EFFECT OF DRIVING SIMULATION PARAMETERS RELATED TO EGO-MOTION ON SPEED PERCEPTION

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Summary: The overall effectiveness of driving simulation as a research tool is linked to how accurately modern technology can model reality. The objective of this project was to conduct a driving simulator experiment to examine the perceptual and behavioral effects of various parameters of the simulation deemed relevant from theories of ego motion. Twenty drivers completed speed production tasks (absolute production, fixed-increase production, and ratio production) while driving through a rural road scenario that was experienced under varied conditions of motion, field of view, and optic flow. The study concluded that field of view (FOV) and optic flow simulation parameters were significant to the perception of absolute speed, with high levels of each resulting in more accurate perception of speed and speed change (acceleration/deceleration). The results of this study will allow researchers to consider the relative importance of simulation parameters in designing future behavioral research pertaining to speed perception using driving simulators.

INTRODUCTION

Proper behavioral validation of advanced simulation research equipment is vital to human factors research. Validation of simulators should be grounded in an understanding of the psychological models of human perception and ego motion. Human guidance of motion requires that spatio-temporal (time and space) information be obtained through the perceptual systems (Lee, 1980). Critical information supporting navigation in both time and space is contained in the visual field (field-of-view), optic flow, as well as vestibular and proprioceptive motion cues. By understanding these parameters, researchers can validate simulators using the criteria that are relevant to the perception of ego-motion in the virtual environment of a driving simulator. The objective of this project was to conduct an experiment to examine the effect of these parameters on speed perception in an advanced driving simulator. Such knowledge may then support the valid and cost-effective utilization of the driving simulators for human factors research and driver training.

METHODS

Sample

Twenty licensed drivers (10 males and 10 females) were recruited from the greater Montana State University (MSU) area. The average age of the participants was 35.8 years with an average of 19.7 years of licensed driving. Participants were screened based on their susceptibility to motion sickness. In order to be considered for participation in the experiment, participants had to meet minimum scores (using the Optec® 5000 Vision Screening Unit) for peripheral vision (140 degrees), far acuity (20/40), and near acuity (20/40). All participants were compensated USD $10 for their participation.

Driving Simulator

Western Transportation Institute's (WTI) high-fidelity simulator was used for the study. This simulator consists of a Chevy Impala sedan mounted on a Moog 200E motion platform with six degrees of freedom (roll, pitch, yaw, heave, surge, and sway). Simulation scenarios were projected forward in front of the driver by five projectors onto a curved screen (240 degree FOV) and behind the driver by one projector onto a flat screen (42 degree FOV). Side-view mirrors were represented by digital screens. Images were projected at a resolution of 1400x1050. Audio for the simulations was delivered through a Logitech 5.1 surround sound system located outside the vehicle.

Independent Variables

This study proposes to extend past research by investigating the main effects and interactions of three simulation parameters (motion, field of view, and optic flow). As shown in Table 1, two contrasting levels of each simulation parameter were chosen to represent the simulated driving environment. The combination of these factors (2^3) resulted in a total eight drives per subject.

Table 1. Factor Level Description

Factor	Level	Description
Motion	Low	Motion base turned completely off
	High	Motion base active on all six axes
Field of View	Low	One of five forward projectors active (55°)
	High	Five of five forward projectors active (240°)
Optic Flow	Low	Straight roadway with few motion cues (minimal vegetation and sand landscape texture)
	High	Dynamic, curved roadway with many motion cues (dense vegetation and cue-rich landscape texture)

Two different roadway environments (Figure 1) were designed to represent low and high levels of optic flow in the visual field.

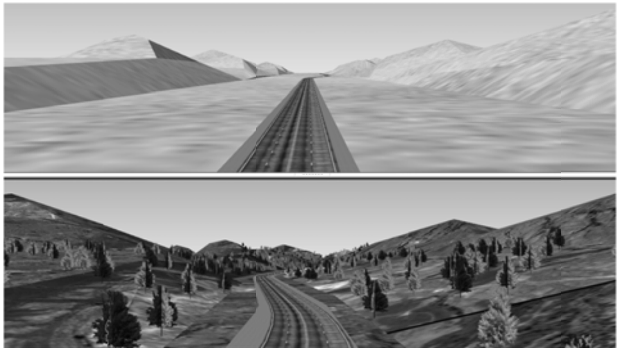

Figure 1. Low (top) and High (bottom) Optic Flow Scenarios

As summarized in Table 2, optic flow was facilitated with respect to (1) number and proximity of objects; (2) granularity of surface textures; and (3) necessity of lateral (and longitudinal) motion defined by the road geometry and speed limits. That is, the high optic flow condition was a combination of increased flow content and dynamic variation (lateral displacement). The intent of this combination of high optic flow condition was to increase both the optic flow and the relevance of motion within that flow.

Table 2. Scenario Optic Flow Characteristics

Characteristic	Optic Flow Level	
	Low	High
Curvature	1 curve per 1,000 m	2 curves per 1,000 m
Signs	1 sign per 4,000 m	5 signs per 4,000 m
Barriers	None	2 per 4,000 m
Texture Image Analysis	19 objects per 1,000 m^2	243 objects per 1,000 m^2
Hill Proximity to Roadbed	Minimum 50 m from roadbed	Minimum 5 m from roadbed
Tree Density	None	17 per 1,000 m^2
Landscape Polygon Density[1]	1.15 polygons per 10,000 m^2	1.95 polygons per 10,000 m^2

[1] Landscape Polygon Density was determined using ImageJ software. Sections of landscape texture (both low and high optic flow levels) 1,000 m^2 in size were converted to binary image type. Numbers of objects indicated in table are the number of dark objects found in the binary image that were between 0.25 m^2 and 625 m^2 in size (roughly 0.5 m to 25 m in diameter). These sizes represent minimum and maximum area thresholds determined by the researcher for dark areas in the texture which may have added to perception of optic flow.

Dependent Variables (Driving Tasks)

Participants were asked to complete a standard set of eleven driving tasks during each of the eight scenario drives (Table 3). Speed (and following distance) production tasks (absolute, fixed increase, and relative change) were represented in the scenario drives. The speedometer was disabled during all scenario drives. Note that this paper only reports on the results of the speed production tasks.

Table 3. Description of Participant Driving Tasks in Scenario Drives

Task #	Drive Section[1]	Task	Start Point (meters)
1	SP	Drive at the 65 mph posted speed limit	100
2	SP	Drive at what you believe to be 50 mph	5900
3	SP	Decrease current speed by half	6900
4	SP	Increase current speed by 10 mph	7900
5	SP	Drive at what you believe to be 25 mph	8900
6	SP	Double current speed	9900
7	FDP	Follow lead car at 300-ft following distance	12900
8	FDP	Decrease current following distance by half	14150
9	FDP	Increase current following time by 100 feet	15400
10	FDP	Follow lead car at 150-ft following distance	16650
11	FDP	Double current following distance	17900

[1] SP = Speed Perception, FDP = Following Distance Perception

Each speed production task was characterized by a relevant dependent variable (Table 4).

Table 4. Speed Perception Dependent Variables

Task	Drive Section[1]	Performance Metric Computed[2]	Units	Type[3]
Average speed (65 mph production)	SP	average speed over 2 minute duration	miles/hr	C
50 mph production	SP	speed at time of production	miles/hr	D
Decrease current speed by half	SP	estimated halved speed / initial speed	miles/hr	D
Increase speed by 10 mph	SP	increased speed - initial speed	miles/hr	D
25 mph production	SP	speed at time of production	miles/hr	D
Double current speed	SP	estimated doubled speed / initial speed	miles/hr	D

[1] SP = Speed Perception, FDP = Following Distance Perception
[2] FD =Following Distance
[3] C = Continuous, D = Discrete

Experimental Design

The simulation factors of motion, field of view, and level of optic flow were tested at two levels (low and high) each for a total of eight different combinations (2^3 factorial design). Each participant drove through all eight of these scenarios drives (treatments), each approximately fifteen minutes in length. The order of exposure to these eight scenarios drives was randomized across subjects.

PROCEDURE

Due to the long nature of the study, the study was broken into two sessions; each session occurring on a different day. In order to control for circadian effects, both sessions were scheduled as nearly as possible to each other in terms of time of day (i.e. both sessions occurring at 1 p.m. on separate days). After initially driving at an estimated speed of 65 mph for two minutes, recorded voice commands were trigged at defined locations along the road to give subject standard instructions on how they were to navigate each scenario (Table 3). Once a subject had completed the task instruction, they pressed the cruise control button located on the steering column that recorded the speed value in the data stream (Table 4).

RESULTS AND DISCUSSION

The data obtained was analyzed with a 2 (two levels of motion) x 2 (2 levels of field of view) x 2 (2 levels of optic flow) factorial repeated measures ANOVA with one between-subjects factor (2 levels of gender). Gender was included as a between-subject factor as male participants drove significantly more per year than female participants. After any necessary transformation of the data, the datasets were checked for extreme outliers that were removed without replacement. Missing data were replaced with mean value in design cell. An alpha level of 0.05 was used to reject the null hypothesis for all cases. A summary of all significant main effects from the analysis are presented in Table 5. There were no significant interactions between factors for speed perception dependent variables.

Table 5. Statistical Significance Summary

Dependent Variable	Factor[1]			
	Within-Subject[2]			Between-Subject
	M	FOV	OF	Gender[3]
Average speed (65 mph production)	-	H (3.9 mph)	H (6.8 mph)	-
50 mph production	-	H (4.1 mph)	H (6.0 mph)	-
Decrease current speed by half	H (3%)	-	-	-
Increase speed by 10 mph	-	-	-	-
25 mph production	-	H (3.4 mph)	-	-
Double current speed	-	-	-	-

[1] The significantly more accurate factor level (and difference from other level) is shown in the table, for example "H (5.0 mph)" indicates that the high level was significantly closer to the target value and the other level (low) was less accurate by 5 mph
[2] M = Motion, FOV = Field of View, OF = Optic Flow, L = Low Level, H = High Level
[3] M = Male, F = Female

Participants were first asked to drive at what they thought was 65 mph for an extended period of time. Participants responded by driving at an average of 124% of the target value (65 mph). Participants were also asked to drive at target speeds of 25 and 50 mph (fixed speed production). When asked to drive at target speeds of 25 and 50 mph, drivers responded by driving at an average of 158% and 136% of the target speed respectively. Many past studies indicate that drivers tend to misperceive speed (drive faster than perceived) when driving in both real and virtual environments (Conchillo, Recarte, Nunes, & Ruiz, 2006; Recarte & Nunes, 1996).

A larger field of view produced significantly more accurate production of average speed (121%) than a smaller field of view (127%). A larger field of view also produced significantly more accurate production of fixed speeds (25 mph, 152%; 50 mph, 132%) than a smaller field of view (25 mph, 165%; 50 mph, 140%). These results were expected, as a smaller field of view reduces the amount of temporal and spatial depth cues presented to drivers (Panerai et al., 2001). A larger field of view provides these cues not only to the forward view of the driver, but also to the lateral, peripheral view. Study results suggest that visual cues in peripheral regions are vital to maintaining accurate perception and maintenance of speed. Past literature has indicated similar results, where Jamson found that a limited field of view induces poor perception of speed by the driver (Jamson, 2000). Jamson (2000) noted that for correct speed perception, a horizontal field of view of at least 120 degrees is needed.

Optic flow also affected speed perception, with a high level of optic flow producing significantly more accurate production of average speed (65 mph) and fixed speed (50 mph) than a low level of optic flow. These results are also expected, as past literature indicates that optic flow is one of the most important types of visual information used for driving and for everyday locomotion (Lappe, Bremmer, & Van Den Berg, 1999).

Unlike fixed speed production tasks, halving and doubling tasks investigated drivers' ability to estimate their speed while increasing/decreasing their speed by a relative amount (half or double). Skills utilized by halving and doubling tasks are used by drivers every day when changing speed zones, merging with traffic, overtaking vehicles, etc. Therefore, the ability to execute accurate vehicle accelerations and decelerations is a vital safety concern for all drivers. Motion was found to significantly affect halving of speed, with a high level of motion producing significantly more accurate production of halving of speed (65% of initial speed) than a low level of motion (68% of initial speed). This result is not unusual as previous studies have indicated that motion cues (vestibular and proprioceptive) play a role in the driver control strategies (Reymond et al., 2001; Van Winsum & Golthelp, 1996). However, the precise role of vestibular and other haptic and kinaesthetic cues in steering and speed control are not fully understood, and therefore must be investigated further in motion-based driving simulation experiments (Penerai et al., 2001).

Admittedly, the intention combination of high optic flow content with increased lateral displacement (curve roadway) did introduce a potential confound between scene elements defining flow content and the task demand of negotiating the curved roads. Thus, it is possible the more accurate speed performance may be due to the specific task conditions and demands of negotiating curves. None the less, the effects of our high optic flow condition are consistent with previous research (Table 6) in spite of this potential confound.

Table 6. Comparison of Simulator Results with Published Research of Real World Tasks

Variable[1]	Current Simulator Study			Comparison Value				Units
	Target Value	Actual Value	% of Target Value	Target Value	Actual Value	% of Target Value	Real Road (RR) or Simulator (S)	
65 mph Production	65	76.8	118%	62	65.0	105%	RR[1]	miles/hr
50 mph Production	50	64.7	129%	50	54.9	110%	RR[1]	miles/hr
25 mph Production	25	36.7	147%	25	30.3	121%	RR[2]	miles/hr
Increase Speed by 10 mph	10	6.4	64%	-	-	-	-	miles/hr
Decrease Speed by Half	0.50	0.64*	78%	0.50	0.61*	82%	RR[2]	-
Double Current Speed	2.00	1.55*	78%	2.00	1.77*	88%	RR[2]	-

* Initial speed or following distance varied for each participant

[1] Recarte, M.A. & Nunes, L.M. (1996). Perception of speed in an automobile: estimation and production, Journal of Experimental Psychology: applied, 2, 291-304

[2] Ward, N. J., Gorgestani, A., Shankwitz, C., & Donath, M. (2004). A preliminary demonstration study of the usability of a vision enhancement system for state patrol vehicles. Journal of Intelligent Transportation Systems, 8, 169-185

CONCLUSION

The objective of this study was to conduct an experiment to examine the effects of various parameters of the simulation (motion, field of view, and optic flow) on perception of ego motion (speed) in a driving simulator. This study demonstrated that field of view and high optic flow simulation parameters were important to the perception of absolute speed. These parameters resulted in more accurate absolute speed perception. Motion was an important determinate of accuracy of change in speed (acceleration, deceleration). Based on these results, it is expected that a simulator with a realistic motion base and large field of view (high-fidelity simulator) will elicit more realistic speed perception and behavior when there is sufficient optic flow in the driving scene. These findings and comparison to previous literature using comparable tasks in the real world (Table 6) can provide a comparative basis to establish the behavioral validity of a driving simulator. Despite the scarcity of real world comparison data, it appears that the biases in speed choice and production are of a similar magnitude in both simulated and real driving tasks.

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