USE OF SIMULATION IN A STUDY INVESTIGATING ALERTNESS DURING LONG-DISTANCE, LOW-EVENT DRIVING

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•THE PURPOSE of the investigation was to (a) identify interactions of the vehicle, driver, and the road environment that tend to reduce driver alertness; (b) objectively measure these decrements in alertness; and (c) delineate a program of research aimed at the development of countermeasures to reduce decrements in alertness. The study was performed in 3 phases: a review of the pertinent literature, an experimental study, and suggested future research and possible methods of reducing the effects of decreased alertness.

EXPERIMENTAL PROCEDURE

This paper deals with the experimental phase of the study that was concerned with the effects of task complexity, acoustic noise level, and duration of trip on measures of alertness. A more detailed discussion of the other phases of research can be found elsewhere (1). In the interests of economy, precision, and safety, the study was conducted by using the CAL driving simulator. This is a computer-based simulator that provides an auditory, visual, and motion environment similar to that encountered in on-road driving situations. The simulator consists of the components described in the following sections.

Hydraulically Actuated Base

A hydraulically actuated base capable of ±40 deg in yaw (rotation about the Z-axis) and ±10 deg in roll (rotation about the X-axis) was used. The response of the base in both degrees of freedom is of 2 Hz bandwidth. The drive for the platform is of relatively low power because it was assembled from the top-raising mechanisms of a convertible. There are two motor-pump units. The motor-pump units are not run continuously with a valve to control flow but are driven by a pulse-width-modulated amplifier to control motor speed. A 12-volt lead-acid automobile battery was used as a power source. It was capable of supplying 60-ampere peak currents.

One of the motor-pump units drives a hydraulic cylinder that moves the platform in yaw. The other drives it in roll. Each cylinder is connected to a linear potentiometer that measures platform motion. These signals are fed back to the computer that compares the platform position to the desired position and drives the amplifiers with the error signals.

Driver Control Station

A driver control station mounted on the base includes an adjustable seat, a dashboard with a speedometer and a button for signaling the experimenter, a steering wheel, an accelerator pedal, and a brake pedal. The control dynamics are passive in terms of feedback and approximate power steering, power brakes, and an ordinary accelerator.

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Visual Display System

A visual display system is composed of a 4-channel oscilloscope, a Schmidt projector, a rear projection screen, and a Fresnel collimating lens. The cathode ray tube (CRT) was removed from the oscilloscope and mounted in the Schmidt projector. The projector has sufficient brightness to produce a clearly visible image in a darkened room. The rear projection screen is curved so that the image remains the same distance from the subject as the platform moves in yaw and so that the image will stay more nearly in the curved surface of focus of the projector. The Fresnel lens is used to increase the apparent distance to the highway. The system provides a field of view of ±25 deg horizontally and ±20 deg vertically.

The signals that represent the highway are generated on the computer and modified to show correct perspective from the position and attitude of the vehicle. The highway is represented by 3 separate lines corresponding to the centerline and sidelines and a filler or lighter area as the road surface. A variably graduated neutral density filter is used over the projection lens. This filter causes the image to be dimmest at the point where the road appears to converge, effectively enhancing the illusion of depth. The voltages that represent the sides and centerlines of the road are produced by passing a sine wave through a double Schmidt trigger producing a staircase wave form. The image is generated from the bottom up at a rate of 30 times per second.

This voltage becomes the horizontal drive of an oscilloscope, whereas a vertical sweep signal is provided by a decaying exponential voltage that approximates an inverse distance function. The roadside voltage is multiplied by this sweep voltage to produce the correct convergence to infinity (the vanishing point). This produces a road picture in correct perspective from the center of the road. Because the rate of change of the sweep voltage is smaller at greater distances, the apparent distance between successive side markers decreases appropriately. The image appears to move because the initial conditions for the sine wave oscillator are provided by a second low-frequency oscillator that runs continuously at a rate proportional to vehicle speed.

Changes in perspective resulting from changes in vehicle position on the road are included in the display by adding a voltage proportional to vehicle position to the staircase voltage before it is multiplied by the perspective circuit. This tends to move the near elements of the picture without shifting the vanishing point. Yaw and roll are not provided electronically in the image but by rotation of the simulator.

Analog Computer

An EAI model TR-48 analog computer performs 3 basic tasks. First, it accepts the driver's input signals and externally produced disturbance signals and produces output signals representing the motion of the vehicle that is being represented by a vehicle dynamics model. Second, the computer closes the position servo loops for the motion platform. That is, the compensating dynamics to make the closed-loop servo sufficiently stable and fast are programmed on the computer. Third, it generates the roadway signals for the projection system. The motion platform servos and the display generator use the vehicle motion signals as inputs. The equations of motion programmed on the computer may be easily modified to represent changes in such vehicle parameters as the steering ratio or roll-axis position. Speed changes due to the use of the brake or accelerator are represented by changing the apparent speed of the road image, the equations of motion, and the reading on the speedometer.

The simulated speed may be controlled in either of 2 ways: (a) in the normal control mode, the driver can control the speed by using his accelerator and brake; and (b) in the automatic mode, the computer controls the speed. The driver can disengage the automatic control by applying the brake. Release of the brake reengages the speed controller. In both modes, the simulator is capable of speeds ranging between 14 and 70 mph.

Acoustic Display

Measurements of noise contours in selected vehicles were performed by using an octave band noise analyzer. Acoustic noise contours similar to those measured in on-road operation were provided by filtering the signal from a white noise generator. The

resulting filtered output was amplified and reproduced by using 3 high-fidelity speaker systems.

External Events

The EAI computer, in conjunction with a pseudo-random noise generator, provides external perturbations that are used to simulate external wind gusts and road irregularities. The perturbations are provided to ensure that the driver makes periodic corrections in order to remain on the road. Because the noise signals are derived from a binary sequence, all subjects received the same perturbations at the same point in the experiment. The computer, in conjunction with a function generator, provides a simulated tire blowout. A dc offset in yaw and roll, a 0.5-Hz oscillation in roll, and a 0.5-Hz acoustic signal on the background acoustic noise were used to achieve an event resembling a blowout.

EXPERIMENTAL RATIONALE

The research effort was aimed at the study of changes in driver alertness during long-duration, low-event driving. The phenomena measured fell into 2 basic classes: measures of changes in skills or ability thought to be basic to safe driving and measures of changes in physiological parameters that have been hypothesized to be correlated with decreased alertness.

Independent Variables

It was hypothesized that acoustic noise, task complexity, and task duration were the independent variables that would affect the onset of decreases in driver alertness.

Acoustic Noise—Acoustic noise may be considered a stressor in the driving condition. As indicated in the literature, extremely high noise levels lead to increased fatigue. However, it was necessary for the purposes of this study to determine whether noise levels of the magnitude of those commonly encountered in on-road driving would lead to variations in alertness. Furthermore, the effect of extremely low noise levels on alertness was of interest. In particular, it was necessary to determine whether very low noise levels would tend to enhance alertness or degrade it in long-duration, low-event driving.

To this end, sound level measurements were made in actual vehicles that represented low, moderate, and high acoustic noise environments. From the measured noise levels of these vehicles, equivalent noise contours were generated and used to represent the 3 levels of an independent variable representing acoustic noise amplitude. With regard to the effect of noise, it was hypothesized that both high and low noise levels would have a detrimental effect on alertness—a high noise environment would increase the rapidity of the development of fatigue and a low noise environment would lull or soothe the driver into reduced alertness.

Task Complexity—Task complexity was also of interest. Although it was usually found in our literature review that drastic reductions in information input to an operator result in decreased alertness, the effects of decreasing output demands on the operator are not clear. To apply this to the on-road situation, we asked the question, Does simplifying the driver's task by providing for automatic control of vehicle speed reduce the driver's alertness? The answer to this question was ascertained by examining 2 levels of task complexity: a low task complexity situation, in which the speed was automatically controlled and could be overriden in emergencies, and a moderate task complexity situation, in which the driver had to control speed throughout the simulated trip.

Task Duration—The effect of duration of drive is of great importance. Although it is to be expected that the probability of degradations in alertness increases with time, the magnitude of this increase and the relative rate at which this degradation increases are of interest. Does degradation in alertness begin immediately, or does it require hours to manifest itself? Do degradations quickly reach an asymptote, or do a series of plateaus occur representing different components of a complex process? In short, it was hypothesized that there would be increased degradation of alertness along time.

All subjects were tested for 4 hours. Performance was recorded continuously during this period.

During this experiment, the subject encountered the following kinds of events:

1. Ramp stimulus was a brightening light that appeared at the convergence point of the road. The subject was expected to respond to it much as he would to the high beams of a car approaching on the highway. The subject encountered this once during practice, 17 times during the experiment, and once during the post-experiment test.
2. Avoidance of an emergency situation involved asking the subject to avoid an object that appeared to be approaching him. This occurred 3 times during the experiment.
3. Hills were only encountered by subjects in the moderate task complexity condition. Hills were indicated by a slowing of the projected display and a change in the speedometer. Subjects were expected to correct speed changes, due to the hill, through use of the accelerator. The simulated hill occurred 4 times during the experiment.
4. In blowout situation, the subject encountered an abrupt change in the motion parameters of the simulator similar to a blowout. The subject was expected to maintain control of the vehicle during the blowout. This occurred once during the experiment.

The 6 treatment conditions and the 4 orders of emergency presentation result in 24 possible treatment-order combinations. The sequence in which the treatment-order combinations were tested was obtained by randomly assigning treatment order to test dates. A random permutation of the 24 test dates was applied to the treatment-order combination. The randomized order was repeated twice in order to provide a sequence for 48 subjects.

Dependent Variables

The following dependent variables were recorded and analyzed:

1. Integrated absolute road position error during normal driving;
2. Frequency of 2-deg steering wheel reversals;
3. Integrated absolute road position error during a simulated emergency (blowout);
4. Response latency to a light that increases in itensity from zero to a maximum;
5. Integrated absolute velocity error; and
6. Frequency of occurrence of alpha rhythm in the occipital EEG's of the subject.

ANALYSIS OF RESULTS

The data to be analyzed, with one exception, represent repeated measures on subjects over time. An analysis of differences between the curves representing the performances of subjects within treatment groups was performed. In such tests, if the data are parametric, coefficients of orthogonal polynomials representing various order polynomials (linear, quadratic, and cubic) are fitted to the data for each subject.

A coefficient representing the degree to which each subject's data fit the trend under test is computed. An analysis of variance on the coefficient representing the fit of each subject's score to the polynomial under question is then performed for each trend analysis.

The analyses of the result revealed the following:

1. The driver's ability to maintain his vehicle on the road under low-event conditions decreases linearly with time over 4 hours ($p < 0.01$, $F = 7.58$ [1,42]).
2. The rate of steering wheel corrections made by the driver decreases linearly with time over 4 hours ($p < 0.01$, $F = 22$ [1,42]).
3. On a per subject basis, there is a significant negative correlation ($\phi = 0.54$) between position error and steering wheel correction ($p < 0.001$, $\chi^2 = 18.55$). This may be taken to indicate that either the subject perceptually samples his road position less frequently after driving a number of hours or he processes and reacts to his road position less frequently over long-duration driving.
4. Measurements of position accuracy during a simulated emergency indicate that the driver is less likely to be able to control his vehicle accurately during an emergency after 4 hours of driving than after 1 hour of driving ($p < 0.05$, $F = 3.0$ [3,24]), and that this decrease in control during the emergency is most severe when the driver has been

exposed to a high level of acoustic noise ($p < 0.05$, $F = 3.62$ [2,36]).

5. Analysis of occipital EEG recordings, using a Wilcoxon matched pair signed ranks test, reveals an overall increase in the frequency of occurrences of alpha bursts for all subjects ($p < 0.004$).

The greatest economy and maximum experimental precision was achieved in the study by using a driving simulator. Use of the simulator provided for complete control of traffic, roadway, and meteorological variables that might have reduced the precision of an on-road experiment. Such conditions might include variations in traffic density, road surfaces, ambient light, and weather. The simulator provided for greater economy in that it did not require rotating or full-time observers to accompany the driver during the experiment.

The fidelity of simulators is often questioned. An argument can usually be made that the simulation of any event does not sufficiently represent the real world. The authors feel, however, that this study represents an example of good matching of the capabilities of a simulator and the requirements of the task. The task of driving on a superhighway at night typically requires the driver to operate the vehicle at constant speed because he encounters very few other vehicles. He is provided with a low density of visual inputs because he can see only that part of the road illuminated by his headlights. His control maneuvers are limited to maintaining his lane position and speed and avoiding the occasional obstacle by temporarily changing lanes. Except for a car radio, the driver hears only the road, wind, and engine noise, or any other noise of his own making, such as singing. Additional information may come from instrument lights or gages, but changes in the status of these gages are infrequent.

Each of these requirements is an attribute of the CAL driving simulator. The visual display provides the essentials of a headlight-illuminated roadway. It shows the centerline and road edge markings, but the brightness of these lines diminishes with apparent distance until they disappear at the limits of the headlight beam. No horizon is visible, nor are any features seen that are off the roadway. Because the road markings are computer-generated, the changes in perspective are faithfully reproduced as the automobile makes changes in road position. Obviously, the detail available in the real world or in simulators using recorded displays on film or video tape is not required to match the visual requirements of the present task.

The few occurrences of obstacles or signals were appropriate for a low-event driving task. Although low in number, the events were sufficient to provide a statistically meaningful experimental design. No car radio was available for distraction; however, simulated road noise was played and the drivers were free to sing to themselves or provide other verbal distractions for themselves. The physiological instrumentation also permitted them to change their posture, if desired. Subjects were provided with a speedometer that indicated simulated speed.

Motion simulation was available and was necessary because in some cases the first cue a bored driver responds to is not visual but is some change in the "feel" of the vehicle. The motions of the driver's station were coupled to the changes in the visual perspective as the vehicle changed in roll and yaw during road position changes. The compatibility of the vision and motion cues resulted in a strong subjective feeling of being in control of an automobile.

Simulation was selected as an appropriate technique for this study. However, each research problem must be examined carefully to determine whether simulation is appropriate and what sort of simulation techniques will be most efficacious. Research into other problem areas (car-following behavior, sign recognition and comprehension, or changes in control precision due to driver aging) might require widely different simulation techniques. Finally, in the event that simulation is chosen and an appropriate technique is available, serious consideration should be given to on-road validation of the findings of a simulator study.

In short, each type of research problem requires a decision as to which kind of simulation technique is appropriate or, alternatively, whether full-scale testing, or some combination of simulation and full-scale testing, would be most efficacious. In line with the preceding considerations, it is anticipated that the results of the study described here will be validated in a full-scale on-road study.

ACKNOWLEDGMENT

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REFERENCE

1. Sussman, E. D., Sugarman, R. C., and Knight, J. R. An Investigation of Factors Affecting Driver Alertness. Cornell Aeronautical Laboratory, Inc., CAL Rept. VJ-2849-B-1.