complexity, it was necessary to evaluate the visual complexity in VEAF. We needed to establish whether adding lifelike elements in VEAF added to the overall visual complexity. Only then we could predict which visual condition was likely to cause the most discomfort due to SS. Human judgements as a measure of visual complexity are not reliable, as can be surmised by the following points [22]:

- **Familiarity**: one can perceive an image as being simple or complex, based on familiarity. The way the stimulus is perceived is important, while the amount of visual elements in it is not.
- **Novelty and Interest**: complex images can be interesting, meaningful and capture our attention. These help us retrieve information in them and thus reduce perceived complexity.
- **Spatial Frequency Information**: a high amount of low spatial frequency information in an image can make it look simpler. In other words, when shading is reduced, so is the perceived complexity.

Algorithms used in image compression techniques are based on the smallest computer program required to store or produce an image seem to offer the most promising development in the measurement of visual complexity. Donderi [20] and Forsythe *et al.* [21], used these techniques in the analysis of visual complexity. A compressed image consists of a string of numbers that represent the organization of that picture. This string is a measure of information content [20]. From computational point of view, when the image contains few elements or is more homogeneous in design, there are few message alternatives and as such the file string contains mostly numbers to be repeated. A more complex picture, on the other hand, will have more elements that are less predictable. Thus, the file string will be longer. Forsythe et al. [21] found that unfamiliar visual stimuli tend to be rated as more complex than they physically are.

These studies revealed that size of compressed image file by using Graphic Interchange Format (GIF) compression has a high correlation to subjective visual complexity [20-22]. Hence, in determining the visual complexity of each condition, we captured all 10,340 frames from each condition by using a video capture software called Fraps [23]. All images were captured from the same starting frame. We obtained 41,360 frames of raw images, and converted these images to GIF by using IrfanView [24], for statistical analyses.

The box-plot of GIF file size in each scene revealed numerous outliers (Fig. 2A). The histogram also did not indicate Gaussian distribution (Fig. 2B). Hence, we employed nonparametric statistical tests to determine whether there was a significant difference in the complexity of the scenes. We used R [25] for statistical analyses. We performed the Kruskal-Wallis rank sum test — a non-parametric equivalent to analysis of variance (ANOVA). It revealed significant differences

between the groups, χ^2 (3, N = 10,340) = 31074.69, p = 0.00. The results showed these four scenes were significantly different from each other. We used a function from "*pgirmess*" package [26], called Kruskal-Wallis multiple comparison, for our non-parametric post-hoc analysis. Multiple comparison test after Kruskal-Wallis at p = 0.05 reveals significant differences between visual groups.

There was a significant file size jump from condition A to D. This signified that condition D had greater visual information than did A. In VEAF, replacing simple AVAs with complex AVAs also significantly increased the overall visual complexity (conditions A to B). However, we found that replacing simple a VE with a complex VE, and leaving simple AVAs in the scene, greatly increased the compressed file size (conditions A to C). Hence, the order of overall scene's visual complexity is corresponds to the rank of image size as shown in Fig. 2, that is (A) simple, (B) simple world, (C) simple AVAs, and (D) lifelike.

Adding visual details in VE — cracks, reflections, lifelike smoke and fire, and detailed vehicles — increased the overall details more so than did changing the AVAs alone. However, we doubt that this is generalizable. In VEAF, the VE had a larger portion on the display than did the AVAs. Other VR simulations with a greater portion of AVAs than the VE might yield different results. This requires further investigation. This study extends the previous investigations by Kartiko et al. [14] by asking is SS associated with the scene's visual complexity? If so, does the most visually complex VE have the greatest effect on SS? Based on the statistical analyses of the visual complexity of VEAF, theories and literature on SS (Section A above), we predicted that:

1. SS ratings will follow the order of overall scene's visual complexity such as (A) simple, (B) simple world, (C) simple AVAs, and (D) lifelike
2. Visually complex VE, conditions (C) simple AVAs and (D), will have the greatest effect on SS

Fig. 2 Panel A shows the box-plot of log size of GIF file size of frames from different experimental conditions. The box represents the interquartile range (IQR). The right hinge of the box represents the 3rd or upper quartile, and the left hinge of the box represents the 1st or lower quartile. The bold vertical line in the box indicates the median value. The whiskers on both sides of the box show the lower and upper values of 1.5 × lower quartile and 1.5 × upper quartile. Lastly, the black dots indicate the outliers in the data. Panel B shows the log file size frequencies of GIF file size of experimental conditions.

II. METHODS

A. *Participants and Experimental Design*

The 88 participants were Macquarie University students and staff, as well as members of the public (43 males and 45 females), with a median age of 22 (*IQR* = 20–25). A group of one to six people participated in the experiment at the same time. Each person was randomly assigned to one computer with one of four experimental conditions differing in AVA and VE visual complexity (Fig. 1). Twenty-three participants learnt with simple condition (visually simple AVAs and background objects), 21 participants with simple world (visually complex AVAs and simple background objects), 21 participants with simple AVAs (simple AVAs and visually complex background objects) and 23 participants with lifelike visually complex AVAs and background objects.

B. *Material and Apparatus*

VEAF was run on an Intel Core2 Duo E8400 desktop PC with NVIDIA GeForce GTX 260 graphics card and 4GB RAM. It ran smoothly at maximum frame-rate at 1,680 × 1,050 pixels resolution on a 473 mm × 300 mm viewable screen area. The participants were seated approximately 60 cm away from the computer screen. Thus, the physical horizontal field of view (FOV) was approximately 43°. VEAF informed the participants about the hazards of firefighting in cases of motor accidents and the best practice to approach safely and prevent the spread of fire. The learning material was developed based on the `Village Firefighter' handbooks: *Village Firefighter (VF) Manual* [27, Chapter 3, section 9], *Specialist Training Manual: Compressed Air Breathing Apparatus* [28, CABA], and *Compressed Air Breathing Apparatus Standard Operating Procedures* [29].

VEAF was organised into eight continuous scenes: (1) introduction, (2) compressed air breathing apparatus, (3) vehicle roll and tip hazard, (4) explosion hazard, (5) hazardous material, (6) electrical hazard, (7) vehicle with no fire and (8) summary. The duration was eight minutes and the camera moved from one location to another, following the narration at a normal speaking pace. The AVAs were visible in all scenes. We used Blender [1] for 3D modelling and animation, and GIMP [30] and Inkscape [31] to texture the virtual world. The 3D graphics engine used to display VEAF was Blender itself.

The scene was composed of AVAs and a VE displaying the car accidents. The VE consisted of roads, a tunnel, hills, vehicles and environmental effects, such as smoke, water and fire. Throughout the experiment, the scenario, screen resolution, FOV, movement and narration were kept the same for all conditions. The independent variable was the visual complexity of the scene, which was different for each group. None of the students had attended the simulation before. Since interactivity was disabled within VEAF for the purpose of this experiment, the participants had an equal duration of visual exposure.

This study employed a well-established SS questionnaire (SSQ) [17] to assess the severity of discomfort in the simulation. The SSQ was administered before and after exposure to the VR presentation. The participants were required to rate a scale from zero to three on each of the 16 symptoms listed: general discomfort, fatigue, headache, eye strain, difficulty focusing, increased salivation, sweating, nausea, difficulty concentrating, fullness of head, blurred vision, dizziness (eyes open), dizziness (eyes closed), vertigo, stomach awareness and burping. The ratings were summed to obtain three sub-scores of SS: nausea, disorientation and oculomotor, which could be added for a total severity score.

C. *Procedure*

Upon arrival in the computer lab, the group of participants were asked to fill in the consent form, and each participant was randomly assigned to one computer with one of four experimental conditions. The participants were then reminded about SS and the procedure to follow if they felt sick during the simulation. The SSQ ratings were collected before and after viewing the simulation.

D. *Results*

Initial assessment using the Shapiro-Wilk normality test and the Levene test for unequal variances found violations for the assumptions needed for parametric statistical tests. Therefore, we employed nonparametric tests in this study. All statistical analysis methods were performed using R [25]. Table 1 lists the median (*Mdn*) and the interquartile range (*IQR*) of the three sub-scale measures (nausea, disorientation and oculomotor), and the total SSQ score for each group. Fig. 3 shows the box plots of dependent variables. The increase of total severity scores was obtained from subtracting post-exposure of total severity scores with pre-exposure total severity scores. We formed two research questions:

Question 1: Is SS correlated with the scene's visual complexity?

If SS is correlated with the scene's visual complexity, the difference between the total severity scores of each condition must be significant. The results, as shown in Table 1 and Fig. 3, did not indicate that this was the case. A Kruskal-Wallis nonparametric ANOVA test was performed with experimental conditions 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: $\chi^2(3, N = 88) = 3.11$, $p = 0.37$. Thus, the results did not support the prediction, and showed no increase in SS in any experimental condition.

Question 2: Does the most visually complex VE have the greatest effect on SS?

The increase of the total severity score, as shown in Table 1 and Fig. 3, did not indicate that the most visually complex VE, groups C and D, have the greatest effect on SS. Unsurprisingly, the Kruskal-Wallis nonparametric ANOVA test did not support the prediction that the most visually complex VE induce the greatest SS rating. No significant differences were found between the increase in severity score between groups C and D, and groups A and B.

TABLE 1 MEDIANS AND IQR SCORES OF DEPENDENT VARIABLES IN EACH GROUP

Group	N	Nausea *Mdn*(*IQR*)	Disorientation *Mdn*(*IQR*)	Occulomotor *Mdn*(*IQR*)	Total Severity *Mdn*(*IQR*)
Pre-SSQ					
A	23	0.00(0.00–23.85)	13.92(0.00–27.84)	15.16(0.00–22.74)	7.48(0.00–31.79)
B	21	0.00(0.00–9.54)	0.00(0.00–13.92)	0.00(0.00–15.16)	3.74(0.00–11.22)
C	21	0.00(0.00–19.08)	0.00(0.00–13.92)	0.00(0.00–15.16)	0.00(0.00–18.70)
D	23	0.00(0.00–4.77)	0.00(0.00–6.96)	7.58(0.00–15.16)	3.74(0.00–11.22)
Post-SSQ					
A	23	0.00(0.00–4.77)	0.00(0.00–13.92)	0.00(0.00–15.16)	3.74(0.00–13.09)
B	21	0.00(0.00–9.54)	0.00(0.00–27.84)	7.58(0.00–15.16)	7.48(0.00–18.70)
C	21	0.00(0.00–9.54)	0.00(0.00–13.92)	0.00(0.00–15.16)	0.00(0.00–14.96)
D	23	0.00(0.00–14.31)	0.00(0.00–13.92)	7.58(0.00–15.16)	3.74(0.00–16.83)
Increase (Post-SSQ – Pre-SSQ)					
A	23	0.00(–19.08-0.00)	0.00(-20.88–0.00)	0.00(-15.16–0.00)	0.00(-24.31–0.00)
B	21	0.00(0.00–0.00)	0.00(0.00–13.92)	0.00(0.00–7.58)	0.00(0.00–3.74)
C	21	0.00(0.00–0.00)	0.00(0.00–0.00)	0.00(0.00–0.00)	0.00(0.00–0.00)
D	23	0.00(0.00–0.00)	0.00(0.00–0.00)	0.00(-7.58–0.00)	0.00(-7.48–0.00)

EXPERIMENTAL CONDITIONS: (A) SIMPLE, (B) SIMPLE WORLD, (C) SIMPLE AVAS, AND (D) LIFELIKE

III. DISCUSSION

Recent developments in computer graphics allow VR developers to create complex visuals more easily. More and more AVAs and VEs are being used in educational settings because their cost has decreased. Visual complexity is attractive, particularly in the entertainment industry, the purpose of which is to meet market demand [4]. However, the concern is that greater visual complexity could lead to higher SS ratings. This study examined the effects of the visual complexity of AVAs and VEs on SS. The findings revealed that (1) there is no association between scenes' visual complexity and SS, and (2) the VE's visual complexity did not significantly contribute to SS. Our results confirm the findings of Kartiko et al. [14], which also showed no association between the AVAs' visual complexity and SS. In addition, the results of this study reveal that the visual complexity of a VE does not correlate with SS. Overall, the results contradict the findings of So et al. [16] and Kavakli et al. [15] because the participants reported low SS ratings at the end of the simulation. Drawing from other studies in SS, we can present some explanations for these results.

First, VEAF was a short presentation of less than 10 minutes, which may not have been sufficient to induce SS. Stanney and Zyda [32] showed that participants who had 45 to 60 minutes of exposure gave higher SS ratings. Similarly, So et al. [33] found that longer exposure led to higher SS ratings. This issue requires further examination, with longer exposure to complex visuals.

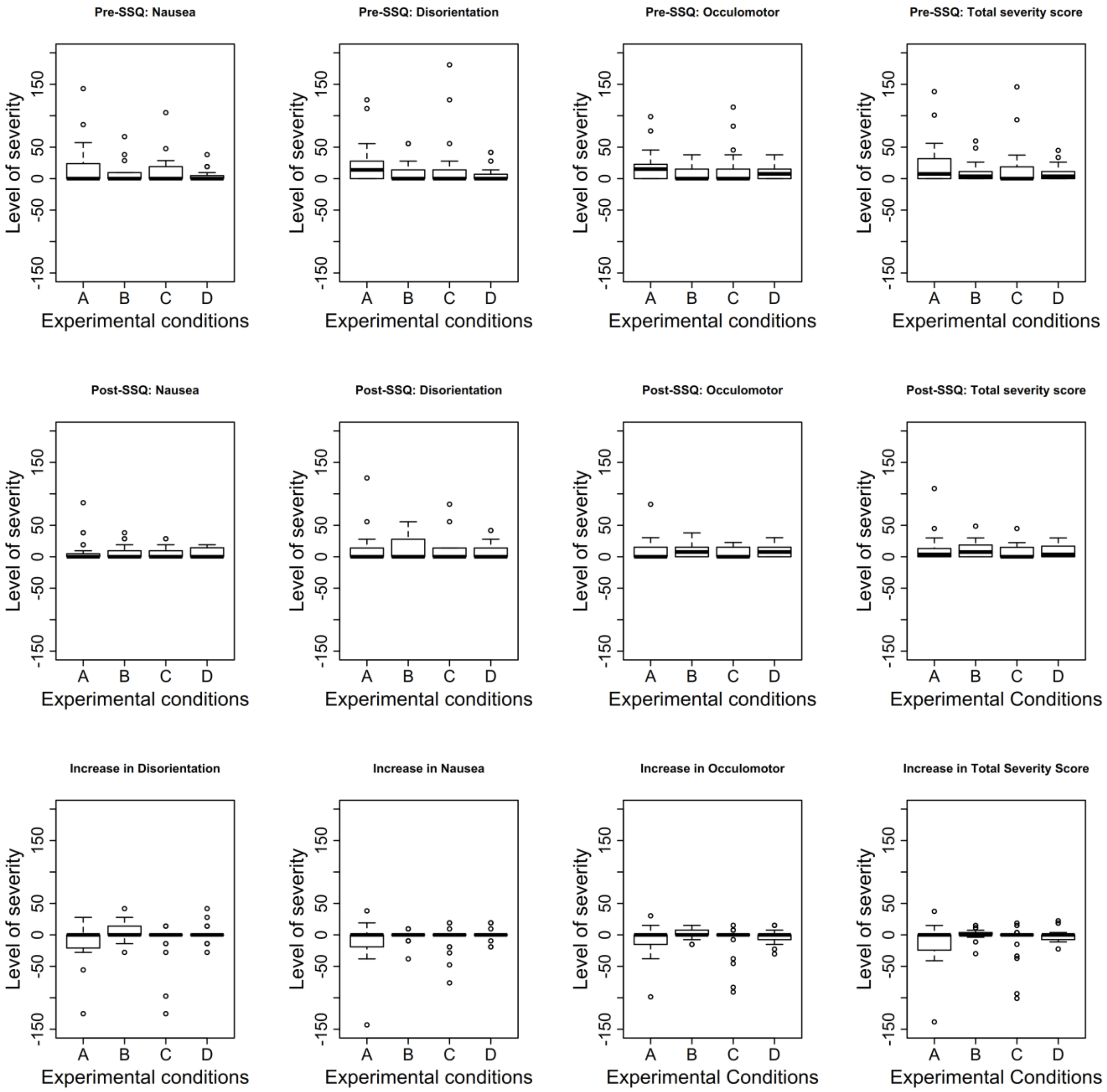

Fig. 3 Box plots of the dependent variables. Experimental conditions A, B, C and D refer to simple, simple world, simple AVAs and lifelike conditions respectively. The box represents the interquartile range (*IQR*) of the data. The upper hinge of the box represents the 3rd or upper quartile, and the lower hinge of the box represents the 1st or lower quartile. The bold line in the box indicates the median value. The whiskers show the lower and upper values of 1.5 × lower quartile and 1.5 × upper quartile. Lastly, the white circles indicate the outliers in the data.

Second, the participants of this study, aged 20-26, might have been habituated to viewing digital media (movies, games and other VR simulations), and such habituation may lessen SS. Hill and Howarth [34] exposed 26 subjects to a hovercraft racing game called 'Wipeout' for 20 minutes on five consecutive days, and the subjects reported less nausea over time. A study by Bigoin et al. [35] also showed that those who were familiar with and played computer games were not affected by SS as much as those who had little familiarity. In the current study there was no measure of how familiar the participants were with playing computer games.

Third, the low SS ratings could be attributed to the lack of sudden or fast vertical camera movement and relatively small physical FOV, attributed to the conventional computer screen used in this study. Previous studies in SS have indicated that vertical acceleration and the frequency of sinusoidal movement in a VE is significant in inducing SS [36, 37]. Kavakli et al. [15] used a large 6m × 2m semi-cylindrical projection with approximately 160 degrees of physical FOV screen to display the Virtual Roller Coaster simulation. Thus, the participants who attended the Virtual Roller Coaster simulation were likely to experience greater vertical sinusoidal acceleration and frequency, which led to greater SS ratings. Again, the current study had no quantitative measure of these variables, and this requires further attention in future studies.

Last but not least, the primary cause of SS is the cue conflict between the visual and vestibular systems [17]. Symptoms of SS can be influenced by display elements such as the camera movement, screen resolution, refresh rate, field of view and stereoscopic view, as well as digital content and scene complexity. In a more comprehensive study, each display element should be examined for its contribution to SS levels. For example, the use of stereoscopic goggles in the study conducted by Kavakli et al. [15] may be the reason for their finding higher SS rates than this study. Our study measured the differences between visual complexity and SS in a non-stereoscopic environment.

IV. CONCLUSION

This study examined the associations between SS and the visual complexity of a virtual scene involving AVAs and VEs in a non-stereoscopic environment. Prior to establishing the predictions of this study, we established the measure of visual complexity apart from the influence of human judgements. We tested the visual complexity of stimuli presented to each group by measuring the log size of GIF compressed files of all frames from all conditions and found significant differences between groups. Similar to a previous experiment by Kartiko et al. [14], the results showed that SS is not correlated with AVAs' visual complexity in a non-stereoscopic environment. Further, it showed that SS is not correlated with the level of VEs' visual complexity. The SS ratings were low.

The privileges of free and open-source 3D modelling tools and 3D engines should encourage more research to further investigate the applications of AVAs and VEs in VR applications to support learning. We plan to address the aforementioned issues to examine the association between SS and the visual aspects of digital contents under various conditions and scenarios.

ACKNOWLEDGEMENT

This project was sponsored by the Australian Research Council Discovery Grant, DP 0558852 (Richards, Kavakli, Dras) titled ‘Risk Management Using Agent Based Systems’ and the Australian Research Council Discovery Grant, DP0988088 (Kavakli) titled ‘A Gesture-Based Interface for Designing in Virtual Reality’. The study was conducted when the first author was affiliated with Macquarie University.

REFERENCES

[1] Blender Foundation, Blender, http://www.blender.org, Blender's official website, Last accessed January 2014.

[2] Carnegie Mellon University, Panda3D, http://www.panda3d.org, Panda3D's official website, Last accessed January 2014.

[3] S. Streeting, Ogre3D, http://www.ogre3d.org/, Ogre3D's official website, Last accessed January 2014.

[4] M. Zyda. “From visual simulation to virtual reality to games,” *Computer*, 38(9), pp. 25-32, 2005.

[5] J. M Hoc. Cognitive ergonomics: a multidisciplinary venture. *Ergonomics*, 51(1), pp. 71-75, 2008.

[6] R. Moreno and R. E. Mayer, “Personalized messages that promote science learning in virtual environments,” *Journal of Educational Psychology*, 96(1), pp. 165–173, 2004.

[7] R. E. Mayer, “The promise of multimedia learning: using the same instructional design methods across different media,” *Learning and Instruction*, 13(2), pp. 125–139, 2003.

[8] R. Moreno and R. E. Mayer, “Virtual reality and learning: Cognitive and motivational effects of students' sense of presence,” In *the Ninth International Conference on Human-Computer Interaction*, pp. 65–67, 2001.

[9] R. E. Mayer, *Multimedia Learning*, Cambridge Press, 2001, ISBN 9780521787499.

[10] W. Schnotz and M. Bannert, “Construction and interferences in learning from multiple representation,” *Learning and Instruction*, 13 (2), pp. 141–156, 2003.

[11] S. Choi and R. E. Clark, “Cognitive and affective benefits of an animated pedagogical agent for learning English as a second language,” Journal of Educational Computing Research, 34(4), pp. 441–466, 2006.

[12] K. Johnsen, A. Raij, A. Stevens, D. S. Lind and B. Lok, “The validity of a virtual human experience for interpersonal skills education,” In *CHI '07: Proceedings of the SIGCHI conference on Human factors in computing systems*, pp. 1049–1058, New York, NY, USA, 2007. ACM.

[13] K. S. Hale, K. M. Stanney and L. Malone, “Enhancing virtual environment spatial awareness training and transfer through tactile and vestibular cues,” *Ergonomics*, 52(2), pp. 187–203, 2009.

[14] I. Kartiko, M. Kavakli and K. Cheng, “The impacts of animated - virtual actors' visual complexity and simulator sickness in virtual reality applications,” In Bob Werner, editor, *Proceedings of the 2009 6th International Conference Computer Graphics, Imaging and Visualization*, pp. 147–152. IEEE Computer Society, 11-14 August 2009. ISBN 978-0-7695-3789-4.

[15] M. Kavakli, I. Kartiko, J. Porte and N. Bigoin, “Effects of digital content on motion sickness in immersive virtual environments,” In *Proceedings of the 3rd International Conference on Computer Science and Information Systems*, pp. 1–12, July 2007.

[16] R. H. Y. So, A. Ho and W. T. Lo, “A metric to quantify virtual scene movement for the study of cybersickness: Definition, implementation, and verification,” *Presence: Teleoperator and Virtual Environment*, vol. 10(2), pp. 193–215, 2001.

[17] R. S. Kennedy, N. E. Lane, K. S. Berbaum and M. G. Lilienthal, “Simulator sickness questionnaire: an enhanced method for quantifying simulator sickness,” *International Journal of Aviation Psychology*, vol. 3(3), pp. 203–220, 1993.

[18] K. Cheng, S. J. Shettleworth, J. Huttenlocher and J. J. Rieser, “Bayesian integration of spatial information,” *Psychological Bulletin*, vol. 133(4), pp. 625–637, 2007.

[19] B. E. Riecke, J. Schulte-Pelkum, M. N. Avraamides, M. von der Heyde and H. H. Bülthoff, “Scene consistency and spatial presence increase the sensation of self-motion in virtual reality,” In *APGV ‘05: Proceedings of the 2nd symposium on Applied perception in graphics and visualization*, pp. 111–118, New York, NY, USA, 2005. ACM Press.

[20] D. C. Donderi, “Visual complexity: A review,” *Psychological Bulletin*, vol. 132(1), pp. 73–97, 2006.

[21] A. Forsythe, G. Mulhern and M. Sawey, “Confounds in pictorial sets: The role of complexity and familiarity in basic-level picture processing,” *Behavior Research Methods*, vol. 40(1), pp. 116–129, 2008.

[22] A. Forsythe, “Visual complexity: Is that all there is? In Don Harris, editor, *Engineering Psychology and Cognitive Ergonomics*, volume 5639 of *Lecture Notes in Computer Science*, pp. 158–166. Springer Berlin Heidelberg, 2009.

[23] Fraps, http://www.fraps.com/, Fraps' official website, Last accessed October 14th, 2013.

[24] Irfan Skiljan, Irfanview, http://www.irfanview.com/, Irfanview's official website, Last accessed January 2014.

[25] R Development Core Team, *R: A Language and Environment for Statistical Computing, R Foundation for Statistical Computing, Vienna*, Austria, 2014, ISBN 3-900051-07-0.

[26] P. Giraudoux. pgirmess: Data analysis in ecology, 2013. R package version 1.5.8.

[27] NSW Rural Fire Service, *VF/1-6 (1999), Village Firefighter (VF) Manual*, NSW Rural Fire Service, 1999. ISBN 0731097303x.

[28] NSW Rural Fire Service, *Compressed Air Breathing Apparatus Standard Operating Procedures*, NSW Rural Fire Service, 2001.

[29] NSW Rural Fire Service, *SP/3 (1995), Specialist Training Manual: Compressed Air Breathing Apparatus (CABA)*, NSW Rural Fire Service, 2001, ISBN 0731064321.

[30] Gimp Development Team, Gimp, http://www.gimp.org/, Gimp's official website, Last accessed January 2014.

[31] Inkscape Development Team, Inkscape, http://www.inkscape.org/, Inkscape's official website, Last accessed January 2014.

[32] K. M. Stanney and M. Zyda, *Handbook of Virtual Environment: Design, Implementation and Applications*, chapter Virtual Environments in the 21st Century, pp. 1–14. Lawrence Erlbaum Associates, 2002.

[33] R. H. Y. So and S. L. Yuen, “Comparing symptoms of visually induced motion sickness among viewers of four similar virtual environments with different color,” In *ICVR'07: Proceedings of the 2nd international conference on virtual reality*, pp. 386–391, Berlin, Heidelberg, 2007. Springer-Verlag.

[34] K. J. Hill and P. A. Howarth, “Habituation to the side effects of immersion in a virtual environments,” *Displays*, 21(1), pp. 25–30, 2000.

[35] N. Bigoin, J. Porte, I. Kartiko and M. Kavakli, “Effects of depth cues on simulator sickness,” In *Proceedings of the 1st International Conference on Immersive Telecommunications - IMMERSCOM* 2007, pp. 1–4, 2007. ACM SIGMM Technically sponsored by Create-Net and EURASIP.

[36] J. F. O’Hanlon and M. E. McCauley, “Motion sickness incidence as a function of frequency and acceleration of vertical sinusoidal motion,” Aerospace Med., vol. 45, pp. 366-369, 1974.

[37] J. E. Bosa and W. Bles, “Modelling motion sickness and subjective vertical mismatch detailed for vertical motions,” Brain Research Bulletin, 47(5), pp. 537–542, 1998.