

DEVELOPMENT OF A DRIVING SIMULATOR FOR HUMAN-VEHICLE INTERACTION STUDIES

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ABSTRACT

Driving simulators are a valuable resource for human-vehicle interaction studies. Unfortunately, commercially available driving simulators are expensive and use software that sometimes offers limited flexibility or customizability. Exploiting the maximum potential of simulation requires that all aspects of the simulation software and the virtual driving environment be adjustable. However, in creating custom hardware/software for simulator usage, it is difficult to quantify the relative influence of various cues presented to the driver to weigh cost/benefit of these cues. It is qualitatively known that fidelity of the simulated experience is highly dependent on several issues including motion cues, vehicle dynamics models, immersive visual environment, and the human-vehicle hardware interface. However, quantification is lacking of the exact relationships between cues to the driver and fidelity in measured driver-vehicle interaction.

This work details recent attempts at this quantification at Penn State. To this end, a virtual driving environment is created that is modeled directly after an actual test track facility. The intent of this parallelism is to formally and experimentally compare behaviors measured in the simulator to those measured on the actual track, forcing identical driving tasks in each.

In this paper, animations of driving maneuvers at fixed speeds in the virtual environment are developed and variations of several optical parameters are incorporated. These animations, paired side-by-side with videos of the maneuvers in the actual environment, are shown to participants who rate their comparability on specified visual attributes presented in the environmental display. By analyzing the degree of participant attention to incremental changes in visual attributes, the predominant optical driving cues are educed.

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1 INTRODUCTION

In the process of developing a virtual environment for a driving simulator, the number of visual details that could be incorporated for representation is very large. The amount of time required to add details to the driving environment is quite substantial and therefore costly. Consequently, a cost/benefit analysis of these details must be performed in order to make sure that the visual cues most important for driving are presented faithfully. A number of driving-specific visual studies have been conducted that suggest the relative importance of visual and/or driving details.

Two research teams separately evaluated which parts of the road drivers focus on for steering and braking tasks, respectively. Land and Horwood (1995) found that a view of the distant road decreases the jerkiness of steering, while viewing the near road view improves position in lane. Rogers et al. (2005) showed that, compared with inexperienced drivers, experts drove at higher speeds, looked at the horizon more, and spent less time focusing on the road. These studies suggest that multiple cues are affecting driver response; that these cues are learned over time to correlate with driving behavior; and that speed might be a measure of the perception of such cues.

In particular, several studies showed variations in speed between drivers of real and simulated vehicles. Tornros (1998) recorded higher average driving speed in a simulated tunnel than in a real one, although the difference in speed between driving lanes was similar in both cases. For Godley et al. (2002), participants' speed decreased a similar amount with the presence of rumble strips in both an instrumented car and a driving simulator, but the average speed was higher in the car than in the simulator. Santos et al. (2005) measured a decrease in speed and an increase in speed variation with the level of difficulty of an In-Vehicle Information System in each of three environments: instrumented car, wrap-around driving simulator, and single-monitor driving simulator. It was found, however, that test participants drove the slowest speed with the wrap-around simulator, and that there was more speed variation with the monitor than the other two environments. While all these studies show qualitatively similar responses of vehicle velocity to the particular variable under consideration for both a simulated environment and a real driving environment, they also suggest that there are measurable differences in perceptions of velocity when comparing simulator to actual vehicle driving scenarios.

Additional studies have looked at other factors of perception of motion involved in computer-generated images. Sudarsan et al. (1997) examined how driving control is affected by video update frequency and image delay, with the result being that increases in frame lag and decreases in update frequency increased the time to complete the task. This study suggests therefore how simulator-specific attributes with rendering a scene might have specific impact on perception. Lin et al. (2005) exposed 12 participants to complex visual motion through a simulated environment. When indicators of the upcoming path were present, simulator sickness was reduced and driving seemed smoother and more enjoyable, even when participants could not say afterward whether or not the motion was following the darkened path. In a separate experiment, the same effects were achieved by an avatar that predicted upcoming turns 0.5 seconds in advance. This study is important because it suggests that human-based modification of the visualization, even if the modifications are artificial, may have positive impact on human perception of the driving task.

An evaluation of the kind of visual information used in anticipating rear-end collisions was done by Cavallo et al. (1995), that suggests that even details considered minor in most rendering systems, such as roadway texture, may have a large impact on driver perception.

Yet even apart from collision with obstacles, accurate perception of vehicular speed is important in avoiding loss of control during curve negotiation or operation under hazardous roadway conditions. An evaluation by Hoskins et al. (2002) along with the Pennsylvania Department of Transportation found that measures of driver performance through ratings from professional driving instructors largely agreed with numerical records from the simulator recording capability. The validation of driving simulators was also the focus of a literature survey published by Hoskins and El-Gindy (2006). In general, the correspondence of driving performance in a simulator versus a vehicle is the broader area within which visual speed cues are a specific focus. However, the relative influence of visual features of the driving environment on the perception of speed has not been sufficiently determined.

An experiment was thus designed to investigate how perception of speed is affected by characteristics of the visual scene. The remainder of the paper is organized as follows: methodology, computer experiment, method of analysis, results and discussion, and conclusion.

2 METHODOLOGY

A unique approach to this research was the development of a driving simulator built primarily from software toolsets used within the video game industry rather than from software more typical of academic or research-oriented rendering systems. Real-time game engines were found to be far easier to use in research settings, significantly more realistic, and far more capable of utilizing the latest video capabilities of modern computing resources. Game development software inherently supports coding of custom behaviors such as inputs from the keyboard, mouse, or even outside TCP/IP connections to control features of the virtual environment. Standard game outputs include real-time video streaming, stand-alone animations, storage of frames in memory, as well as output streams of user-defined data parameters to file. For this specific study, the 3-D modeling program 3D Studio Max was adopted due to its pervasive use in the game development community. This program enables the application of visual textures to CAD drawings as well as GIS-generated topography and roadway features. To render the scene in real-time, the Virtools game engine was selected for its quality and ease of use.

Development of the virtual environment focused on accurate rendering of the Pennsylvania Transportation Institute (PTI) test track, and this work began with the acquisition of

survey data in CAD format from a local engineering firm, Sweetland Engineering. Far-field terrain features were imported from US Geological Survey terrain data files. The roadway and terrain geometry were overlaid with visual textures in 3D Studio Max, and features such as street lamps, buildings, and trees were added. Digital still and video camera recordings were made of the track as a basis for placing visual features and correcting obvious errors in the CAD survey data. The results were exported to Virtools for real-time display.

Comparisons between the actual and virtual environments were made by creating video recordings outside the front view of a Mercury Sable while driving around the test track at fixed speeds between 6.7 and 15.6 m/s (15 and 35 mph). An approximate equivalent in the virtual environment was created by designing a virtual camera animation path around the track in 3D Studio Max. This path was used to render animation video files of predetermined length to match the driving videos. A web page was created using Java script to display both videos side by side at the same time. This comparison clearly revealed visual differences between the animation and the real driving videos, notably pavement texture variations on the real track that were obviously misrepresented in the virtual track. Questioning the relative importance of such driving cues, formal study began on the effects of visual features of the virtual environment on the viewer's perception of speed.

3 COMPUTER EXPERIMENT

In order to isolate as much as possible the central (non-peripheral) visual cues influencing perception of speed, a computerized testing routine was developed in which the relative importance of visual cues was evaluated by having test participants perform a dynamic matching exercise. Test participants adjusted the speed of motion on virtual roads containing the combinations of visual cues listed below to match the speed of a video of driving at each of two fixed speeds. The various combinations of cues were presented in random order.

Seventeen participants, thirteen male and four female, took part in the experiment. All participants were asked to fill out a Background Questionnaire with demographic information and information related to driving and video game experiences. The use of volunteer participants in this study was approved by the Penn State University Office for Research Protections.

Instructions for the virtual driving task were presented verbally by an investigator, and also in written form on the computer monitor before presentation of the computerized task. Participants were seated at a table in front of a computer monitor. During the laboratory experiment, computer animations of a straight section of road, similar to the virtual version of the test track, were paired side-by-side with looped videos of fixed-speed maneuvers collected at the actual test track facility, shown in Figure 1. The images were both displayed with a screen size of 640 pixels by 480 pixels on a standard 0.48 m (19 in.) computer monitor set to a resolution of 1600 pixels by 1200 pixels. Participants were asked to adjust the speed of an interactive virtual driving environment (hereafter referred to as "animation") on the left to visually match the speed of the real driving video on the right, by using the up and down arrow keys on the computer keyboard to speed up or slow down the animation, respectively. When the participant was satisfied that both speeds are equal, they clicked the "Next" button and the next slide appeared. No feedback on the accuracy of estimations was given.



Figure 1. Speed-adjustable animation side-by-side with control video.

Participants completed one or more computerized practice trial to become familiarized with the task. They were allowed to ask questions at anytime during the practice trials. Once familiar with the task, participants completed a computerized session consisting of 48 test trials.

The effect of three visual cues on perception of speed was tested by five environment features, which were selected for ease of scene preparation. They were: horizontal scaling factors (roadway width and road lane markings), optical flow of the traveled path (roadway texture and road lane markings), optical flow of objects outside the traveled path (roadside trees), and expansion of objects in the view field (trees along narrow roadway). Two videos of forward motion—15 and 35 mph (6.7 and 15.6 m/s)—were used for comparison. The five environment features were presented in combination via eight scenarios, which were presented in random order. Each scenario was repeated three times with each video speed, to gain a sense of the variability of each cue, for a total of forty-eight trials. The eight scenarios are shown in Figure 2.

4 METHOD OF ANALYSIS

Differences in visual cues were tested using paired t -tests. Paired t -tests are used in estimating the difference of two means when data are taken from the same participants for both experimental conditions and yet the variances of the two sets of results are not necessarily equal. For another example of the use of this test, see Lin et al. (2005). Paired t -tests enable one to choose between two hypotheses. The first hypothesis, called the null hypothesis H_0 , always states that the difference of two means μ_D is equal to a test value d_0 , as shown in Equation 1. The other hypothesis, called the alternative hypothesis H_1 , states an inequality as an alternative to the null hypothesis, as shown in Equation 2.

$$H_0: \mu_D = d_0 \quad (1)$$

$$H_1: \mu_D \neq d_0 \quad (2)$$

The t -value is calculated using Equation 3 for $n - 1$ degrees of freedom, where \bar{d} and s_d are the mean and standard deviation of the normally distributed differences of n random pairs of measurements, and d_0 is the hypothesized mean difference.

$$t = \frac{\bar{d} - d_0}{s_d / \sqrt{n}} \quad (3)$$

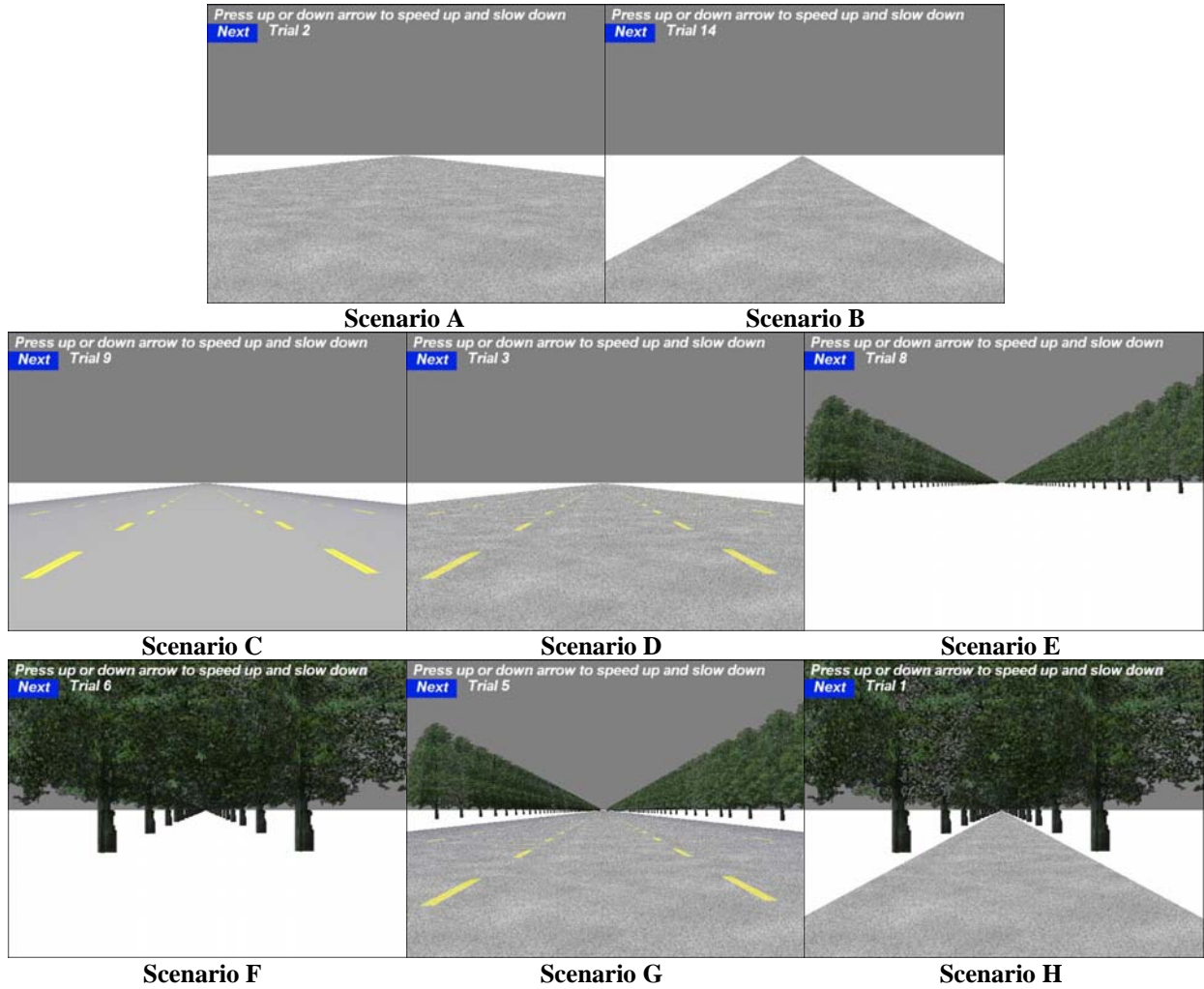


Figure 2. The animation configurations of the experiment.

To decide whether or not to reject the null hypothesis H_0 , a 95% confidence interval is defined between the lower bound θ_L and the upper bound θ_U , as shown in Equations 4 and 5, where the value for $t_{\alpha/2}$ is obtained from a table, using the two parameters $\alpha = .05$ and $v = n - 1$, where α is the area of the t -distribution less than $-t_{\alpha/2}$ and greater than $t_{\alpha/2}$, and v is the degrees of freedom. Tables of t -values are found in any standard statistics textbook, such as Walpole et al. (1998).

$$\theta_L = \bar{d} - t_{\alpha/2} \frac{s_d}{\sqrt{n}} \quad (4)$$

$$\theta_U = \bar{d} + t_{\alpha/2} \frac{s_d}{\sqrt{n}} \quad (5)$$

If the t -value obtained in Equation 3 falls between the lower and upper bound, then the null hypothesis H_0 is not rejected, and otherwise it is rejected in favor of the alternative hypothesis H_1 .

In this study, the random pairs of measurements are the participant's final animation speeds for the two scenario-video combinations being compared. In all cases in this study the value of d_0 was set to 0, since the object of the comparison was to determine whether the results

of one scenario-video combination were or were not the same as the results of a different scenario-video combination. A p -value was also calculated automatically for each t -value using Microsoft Excel. The p -value is the probability, based on the number of pairs of measurements n and standard deviation s_d , of rejecting the null hypothesis H_0 when it is true. When the t -value is between the upper and lower bound for $\alpha = .05$, then the p -value is greater than 0.05, and otherwise the p -value is less than 0.05. Although calculation of the p -value usually requires statistical software, due to its complexity, a rough estimate may be obtained by comparing the t -value obtained using Equation 3 with the t -values found in a table, and interpolating between the corresponding values of α . The results of this study were analyzed for significance at a probability level $p < .05$, meaning that the results of the two scenario-video combinations are considered to be significantly different only if the confidence level is above 95% that the null hypothesis H_0 may safely be rejected.

5 RESULTS AND DISCUSSION

In the experiment, each participant adjusted each animation to a speed deemed to match the speed of the corresponding video. The final animation speed, as adjusted by the participant, is the result by which one scenario is compared to another.

The effect of varying the control video is illustrated in Figure 3. A normalized speed measure was created by dividing animation speed by the control video speed. In all cases, the mean normalized speed was greater for the 6.7 m/s (15 mph) control video than for the 15.6 m/s (35 mph) control video, although in the case of scenario A, the difference was not significant ($p = .1008$). Scenario A displayed a five-lane roadway with asphalt texture. The differences in results depending on which control video was presented may be due to differences between the two control videos of lateral position relative to the lane of travel or of starting position.

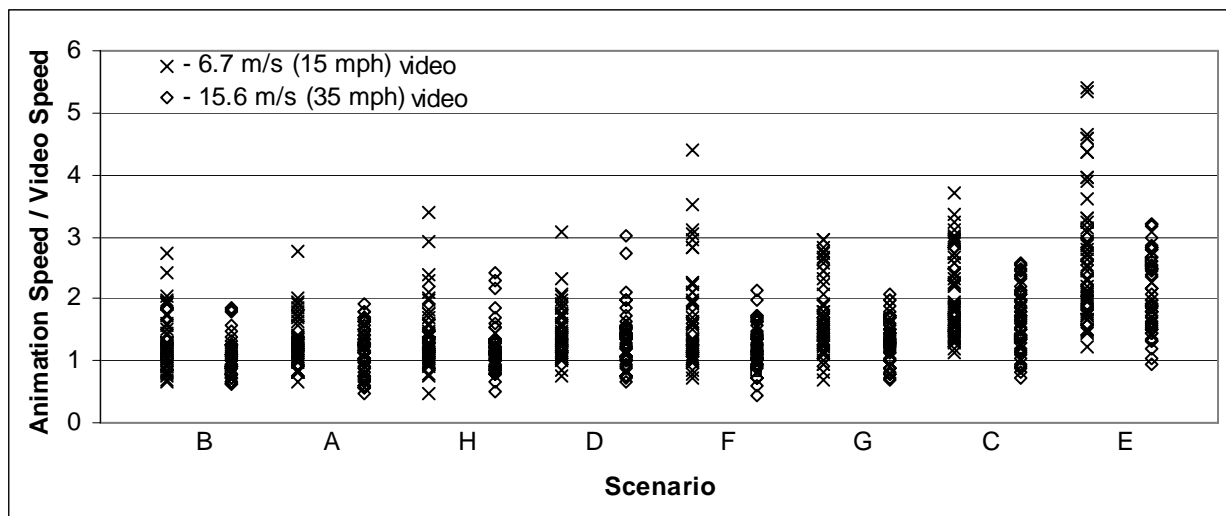


Figure 3. Comparison of scenario results distinguished by speed of control video.

A comparison of the three runs for each scenario comparing the effect of run order using paired t -tests determined that the results did not vary significantly as a function of when the run occurred ($p > .05$). Consequently, the three final animation speeds for each scenario by a given participant were averaged as a basis for further comparisons of visual cues.

Each scenario was then compared with every other scenario. The mean scenario results are provided in Table 1 and illustrated in Figure 4. The results in general show that all scenarios caused participants to adjust the animation speed to a velocity in excess of that of the control video. Two scenarios in particular, C and E, exhibited speed mismatches of magnitude noticeably larger than those of the other six. It may be noted in Figure 2 that neither scenario C nor scenario E provided near-field texture as a cue for judging velocity.

Table 1. Average animation speed results as a function of video speed.

Video Speed (m/s)	Scenario							
	A	B	C	D	E	F	G	H
	Animation Speed (m/s)							
6.71	8.76	8.66	14.14	9.69	18.32	11.16	11.55	9.41
15.65	18.16	16.42	26.56	21.00	33.05	19.47	20.91	18.70

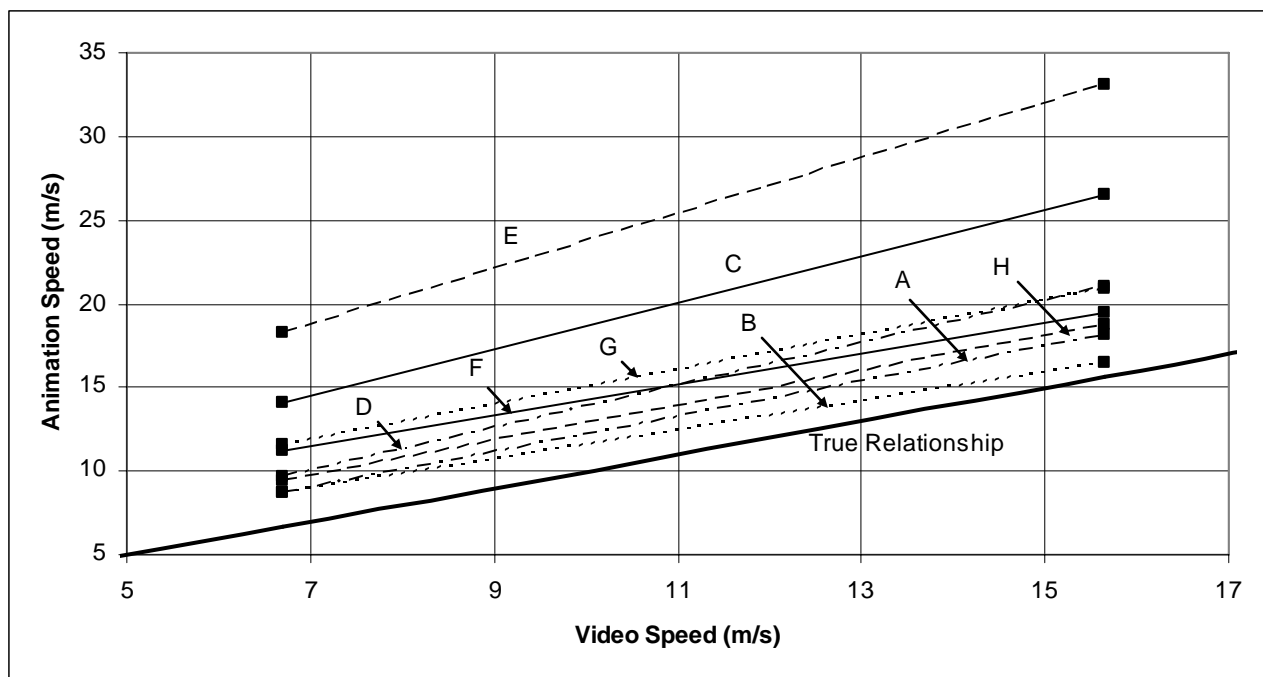


Figure 4. Average animation speed results as a function of video speed.

Subsequently, the effect of individual visual cues on test results were evaluated by performing paired *t*-tests on scenarios displaying variations of the particular cue. The addition to a scenario of one cue in particular, roadway texture, resulted in significant improvement of performance in every case ($p < .05$). In contrast, adding other cues to scenarios already containing roadway texture decreased performance ($p < .05$), except in the case of scenario H ($p = .0690$). As can be seen in Figure 2, scenario H adds texture-dense trees to both sides of a single-lane textured roadway. The combination of two near-field texture-dense cues, trees and roadway, in this scenario, did not result in decreased performance.

6 CONCLUSIONS

The primary conclusion is that with minimal cues participants were able to rather accurately match the animation and video speeds to within 20%. The quality of simulation, even with the barest cues, is high enough to enable velocity estimation at a level allowing rapid comparison with a nearby image stream.

A secondary point of interest is that adding more cues does not necessarily help the perception of speed. In fact, in this study, adding more visual detail to the scenario resulted in reduced speed perception accuracy. In essence, increasing the number of detailed visual cues also leads to increased possibility of visual distractions and disparities that subsequently reduce performance.

The results of the experiment suggest that in driving simulator design, the texture of the near field is an important visual cue for estimation of forward velocity. The presence of untextured objects in the near field (lane markers in scenario C) or of textured objects in the more distant view-field (trees in scenario E) did not make up for the absence of roadway texture. The presence of texture-dense objects in the near field (trees in scenario F) did, however, allow participants to estimate speed relatively accurately. These results are in agreement with those of Cavallo et al. (1995), which suggest that roadway texture can have a large impact on driver perception.

The results of this pilot study point the way forward in a number of directions. Additional study is required to verify the effect of near-field texture, as well as to determine ranges of texture density yielding appropriate driver response. Replacing the control video with a control animation may yield more conclusive results.

The effects of viewing size and field of view are undetermined. A repetition of the same experiment using projection screens and wider fields of view may yield different results.

7 ACKNOWLEDGEMENT

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