THE EFFECT OF VISUAL PROPERTIES OF THE SIMULATED ENVIRONMENT ON SIMULATOR SICKNESS AND DRIVER BEHAVIOUR

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Abstract

This study aimed to explore the idea of visual complexity in the TRL driving simulator in terms of how it might be quantified and systematically reduced and the effect this would have on simulator sickness levels and driver performance. Three novel simulator environments were designed to explore several visual factors: the presence of textures; the realism of textures; and the presence of vertical relative size cues. These environments were compared to a standard realistic simulation of an urban street. Twenty female participants drove each of the four simulations and completed a set of standardized tasks including natural speed choice, distance judgement and speed maintenance with and without use of the speedometer. Simulator sickness scores were measured before and after each condition.

Results indicated no benefit of reduced complexity in terms of simulator sickness. Participants tended to choose a higher speed in all of the reduced complexity environments compared to the standard realistic simulation. When judging speeds without the speedometer participants tended to over estimate their speed, travelling slower than required when attempting to maintain 20 mph but when attempting to maintain 50 mph they tended to under estimate their speed and travel faster than the required 50 mph in all conditions.

Overall, the results of this study suggest that a reduced complexity abstract environment might be suitable for some research applications, particularly where the performance of abstract tasks is of interest rather than real-world behaviour and where development resource is an issue.

Keywords

Simulator, Sickness, Driver Performance, Urban Area, Speed

Résumé

Introduction

When developing road and traffic environments for driving simulation there is the implicit assumption that a photorealistic and therefore complex scene is best. However, the development time involved in pursuing this aim is substantial and a high level of complexity and realism may not always be necessary or appropriate for all applications. This study aimed to explore the idea of visual complexity in the TRL driving simulator in terms of how it might be quantified and systematically reduced, and the effect this would have on simulator sickness levels and driver performance.

There has been limited interest in the visual complexity of the simulated environment to date and most of these studies have concentrated on performance measures of specific tasks. Pausch and Crea (1992) describe previous research from the military flight simulation domain on scene content and state that scene detail can produce performance advantages in some circumstances and that the size of the effect is dependent on the task.

Rizzo, Severson, Cremer and Price (2003) used a reduced complexity abstract environment to test decision making ability in brain damaged participants. This research provided the original inspiration for the current study because it involved a participant group who were particularly vulnerable to simulator sickness and data collection was successful using the novel database design. Other studies have investigated the differences in sickness levels between different types of environments, such as highway driving compared to rural or city driving (e.g. Mourant and Thattacherry, 2000). To our knowledge, there has not been any published research which has examined visual complexity specifically in relation to simulator sickness.

Reducing the complexity of the scene can reduce the load on the simulation hardware and software and this may reduce the amount of display flicker and improve the graphics update rate. Flicker and slow or variable graphics update rates have been shown to provoke simulator sickness (Mollenhauer, 2004).

Therefore, the aim of this project was to create three novel "reduced complexity" environments with different characteristics and examine their effect on simulator sickness and performance of several standardized driving tasks.

Method

Participants

Twenty female participants took part in this study. The age range of participants was 25-50 years old. All participants had driven the TRL driving simulator in the past but had not taken part in any simulator research in the month prior to the trials.

Scene content and experimental design

In the TRL driving simulator, participants cannot employ binocular cues to motion and depth because the driving environment is a two-dimensional picture projected onto a flat surface.

Therefore, they must rely on pictorial cues in order to perform driving tasks. Relative size, linear perspective and gradient cues are important and they were considered in the design of the novel environments (See **Error! Reference source not found.**).

Table 1 – Detailed description of experimental conditions

Condition			**Linear perspective cues**	**Relative size cues**	**Texture gradient**
Description	**Texture**	**Posts**			
1 – Realistic urban street	Realistic	Yes	Road edges; Yellow lines; Road centre line; House tops/bottoms; Divisions between windows and shop fronts – **6 sources**	Bollards; Lamp posts; Vertical house boundaries; Windows; Gables; Chimneys – **6 sources**	Road texture; Pavement texture; House textures – **3 sources**
2 – Abstract world with posts	Abstract	Yes	Road edges; Road centre line; Block bottom/tops – **3 sources**	Bollards; Posts; Divisions between blocks – **3 sources**	Road texture; Pavement texture; Block surface texture – **3 sources**
3 – Abstract world without posts	Abstract	No	Road edges; Road centre line; Block bottom/tops – **3 sources**	Divisions between blocks – **1 source**	Road texture; Pavement texture; House texture – **3 sources**
4 – Flat world	Flat Colour	Yes	Road edges; Road centre; Yellow lines; House top/bottoms; Divisions between top and bottom of houses – **5 sources**	Bollards; Lamp posts; Vertical house boundaries; Gables; Chimneys – **5 sources**	**No sources**

The visual complexity aspect of VEDACS (Virtual Environment Description and Classification System, cited in Ruddle, 2004) was selected as the most appropriate framework in which to consider the visual complexity of the novel environments. VEDACS quantifies visual complexity in terms of the number of textures and the number of objects as well as a subjective rating of complexity.

The predicted complexity ranking of the environments based on VEDACS from most complex to least complex is Condition 1 – Realistic environment, Condition 4 - Flat texture environment, Condition 2 – Abstract textures with vertical markers, Condition 3 – Abstract textures without vertical markers.

Figure 1 – Screen captures of the four conditions

Condition 1 – Realistic urban street

Condition 2 – Abstract textures with vertical markers

Condition 3 – Abstract textures without vertical markers

Condition 4 – Flat textures

This study employed a within subjects design. The conditions provide a comparison of three key visual property factors and were designed to be equivalent as far as possible in all other visual factors. The key factors are:

- **Realism**: realistic surface textures vs. abstract surface textures (1 vs. 2)
- **Vertical markers**: present vs. absent (2 vs. 3)
- **Textures**: present vs. absent (1 vs. 4)

The order of conditions was varied to reduce the impact of learning effects.

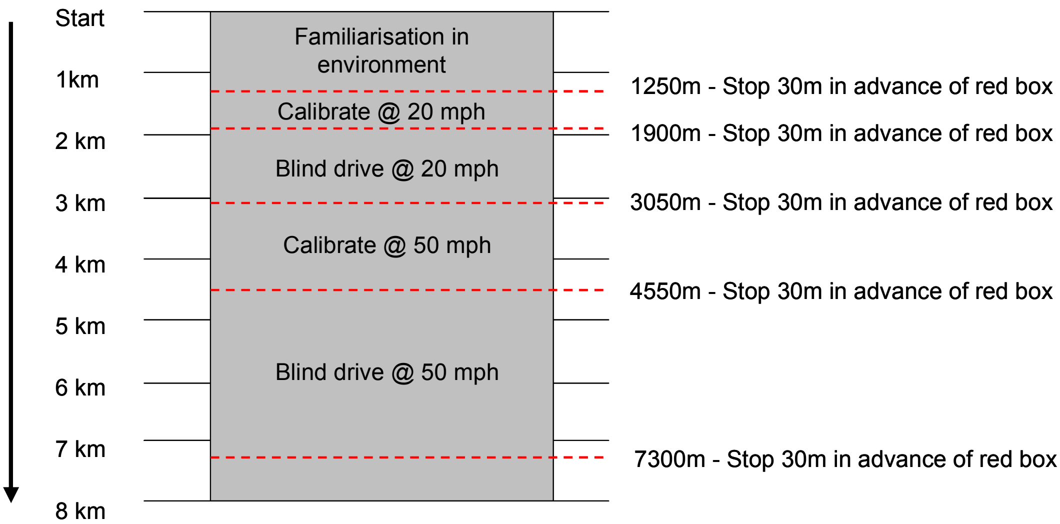
Route and scenario design

Participants initially drove a short familiarisation route for 8-10 minutes. This consisted of a rural scene.

There were four experimental databases. Each database formed a route of approximately 8 km/10 minutes in length/duration made of repeated straight sections.

During the drive participants completed several tasks which are summarised in Figure 2.

Figure 2 – Trial scenario



The total length of the trial scenario was 7300m. Identical tasks were completed in the order shown in Figure 2 in each condition.

- **Familiarisation in environment** - Participants drove at their chosen speed for a distance of 1250m.
- **Stop 30m in advance of red box** - Participants were required to stop at a distance they judged to be 30m in advance of a red box in the road at five points in the drive, 1250m, 1900m, 3050m, 4550m and 7300m.
- **Calibrate @ 20/50mph** – Participants were required to travel at 20mph or 50mph with reference to the speedometer.
- **Blind drive @ 20/50mph** – The speedometer was occluded and participants attempted to maintain a speed of 20mph or 50mph without reference to the speedometer.

Equipment

The trials were conducted using the TRL Driving simulator. The simulator consists of a Honda Civic family hatchback. The engine and major mechanical systems have been replaced by a sophisticated electric motion system which imparts motion in three axes (heave, pitch, and roll).

Large display screens are used to display the projected graphic images that represent the external environment to the driver at resolution of 1280×1024. Three forward screens give the driver a 210º horizontal forward field of view and a rear screen provides a 60º rearward field of view which enables normal use of all mirrors. A stereo sound system with internal and external speakers generates realistic engine, road, and traffic sounds. SCANeR II software is used to implement the simulation.

An in-car colour LCD display was used to display a speedometer. This allowed the speedometer to be occluded and revealed automatically for the purpose of the driving tasks.

Procedure

All trials were conducted in the morning. Each participant completed a short familiarization drive followed by four experimental drives presented in a varied order. Standard instructions were given before each experimental drive and automated instructions were issued during the drives via the PA system. There was a break of approximately 30 minutes between each drive during which participants were permitted to drink water only.

Prior to the familiarization drive participants completed a driver characteristics questionnaire containing basic demographic items and questions about history of driving the TRL car simulator. Participants also completed a The Kennedy Simulator Sickness Questionnaire (SSQ – Kennedy, Lane, Berbaum and Lilienthal, 1993) immediately prior to and immediately after each drive, including the familiarization drive. At the end of the trial participants completed a final questionnaire relating to the perceived complexity and comfort of each condition.

Results

All analysis was conducted using the Wilcoxon Signed Ranks test. Comparisons were made according to the key visual factors, Realism (Condition 1 vs. 2), Vertical Markers (Condition 2 vs. 3) and Textures (Condition 1 vs. 4)

Simulator Sickness - Mean post-drive SSQ scores for each condition are reported in Table 2 for comparison to other studies. There were no significant differences between conditions in post-drive SSQ, increase in SSQ score post-drive or any of the SSQ subscales, Nausea, Occulomotor discomfort or Disorientation.

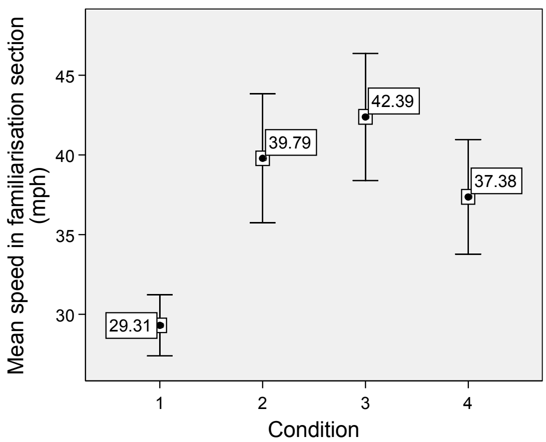
Table 2 – Post-trial SSQ scores

Condition	N	Min	Max	Mean (2 d.p.)	S.D. (2 d.p.)
Fam	20	0	71.06	8.60	16.37
1	20	0	67.32	10.29	15.82
2	20	0	86.02	11.97	19.96
3	20	0	78.54	14.77	18.62
4	20	0	63.58	11.59	16.46

Distance judgement - There were no significant differences in distance judgement between conditions. Distance judgement was poor in all conditions. The average distance participants stopped in front of the box was 104m (nearest metre).

Speed choice - In the initial section of each condition participants were instructed to "drive as you would normally at a speed you feel is appropriate". The speed chosen during this section of the route was analysed as a measure of natural speed choice in unrestricted conditions.

Figure 3 – Mean speed choice in familiarisation section according to condition (mph)

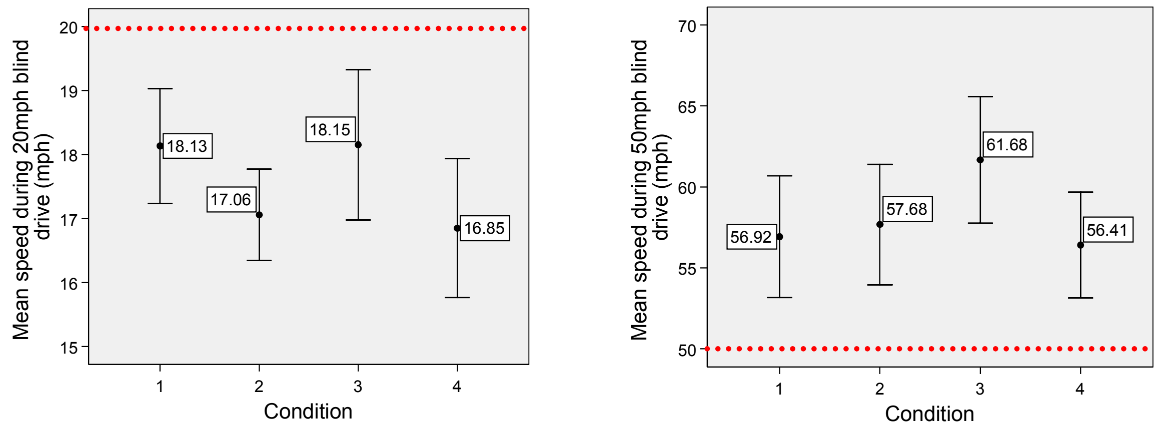


Participants traveled significantly faster when the textures displayed were abstract rather than realistic (Condition 1 vs. 2: $Z = -3.743$, $p < 0.001$). When vertical marker cues were removed from the scene participants tended to travel faster (Condition 2 vs. 3: $Z = -2.165$, $p = 0.03$). Finally, there was a significant difference between conditions 1 and 4 ($Z = -3.702$, $p < 0.001$). The mean speed of travel in condition 1 was 29.3 mph which is just below the speed limit in the UK for built-up areas as depicted in condition 1.

Speed during blind drives - The average speed participants travelled at during the 20 mph blind drive task was compared between conditions. In all conditions participants tended to over estimate their speed, travelling slower than the required 20 mph. There were significant differences between conditions 1 and 4 ($Z = -2.678$, $p = 0.007$) and the difference between conditions 1 and 2 approached significance ($Z = -1.1851$, $p = 0.064$). These results suggest that participants estimated their speed more accurately in condition 1 compared to either condition 2 or condition 4.

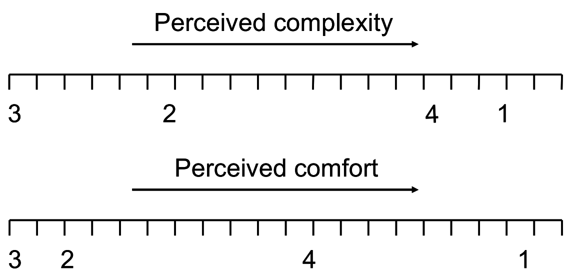
In contrast, during the 50 mph blind drive participants tended to under estimate their speed and travel faster than the required 50 mph. Statistical analysis indicated there was a significant difference between conditions 2 and 3 ($Z = -2.128$, $p = 0.033$). Participants were worse at judging their speed in condition 3 compared to condition 2.

Figure 4 – Mean speed during 20mph and 50mph blind drives



Ratings of perceived complexity and comfort - Participants ranked the complexity and comfort of the each environment condition using paired comparisons. This method allows different options to be compared on a uni-dimensional scale, which permits not only the rank order to be investigated but also the relative differences between each option. The results of the paired comparisons for complexity and comfort are shown in Figure 5. The rank order of each condition in terms of perceived complexity was consistent with that of predicted complexity.

Figure 5 – Participants' relative rankings of visual complexity and comfort for each condition



The results show that participant comfort declines as complexity declines.

Discussion

The results of this study showed no benefit of reduced complexity in terms of reduced simulator sickness. The SSQ scores were generally low and this may be in part due to the sampling strategy. All participants were previous users of the simulator who were willing to participate; therefore, it can be assumed that they were not prone to suffer any serious simulator sickness symptoms. Any benefits may be more readily observed in participants who are more vulnerable, for example, first time users, brain damaged or drug/alcohol impaired.

In addition to the participant group, the routes developed for the purpose of this trial were straight and the maximum length of each drive was ten minutes. Negotiating curves and turning corners is thought to increase the risk of simulator sickness (Nilsson, 1993). A greater exposure may also be necessary to observe any benefits.

When given a free choice over their speed, drivers chose to travel faster in Conditions 2 and 4 compared to condition 1. The mean speed in condition 1 was 29.3mph. This corresponds to the speed limit in the UK for a built-up road like the one in the Condition 1 database. The results suggest that the removal of the realistic look of the database changes participants' perceptions of the road rules that apply. The implication of this is that, if abstract environments are used in research where speed choice is an important measure, cues may need to be added to the scene to inform drivers which rules apply or the validity of the driving behaviour will be compromised.

An unexpected result of this study was that participants tended to overestimate their speed, travelling slower than the desired speed, when asked to travel at 20mph without using the speedometer and yet tended to underestimate their speed, travelling faster than the target speed, when doing the same task at 50mph. The direction of this result was the same for all conditions.

The majority of participants' ratings of complexity were in line with the predicted ratings which were based on the Virtual Environment Description and Classification System (VEDACS). This result suggests that the visual complexity factors identified in VEDACS might be valid for use in a driving simulator environment. The potential application of VEDACS, or a modified version of it, to driving simulation would be an interesting subject for further study. This could provide a standardised measure of the visual properties of the simulated environment which could be used as a variable in research studies such as this one. It could also be used as a control measure to ensure comparability across conditions in an experimental set-up.

The paired comparison analysis strongly indicated that participants were most comfortable in the familiar realistic environment of Condition 1. The issue of participant comfort and other user experience factors is important as this influences the tendency for participants to volunteer for research. It is particularly relevant in training applications as when trainees suffer discomfort, for example, through simulator sickness, the benefits of the training may be reduced (Brook-Carter, Luke and Parkes, 2004). In this study comfort was only explored using one questionnaire item and it is unclear which factors have influence.

Overall, the results of this study suggest that a reduced complexity abstract environment might be suitable for some research applications, particularly where the performance of abstract tasks is of interest rather than real-world behaviour and where development resource is an issue. A benefit in terms of reduced simulator sickness was not observed in this particular group and task scenario and further research would be required to confirm whether this result applies to more vulnerable groups and more challenging situations.

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