Comparison of Driver Dynamics With Actual and Simulated Visual Displays

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As part of a comprehensive program to explore driver-vehicle system response in lateral steering tasks, describing functions and dynamic data have been gathered in several milieu. These milieu include a simple fixed-base simulator with only an elementary roadway delineation display; a fixed-base statically operating automobile with terrain displayed by a wide-angle projection system; and a full-scale moving-base automobile operating on the road. Dynamic data with the two fixed-base simulators compared favorably and implied that the impoverished visual scene, lack of engine noise, and simplified steering wheel characteristics in the simple simulator did not induce significant driver dynamic behavior variations. The fixed-base versus moving-base comparisons showed that the moving base had substantially greater crossover frequencies on the road course; this frequency can be ascribed primarily to a decrease in the driver's effective latency. When considered with previous data, the moving-base full-scale versus fixed-base simulator differences are ascribed primarily to the motion cues present on the road course rather than to any visual field differences.

Over a period of several years, we have completed a variety of programs to explore driver-vehicle system behavior in directional control tasks. These programs have been conducted to satisfy different and, in general, unconnected purposes; yet, similar techniques and procedures have been applied. As a consequence of and incidental to the individual program purposes, we have gathered driver-vehicle system describing function and other dynamic data in several different milieu. Comparison of data from three of these settings gives some interesting insights into visual cue needs for driving and into the effects of motion and visual cues when these effects are contrasted with visual cues alone. Unfortunately, we have to be satisfied with the interesting insights rather than the concrete significant differences, since we have no common populations of subjects in the three situations.

The driver's visual field, in general, is extremely complicated and defies description. On the other hand, the importance of the visual field in relation to the driver's guidance and control may be very simple to describe in principle and to determine in practice. Imagine an experimental series in which the visual field content is successively modified by removing texture and objects in the surround, adjusting delineation features, and so on. Only the driver's visual field is varied, and the factors held constant include the vehicle dynamics, the driver subjects, and the excitation against which the car is to be regulated. For each treatment in this imaginary experimental series, a set of lane regulation tasks are run, and measurements are taken of the driver's dynamics and the driver-vehicle system performance. If the visual field variations indicated no change in the basic driver characteristics, then the differences between the complex and the simple visual scenes would be redundant for the development of appropriate guidance and control feedback signals by the driver. On the other hand, if driver dynamic differences were apparent, then the visual differences in the comparative scenes would be important in terms of the particular driver functions modified. If this experiment were performed for a sufficient variety of visual scenes, we would have a complete story on the driver's guidance requirements in general. This imaginary experiment can be expanded further to include the effects of motion cues by contrasting driver behavior measurements taken in a fixed-based situation with its full-scale automobile equivalent.

REVIEW OF EXPERIMENTS

We can now fill in the outline of this imaginary experiment with data taken from three experimental series. The first is the full-scale roadway experiments reported by McRuer and others (1). In that experiment, the physical scene was a complete roadway, well marked, and viewed through the windshield of a 1974 Chevrolet Nova. The automobile was fitted with a disturbance generator and a describing function analyzer so that the describing function and other driver-vehicle system measurements could be made. The general character and nature of the measurements in this and the other two experiments to be considered were accomplished as described by McRuer and others (2). The driver's task

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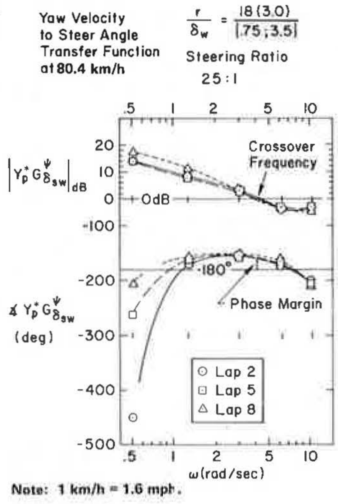

Figure 1. Effective open-loop describing function for initial test series.

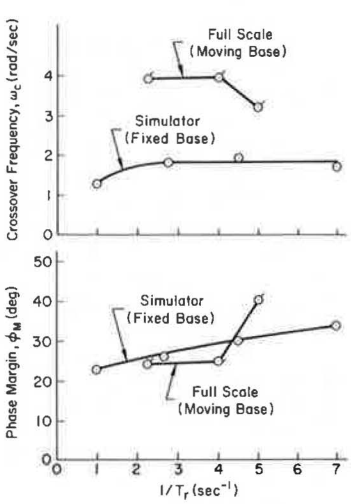

Figure 2. Comparison of full-scale automobile and fixed-base simulator dynamics for test driver subject.

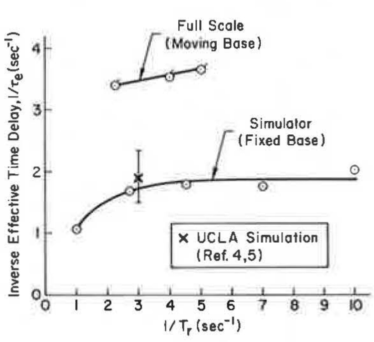

Figure 3. Comparison of full-scale automobile and fixed-based simulators inverse effective time delays.

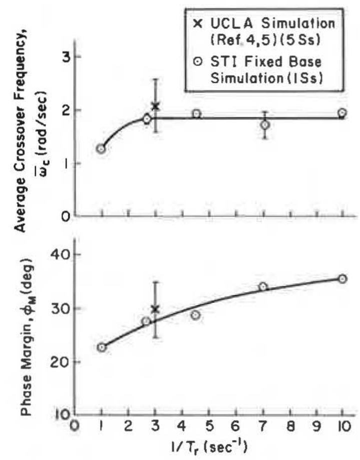

Figure 4. Comparison of data from fixed-base simulator with elaborate and impoverished visual fields.

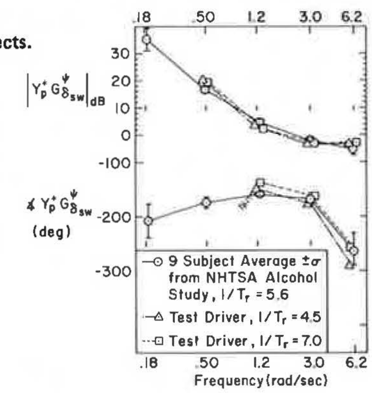

Figure 5. Comparison of test driver with nine subjects.

was lane regulation in the presence of a simulated strong crosswind disturbance. The disturbance was applied by moving the front wheels with an extensible link servomechanism. This servomechanism is installed in series and is backed up by the driver's power steering unit, which serves to isolate the servomechanism motions from the steering wheel. The driver's regulation task is simply to keep the car centered in the lane by applying corrective steering inputs. In the experiments by McRuer and others (1), this task was performed many times by all 16 subjects at 80 km/h (50 mph). The measurement interval was 25 s, and the primary response data of the driver vehicle system dynamics are given in terms of the effective single- and open-loop describing function ($Y_p^{*}G_{\delta_{sw}}^{\psi}$). This measurement was taken with the describing function analyzer (3), and a representative sample is shown in Figure 1. In this typical example, the amplitude ratio is very close to an ideal crossover model form (4).

The second experimental series (5, 6) was conducted on a fixed-based simulation by using the University of California, Los Angeles (UCLA), driving simulator. In this experimental series, the driver was seated in a 1965 Chevrolet sedan that was mounted on a chassis dynamometer. The dynamometer drum speed, controlled by the driver via the accelerator and brakes, determined the landscape velocity of a moving model landscape that was related by a black and white TV camera. The landscape was projected on a large screen to provide the driver's visual cues. The driver's steer angle output was fed to an analog computer containing the vehicle equations of motion and then to the TV camera servomechanism that moved the car over the model terrain. The net motions of camera and model landscape provided the displayed motion presented to the driver. Because the included horizontal angle of the visual field was about 40 deg, the relative motion and geometric cues used for directional control were adequate for foveal and parafoveal vision. The visual field resolution was such that an object the size of an oncoming vehicle could be distinguished at an equivalent full-scale distance of about 402 m (1320 ft) that was the length of the moving belt landscape. The overall impression with the UCLA simulator is of a highly realistic driving situation in desert terrain under a dark overcast.

The third series was a fixed-base operation in the Systems Technology, Inc. (STI), simulator. Data from two experiments (1, 7, 8) in which this simulator was used are appropriate. In these experiments, the visual

scene was made as simple as possible, i.e., it consisted of only two-lane edges, drawn in perspective on the cathode ray tube with decreasing intensity in the distance. Heading and lane deviations of the car resulted in motions of the road relative to a fixed mask of a car hood, left fender, and windshield outline. The simulator consisted of a modified 1968 Mustang cab with the steering wheel adjusted to approximate the force-feel characteristics of a power steering unit.

DATA INTERPRETATION AND CONCLUSIONS

By comparing the driver-vehicle system performance data from these three experiments, we can deduce the relative importance of vehicle motion and of the features in the three visual scenes presented. The data more readily at hand are for the system crossover frequency and phase margin and primarily reflect the driver lead equalization and heading gain properties.

The first and most direct comparison is between the STI simulator and the full-scale moving-base results. In this comparison, the subject and the task are the same. The crossover frequency and phase margins for comparable vehicle dynamics are shown in Figure 2 as a function of the vehicle yaw time constant (T_r). The full-scale data have higher crossover frequencies but similar phase margins. These data can also be interpreted in terms of effective system latency. For the crossover model of manual control this is given by

$$\tau_e = (\pi/2 - \varphi_M)/\omega_c \qquad (1)$$

Because the describing function data (1) are approximated quite well by the crossover model, this formula is applicable. A comparison of data in the form of $1/\tau_e$ is given in Figure 3 ($1/\tau_e$ is a preferred representation because it is approximately normally distributed and is also more readily related to frequency regions of interest). The general trends with $1/T_r$ appear parallel, but the moving-base results exhibit much lower effective system latencies. Over the common $1/T_r$ range, the average τ_e for fixed base is about 0.55 s while that for moving base is 0.28 s. Previous experiments (4, 9) in which separate describing function measurements were made for motion and visual cues indicate that this effective time delay difference can be attributed to motion (vestibular) feedback effects (due primarily to the semicircular canals) that are active in the moving-base case and not in the fixed-base case.

When the results from the UCLA simulation are compared with the STI fixed-base results, as shown in Figures 3 and 4, the crossover frequency, phase margin, and effective time delay are similar. The data points represent the mean and standard deviation for five drivers in the UCLA series and the mean and standard deviation of repeat runs using one test driver in the STI series. Because the crossover frequency and phase margin data for the two simulation series compare favorably, the implication is that the impoverished visual scene, lack of engine noise, and simplified feel characteristics of the steering wheel present in the STI simulator did not induce significant driver dynamic behavior variations.

Figure 5 is an associated comparison that contrasts the test driver with nine subjects taken from a previous study (7), all using the STI simulator. This comparison indicates that the test driver used for both simulator and full-scale results is representative of a much larger randomly selected sample of the driving population.

In summary, when the data for similar vehicle dynamics in moving-base and two fixed-base situations are compared, the differences between the impoverished visual field and an actual windshield field are unimportant to the development of the visual guidance cues. The experiments indicate that a visual field that has only two high-contrast lane markings presented to the driver with appropriate motion perspective is a sufficient visual scene from which to develop the requisite guidance and control information. Texture, other objects in the surround, and so on may provide information that is useful but not essential to the driver's steering operations in the regulation task. Finally, the principal effect of motion is to permit a reduction in the effective driver time delay when the total control task is treated only as an equivalent visual-input operation.

ACKNOWLEDGMENT

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