Available online at www.sciencedirect.com

ScienceDirect

Displays 28 (2007) 145–149

DISPLAYS

www.elsevier.com/locate/displa

Optic flow and geometric field of view in a driving simulator display

Ronald R. Mourant *, Najla Ahmad, Beverly K. Jaeger, Yingzi Lin

Virtual Environments Laboratory, Northeastern University, Boston, MA 02115, USA

Received 28 January 2007; accepted 23 April 2007
Available online 29 April 2007

Abstract

Conditions of high and low optic flow were generated in a display used for a driving simulator. Thirty drivers were requested to produce vehicle speeds of either 30 or 60 mph with the geometric field of view at 25, 55, or 85 visual degrees. Drivers overestimated the production of 30 by 20 mph. It was also found that the production of speed was highly dependent on the geometric field of view. These results suggest that optic flow presented in a driving simulator display does not correspond with optic flow found in real-world driving.

Keywords: Optic flow; Driving simulator; Geometric field of view; Focus of expansion

1. Introduction

Displays used in virtual reality based driving simulators have special requirements. When a driver/vehicle traverses a modeled 3D environment, the generated optic flow should be similar to that found in the real world [8]. It has been proposed that optic flow can be utilized in a number of driving tasks: (1) to obtain heading information when driving on straight and curved roads, (2) to steer around parked vehicles, roadside trees, etc., and (3) in braking and/or steering to avoid collisions when approaching other moving vehicles [2]. Several researchers have studied optic flow while driving in combination with where a driver looks. It has been found that drivers focus near the point where the roadway meets the horizon [7]. This location is known as the *focus of expansion* since it appears stationary and optic flow expands from it towards the vehicle. Several researchers have reported that drivers focus on a tangent point when negotiating curves [4,5,9]. This tangent point may also be considered a focus of expansion since it is (instantaneously) without motion and optic flow expands from it. The tangent point then moves as a driver traverses the curve. Using a focus of expansion as a "home base" for visual scanning may be optimal in terms of a driver monitoring changes in the pattern of optic flow. When the fovea of the eye is directed at the focus of expansion, optic flow can be detected in the peripheral part of the eye's retina. The periphery of the retinal region, consisting predominantly of rods, is primarily a detector of motion [3].

In the present study we investigate drivers' use of optic flow when producing a specified vehicle velocity. In real-world driving, drivers may refer to the vehicle's speedometer to assist them in obtaining or maintaining a velocity specified on a road sign. Glancing at a vehicle's speedometer entails suspending monitoring of the forward scene for about three-quarters of a second [6]. Unskilled and impaired drivers could choose inappropriate times to make glances to the speedometer that result in unsafe driving.

Optic flow in a driving simulator is inherently different from that seen in the real world. The huge horizontal width of optic flow in the real world is difficult to duplicate with computer monitors or large screens used by driving simulators. By necessity, many simulators compress the horizontal view in the real world by specifying a virtual scene field of view (FOV) that is greater than the projected FOV. This FOV, which is specified in computer software, is known as the geometric field of view (GFOV). Furthermore, the great variety of displays used in driving simulators, ranging from small computer monitors to large screen displays that

---

* Corresponding author. Tel.: +1 6173733931; fax: +1 6173732921.
E-mail address: mourant@coe.neu.edu (R.R. Mourant).

0141-9382/$ - see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.displa.2007.04.011

provide a 270-deg FOV, make it difficult to compare optic flow among simulator configurations.

It has been suggested that synthetic driving environments should be constructed so that they correspond to real-world experiences, especially with regard to the perception of velocity [1]. Driving simulators, in particular, should accurately portray optic flows found in the real world. This would enable simulator users to accurately estimate and generate vehicle velocities. In this study, we investigate the production of vehicle velocity in a driving simulator as a function of increasing GFOVs and the amount of optic flow.

2. Method

2.1. Participants

Thirty subjects (15 female and 15 male) participated in the study. They ranged in age from 22 to 35 years of age and had 20/20 or corrected to 20/20 vision. All subjects held a valid driver's license and had at least 3 years driving experience. Each participant was paid a $10 honorarium for participating in the study.

2.2. Apparatus

Northeastern University's Virtual Environments Driving Simulator, shown in Fig. 1, was used to collect data. A real vehicle buck allowed the driver to sit in and operate an actual automobile and its physical controls for the experimental activities.

An LCD projector, mounted behind the vehicle, displayed a 45 deg horizontal by 33.75 deg vertical image on a curved screen in front of the vehicle. The image resolution was 1600×1200 pixels presented with a constant frame rate of 60 per second. The vehicle's force feedback steering wheel, and accelerator and brake pedals were connected to the computer, which rendered the scene according to inputs from these devices. The speedometer readout was covered for the duration of the experiment.

2.3. Procedure

Participants were given a short practice run in the simulator to become familiar with the steering, acceleration, and braking characteristics of the vehicle. Each participant was requested to produce specified vehicle velocities. For consistency and clarity, subjects were read the following instructions, *"In each of the following runs, you will see a straight roadway. Before you begin each run, I will tell you a target speed, which will either be 30 miles per hour or 60 miles per hour. As soon as you feel that you are traveling at the target speed, pull up on the turn signal to the left of the steering wheel. There will be twelve runs, a short break, and then twelve more runs"*. Each time the driver activated the turn signal, the computer recorded the vehicle's instantaneous velocity and wrote it to a data file.

2.4. Experimental design

A three-factor $2 \times 2 \times 3$ experimental design was used in this study. Factor A was target velocity (30 or 60 mph). Factor B was optic flow (low or high). Trees were placed along the edges of the road to create a high optic flow condition. Views of the low and high optic flow conditions are shown in Figs. 2 and 3, respectively. Factor C was geometric field of view (25, 55 or 85 deg). Each participant was tested on the 12 conditions twice. The order of the presented conditions was randomized across subjects and runs.

3. Results

A three-factor ANOVA was used to analyze the results. Tukey post hoc tests were used to establish the degree of pairwise significance of means for F ratios at $p < .05$.

Fig. 1. Driving simulator configuration.

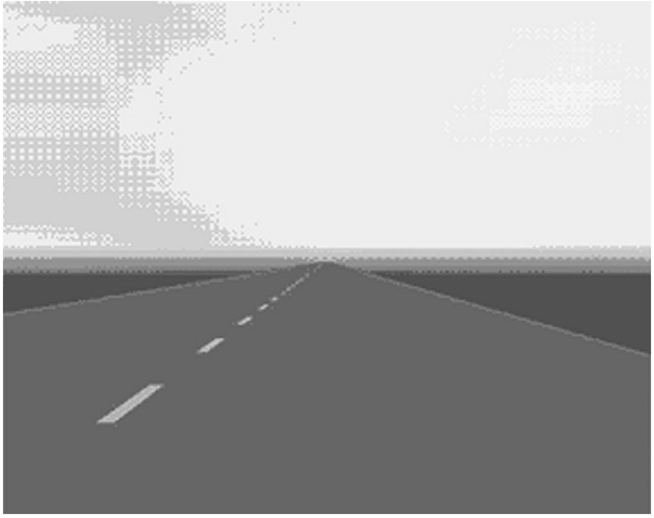

Fig. 2. Low optic flow condition.

Fig. 3. High optic flow condition.

Main effects. All three main effects, target velocity ($F = 317.4$, df = 1,708), optical flow ($F = 12.3$, df = 1,708), and geometric field of view ($F = 247.1$, df = 2,708) were highly significant with $p < .001$ and are presented in Figs. 4–6, respectively. A surprising finding was that subjects greatly underestimated vehicle speed when attempting to produce a velocity of 30 mph. For example, as shown in Fig. 4, the magnitude of average error reached as high as 20 mph over the target velocity. This overproduction of vehicle velocity was due to subjects underestimating vehicle velocity when going 30 mph. When the target velocity was 60 mph, the subjects produced an average velocity of 61.7 mph.

Fig. 5 shows that the presence of high optic flow resulted in the mean produced velocity being smaller than the requested target velocity. However, the amount of difference between low and high optical flow conditions was only 2.4 mph.

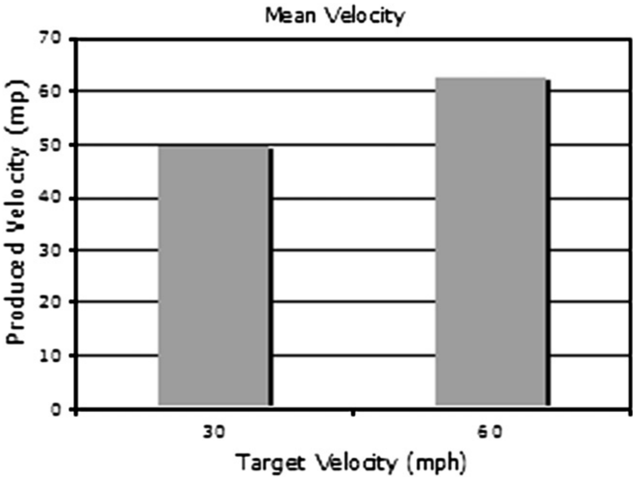

Fig. 4. Produced velocity by target velocity.

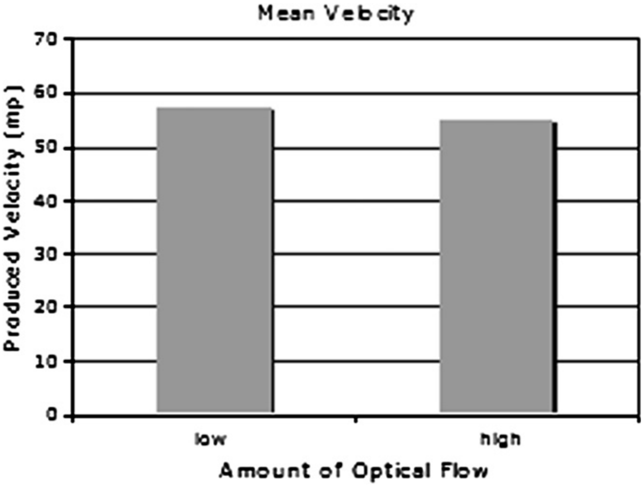

Fig. 5. Produced velocity by optical flow.

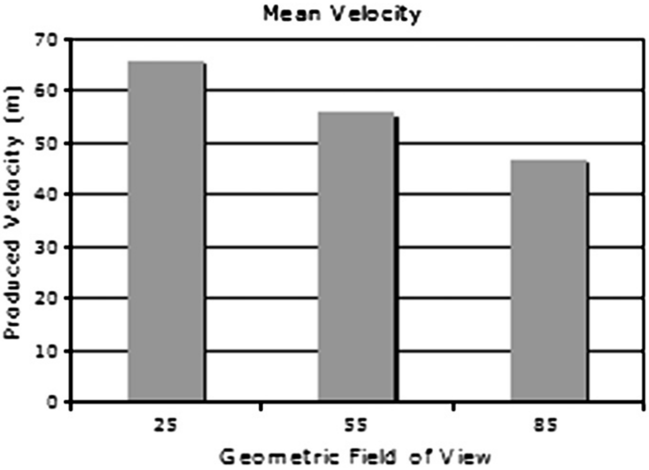

Fig. 6. Produced velocity by GFOV.

If subjects had produced accurate velocities at both 30 and 60 mph, the average of their produced velocities would be 45 mph. Thus the high optic flow condition can be considered to be slightly more accurate than the low optic flow condition.

Fig. 6 shows that the means of velocity production decreased as the GFOV increased. This suggests that a wider geometric field of view leads to the perception of traveling at a higher velocity. As a result, the subjects produced lower velocities as the GFOV increased.

Interactions. A highly significant interaction was found ($p < .001$) between target velocity and GFOV, as shown in Fig. 7. Here, it can be seen that the decreasing slope of the 30 mph condition is greater then that of the 60 mph condition.

Fig. 7 also illustrates that, for the 60 mph condition, subjects were most accurate in velocity production when the GFOV was 55 deg. For the 30 mph condition, subjects were most accurate when the GFOV was 85 deg.

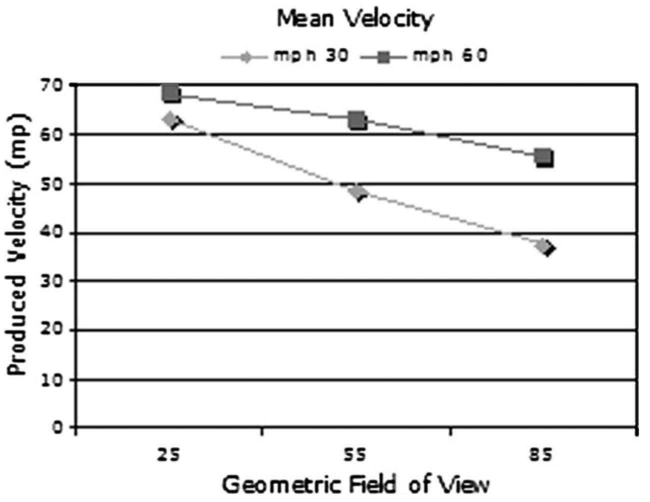

Fig. 7. Interaction of produced velocity with GFOV.

4. Discussion

The finding that subjects were considerably inaccurate when producing 30 mph velocities was unexpected. As the significant interaction of produced mean velocity with GFOV shows, the accuracy of subjects production of 30 mph velocities increased as the GFOV became larger. The trend of subjects producing smaller velocities as the GFOV increased also occurred, to a smaller degree, during 60 mph velocity production. Why did subjects perceive their vehicle to be moving faster in the virtual environment with the large GFOV as compared to the small GFOV? At this time, we do not know. However, a similar result has been reported in which it was observed that subjects perceived oncoming traffic to be traveling faster at higher GFOVs [1].

Interestingly, subjects were most accurate in the 60 mph velocity production task, when the GFOV was 55 deg. When producing 30 mph velocities, subjects were most accurate when the GFOV was 85 deg. Thus if an experiment were to be designed such that vehicles traveled around 60 mph, a 55 deg GFOV would be best to have drivers feel that they were really going 60 mph. Similarly, an 85 deg GFOV would be best if traveling around 30 mph. What should be done if the environment called for driving at both 30 and 60 mph or at speeds that could traverse this range? Should we compromise somewhere between 55 and 85 deg? Hopefully, future research will help answer this question.

Many research driving simulators and almost all driving simulators used for driver education and driver evaluations do not permit the GFOV of view to be changed. Thus, most simulators cannot be optimized to reflect optic flow similar to that in the real world. One advantage of our research simulator is that we can easily change the GFOV, since we composed the source code and made it easy to change the GFOV using a configuration file.

The large amount of overproduction error (20 mph) that was found when subjects tried to produce a velocity of 30 mph has implications for almost all driving simulators. This result suggests that the production of a 30 mph velocity (and presumably slower velocities) in a simulator is very different from that in the real world. When subjects drive too fast in simulators, their reactions to many driving events in the simulator would not correspond with real-world driving, due to this phenomenon.

Apparently this phenomenon does not exist in real-world driving. It has been reported on participants estimating vehicle velocities in the real world [10]. When trying to estimate a velocity of 33 mph, the error during nighttime driving was only 1 mph. Under daytime driving, the error was 6 mph less than the actual speed of 33 mph.

Casual observations of drivers in neighborhoods (where speed limits are 25/30 mph) found that drivers can accurately produce velocities in the range of 25–35 mph, and realize when they are driving too fast. This also suggests that the perception of optical flow when driving at 30 mph in the real world is different from that in a driving simulator.

The finding of little difference (2.5 mph) between the low (no trees) and high (with trees) optic flow conditions may be due to both conditions having lane markings. Under the low optic flow condition, participants may have used the flow of the lane markings to help produce the requested velocity. The addition of trees to that environment may have added only a nominal amount to their perception of the amount of optic flow used by a driver.

5. Future research

This research is a first step towards investigating differences in the perception of optic flow between driving simulators and real-world driving. The goal is to design driving simulators with optic flow characteristics similar to real-world driving. Creating a simulator configuration capable of reproducing real-world reactions and responses will assist in using simulators to emulate actual scenarios and allow further generalization of results to real-world circumstances.

Additional targeted velocities need to be studied in order to estimate bounds for the overestimation effect found at 30 mph. There are many interesting questions that need to be answered. For example, can we expect overestimation when trying to produce velocities of 10 or 20 mph? Is the amount of overestimation at 10 and 20 mph greater than that found at 30 mph?

The driving environment may also have an effect on generating velocities. For example, if one drove 50 mph in a suburban neighborhood, the awareness of speeding should be apparent. However, when driving on a straight and level interstate highway, awareness of vehicle velocity may be difficult. This issue needs further study.

Finally, the effect of prior vehicle velocity on the production of specific velocities, needs to be studied. For example, if a car is traveling at 70 mph then going at 30 mph may seem slower than it actually is. That could cause drivers to have over production errors as found in the present study.

References

[1] C. Adetiloye, Q. Wu, R. Mourant, Perception of optical flow and geometric field of view, in: Proceedings of the 32nd International Conference on Computer Graphics and Interactive Techniques (2005) (Poster Paper).

[2] J.J. Gibson, Visually controlled locomotion and visual orientation in animals, British Journal of Psychology 49 (1958) 182–194.

[3] R.L. Gregory, Eye and Brain, McGraw-Hill, New York, 1966.

[4] M. Land, D.N. Lee, Which parts of the road guide steering? Nature 377 (1994) 339–340.

[5] D.R. Mestre, F. Mars, S. Durand, F. Vienne, S. Espie, Gaze behavior during simulated driving: elements for a visual driving aid, in: Proceedings of the Third International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle, Design (2005) 304–310.

[6] R.R. Mourant, T.H. Rockwell, N.J. Rackoff, Drivers' eye movements and visual workload, Highway Research Record 292 (1969) 1–11.

[7] R.R. Mourant, T.H. Rockwell, Strategies of visual search by novice and experienced drivers, Human Factors 14 (1972) 325–335.

[8] R.W. Noel, C.M. Hunter, Mapping the physical world to psychological reality: creating synthetic environments, in: Proceedings of the 27th International Conference on Computer Graphics and Interactive Techniques (2000) 203–207.

[9] D. Shinar, E.D. McDowell, T.H. Rockwell, Eye movements in curve negotiation, Human Factors 19 (1977) 63–71.

[10] T.J. Triggs, J.S. Berenyi, Estimation of automobile speed under day and night conditions, Human Factors 24 (1982) 111–114.