Perceptual Analysis of the Driving Task

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This paper attempts to develop a unified and comprehensive model of the driving task having practical and psychological validity. The model specifies the critical tasks of driving, the critical skills to perform these tasks, and some objective measures of these skills.

In the model, the major tasks for the driver are the perceptual organization from moment to moment of a field of safe travel (a region in which the car can move unimpeded), a minimum stopping zone (the smallest region through which the car must move to come to a full stop), and a comparison of these two fields. The driver's organization of these two fields, or the field-zone ratio, is a control stimulus guiding the control actions to the vehicle. That is, the driver varies the speed and direction of movement of the vehicle to maintain a safe field-zone ratio—one in which the field is greater than the zone.

Objective measures of driving skill derived from the model include the "smoothness" of driving, measured by speed and direction changes over time; i.e., the driver who from moment to moment correctly perceives his field of safe travel and minimum stopping zone and maintains the field of safe travel greater than the minimum stopping zone has little occasion for sudden and jerky movements due to contingencies that could have been foreseen.

Experiments are designed to test the predictions derived from the model and to further develop the model.

•MOST STUDIES of human factors related to driving performance attempt to relate some characteristic of the driver, independently measured, to a measure of driver performance. Few studies have been concerned with the behaviors carried out in the process of driving itself (1). According to DeSilva (2), "A really thorough analysis of all the various factors which go to make up driving skill has never been made."

In this paper we begin to develop a model of the driving task which specifies: (a) the critical tasks to be performed and the critical skills required to perform these tasks, and (b) the conditions the driver tries to optimize as he moves along the road. We also describe objective measures of driving that seem useful, as well as a researc program and a pilot study to investigate the relationship of these skills to roadway and driving conditions, driver experience, and physiological and emotional states.

To date several models of the driving process have been presented (5, 6, 7, 8, 9). Of the two general models of the driving task, Michaels' model (5) is concerned broadl with the human functions involved in driving to discover what aspects of the driving tas overload human capabilities and thereby to suggest roadway designs better matched to human capabilities. Task simplification is the major concern. Ross (6) developed two models of driving to explicate the causes of accidents. Thus, he is concerned with factors which cause the breakdown of single driver-vehicle-roadway or multiple driver vehicle-roadway systems.

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The other three attempt to define skillful driving more closely. Interpreting empirical data, Smith and Cummings (7) have singled out certain goals, routines and procedures which distinguish the skillful driver from the accident-producing driver. The critical value for driving effectiveness of the routines and procedures developed by Smith and Cummings has not yet been conclusively demonstrated in an experimental evaluation. The Christner and Ray (8) model of the driving task is based on systems analysis, control and information theory. It is concerned with superhighway driving and framed in terms of engineering requirements rather than behavioral skills. Moreover, it does not yet identify objective indicators of driving skill. Over twenty-five years ago Gibson and Crooks (9) presented a basic framework of critical stimuli guiding driving and critical states the driver tries to maintain. To develop the model further, perceptual skills must be identified and objective measures of the skills developed.

Among the studies which present quantitative methods and measurements which may be used to evaluate driving skill are those of Jones and Potts (10) and Greenshields (11). The former deals with a specific quantity, "acceleration noise," or variability as an overall measure of driving performance. The Greenshields study presents a detailed method of investigating driving skills and several measures aimed at reflecting skillful driving, one of which, total speed change, is closely related to acceleration variability.

THE CURRENT MODEL

Following Gibson (9) our model would view driving as a form of locomotion with a tool, the car. Locomotion is guided by perception, so that paths are found in the visual field leading to a destination without collision with obstacles. Hence, in driving, visual perception is considered more critical than the motor skills of controlling the vehicle. For most driving tasks, the motor responses are relatively simple, easily mastered and relatively invariant, once the driver knows the relationship between his responses to the vehicle and the vehicular output. The visual scene the driver perceives is constantly changing and must be continually organized. On the basis of this organization, the driver is seen as making compensatory motor responses to the vehicle in the form of speed and direction changes.

Critical Tasks of Driving—Assessment of Optimal State

The critical tasks to be performed and the conditions to be optimized are as follows:

1. The perceptual organization from moment to moment of a path or series of paths, the "field of safe travel," where the driver can move without colliding with obstacles or leaving the roadway. This field as perceived by the driver should be in reasonable accord with objective reality.
2. The perceptual organization from moment to moment of the smallest region within which the driver could come to a full stop if necessary, the "minimum stopping zone." This should also be in reasonable accord with reality for the speed at which the car is moving, the condition of the brakes and the roadway surface.
3. The comparison of these two fields to assess the optimal state; i.e., the minimum stopping zone at a given moment is less than the field of safe travel. The driver should maintain a field of safe travel greater than the minimum stopping zone; the ratio of the field to the zone should be greater than unity, for if they are roughly the same, the space needed to stop the car is the only space available in which the driver can move and the driving is dangerous. If the field becomes less than the zone and the driver has to stop suddenly, he will have a collision.
4. The translation of the overall route to the destination into a series of momentary courses to follow, with planning far enough in advance so that at any instant the course lies within the field of safe travel. For example, if a driver wants to make a right turn from a fast moving stream of traffic, he must move into the proper lane well ahead of time, give up his desired course now outside the field of safe travel, or take the risk that might be dangerous.
5. While carrying out the specified tasks, a driver is continually making compensatory changes in the car's direction and speed to achieve an optimal state; namely: (a) the

car should be headed within the field of safe travel, (b) the minimum stopping zone should be less than the field of safe travel, and (c) the car should be moving on a course leading to the ultimate destination.

While organizing the information from the terrain and making control responses to the car, the skilled driver is also organizing the perceptual information he receives from the car itself as it moves along the terrain. These kinesthetic, auditory, tactual and visual cues from the car, in combination with cues from the terrain, form the totality of cues on which driving is based.

Critical Perceptual Skills

According to Gagne (12), the nature of the information-processing skills required to perform the critical tasks of driving are (a) observing, (b) identification, and (c) interpreting skills.

Sensing or Observing.—This involves noting the presence or absence of differences in stimulus information. Since sensory capacity per se has not been correlated with driving performance (4), it is reasonable to assume that the critical factor is the ability of the driver to use his sensory capacities systematically. Under pressures of time, the driver must develop an efficient observational procedure enabling him to sense changes that occur.

Efficient scanning may be accomplished by a sequential scanning routine, as taught by the Smith system (7). Thus, the observing behavior is carried out under a set of instructions by which the individual continues to tell himself where to look (12). Some kind of scanning and search routine, not necessarily intuitively obvious, is evidently a requirement for efficient driving. Gagne reports (12) that scanning and search routines as a prelude to detection have been successfully taught to military personnel who must carry out missions in the dark. An initial sensing of movement puts into operation a systematic routine of observing "out of the corner of the eye" to use the more sensitive foveal receptors. Such routines must be systematically learned because they are counter to daytime seeing habits. Studies are needed to explore the advantage of different scanning and search routines for varying driving conditions, night vs day, for example.

Identification.—This involves classifying the stimuli into meaningful categories on the basis of information stored in memory against which the input can be matched. The meaningful categories are environmental changes which may affect the field of safe travel or the minimum stopping zone. According to Gibson some of these factors are (a) stationary obstacles such as parked cars, walls, curbs, or ditches, which determi the boundaries of the field of safe travel; (b) moving obstacles, e.g., pedestrians, other vehicles, particularly those approaching from the front or side, and vehicles in the rear when the driver slows down or turns; (c) barriers to sight, e.g., darkness, rain, fog, headlight glare, curves in the road, crests of hills, blind corners, or parke cars; (d) legal obstacles such as traffic lights, road markings, and rules of the road, e.g., not passing on the right; and (e) the speed of the driver's own vehicle because increasing speed decreases maneuverability, thus narrowing the field of safe travel.

Interpreting.—This skill involves the development of expectations—translating the present stimulus information into possible future outcomes on the basis of rules or strategies stored in memory. For example, the driver who wishes to pass another driver has to interpret various cues and rules and decide whether or not he will be able to pass the other car. The rules or strategies he uses in interpreting are of three types: (a) rules of the road, e.g., the width and curvature of the roadway and whether the roadway is one-way or is accommodating two streams of traffic; (b) the rules based on nonhuman cues on the part of the other driver such as the way his wheels are turned, or whether his taillights are on indicating that he is slowing down; and (c) rules having to do with human behavior in general, e.g., the age and sex of the other driver, whether the other driver appears fatigued or perhaps intoxicated—all of which yield additional information about the other driver's possible course of action.

Objective Performance Measures of Driving Skill

As the driving scene changes from moment to moment, the driver tries to compensate for or match these changes by his control responses to the vehicle to maintain an optimal state. An optimal state was defined as that in which the field of safe travel is greater than the minimum stopping zone. Therefore, skill in driving is reflected by the accuracy with which the driver perceives the field of safe travel and the minimum stopping zone, and in the ratio of the field to the zone he maintains over time. Driving skill could also be measured by the driver's output to the vehicle which reflects his perception of the two fields and the field-zone ratio.

We have elected the measures derived from the driver's output to the vehicle to measure his performance. Specifically, we have selected "smoothness" of driving as measured by speed changes over time, called acceleration noise by Jones and Potts (10), and direction changes over time as the two main objective performance measures of driving skill. Clearly, the smoothness of a driver's speed-time plot or direction change-time plot will reflect the nature of the roadway and traffic conditions. These plots will also reflect skill in processing and organizing the information of the driving scene. A driver who accurately processes the incoming information has less occasion for abrupt speed and direction changes due to unexpected contingencies. The skillful driver would tend to be a "smooth" driver.

Additional measures of driving skill which can be derived from the model were singled out by Greenshields (11). He found that drivers of different skill levels (as measured by their past histories) varied in the total number of control responses made. Specifically, the more skilled drivers had fewer accelerator actions, brake actions, total speed changes, and steering wheel reversals.

EXPERIMENTS TO TEST MODEL AND DEVELOP PARAMETERS OF DRIVING PERFORMANCE

In the experiments planned and under way, the critical skills and the task conditions are the independent variables; measures derived from the control responses to the vehicle are the dependent variables. The experimental equipment consists of a standard four-door passenger car equipped with a Drivometer and a tachometer. Experiments were divided into four classes, as we attempted the following:

1. Class I—to manipulate variables affecting the field-zone ratio (width and curvature of road, etc.) and to show that changes in these variables are mirrored in changes in driving performance, e.g., smoothness of driving as measured by the plot of speed changes over time (acceleration noise);
2. Class II—to show that the performance measures singled out as critical (the plot of speed changes over time) do, in fact, reflect driving skill by obtaining driving performance measures from drivers of different skill levels as assessed from past driving histories;
3. Class III—to identify and measure the critical driving skills (search, identification, and interpretation) and to show the relationship of these skills to performance measures derived from output responses to the vehicle.
4. Class IV—to single out emotional and/or physiological states which significantly affect the driver's perceptual skills and to evaluate the effect of these physiological and emotional states on the driver performance measures.

PILOT STUDY

To date we have analyzed one pilot study which yields data supporting some of the hypotheses to be tested in Class I and II experiments. The equipment used consists of an experimental car equipped with a Greenshields Drivometer (11) which measures total number of steering wheel reversals, speed changes, accelerator actions, and brake actions per trip, and total trip time, which according to the current model reflect smoothness of driving or driving skill. The vehicle is operated by subjects (Ss) on an experimental track at Bolling Air Force Base made up of unused airstrips and taxiways a little over a mile in length in the shape of a U.

The Ss were twelve AirForce personnel ranging in age from 19 to 24. Each filled out a Driver Inventory form indicating how long he had been driving, how many miles he drove per year, the type of driving he had done (e.g., rural or urban), and his violation and accident history. All Ss were tested in the experimental car along the U-shaped track on two consecutive days. Each day they drove along the track for 16 trials or laps. Each S alternately made four laps of outside turns followed by four laps of inside turns until the 16 laps were completed. On the first day all drivers were asked to drive at 30 mph. On the second day, half of the experienced and half of the inexperienced drivers were asked to drive at 45 mph and the remainder at 30 mph.

The main independent variables in the experiment were the two variables postulated to affect the field of safe travel and the minimum stopping zone: (a) taking turns on the inside vs outside of the track, and (b) going at different speeds along the track. The third variable was driving skill defined in terms of total driving experience. The main dependent variables were the Drivometer measures.

The following experimental questions are to be answered by the study:

1. Are the measures reliable?
2. Do they covary with manipulable roadway conditions, factors which affect the field of safe travel and the minimum stopping zone, of the current model?
3. Do they reflect driving skill?

TABLE 1

DRIVING PERFORMANCE MEASURES OF SIX SUBJECTS ON TWO CONSECUTIVE DAYS[a]

Driving Performance Measures	Mean No. per 16-Mile Trip		
	Day 1	Day 2	t Value[b]
Speed changes	851.0	874.8	1.0
Accelerator actions	72.5	61.5	1.89
Steering wheel reversals	967.8	938.0	0.58
Brake actions	92.8	106.5	1.71
Total time	415.6	410.6	0.78

[a]Conditions were identical for both days.
[b]None of the differences were significant.

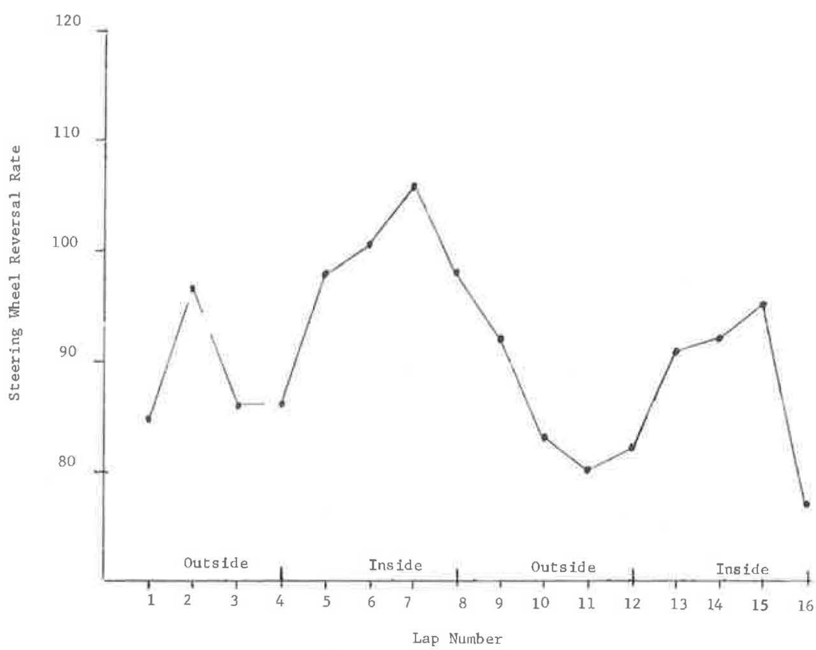

Figure 1. Mean steering wheel reversal rate for six subjects driving on outside (laps 1-4 and 8-12) and inside of track (laps 4-8 and 12-16).

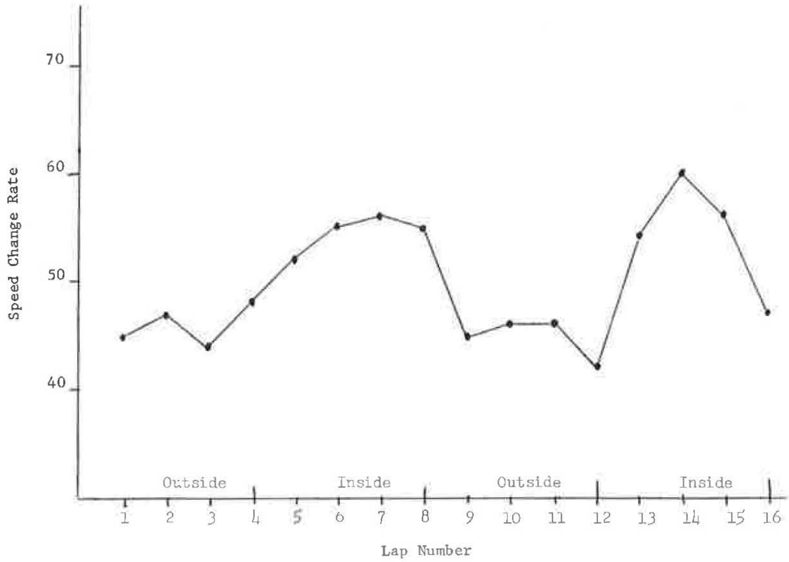

Figure 2. Mean speed change rate for six subjects driving on outside (laps 1-4 and 8-12) and inside of track (laps 4-8 and 12-16).

Results

The results indicate that the measures are reliable in comparing each S's performance across the 16 laps. Using Kendall's Coefficient of Concordance, the correlation across trials was +0.44 (significant at the 0.01 level) for the measure of speed changes and +0.58 (significant at the 0.01 level) for steering wheel reversals. Furthermore, the data of the six Ss who were tested at 30 mph on two different days indicated that their mean performance on all measures was not significantly different on the first and second days (Table 1). In fact, in the case of steering wheel reversals and accelerator actions, the correlations between the first and second days (using Spearman Rho) was +0.95, significant at the 0.01 level.

The measures were found to covary with manipulable roadway conditions which affect the field of safe travel and minimum stopping zone. For example, in comparing the driver's total number of steering wheel reversals and speed changes on the inside of the track with those on the outside (Figs. 1 and 2) and a "t" test, more total steering wheel reversals and speed changes on the inside of the track were observed. The "t" was significant at the 0.01 level for steering wheel reversals and at the 0.001 level for speed changes (Table 2).

TABLE 2

DRIVING PERFORMANCE OF TWELVE SUBJECTS ON INSIDE VS OUTSIDE OF TRACK

Driving Performance Measures	Mean per 8-Mile Trip		
	Inside of Track	Outside of Track	t Value
Speed changes	450.7	391.6	6.29[a]
Steering wheel reversals	537.1	488.3	3.43[b]

[a] $p < 0.001$ [b] $p < 0.01$.

TABLE 3

COMPARISON OF DRIVING PERFORMANCE OF SIX SUBJECTS UNDER TWO EXPERIMENTAL CONDITIONS[a]

Driving Performance Measures	Mean No. per 16-Mile Trip		
	45 mph	30 mph	t Value
Speed changes	980.3	847.8	8.2[b]
Accelerator actions	131.6	84.6	2.9[c]
Brake actions	123.0	78.0	4.05[d]
Steering wheel reversals	950.5	1,148.0	4.12[c]

[a] Condition 1 at 30 mph, Condition 2 at 45 mph; Condition 1 was administered on Day 1; Condition 2 on Day 2.
[b] $p < 0.001$. [c] $p < 0.05$. [d] $p < 0.01$.

As for the effect of higher speed (45 mph vs 30 mph) on these measures (Table 3), it was found, using "t" tests, that there were more total speed changes (significant at the 0.001 level), more brake actions (significant at the 0.01 level), more accelerator actions (significant at the 0.05 level), but fewer steering wheel reversals (significant at the 0.01 level).

None of the measures appeared to differentiate drivers on the basis of amount of driving experience per se, except for total trip time. That is, the more experienced drivers drove around the track faster. Using the Mann Whitney "U" Test, this finding was significant at $p < 0.07$. However, in comparing the highly experienced drivers who had one or more accidents for which they were responsible (N = 3) with those who had none (N = 3), the trend was for the accident drivers to have more total driver actions, e.g., speed changes, accelerator actions, brake actions, and longer total trip times. However, only this last finding was significant at $p < 0.05$. The accident drivers had fewer steering wheel reversals, possibly because they took more time.

Discussion

In general the results of the pilot study support the current model of the driving task. The finding that Ss driving on the inside of the U-shaped track had more steering wheel reversals and total speed changes could be predicted from the model. In the inside lane, the driver has a more variable and smaller field of safe travel (the field of all possible paths through which he can move unimpeded and without leaving the roadway). Thus, the driver must make more compensatory changes in the field of safe travel and minimum stopping zone to have a safe field-zone ratio.

The finding that at higher speed (45 mph vs 30 mph) the drivers had more speed changes, accelerator and brake actions can also be explained by the model. Higher speed reduces the field of safe travel and increases the minimum stopping zone resulting in a smaller field-zone ratio; thus, the driving is less smooth as evidenced by the greater number of accelerator and brake actions and speed changes. Also, at the higher speed, the driver is covering more area in a unit of time and has fewer possible paths available to him. He, therefore, does less steering or selecting of the possible paths he can take.

The driving task was evidently too simple to reflect differences in driving experience. However, with our very small sample of three accident and three non-accident drivers the general trend was for the measures to reflect driving skill, as was found by Greenshields (11). However, final confirmation of these results must await a larger scale study.

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