COMPARISON OF DRIVER VISUAL DEMAND IN TEST TRACK, SIMULATOR, AND ON-ROAD ENVIRONMENTS

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ABSTRACT

The demands on a driver to maintain a consistent path is reflected in the driver's workload. Visual demand, which can be measured using vision occlusion, can be used to quantify driver workload. Vision occlusion blanks out the driver's vision of the roadway using a visor or other similar device. By measuring the amount of time the driver is viewing the roadway, a measure of the information load on the driver is obtained.

Experiments were conducted in a driving simulator, on a test track, and on a public road to examine the reliability and repeatability of vision occlusion. The results showed that the effects of curve radius on visual demand were similar for all three test conditions. However, differences in the baseline demand level occurred between contexts. These results indicate driving simulator and test track results can be used to estimate changes in visual demand of real roads.

KEYWORDS

Visual Demand, Driver Workload, Test Track, Simulator, Roadway Geometry, Horizontal Curves

INTRODUCTION

The examination of driver workload has considerable promise in evaluating the demands on a driver. One of the elements contributing to driver workload is the task of tracking the lane or path selected by the driver. This tracking task requires a driver to visually evaluate the path ahead, predict the steering and speed control inputs necessary for maintaining the desired path, make control inputs, and then, using visual feedback, manipulate the controls to compensate for lane deviations.

One of the methods used in the evaluation of driver workload is vision occlusion.[1, 2, 3, 4, 5] Under the assumption that the driver only needs to observe the roadway part of the time, this method blanks out the driver's vision of the roadway using a visor or other similar device. By measuring the amount of time the driver is viewing the roadway, a measure of the information load of the driver is obtained. This measure of workload, termed visual demand (VD), has been found to increase as the difficulty of driving increases.

Visual demand has been defined as the proportion of the time that the driver actually views the roadway over a segment of interest. That is, if a driver is viewing the roadway 10 percent of the time while driving a horizontal curve, VD for that complete curve would be 0.10. The definition of the segment of interest with respect to horizontal curves was made in two different ways. The first, visual demand averaged over the length of the curve (VD_L), represents VD for a complete curve. This metric is intuitively attractive, although it is somewhat problematic. Visual demand typically peaks near the start of a curve and then declines. For longer curves the high VD found near the start of the curve is thus averaged with a long period of lower VD to result in a lower VD_L. Because the length of this decline appears to be correlated to the length of curve, another measure was also used. In this measure, visual demand was averaged over the first 30 m of the curve (VD_{30}), avoiding the correlation described above.

OBJECTIVES

To utilize visual demand as a reliable source of information about a roadway alinement, designers must know whether the information is reliable and consistent. A basic tenet of the scientific method is that research must be reproducible. In the interest of evaluating the reproducibility of those aspects of visual demand, comparisons were made between similar aspects of the visual demand efforts conducted currently [1] on a test track, on local highways, in a simulator, and previously[2,3] on a test track (called Test Track, On-Road, Simulator, and Previous

Test Track, respectfully). All comparisons centered around the test track study. Each of the other studies was compared to that study, in turn. Key points of each study are listed in table 1. The studies were conducted at the Texas Transportation Institute (TTI) in and near College Station, Texas and at the University of Michigan Transportation Research Institute (UMTRI) in Ann Arbor, Michigan, as indicated in table 1.

Table 1. Comparison of Studies.

Study	Test Track[1]	On-Road[1]	Simulator[1]	1995 Test Track[2,3]
Characteristics	Three closed courses	Two local rural highways	One closed course	Mix of closed courses and individual curves (two separate studies)
Location	TTI	TTI	UMTRI	TTI
Sample size	23 drivers	6 drivers	24 drivers	40 drivers in one study, 15 in second study (some overlap)
Number of Runs‡	6	4	6	4
Independent Variables	1/Radius	1/Radius	1/Radius	1/Radius
Dependent Variables†	VD_L VD_{30}	VD_L	VD_L VD_{30}	VD_L VD_{30}

‡Represents the number of replications through a particular curve.
†Although other measures of VD may have been used in the referenced studies, VD_L and VD_{30} values were calculated and/or provided for the purposes of the comparisons presented in the chapter.

TEST TRACK

A vision occlusion test was completed at Texas A&M University's Riverside Campus test facility, a former airport. In this test, drivers used a liquid crystal display (LCD) visor while driving a 1991 Ford Taurus station wagon in a controlled testing environment. The visor blocked the drivers' vision until a floor-mounted switch was depressed. When the switch was depressed, a brief (0.5 second) glimpse of the roadway was provided by clearing the LCD visor. The period between glimpse requests was used to determine the percentage of time that the driver was observing the roadway. This metric, termed visual demand (VD), was used as a surrogate for driver workload as described previously.

Driving on three separate closed courses, 23 drivers traversed 6 different test curves six times. Average values of VD were determined for the first 30 m of each curve (VD_{30}) and for the entire length of each curve (VD_L). In general, a significant run effect was found in the analyses of VD, i.e., the results from run to run within a driver were correlated, indicating some learning pattern over time (*1*). Most often, the results from the first run were statistically different from those obtained from runs 2 through 6 (or 2 through 4), while no difference could be found among runs 2 through 6 (or 2 through 6). It was thus decided to segregate run 1 results (representing a first time encounter) from the other runs and group the remaining runs (representing familiar conditions) for comparisons. This learning effect and methodology were followed for all of the comparisons where appropriate.

ON-ROAD STUDY

The on-road study was completed largely for the purposes of further evaluating the workload measures obtained in the test track study. The key differences between this study and the test track were that only 6 drivers were tested (compared to 23) and only 4 repetitions per curve per driver were made (compared to 6). In addition, it was not possible to select curves which were exactly comparable to those tested at the Riverside Campus test facility; instead, researchers selected five curves that covered the approximate range of radii and deflection angles present in the test track study. Drivers used the visor described previously.

VD_L Comparisons

Linear regression analysis was performed to relate changes in visual demand to inverse curve radius using VD_L. Comparisons were systematically made between regression equations developed from the two databases, examining both slope and intercept for differences and similarities. A visual comparison is shown in figure 1, viewing the plots of the regression equations developed for the test track study and the on-road study.

In a first approach at a systematic comparison, researchers examined the overall model using all available data. In this approach, the data from 6 drivers and 4 repetitions were directly compared to data from 23 drivers and 6 repetitions. Using an F-test, it was found that no statistical difference between the regression slopes (with respect to the inverse of radius) existed at the 95 percent confidence level (used hereafter as the standard of comparison). A significant difference was found, however, with respect to the intercept indicating only an offset across all radii (see table 2). Plots of the regression lines for the two databases are shown in figure 1; the regression equations compared may be found in table 3.

Table 2. Summary of Differences Between Test Track Study and Studies Conducted in Other Environments.

Study	Run	VD_L		VD_{30}	
		Slope of 1/R	Intercept	Slope of 1/R	Intercept
On-Road	1	No significant difference p=0.0588	Significant Difference p=0.0001	*na*	*na*
	2-4	No significant difference p=0.2777	Significant Difference p=0.0001	*na*	*na*
Simulator	1	Significant difference p=0.0317	Significant Difference p=0.0001	No significant difference p=0.7932	Significant Difference p=0.0001
	2-6	Significant difference p=0.0490	Significant Difference p=0.0001	No significant difference p=0.5794	Significant Difference p=0.0001
1995 Test Track(1)	All	No significant difference p=0.804	Significant Difference p<0.001	No significant difference p=0.5332	Significant Difference p=0.0001

Table 3. Curve Equations for Overall Comparisons Using VD_L.

Test track[1]	Run 1:	$VD_L = 0.297 + 25.8 \frac{1}{R}$
	Runs 2-6:	$VD_L = 0.285 + 23.133 \frac{1}{R}$
On-road[1]	Run 1:	$VD_L = 0.173 + 43.0 \frac{1}{R}$
	Runs 2-4:	$VD_L = 0.198 + 29.2 \frac{1}{R}$
Simulator[1]	Run 1:	$VD_L = 0.388 + 34.7 \frac{1}{R}$
	Runs 2-6:	$VD_L = 0.367 + 36.5 \frac{1}{R}$
1995 test track[2, 3]		$VD_L = 0.202 + 19.0 \frac{1}{R}$

Next, researchers attempted to increase the similarities between the two databases, with only four runs being utilized from the test track data to match the four runs available from the on-road data. Similar results to the comparisons to the complete database were found, with no significant difference between the coefficients of the inverse of radius and a significant difference between intercepts. Finally, a comparison was made using only the test track data from the six drivers who participated in the on-road study. Again, the same pattern was observed as in the previous two comparisons.

SIMULATOR STUDY

The study completed in the driving simulator was similar in size and makeup to the test track study. Both studies tested about 24 drivers, and both studies completed 6 repetitions per curve per driver. Because the simulator study was conducted on a "virtual" course, researchers were able to construct a single test course that encompassed all of the desired test curves. Otherwise, the lane width, curve radius, deflection angles, and other major scene characteristics were identical. In this study, an LCD shutter was used to block the projection of the driving scene; a foot switch similar to the one used in the test track and on-road studies was used to control the glimpses provided to the drivers.

The simulator data was conducted in the UMTRI's driving simulator, a fixed-based device, based on a network of Macintosh computers (*6*). The simulator consists of a mockup of a 1985 Chrysler Laser passenger car; a projection screen; a torque motor connected to the steering wheel to provide realistic damped torque feedback; a sound system to provide engine-, drive train-, tire-, and wind-noise; a computer system to project images of an instrument panel; and a simulated hood to provide a realistic driver's view. The projection screen, offering a field of view of 33 degrees horizontal and 23 degrees vertical, is located 6.0 m in front of the driver. Bass shakers provide limited vertical vibration to induce some sensation of motion thus reducing the likelihood of simulator sickness. Lateral motion cues were not provided. The simulator is capable of generating a 640 horizontal by 480 vertical pixel image, although the projected image in this study was approximately 80 percent of this resolution.

VD_L Comparisons

Comparisons were first made between regression equations developed using the entire database in both cases. The test track study examined curves with 145 and 290 m radii, although the simulator study also included curves with 194 and 582 m radii. In this comparison, the slopes and intercepts were both found to be significantly different for the two databases for run 1 and for runs 2-6, although the slopes did have similar trends (i.e., VD_L increased with increasing radius). Table 2 provides a summary of the comparisons. In an attempt to discover whether the inclusion of curves with dissimilar radii influenced the resulting regression coefficients (and hence the comparisons), the simulator database was reduced to include only those curves with similar radii to the test track study. For runs 2-6 similar findings resulted, with both regression coefficients significantly different in the two studies. For run 1, however, no significant difference was found for slope ($p=0.2692$); the intercepts were significantly different ($p=0.0001$). Table 3 provides the regression equations, and figure 1 allows a visual comparison.

VD_{30} Comparisons

Next, researchers compared the regression equations using the dependent variable VD_{30}, or visual demand averaged over the first 30 m of the test curves. Comparing findings from curves with similar radii, researchers found that there was no significant difference between the test track and simulator slopes, although a significant difference was found between the respective intercepts. Details of the comparison are shown in table 2, while figure 2 allows a visual comparison of the plots of the equations; the regression equations may be found in table 4.

Table 4. Curve Equations for Overall Comparisons Using VD_{30}.

Test track	Run 1: $VD_{30} = 0.269 + 34.0 \frac{1}{R}$
	$VD_{30} = 0.262 + 30.7 \frac{1}{R}$ Runs 2-6:
Simulation	Run 1: $VD_{30} = 0.429 + 29.8 \frac{1}{R}$
	$VD_{30} = 0.400 + 31.2 \frac{1}{R}$ Runs 2-6:
1995 test track[1]	$VD_{30} = 0.195 + 27.1 \frac{1}{R}$

1995 TEST TRACK STUDY

In the final study comparison, researchers compared the test track study [1] to a test track study reported in January 1995.[2, 3] Key differences in the two studies included a larger number of subjects used in the 1995 study, a reduced number of repetitions (four rather than six), and a mix of test curve layouts (one closed course and several individual curves rather than three closed courses). Available data were limited to values averaged across runs only. LCD goggles were worn by the drivers to limit their vision in the 1995 study, while an LCD visor was worn in this test track study.

VD_L Comparisons

The first comparison with this database was with regard to VD_L. The comparison of slopes revealed no significant differences, although the intercepts were found to be significantly different. The 1995 test track study used four repetitions, rather than six repetitions as in the test track study. Therefore, an additional comparison in which the test track database was restricted to the first four repetitions only. Repeating the comparisons made previously, the slopes were again found to not be statistically significantly different, and again the intercepts were found to be significantly different. Table 2 provides details regarding the models' comparisons based on the entire databases, and figure 1 allows a visual comparison of the regression equations.

VD_{30} Comparisons

Next, VD_{30} values from the 1995 and test track studies were compared.[1, 2] Similarly to the VD comparisons, the comparisons are limited by the available data: the VD_{30} values available were averaged across runs. Initial comparisons were made using the entire databases for the two studies. Comparing slopes, no significant differences were found, but, repeating the findings for the VD values, the intercepts for the two studies were found to be statistically different (see table 2). Similar findings were made when the database for the study was restricted to only four runs to match the 1995 study. Figure 2 provides an overview of the two models.

FINDINGS

Several workload measures and testing environments were compared in this paper. Table 2 summarizes the overall comparisons made between those studies, while figures 1 and 2 provide overall visual comparisons for VD_L and VD_{30}, respectively; tables 3 and 4 provide the regression equations developed for visual demand. Examining the tables and figures, it is apparent that the measures used in the project to represent driver workload were relatively robust. Of the six possible comparisons, five resulted in the conclusion that no significant difference in slope (with respect to the inverse of radius) existed between the TTI test track study regression equations and the comparison equations. This provides a level of confidence that workload differences between features can reliably be predicted. The exception to this finding was between the test track study and the simulator study for one measure of workload, VD_L.

The comparisons between intercepts, or constants, showed that they were usually significantly different. The cause for these differences is difficult to fully explain, but differences in roadway markings (i.e., alternating markers every 9 m compared to markers on both sides every 6 m, painted center stripes and edge lines compared to the lack of lateral motion cues in the simulator, raised markings, etc.), testing environments (test track versus simulator, test track versus highway), the lack of lateral motion cues in the simulator, and the use of different subjects probably account for at least part of these differences.

The finding that there is no difference in the slope of the regression line when comparing test track results with on-road results, but that there is a difference in the intercept, would indicate that *relative* levels of workload can be ascertained, but not *absolute* levels. This finding shows promise in determining *differences* in workload levels between successive highway features, but not baseline levels.

CONCLUSIONS AND RECOMMENDATIONS

Because most applications of driver workload are expected to be with respect to changes in level rather than in absolute terms, the general agreement with respect to the slope of the workload measures used is very encouraging. Although some differences with regard to VD_L were observed, the overall robustness of the visual demand measures should yield a greater confidence in the measures used and lead to further use, research, and future applications.

Visual demand appears to provide a good measure of the change of driver workload when tests are performed under a range of conditions. Because of this characteristic, testing can be expanded to include a variety of conditions not readily encountered or easily tested on public roadways.

Determining acceptable limits to visual demand change would appear to be a promising area of study. This could provide the designer with a means of reviewing a roadway design for areas of suddenly increased workload that could surprise the driver with the demands imposed by the driving task that could lead to increased accident risk.

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