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Driver Response to Simulated Intersections: An Analysis of Workload-Related Variables

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AN ANALYSIS OF WORKLOAD-RELATED VARIABLES

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ABSTRACT

DRIVER RESPONSE TO SIMULATED INTERSECTIONS: AN ANALYSIS OF WORKLOAD-RELATED VARIABLES

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A roadway intersection driving simulation was created to investigate driver information processing at intersections. Research participants were provided a visual simulation of approaching intersections using a video display with a 120 degree visual field. Six groups, each containing 12 subjects, were formed according to age and gender, with age ranging from 18 to 74 years. All participants viewed 14 separate intersections, which varied according to types of traffic control signs and signals. Individual workload was assessed in three categories of response: performance, subjective, and physiological. A MANOVA was performed on six dependent variables in the 3 (age) by 2 (gender) design. Results indicate significant main effects for both age and gender. The three significant dependent variables were pedal response errors, speed of response, and heart rate reactivity to each intersection. The responses suggest greater workloads for older drivers and female drivers. In addition to age and gender, a number of driver information processing characteristics were measured. Stepwise regressions indicated that performance decrements to the simulated driving situations could best be predicted by subjects' scores for field dependency, visual acuity, and depth perception. However, age alone, accounted for more variance in performance than any single information processing variable.

Dedication

This dissertation is dedicated to my parents, Viola and Cleo, whose successes have always been a source of inspiration.

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Introduction

When driving on the nation's streets and highways one encounters a wide variety of traffic control designs for intersections. These designs range from no control device at the intersection to intersections with multiple signs and traffic signals. The purpose, for the most part, of these traffic control devices is to promote a safe, but efficient, traffic flow in a situation where natural conflict exists. Most persons who drive vehicles have been exposed to numerous types of intersections, and undoubtedly have experienced varying degrees of uncertainty regarding safe movement through the intersections. Some intersections are so complicated, due either to road design or signal/sign configuration, that they are associated with relatively large numbers of accidents. However, contrary to popular belief, more restrictive signalization does not necessarily result in a decrease in accidents or unsafe movements (Polus, 1985).

Three components interact to account for accidents on highways--the vehicle, the driver, and the environment (Shinar, 1978). Shinar reports that the research efforts which have attempted to allocate causes of vehicle accidents to each of these factors have found the majority to be a result of the human (driver) component. Similar claims are to be found throughout the literature on highway safety (Greenshields & Platt, 1967).

In order to understand better the variables related to the driver component of the driver/intersection interaction, it is important to look at how individuals process information from the environment of the intersection, and how they react to this information. The purpose of the present study is to examine driver information processing and workload involved in the interactions of drivers and intersections. To this end it was necessary to design a simulation of the intersection setting.

Two driver variables which frequently appear in the literature on vehicle accidents and unsafe movements are driver age and gender. Age has particularly attracted much attention over the last few years (Yanik, 1985). Projected increases in coming years of the percentage of drivers over the age of 55 have caused more attention to be directed recently to the elderly driver (McFarland, Tune, & Welford, 1964; Petrocine, 1979). Much of the variability in driving behavior related to age appears with changes in information processing characteristics that are largely associated with the aging process (McFarland et al., 1964; Harrington & McBride, 1970; Panek, Barrett, Sterns, & Alexander, 1977). As Ford and Roth (1977) point out, however, there is much debate over the extent of the decline in cognitive abilities associated with age.

In general, higher rates of accidents per mile driven are found among the youngest and the most elderly drivers (McFarland et al., 1964; Harrington & McBride, 1970). As will be explained in a later section, however, accident patterns are different for these two groups (McFarland et al., 1964).

Gender, as a factor related to driver behavior, has not received the degree of attention directed towards age. The effect of driver gender on driving behavior has also been less consistent in yielding significant effects. However, there have been several studies which have found differences between males and females in accident involvement and related driver behaviors. Generally speaking, when accident rates are corrected for annual mileage driven, males have higher accident rates than females across all age levels, until age 60, after which the rate of accidents for females exceeds that of males (Harrington & McBride, 1970; Solomon, 1985).

In addition to the driver characteristics of age and gender, this research focuses on the driving environment of roadway intersections as well. Numerous studies have focused on the intersection as the main topic of interest. Depending on the focus of the research, these studies have involved varied approaches:

1. Before-and-after studies of accident rate and type (Radelat, 1966; Andreassend, 1970; Benioff, Carson, & Dock, 1980; Barbaresso, 1984; Polus, 1985).
2. Computer simulation of mathmatical models of the intersection (Moreno & Demetsky, 1982).
3. Naturalistic observations of vehicles approaching and entering intersections (Robinson, Erickson, Thurston, & Clark, 1972; Ebbesen, Parker, & Konecni, 1977; Edwards, Hahn, & Fleishman, 1977; Mahalel, Peled, & Livneh, 1985).
4. Field studies of drivers, employing instrumented vehicles (Brown & Huffman, 1972).
5. Varied types of driving simulators with visual displays (Ashton, Savage, Thompson, & Watson, 1972; Watts & Quimby, 1979; Hicks & Wierwille, 1979).

Of interest to the present research is the type of signal/sign employed at the intersection, especially the flashing amber/red traffic signal. This interest is due in large part to the novelty of such signalization, and the scattered findings which indicate increases in particular types of accidents and their severity at locations where signals have been changed from "normal" operation to the flashing mode during certain hours of operation (frequently early morning). As Barbaresso (1984) points out, "flashing signals provide drivers with a set of stimuli that differ from those that they encounter during normal, daytime driving" (p. 27). The potential for confusion or increased workload for the typical driver, therefore, causes the flashing signal to be of special interest from a human factors perspective.

The research reported in this paper involved the creation of a simulation of the intersection environment. Drivers' reactions to the simulation were studied by assessing performance responses, subjective responses, and physiological responses. A large number of driver characteristics were measured to determine their relationships to the response variables. The main effects studied were driver's age and gender. Numerous measures, related to information processing, were also analyzed to determine their relationships to the drivers' responses. The overall model of the relationships of these variables was conceptualized in the framework of a Situation--Organism--Response model (S-O-R model). The model, presented in the next section, is a composite of the information processing models presented by a number of previous investigators. The model is used only to guide in the selection of variables for the study. Its presentation should not be interpreted as a research effort to develop an ideal model of driver information processing.

The immediate goal of this research was to design a simulation of the intersection environment and to use this simulation to provide an explanation of driver responses to intersections. The ultimate goal is to suggest possible interventions which will lead to decreases in the number of accidents at intersections. These interventions may take the form of improving (a) the driver/intersection interaction through changes in the design of intersections or (b) the education/training of drivers.

Background

As stated previously, the overall orientation of this research is conceptualized from the perspective of an S-O-R model. Presented first, are various situational variables involved in studying driver behavior, especially those related to the intersection. Next, research related to the driver variables of age and gender is discussed, along with accident and traffic violation statistics for various age/gender groups. Finally, the conceptual model of information processing is presented. This model was utilized to organize the selection of organism variables and response variables involved in the processing of information in the driving environment.

Studies of Driver Behavior (The Situation)

As stated previously, studies of driver behavior can be classified into a number of broad categories, each of which may be applied to the driver/intersection interface.

Before-and-After Studies. The most prevalent studies of intersections are those which attempt to analyze whether a change in intersection design has affected the frequency or severity of various types of accidents. Typically a large number of intersections are analyzed by gathering archival data for several years prior to a change in the intersection. These data are then compared to accident data for a period after the change.

It is based upon this type of before-and-after study that researchers have concluded that increasing the level of traffic control at intersections may increase or decrease accidents, depending on the types of accidents being studied (Polus, 1985). The prevailing finding appears to suggest that the installation of traffic signals, where stop signs previously existed, changes the pattern of accidents. Conventional signals often appear to decrease right-of-way accidents but increase rear-end collisions (Short, Woelfl, & Chang, 1982). Short et al. (1982) found that when 31 intersections, in Milwaukee, were equipped with traffic signals a decrease of 34% in the number of "right-angle" accidents was accompanied by a significant increase of 37% in "rear-end" accidents, and a significant increase of 41% in "other" accidents.

Studies at intersections where the change was from "normal" traffic signal to "flashing" mode after a certain hour have also found subtle relationships. Accident rates do not appear to have changed drastically, but the severity of the accidents generally increases where signals are on flashing mode (Short et al., 1982). Also, the prevalent type of accident is different from that with the full signal operation (Mahalel et al., 1985). For the flashing operation, there are larger proportions of right-of-way conflicts (near accidents or evasive maneuvers) and accidents, as compared to the regular signal operation, where the proportion of rear-end conflicts and accidents is higher. More will be said about the flashing signal intersection later.

Computer Simulation Studies. A second type of study of intersections involves the use of computer simulation. In this type of research mathematical equations are stored in computers. These equations are often based upon archival data from previous studies of intersections. By entering a given set of characteristics for a specific intersection, the researcher can have the computer mathematically generate probable outcomes related to accident type, severity, and frequency. Usually, such computer modeling is used to generate information on traffic flow patterns (Moreno & Demetsky, 1982). Such studies do not deal with driver workload or information processing, and will not be discussed further in this paper.

Naturalistic Observation Studies. Another type of study which relies upon naturalistic data, but gathered by observation rather than archival statistics, is that of the naturalistic observation of intersections. Generally, studies in this category involve numerous trained observers. These individuals observe drivers encountering intersections and rate the drivers' responses according to various predesigned recording formats. In one such study by Robinson et al. (1972), observers watched as drivers approached an intersection and recorded driver head movements (left, right, and center). These researchers concluded that increased complexity of the visual input task, at the intersection, leads to more visual search time. A "last-look" problem is created in processing information from multiple directions. Any change in conditions, between the time the driver makes a last look in a given direction and when the vehicle moves forward, may be critical to safe movement. Obviously, the more directions containing potential conflict situations, the longer the time since the last look, and the increased risk for safe movement.

A similar observational method was used by Evans and Rothery (1976) in assessing driver reactions to the amber phase of a traffic signal. The researchers collected data on approach speed, distance from intersection when amber appeared, deceleration, and vehicle make/model. The researchers found that the drivers of newer vehicles were more likely to drive into intersections after the light had turned red, where the speed limit was 50 miles-per-hour in their artery.

Still other studies of uninformed drivers have involved the observers actually being in the vehicle with the driver. In one such study by Edwards et al. (1977) a pair of observers hailed a taxi from a busy street corner, to be driven to a suburban office building. During the trip the observers recorded the driver's behaviors on prepared behavioral checklists. The researchers were then able to solicit the drivers, at the end of the drive, to engage in simulator driving and to provide background information (driving history). The purpose of this research was to determine the validity of simulator performance by comparing it to driving/accident history and actual driving performance. Few of the scores from the simulators or perceptual-motor tests were found to be significantly correlated to actual street performance or accident history. The authors suggest caution in extrapolating data from their simulators to on-the-street behavior.

Controlled Field Driving Experiments. A fourth type of study, referred to as the controlled field driving experiment, involves the subjects being recruited as participants in a study of actual driving behavior. The experimenter generally rides in the vehicle to operate instruments and collect data related to various driver responses. Many of the studies of physiological responses of drivers have involved such instrumented vehicles (Brown & Huffman, 1972).

There is, however, some difficulty in utilizing instrumented vehicles to study driver behavior at intersections. The problem is one of safety for the participant, other drivers, and the experimenter. This is of special concern if extra demands are being placed upon the participant (e.g., being evaluated on secondary tasks or being asked to make subjective evaluations of the road environment). There is also the liability involved if a researcher, who considers certain naturally occuring intersections to involve excessive workload and risk, knowingly takes the participant into the intersection. In order to avoid these problems many driving studies have involved some form of simulation. However, eventually some form of naturalistic "on-the-road" assessment has to be made to verify findings that result from more controlled experimental studies.

Driving Simulator Studies. There are numerous forms of simulation available for experimental research of driving behavior (other than the previously mentioned mathematical computer simulations, which are not really experimental procedures). These simulations range from extremely sophisticated moving-base simulators (Wierwille & Gutmann, 1978; Hicks & Wierwille, 1979) to various part-task simulations of single aspects of the driving experience (Shinar, 1978). In many simulations the attempt has been made to provide the driver/participant with a visual perspective like that encountered in the actual driving situation. Since the driving situation is generally considered to be one of visual processing (90 percent or more), visual image fidelity is a critical component of the simulation (Hills, 1980). Some of the more sophisticated simulations have also attempted to provide the participant with auditory and kinesthetic feedback sensations. Many simulators also involve the driver manipulating the steering wheel, brake, and accelerator.

There are some driving simulators, however, which do not provide a realistic visual perspective for the driver. In a simulation of perceived danger at intersections, Currie (1969) utilized a model car track with small cars controlled by the experimenter. The participant had foot controls with which he could regulate the speed of his vehicle. However, the subject's view of the driving scene was from an overhead angle to the track. The driver's judgments of acceptable gaps in crossing an intersection are difficult to relate to actual driving situations, where the approaching vehicle provides very different visual cues of its relative closing speed.

In a similar study to that of Currie, Colbourn (1978) investigated perceived risk in relation to driver acceptance of closing gaps at intersections. Again, the simulation was from an overhead perspective. However, Colbourn's simulation of the intersection was created as a computer graphic. Two square boxes moved from each side of the computer screen toward the center. The subject's task was to select the appropriate moment to move the box at the bottom of the screen (the subject's vehicle) through the intersection in the middle of the screen. More will be said later about the results of Colbourn's research.

Returning to the realistic perspective simulators, as mentioned earlier, at the most refined end of the continuum we have the moving-base simulators. Within this general class of simulators there are numerous levels of sophistication. The most highly developed can present the participant with a realistic picture of the driving environment which changes relative to his/her manipulation of the vehicle's controls (steering, accelerator, braking). Vehicular sounds correspond to images in the visual perspective. Somatic sensations of lateral and longitudinal movement are attempted with some accuracy. Motion sensations have been the most difficult to simulate, and to some extent are still a problem on all automobile simulators (Shinar, 1978; Casali & Wierwille, 1980; Casali, 1981). The inability to simulate motion accurately has resulted in a restriction of the range of longitudinal and lateral motion simulations available in the most sophisticated simulators.

Simulators which present the subjects with a visual display involving changes in vehicle speed and curves/turns, without providing the participants with accurate simulations of the kinesthetic and proprioceptive feedback, have been found to result in mild to severe cases of simulator sickness (nausea or motion sickness) among many participants (Goodenough, 1976). Part of the problem is that the feedback from the simulator vehicle fails to match the expectations to the viewed perspective (e.g., sharp curves). However, Casali (1981) lists several additional possible causes of simulator sickness, one of which includes the wide-screen display used in some simulations.

The problem of simulator sickness is especially of concern in research efforts. As suggested by Casali (1981), it is not natural to get sick while driving. Participants who do become sick should be eliminated from the study, since one would assume that sickness would have some effect upon performance. However, eliminating subjects who get sick in the simulator also presents serious problems. It appears that certain types of individuals (e.g., field-independent subjects) are more likely than others to experience simulator sickness (Goodenough, 1976). More will be said about such moderator variables related to driving abilities later. For now, it is necessary to say only that eliminating subjects who get sick may significantly alter the representativeness of the sample for the population of concern.

Fixed-base simulators, those where no motion cues are provided, generally expose the subject to more motion sickness than moving-base simulators but, being aware of the potential problem, many researchers do not present the participants with visual input involving drastic changes in lateral and longitudinal motion (Watts & Quimby, 1979).

Of the full simulations, the above two types... moving- and fixed-base, largely represent the full set. As far as controls available, the driver may have full control of the simulator, partial control, or no control. In full control the driver has numerous alternative directions and speeds which may be dictated to the vehicle/scene. These may be computer generated images or real-time video images recorded from a camera mounted on a transport system that responds to the driver's manipulations of controls as the camera travels over a miniature driving terrain (Blaauw, 1982).

At the level of no control of the visual image in the simulation, the driver views a pre-recorded video driving scene and may or may not be asked to follow the scene with manipulations of the steering wheel and foot controls (Edwards et al., 1977). The "controls" serve no functional purpose, other than that they are generally believed to give the subject a feeling of being involved in the scene.

At the opposite end of simulator sophistication, from whole-task simulation, is the part-task simulation. A typical part-task simulation might involve the participant sitting in a chair viewing slides of a driving environment while having one or more responses to the scene being recorded. Such an experiment on eye-scan patterns was conducted by Cohen (1981). Unfortunately, these studies are often criticized for their lack of generalizability to the actual driving situation since they sample such a simplified portion of the overall driving task. In fact, Cohen (1981) found that the eye fixation patterns of subjects viewing slides of driving scenes did not agree well with the eye fixation patterns of the same subjects viewing the same actual roadway scenes.

To a large extent this distinction between various levels of simulator sophistication reflects the general tradeoff between in vivo studies and laboratory simulations. The latter providing more control and manipulation of critical variables, but the former being more representative of actual situations to which the experimenter wishes to generalize findings.

Intersection Simulations. Simulations of intersections have been reported in varied forms. There have been numerous computer simulations based upon mathematical models (Moreno & Demetsky, 1982). Of those simulations which have attempted to analyze some aspect of driver behavior, the majority appear to be of the variety where the participant looks down upon an intersection (either model or computer graphic) and responds to the conditions presented by either manipulation of the controls or self-report of his/her cognitive assessment of the situation. As stated earlier, the problem with this perspective is that the closing gaps of intersecting traffic appear different from an overhead perspective than from a ground-level position.

One of the problems with simulating an intersection from the driver's perspective is the complexity required to create an interactive relationship between the driver and the visual perspective. Initially, the visual scene for an intersection needs to allow for a much wider field of view than is commonly displayed in simulators. In order to allow the driver to "see" in both directions of the intersecting roadway the subject needs a field of view approximating 180 degrees.

The problem of producing a sufficiently wide field-of-view can be addressed by filming the scene with several cameras. However, the creation of an interactive driver/roadway perspective is not so easily achieved. Frequently in driving simulators the driver is able to slow or speed the visual image, containing the scene ahead, by manipulating the brake or accelerator of the simulator. With the foot controls connected to the motor drive for the filmed scene this allows for a reasonably realistic perspective. This is true as long as everything in the roadway environment is stationary. However, if there are other moving vehicles in the visual field these vehicles should appear to move independent from the drivers' vehicle. Therefore, a situation is created where some objects must move relative to the driver's speed and others must remain independent from this perspective.

There are two obvious ways to handle this problem, however, both involve very expensive systems. The first, is to utilize the camera mounted on a transport system which moves over a terrain in response to the driver's manipulation of the controls. The driver sees the real-time image projected from the moving camera. For intersections, however, one would wish to have a wide angle of view, requiring more than one mounted camera. Such a simulation was created by Blaauw (1982).

The second method is to use a very sophisticated computer-generated display. Although the capability exists of generating images of 180 or more degrees of visual field, there are only a few in existence known to the author, the best known being that of the Mercedes-Benz Laboratory, located in West Berlin.

One also is reminded that in many studies which have increased the field of view beyond a 60-degree horizontal arc, there have been significant increases in simulator sickness (Casali, 1981). However, this should not present a problem in the simulation unless the simulator's visual display depicts curves in the roadway and drastic changes in speed.

Assuming the two simulations above are not available, there are at least two other alternative approaches. The first, referred to previously, is the method of allowing all visual images to slow down or speed up in response to the driver's controls. The corresponding changes in speed of other vehicles recorded may not be critical to the design of the study.

The second approach, used with some regularity, is to have the scene projected to the driver just as it was filmed, with no provision for the driver to manipulate the images by the vehicle "controls". In such studies, the participant is generally asked to mimic the control movements necessary to follow the image viewed, especially the steering movements. This last approach, despite its possible drawbacks, was chosen for the present study.

Flashing Signals. An intersection control device of special interest in this research, due to increases in accidents associated with such intersections, is that of the flashing amber/red signal (Benioff et al., 1980). These are generally regular (red-amber-green) traffic signals which have automatic switches allowing them to enter the flashing mode. The flashing amber/red signals are typically installed with the flashing amber lens facing the main road and flashing red facing the lower volume artery. The intended meaning in the United States is that flashing red is for all traffic to stop before proceeding, and flashing amber is for traffic to proceed with caution. Utilization of the flashing mode is typically based upon the traffic volume of approaching arteries (Benioff et al., 1980).

There have, however, been some instances where the flashing signals have been designed to flash red or flash amber in all directions leading into an intersection (Mahalel et al., 1985). These are somewhat rare in the United States, but appear to be frequent alternatives in other nations of the world.

In the United States, the first flashing amber/red signals were utilized in the 1930's (McNeil, 1936) and are referred to in the Manual on Uniform Traffic Control Devices (MUTCD) of 1934 (U.S Bureau of Public Roads). Even then, the consideration was for fuel economy (from reducing unnecessary idling and changes in acceleration) and improved traffic flow at low-volume intersections.

Due, in part, to the general search to reduce overall energy consumption in the U.S. such signalization, during periods of low traffic volume, became popular in the early 1970s, and has continued to increase somewhat in utilization (Mahalel et al., 1985). In a review of research related to use of the flashing amber/red signal, Benioff et al. (1980) report that the use of such traffic control devices can reduce intersection delay, reduce gasoline consumption, and conserve electrical energy (less energy being required to operate signals in the flashing mode).

As stated above, such modes of signalization generally involve a typical or "normal" traffic signal changing to an amber/red flashing mode during periods of low traffic volume (Federal Highway Administration, 1983). In general, these flashing modes are activated on a timing cycle, in many cases initiating the flashing mode between 11:00 and 12:00 p.m. and returning to normal operation between 6:00 and 7:00 a.m.

The literature for utilization of the flashing mode is described by Benioff et al., (1980) as lacking in guidelines. The authors indicate that the 1961 MUTCD flashing operation warrants serve as the guidelines for most utilizations of the flashing mode:

> When for a period of four or more consecutive hours any traffic volume drops to 50 percent or less of the stated volume warrants, it is desirable that flashing operation be substituted for conventional operation for the duration of

> such periods. However, such flashing operation should be restricted to no more than three separate periods during each day. (p. 4)

For a more thorough review of the area of flashing signal operations, the reader is referred to the report by Benioff et al. (1980).

Studies of driver behavior at intersections employing a flashing mode have generally indicated that when such intersections are changed from "normal" mode to flashing (for the same hours of the day) there is a change in the pattern of traffic conflicts and accidents (Barbaresso, 1984; Mahalel et al., 1985), with a decrease in rear-end conflicts and accidents but an increase in right-angle conflicts and accidents.

A study conducted in the District of Columbia during the 1960s (Radelat, 1966) looked at accident patterns at intersections with flashing signals. The research compared the accident rates at intersections where signals were changed from flashing operation to normal operation to the accident rates at intersections that continued on flashing mode. The general conclusion was that changing flashing signals to normal operation significantly reduced the number of accidents at these intersections during the early morning, low volume periods. Radelat is quick to point out, however, that there are possible tradeoffs, with normal operation possibly leading to frustrated drivers, robberies of stopped drivers, and impeded traffic flow.

From a survey questionnaire, in which 232 traffic agencies responded, Benioff et al. (1980) found similar indications of increased accident rates at flashing mode intersections over conventional signals. In a number of the responding agencies, the flashing operation had been replaced with the conventional system or a red/red flash on all arteries. "Most [agencies] indicated some problems with flashing operation" (p. 49). The authors concluded from the responses to their survey that the intersections with amber/red flashing signals were confusing to both the drivers facing the red and those facing the amber signals. One possible explanation provided was that some drivers stopping for the flashing red assumed the cross-street also to have flashing red, and pulled out in front of oncoming traffic (p. 32). A large number of the agencies surveyed had returned to the standard signal operation after experiencing accident problems.

To investigate further the possible confusion experienced by drivers facing the flashing mode signal, Benioff et al. (1980) conducted a brief survey of drivers in four cities. The drivers involved in the study were given verbal directions as a traffic signal head was manually operated. The drivers were asked, in a written multiple choice format, to indicate their understanding of the meaning of the flashing amber and flashing red signals. Ten percent of the drivers given a choice between "stop..." or "slow..." when approaching a flashing amber signal incorrectly indicated they should stop, with inexperienced and older drivers being most inclined to give the incorrect "stop" response.

Faced with the amber flashing signal, nearly 50 percent of drivers were incorrect about the behavior of traffic on the cross-street, with equal proportions indicating "slow..." or "can't tell".

Interpretations of the responses to the red flashing signal were not quite so clear, in part due to uncertainty about the cross-street when approaching a red-flashing signal (it may be an amber-red intersection or a red-red intersection). Most drivers knew that the red-flashing signal, as they approached, meant to stop. But as a group there was much confusion regarding what the cross-traffic would do at the intersection.

A final study of the utility of flashing operation, provided by Benioff et al. (1980), involved an analysis of accident and traffic operations at 94 intersections utilizing flashing operations. The intersections were either changed from flashing to conventional operation or conventional to flashing operation. The results indicate a significant increase in accidents, especially right-angle accidents, at intersections which changed from regular to amber/red flash at night. The authors reasoned that drivers entering intersections at hazardous times probably did so due to either lessened decision-making capabilities at night or the inherent ambiguity of the flashing red light. However, the authors recognize that in certain conditions the flashing signal is relatively safe, these being where the ratio of main street to side street volume is 3 to 1 or greater, or where the main artery's two-way volume is less than 200 vehicles per hour. The authors continue by suggesting an accident experience warrant for discontinuance of flashing operations. Similar suggestions are provided by the Federal Highway Administration (1983) and by Moreno and Demetsky (1982).

Other studies which have looked at unsafe behavior at flashing amber/red intersections have found similarly increased accidents or unsafe behaviors at such intersections. Barbaresso (1984), in a before-and-after analysis of intersections utilizing signals in the flashing mode during nighttime periods, found that the severity of up to 100 percent of late night, right-angle accidents could be reduced by returning to normal operations. He also reports that significant reductions in nighttime right-angle accident frequency and rate can be attained by eliminating flashing signal operation at four-legged intersections of two arterial roadways. However, we are not told how the intersections, which were changed from flash to normal modes, were chosen. If these had been problem intersections, one would suspect a regression toward the mean as an explanation for the reduction in accidents after the signal changes were made.

Organism Variables in Driving

In the area of highway safety, many studies have looked at the outcome of altering characteristics of the roadway in order to study the rates and types of accidents or other related variables. However, if one wishes to analyze the processing of information related to accidents or unsafe movements, it is necessary to study a wide variety of organism variables. The most commonly studied organism variables include driver age, gender, and various information processing abilities/characteristics.

Age Variable. The driver age variable is perhaps the most popular of the driver variables currently under study, especially the "elderly" driver. If one wishes to define the elderly driver on the basis of chronological age, the majority of studies appear to suggest anywhere from 55 to 65 as the age at which certain human abilities appear to alter enough to affect driver behavior in a significant manner (Panek et al., 1977; Petrocine, 1979). However, there are some visual abilities which display decreases at earlier ages (Cristarella, 1977; Panek et al., 1977).

Panek et al. (1977) list the following visual abilities as altering with the age of the driver, and possibly being related to driving performance: absolute threshold, accommodation, acuity (static and dynamic), color vision, adaptation, size of visual field, fusion, angular movement, phoria, glare sensitivity, fixation, and movement in depth. Cristarella (1977) provides a similar listing of visual abilities affected by age, many displaying decrements as early as 30 to 40 years of age.

In addition to perceptual abilities, certain cognitive abilities are also believed to alter with age: perceptual style, selective attention, perceptual-motor reaction time, vigilance, and decision making (Panek et al., 1977). It should be pointed out, however, that among individuals of the same chronological age there is much variability in the effects of the aging process. Defining a "functional" age is advocated as the desirable goal of much of the research on the "age-related handicap" driver (Petrocine, 1979).

According to current research estimates, 25 percent of passenger vehicle drivers are over the age of 55 (Winter, 1984). This figure is expected to increase to 28 percent by the year 2000, and 39 percent by 2050. Thus, there is a growing proportion among the population of drivers in the United States of persons over the age of 55. Although older drivers generally drive fewer annual miles, compared to younger drivers, Petrocine (1979) reports figures that suggest that drivers over the age of 65 drive more miles today than in previous years.

Research in many fields is focusing upon the needs related to the shift in the average age of the American population. Accommodating the increasing numbers of older drivers on our streets and highways is one critical area where these needs must be studied and met (Winter, 1984).

Fortunately, many impaired elderly drivers appear to have placed self-imposed restrictions on their driving habits (Petrocine, 1979; Rackoff & Mourant, 1979; Yee, 1985), driving less at night, driving less in congested areas, driving slower, and using their brakes more often than their younger counterparts.

Although the elderly driver accounts for a relatively low per driver ratio of accidents and vehicle violations, this is largely due to the fact that elderly motorists drive fewer miles than younger drivers (Petrocine, 1979; Winter, 1984; Yanik, 1985). Accidents and violations per mile driven are more accurate indicators of decrements in driving performance than are the same incidents quantified per driver (Yanik, 1985). The accident per driver statistic indicates the overall threat of elderly drivers, but masks the performance decrement of the elderly driver population when they are on the road.

Based upon data from the 1977 National Personal Transportation Survey, and from the Fatal Accident Reporting System, A. F. Williams (1985) has computed mileage-based fatal crash involvement rates for drivers by age, sex, and time of day. Teenage drivers and drivers over the age of 60 were found to drive least, with comparable annual mileage rates for each group. Adjusting for annual mileage, younger drivers (both male and female) were found to be overly represented in fatal passenger vehicle crashes. The rates of these accidents drop rapidly from age 16 to age 25. Two explanations are provided for these high rates of accidents among young drivers and their decrease with age. First, younger drivers are inexperienced and might therefore be expected to be involved in more accidents. Secondly, data indicate that teenagers drive a larger percentage of their miles during the high risk nighttime hours. Nighttime mileage percentages drop steadily as age increases. For all ages, nighttime rates for fatal crashes are higher than daytime rates.

A. F. Williams' data (1985) also indicate a slight increase in fatal vehicle crashes per mile after age 50, becoming especially noticable among drivers over 70. The rate of fatal crashes for males was twice that for females, up to the age of 25, with a steep descent for both sexes during the first 10 years of driving (16 to 25). The rate of fatal crashes for 70 year-old drivers is comparable to that of 18 and 19 year-old drivers. Also, after age 60, female drivers involved in fatal crashes exceed male drivers for the first time.

Another distinction found among age groups concerns the types of violations and accident-violations prevalent among the various groups (Harrington & McBride, 1970). Among younger drivers violations and accident-violations are generally related to "speed"; whereas, among drivers over the age of 55 there is a drastic increase in the rate of "right-of-way" accident-violations. Other increases in accident-violations for the older drivers are found for "sign", "turning", and "passing" violations. As previously indicated, these are the types of accidents which increase at flashing amber/red intersections, causing one to expect older drivers to be overly represented in such accidents. Winter (1984) summarizes these types of accident-violations among the elderly by pointing out that risk for elderly drivers is especially high at intersections.

McFarland et al. (1964) suggest, from their review of the elderly driver literature, that such intersection accidents may result from a slowness in information processing speed, causing information to "be stale" (from the first artery viewed) by the time the driver processes information from the last intersecting artery. A driver might, therefore, look in one direction at an oncoming vehicle, look in the opposite direction, see no vehicles, and pull out, forgetting the information from the first artery.

Gender Variable. Both males and females are often recruited as research participants when the researcher desires to generalize to large segments of the population. In certain situations there is strong justification for hypothesizing that gender will actually function as a significant moderator variable. However, in many cases it is merely convenient for the researcher to take advantage of the equal numbers of each gender among the participants, allowing gender to function as one of the categorical independent variables. In spite of these justifications for including gender as a variable in research on driving performance, Hagen (1975) claims that little systematic effort has been made to compare gender differences in driving performance. However, accident involvement and related statistics have generally indicated different patterns of accident involvement between males and females.

Current findings indicate that males generally drive more passenger vehicle miles than females, throughout all age levels (A. F. Williams, 1985). As with age, it is necessary to compare driving abilities based upon a ratio of incidents to miles driven. The rate of fatal passenger vehicle crashes per 100 million miles is much higher for males, generally being double the rate for females, across all age levels until age 50. As noted previously, a drastically decreasing rate of fatal accidents for both sexes occurs from age 16 to 30, where it levels off. However, at about age 50 the rate of fatal accidents per million miles begins to increase for both sexes, with females displaying a higher rate than males by age 60 (A. F. Williams, 1985).

An earlier study (Harrington & McBride, 1970), conducted in the 1960s, also indicates gender, as well as age, to be an important determinant in traffic violation patterns. Prior to mileage adjustment (looking at the number of violations per 100,000 drivers), males appeared to have many times more violations than females, averaging approximately three times the number of violations among females (Harrington & McBride, 1970). However, as found with age differences, some of the gender difference in violations and accident-violations disappeared when the sexes are adjusted for mileage driven.

Harrington and McBride (1970) found that males tended to have a higher rate of "speed" related accident-violations, whereas, females displayed a higher rate for "sign" and "right-of-way" accident-violations. There are a number of studies which have attempted to account for gender differences in driving performance by experimental methods. Hagen (1975) evaluated the gender differences in psychomotor performance of licensed drivers using a driving simulator. His results indicated a significant difference in measures of driving performance on the simulator, with this difference being especially extreme between young (16-24) males and females. There was no attempt made to establish one gender as superior to the other in performance, only a discriminant analysis which yielded different weighted group means (based upon the performance variables under study). Hagen reports that the male drivers (in contrast to the females) drove closer to the centerline, maintained a higher rate of speed, had a higher rate of accelerator input, and were less consistent in their operation of the accelerator. The females, on the other hand, operated the simulator at a lower rate of speed, and demonstrated less accelerator input, lower accelerator reversal rate, and higher consistency scores for accelerator operation. Overall, the discriminant weights reflect a willingness of males to operate the simulator at a higher rate of speed. Hagen advocates for interventions that will make the driving styles/characteristics of the two sexes more similar, suggesting that the streets and highways are safer when drivers are more alike in performance characteristics.

This concludes the review of the organism variables of age and gender, both of which are related to accident rates. While it is true that females from age 16 to 60 have lower accident-violation rates than their male counterparts, the general conclusion is that females, over the age of 60, are more likely to be involved in accident-violations than male drivers. Also, female drivers display higher rates of accident-violations at intersections than males across all age levels. Obviously, age and gender are only indirectly related to driving performance. It is important to look at the underlying information processing variables found among age and gender groups.

Other Driver Characteristics. A third set of organism variables of concern to this research are those dealing with driver information processing. These include characteristics related to (a) sensory abilities, (b) perceptual abilities, and (c) higher order processing abilities (e.g., perception of risk, decision making style, and trait anxiety). In the previous two sections the variables of gender and age were discussed as if they directly related to driving ability. It must be realized, however, that neither variable is directly related to driver performance. Many studies look at these variables as they relate to outcome, but their effects must be through intervening variables of some aspect of information processing or motor performance. A number of studies in various areas of human performance suggest a gender difference in the processing of information (Goleman, 1978). The same is true for many abilities which relate to information processing in the driving environment. The result is that many of these abilities correlate significantly with age or gender of drivers. The researcher is therefore aided in the selection of information processing variables, knowing that gender groups and age groups have different accident patterns and different abilities to process information in other situations. It is only logical to assume that some of these variables may explain the different accident patterns found among the gender and age groups.

It is impossible to look at all potential information processing variables in just one study. As an aid in designing research, it is helpful to develop a conceptual model of driver information processing, with categories of variables as components in the model. Such a model is shown in Figure 1.

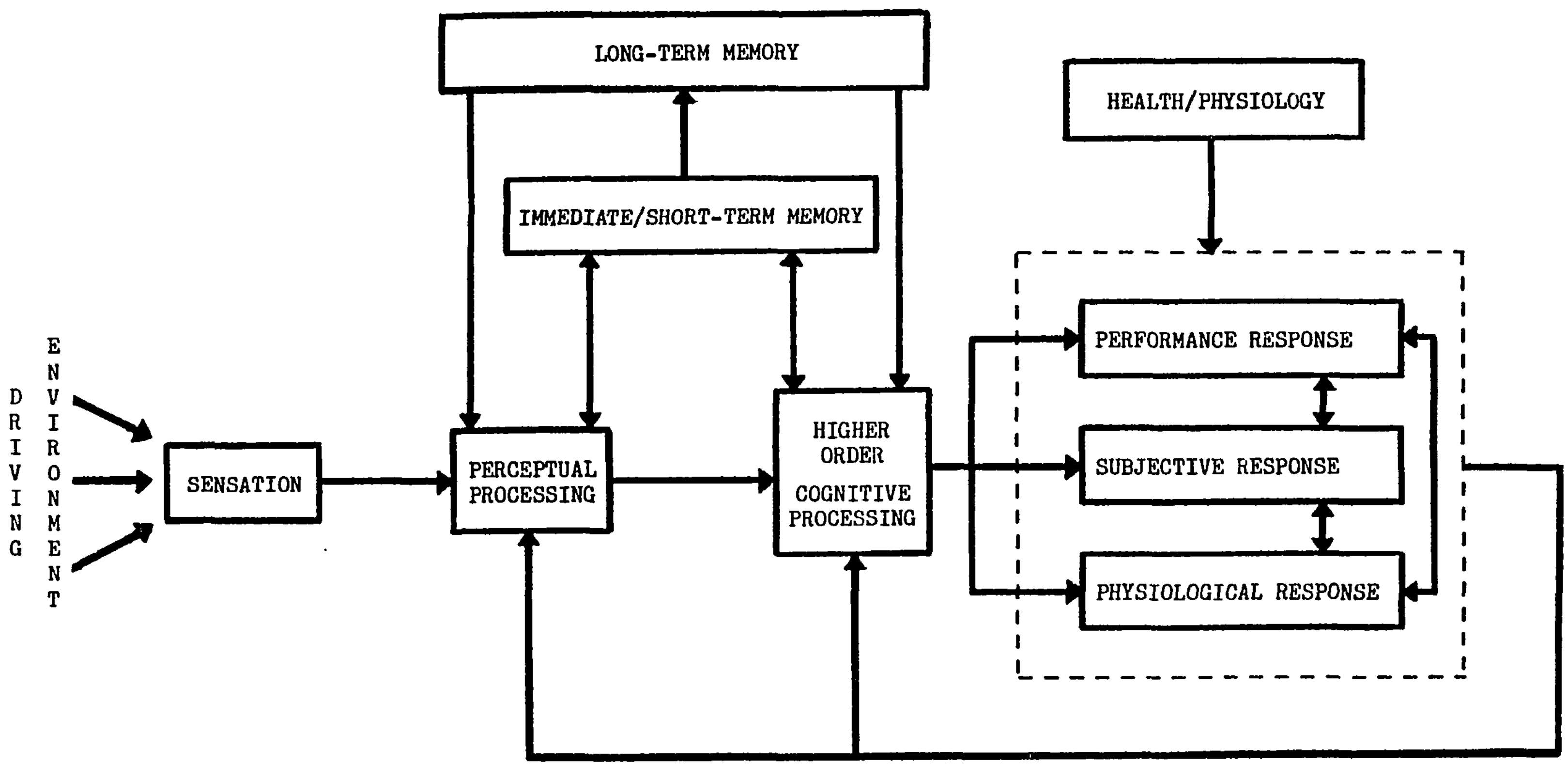

Figure 1. Model of Driver Information Processing.

The model presented in Figure 1 is a composite of various information processing models presented by a number of previous investigators (Rockwell, 1972; Shinar, 1978; Wickens, 1984). It is not argued that this model is more correct than any other model. The purpose of the model is to guide the research by aiding in the selection of variables. This process of selecting relevant variables is facilitated by maintaining a consistent conceptual model.

The first component of the model is the "DRIVING ENVIRONMENT". To begin, only some proportion of the stimuli in the driving environment ever reach the sensory receptors of the driver. Various characteristics of the driver play a role in how the driver directs his/her attention in order to be exposed to the roadway environment.

The first information processing component in the model is labeled "SENSATION". Sensation is generally accepted to be the process where a stimulus initially comes into contact with the human body, exciting the receptor cells which respond with a generator potential, and resulting in sensory nerve impulses which travel to the brain's cortex. Since visual input is considered the primary mode of information in the driving environment, the visual process will be used in examples of how the model works.

The receptors for visual stimuli are the rods and cones of the retina. However, prior to reaching the receptors the light stimulus must pass through various structures that make up the eye. For our purposes everything that goes on from the time that the light reaches the eye's cornea, until the neural message reaches the cortex, is considered to be sensation. Therefore, anything that relates to processing in the eye, or defects of the eye, might be classified as affecting sensation.

The second level of visual processing is "PERCEPTUAL PROCESSING". This level of the model involves the recognition and verbal coding of the visual input. Here, information is also transferred to immediate or short-term memory, and from there to long-term memory. In turn, information already in either of these forms of memory affects the actual perceptual processing of new information. The information so processed then communicates to other areas of the cortex for higher order cognitive processing.

The "HIGHER ORDER COGNITIVE PROCESSING" component is perhaps the most complicated portion of the model. Previously acquired information interfaces with the new input. Much of this information might be conceptualized as existing in either short-term or long-term memory. It includes prior learning histories, especially those that relate to the driving environment. However, it also includes much broader cognitive processes, those that are generally categorized as personality characteristics and as cognitive abilities. A last stage in this level of processing is typically that of decision making, perhaps the decision of when to pull out into an intersection.

The fourth major component in the model is the response made by the individual driver. The response component is critical to various models of information processing because it is this component that generally provides the dependent variables in much of the research. In one form or another, the response variables are often conceptualized as reflecting the workload level experienced by the operator.

In the conceptual model of Figure 1, three categories of response have been identified: performance response, subjective response, and physiological response. Much of the literature on workload identifies a similar clustering of dependent variables (Casali & Wierwille, 1980; Meister, 1985). The design of the model indicates that each mode of response is affected by the other two types of response, and yet, each response is somewhat independent from the others. In other words, a performance response is affected by both the operator's subjective appraisal of the situation and his/her physiological response. However, a driver may experience decrements in one or two modes of responding, and indicate no decrements in the remaining response mode(s). For these reasons, it is important to attempt to assess the participant's response in all three modes in any study of information processing or workload.

The driver's responses are also more than just the product of the higher order cognitive processes. The responses are a product of the interaction between these cognitive processes and the physiology of the operator. The health and physiology of the individual may actually play a role at all component levels in the model, but are probably most obvious at the level of the response component.

The last aspect of the model, remaining to be explained, is the feedback loop from the responses to the components of perceptual processing and higher order cognitive processing. The purpose of this loop is to indicate that the ongoing information processing is affected by the immediately prior responses to the situation.

This generally concludes the explanation of the model. One should be reminded that this is only a conceptual model and should not be taken literally. There is no claim that this model is the most accurate model of information processing. The model is a composite of previous models, available in the literature, used to facilitate the selection of independent and dependent variables for research.

Sensation Variables. As stated previously, most of the critical sensory information in the driving situation is the visual information. For this reason the focus here is on the visual abilities and characteristics of the driver. These abilities and characteristics include visual acuity, color vision, accommodation, phoria, glare recovery, dark adaptation, and visual field. This is by no means a comprehensive list, but it does include many of the more critical sensory characteristics.

Reviews by Cristarella (1977) and Panek et al. (1977) have generally found that older individuals, as a group, display decrements in most of these visual abilities. The findings among older drivers generally indicate poorer visual acuity (Burg, 1966; Bogard, 1974; Cristarella, 1977; Sturgis & Osgood, 1982), poorer color vision (Cristarella, 1977), decreased accommodation ability (Birren, 1964), problems with phoria (Burg, 1968a), degraded glare recovery (Reading, 1968; Wolbarsht, 1977; Pulling, Wolf, Sturgis, Vaillancourt, & Dolliver, 1980; Sturgis, Pulling & Vaillancourt, 1981), difficulty in dark adaptation (Petrocine, 1979), and reduced lateral visual field (Burg, 1968b). The relation of these degraded visual abilities to actual driving performance, however, has not been clearly demonstrated. Numerous studies have failed to show more than minimal relationships between visual abilities and accident patterns (Burg, 1971; Hills, 1980; Yanik, 1985). The general conclusion is that difficulty in predicting accidents is caused by vision being only one of many factors influencing driving performance.

Burg (1968b) looked at lateral visual field as it related to age and gender. Both variables appeared significantly related to the size of the visual field. Beyond age 40, various measures of visual field indicated decreasing field. In regards to gender differences, almost without exception, females demonstrated larger visual fields than males. Burg presents several possible explanations for the age/field relationships but admits difficulty in providing possible explanations for the gender/field relationships.

For most of the degraded visual abilities that occur with increasing age, there are physiological explanations. Most are related to changes in the structure of the eye (Cristarella, 1977; Allen, 1985). Decreases in the size of the pupil, the presence of cataracts, yellowing of the lens, and broken blood vessels in the eye contribute to less light reaching the eyes of older individuals. By some estimates the retinas of individuals over 60 receive only one-third the light as does that of a 20 year-old (Petrocine, 1979).

Perceptual Processing. Extending the model of processing driving information to the second stage, the perceptual level, several factors are commonly listed. These characteristics include depth perception, perceptual style, selective attention, and perceptual-motor reaction time (Panek, Barrett, Sterns, & Alexander, 1977).

In a study of depth perception as a function of age Bell, Wolf and Bernholz (1972) found that depth perception begins to deteriorate between the ages of 40 to 50 years. Bell et al. (1972) report that this poorer depth perception occurs about the same age that accommodation and convergence abilities begin to deteriorate noticeably.

Perceptual style is commonly defined in the information processing literature as an individual's degree of field dependence/independence (Mihal & Barrett, 1976). As indicated by Goodenough (1976), one of the most heavily researched of driver characteristics has been the relationship between field dependency and accidents. Field independence is the ability to view a complex visual field and separate, or distinguish, certain target shapes or objects from the other elements in the field. There are several techniques commonly used to assess an individual's degree of field dependence/independence. One method often utilized is the Embedded Figures Test (Witkin, Oltman, Raskin, & Karp, 1971).

Studies of field dependency indicate that individuals become more field dependent with age and that females are slightly more field dependent, as a group, than males (Witkin et al., 1971). Studies of simulator sickness have found that field-independent subjects are more likely to experience sickness than field-dependent subjects (Barrett & Thornton, 1968).

Goodenough (1976) reports that a consistent positive relationship between field dependency and increased accidents or violations appears to exist. The reason for the relationship is, however, more elusive. A possible explanation is that the field-dependent driver is less likely to detect other vehicles or important signs in the roadway environment (Loo, 1978).

Based upon accidents reported over a three year period, Harano (1970) found that the number of accidents could best be predicted by three variables: the number of traffic convictions, annual mileage, and scores on the Embedded Figures Test (Witkin et al., 1971). Although a consistent relationship between field dependency and increased accidents appears in the research literature, the Embedded Figures Test has been inconsistent in demonstrating this effect. J. R. Williams (1977) argues for a three dimensional test of perceptual style, which he has developed and found superior to the two dimensional Embedded Figures Test in predicting accident involvement. Still other researchers (Mihal & Barrett, 1976) argue in favor of the rod-and-frame test (Oltman, 1968) which they have found superior to the Embedded Figures Test in predicting accident involvement.

Regardless of the method of assessing perceptual style or field dependence/independence, many studies have found a significant relationship between these measures and accident involvement. However, as Goodenough (1976) points out, the field-dependent behaviors that may cause accidents, or the field-independent behaviors that may avoid accidents, remain to be specified. Also, more recent studies of the field dependent/independent relationship to accidents have failed to demonstrate a significant relationship (Clement & Jonah, 1984).

In two studies that examined the relationship between field dependence and on-the-road visual search behavior Shinar, McDowell, Rackoff, and Rockwell (1978) found that field-dependent subjects had less effective visual search patterns and required more time to process the available visual information than field-independent subjects.

Concerning the perceptual process of selective attention, Barrett, Mihal, Panek, Sterns, and Alexander (1977) and Panek et al. (1977) report significant relationships between selective attention ability and roadway accidents, with individuals who have difficulty attending to tasks being overly represented in accident involvement. Similar findings are reported by Kahneman, Ben-Ishai, and Lotan (1973) and Mihal and Barrett (1976). While the review provided by Panek et al. (1977) reports studies which indicate decrements among older subjects for selective attention, the authors present additional findings that indicate this decrement may actually be the result of declines in short-term memory.

There have been numerous studies which have investigated how age differences in performance relate to reaction time. These studies have involved simple, choice, and complex reaction times. Generally, most studies of simple reaction time have shown some age-related effects. Woodworth and Schlosberg (1954, chap. 2) report that reaction time decreases from childhood to about age 25, where it is maintained until about age 60, after which it begins to lengthen slowly. However, studies of driver information processing focus more on choice and complex reaction times (Panek et al., 1977).

Barrett et al. (1977) failed to find a significant age effect for simple reaction times for younger and older drivers in their study. However, the younger drivers did display shorter reaction times for choice and complex tasks, with complex reaction times being especially significant.

Woodworth and Schlosberg (1958, chap. 2) describe choice reaction time as commonly being about 100 ms longer than simple reaction time. The general conclusion is that this difference relates to information processing speed. It is logical to assume that complex reaction time would yield even longer reaction times, reflecting additional cognitive processing. The greater differences between younger and older subjects in reaction time, as the task becomes more complex, might be assumed to reflect a difference in the speed of cognitive processing.

In a study in which Fergenson (1971) looked at the relationship between information processing and driving accident and violation record, the researcher used the difference between simple reaction times and choice reaction times, for each subject, as an indicator of information processing speed. Fergenson concluded that a relationship exists between automobile accidents and information processing speed. He found that individuals involved in traffic accidents tended to display greater differences between simple and choice reaction times (slower information processing) than individuals who had no accidents. The author concluded, however, that a study involving a larger sample, spread over a wider range of age and sex, is needed before reaction time can be utilized to predict accident patterns.

Panek et al. (1977) summarized the relationship between age and perceptual processing by stating that with increasing age, individuals become more field dependent, have more trouble in maintaining attention to task elements, and manifest psychomotor slowing.

<u>Higher Order Cognitive Processing</u>. Higher order cognitive processing variables generally include all the information processing that takes place from the point of the driver's initial awareness until a response is made. This stage of the model is typically identified with decision making. Decision making is obviously a very complicated process and involves such individual characteristics as risk-taking, judgment ability, and trait anxiety. In addition, this is where long-

term memory plays its most significant role. Variables which are a part of memory include all the learning experiences of the driver, especially those involved in driving. These variables may include the number of years driving, accident history, annual driving mileage, and various conditions under which the individual typically drives.

In a series of studies related to perception of risk at intersections, Colbourn (1978) found significant differences, for age and gender, in driver performance during simulations of the intersection. However, subjective assessments of risk made by the subjects were unsuccessful in distinguishing risk perception. It appeared that older females made more risky decisions in the intersection simulations than older males or younger males and females, but due to insignificant subjective judgments of risk Colbourn was undecided regarding the meaning of the results. Decision latency measures indicated that younger males made faster decisions than older males, and that older females made faster decisions than older males. There were no significant differences between the two younger groups or between the two female groups.

A final group of organism variables which are indirectly related to the information processing sequence are variables which reflect the individual's past driving history and related background variables. Topics include accident history, violation history, driving experience, types of road conditions commonly encountered, night driving experience, and typical speeds driven. Harano, Peck, and McBride (1975) concluded from their research that drivers possess traits that differentially predispose them to accidents. The researchers measured over 500 drivers on a wide variety of variables (which included biographical data, psychometric tests, and simulator performance measures) in an attempt to establish a battery of predictors of accident liability. After cross-validation, the predictors that remained significant were marital status, mileage, traffic conviction record, socioeconomic factors, self-rating of one's driving ability compared to elderly drivers, and personality and attitudinal factors derived from the California Inventory of Driver Attitudes and Opinions. None of the perceptual-motor variables or simulator performance variables were significant in predicting accidents.

Combining the information processing components, past driving experience, age, and gender, we have a large portion of what the S-O-R model refers to as the O - organism variables. These variables are generally conceptualized as the characteristics the individual brings into the stimulus situation (S). For the present research, this situation is the intersection, with the varied utilization of traffic control devices. That portion of the S-O-R model yet to be described is the R component, the "R" representing response.

Response Variables of Drivers

The variables which reflect a driver's situation (S) and organism characteristics (O) typically form the independent variables of much of the driving research. The driver responses (R), which should reflect the interaction of the S and O variables, typically make up the dependent variables. In the model these responses form the fourth stage and are divided into three categories: (a) overt motor or performance responses, (b) subjective responses, and (c) physiological responses.

Overt Motor (Performance) Responses. Driving research has utilized various forms of response, depending upon the focus of the study being conducted. In observational research these responses are typically overt behaviors or consequences of behaviors. At the least refined level, these include archival accident or violation data of actual intersections.

In a laboratory setting, however, the experimenter has greater ability to assess the less obvious behaviors, such as brake manipulation, accelerator manipulation, and steering of the vehicle (forms of lateral and longitudinal control). Some insight into the processing of information by the driver can be obtained by measuring such overt behaviors as head turns, eye fixations, instrument scanning, lane changes, braking distances, and decision-making latency (Hagen, 1975; Colbourn, 1978).

Subjective Responses. A second mode of responding is that of the subjective response. For the most part this form of measurement involves the subjective assessment by the driver, either on the road or in the laboratory simulation, of aspects of the driving environment. The driver typically rates the situation on scales which reflect such dimensions as confusion, complexity, state anxiety, stress, or workload (Ebbesen et al., 1977; Colbourn, 1978; Hicks & Wierwille, 1979). The scales are typically numerical with adjectives anchoring points along the numerical scale.

In a series of studies, Colbourn (1978) investigated driver's risk-taking behavior by measuring the risk that drivers perceived in various stimulus presentations of the driving situation. In the second of three studies, Colbourn (1978) recorded actual traffic scenes on slides. The slides were created to represent either "risky" or "safe" conditions. The subjects were to indicate the level of risk by checking a box representing the probability of needing to make an avoidance maneuver in the developing situation. Boxes corresponded to the probabilities of 1/10, 3/10, 5/10, 7/10, and 9/10. The purpose and context (settings) of the drive functioned as the independent variable. The median rating by each subject, for all slides, served as each subject's score. Colbourn concluded that the more stressful instructions (settings) were associated with greater perceived risk, but one is left with some uncertainty whether the researcher's judgment of stressful versus non-stressful situations was made a priori.

Due to Colbourn's concern over the static nature of slides, his third study involved video recordings of driving scenes. In this study Colbourn (1978) used a magnitude-estimation procedure to rate the level of risk in each scene, wherein subjects were given a standard and asked to compare a scene to this standard scene (e.g., twice as dangerous as the standard).

The results of this final study are unclear. Colbourn discusses the difficulties of obtaining subjective estimates of perceived risk. He suggests one possible alternative to subjective ratings in order to make assessments of covert reactions, that of the electrophysiological measure, specifically galvanic skin response.

<u>Physiological Responses</u>. Over the years advocates for a triple response mode of behavior assessment have argued for its use in

recording individuals' responses to stimuli in certain situations (Meister, 1985), especially when the responses under consideration might be best thought of as intervening variables or hypothetical constructs, (e.g., fear, anxiety, workload, stress). The first two modes of responding--overt behavior and subjective behavior--have already been presented. The third mode of response is the physiological response. Hicks and Wierwille (1979) provide a similar assortment of workload assessment responses for a moving-base driving simulator when they refer to three of five procedures as: physiological, subjective opinion, and primary task performance.

There are a wide variety of physiological response measures which have been used to assess human response to stimuli. Meister (1985) lists 16 "physiologic" measures of workload. Many of these physiological responses are electrical in nature and are, therefore, referred to as electrophysiological responses.

Electrophysiological measures used in studies of driver response have been employed in both specially equipped vehicles (Brown & Huffman, 1972; Rutley & Mace, 1972; Helander, 1978; Zeier, 1979) and in laboratory settings (Ashton et al., 1972; Hicks & Wierwille, 1979). A partial listing of the measures previously employed in driver research include: heart rate, systolic and diastolic blood pressure, brain activity, various electrodermal responses, and musculoskeletal responses. Each of these variables may be assessed in a variety of forms.

A brief review of the use of physiological measures to assess driver reactions to driving conditions, however, has indicated that many such measures have frequently failed to detect an effect of the independent variables under consideration (Hicks & Wierwille, 1979). This may be due, in part, to the lack of sensitivity of some measures, or to the low levels of reactivity to driving conditions on the part of the subjects.

Of the physiological measures which have been employed, the one which appears to have most consistently demonstrated an ability to detect the changing physiological activity of the individual has been some variation of heart rate or pulse (Hicks & Wierwille, 1979). Fortunately, heart rate is also the simplest of the responses to assess and quantify (Meister, 1985).

Heart rate has been used in its basic form in numerous studies (Ashton et al., 1972; Rutley & Mace, 1972) with increases in workload or stress generally being associated with increased heart rate. However, heart rate is also found to decrease during tasks requiring concentration (Andreassi, 1980). Apparently, heart rate slows as the individual concentrates on a task, but increases to a level above normal when task load exceeds a comfortable amount.

A related measure is that of cardiac arrhythmia (Hicks & Wierwille, 1979). This physiological variable is measured by calculating the interbeat intervals of the heart and converting each into an estimate of instantaneous heart rate. The variance of the instantaneous heart rates is a quantification of cardiac arrhythmia. Many consider it a more sensitive measure of workload than basic heart rate. The general findings appear to indicate increases in arrhythmia with boredom, and decreases in arrhythmia during periods of increased mental workload (O'Hanlon & Kelley, 1977).

Summary

The age and gender of drivers have been found to be significant variables related to driver behavior. For the most part, these driver behaviors have been assessed either in terms of direct or indirect (outcomes) of overt motor responses made by the drivers (archival, field, and laboratory studies). Fewer studies have assessed cognitive characteristics of the drivers, or subjective and physiological responses. Still fewer studies have attempted to assess all three modes of responding to the driving situation.

The effect of age upon driving performance, and its implications for the future of highway safety, cannot be denied. The outcome studies are clear in their findings that driver performance decreases in many ways as age increases. However, it is not age itself that directly causes decrements in driving performance, but the effects of the aging process upon the human body and its ability to process information from the driving environment (McFarland et al., 1964). These effects may be sensory, perceptual, cognitive, or motor. Physiologically, persons age at differing rates, so that it is more productive to think of the age of drivers in terms of functional age rather than chronological age, and to look for those variables associated with age which also affect driving performance.

With this in mind, what is needed now are studies which focus upon process, rather than (or in addition to) outcome. For this reason the study below is one in which a multivariate approach is employed, looking not only at age and gender of the driver population, but also at sensory, perceptual, and cognitive characteristics of the individuals. It also attempts to throw further light upon the driver reaction process by looking not only at overt motor responses, but also at subjective evaluations and physiological responding. It is believed that subtle aspects of the driving workload may show up in subjective or physiological responding long before they affect motor performance.

Although it is impossible to incorporate all potential variables (both independent and dependent) into one study of driver response to intersections, an attempt has been made to select variables that best represent factors involved in the intersection driving situation (given time and resource limitations).

Hypotheses

Drawing upon the research cited above, there are several conceptual hypotheses which are formed. The first hypothesis is one based upon findings which indicate that intersections using amber and red flashing signals report higher incidents of right-of-way accidents than similar intersections with more conventional signalization. The resulting hypothesis is that such intersections impose a greater workload and performance decrement upon the typical driver than the more conventional intersections.

The second conceptual hypothesis is that elderly drivers will display greater workload levels at the various intersections than their younger counterparts. For this analysis drivers are divided into three age groups, 18-30, 40-52, and 62-74.

A third conceptual hypothesis is that males will demonstrate less of a workload effect at the various intersections when compared to females.

Operationally, workload is defined in terms of performance decrements in three response modes: subjective responding, overt motor performance, and physiological responding. Such an approach is suggested by Meister (1985).

More specifically, regarding the operational definitions of the three response modes, the subjective response to the intersection is evaluated using each subject's responses to a five-item rating scale completed at the end of each intersection experience.

The overt motor performance is evaluated in several aspects: (a) the distance between the intersection and the point where the subject made the final decision to stop or proceed through the intersection (measured in seconds), (b) the number of times the subject altered the choice of stopping or proceeding through the intersection, (c) the accuracy of the subject's final pedal decision, and (d) the number of head turns (5 degrees or greater) displayed by each subject from the beginning of each intersection scene until the intersection was reached.

The physiological response of each subject is defined in terms of their recorded heart rate, taken during the last five seconds of each intersection. This heart rate measure is compared, for each intersection, with a baseline sample of heart rate in order to produce a heart rate index based on each individual's standard distribution, a method suggested by Ben-Shaknar (1985) to compensate for individual differences in resting heart rate.

The resulting experimental hypotheses are that 62-74 year-old subjects, female subjects, and subjects viewing the intersections with the flashing amber and flashing red control devices will respond with

(a) higher ratings of subjective workload (scores on the rating scale), (b) longer decision time regarding advancement through the intersection, (c) a higher number of decision changes, (d) a higher number of incorrect pedal choices, (e) a higher number of head turns as the subject approaches the intersection, and (f) a higher heart rate reactivity during the final five seconds of each taped intersection.

Beyond the three independent variables in the factorial design of the research, significant correlations are hypothesized between age and visual acuity, visual field, depth perception, field independency, visual memory, cognitive processing time, and various background/health variables. Correlations are also expected to be significant between gender and some of the above variables, with females scoring higher than males on visual field and field dependency.

Measures on the six dependent variables are expected to correlate with age, gender, and decrements in visual acuity, visual field, depth perception, field dependency, visual memory, cognitive processing time, and background/health variables.

Method

Subjects

Participants in this study included 72 individuals between the ages of 18 and 74. Six groups of 12 subjects were formed according to gender and age, with age groups of 18-30, 40-52, and 62-74. Subjects were recruited as paid participants for a study of driver performance conducted by the Federal Highway Administration branch of the Department of Transportation. Individuals were solicited from the the Federal Highway's subject pool and recruited through a job placement service specializing in retired persons. The general context of the research was explained to each potential subject during an initial telephone contact. Each subject was paid $40.00 for 3-hours participation ($10.00 per hour, plus a $10.00 bonus).

All subjects were required to have a valid driver's license and currently to be driving an average of 10 or more miles per week.

Simulation Design

In order to conduct this research it was first necessary to construct a simulation of the driver's perspective of roadway intersections. This was accomplished by using three video camcorders (Panasonic PV-200) to tape intersection approaches. The three cameras were mounted, at different angles, atop a 1979 Dodge. The angles of the cameras were chosen to provide a 120 degree field-of-view. As the vehicle was driven in various areas of several cities in Northern Virginia, the cameras taped approaches to selected intersections.

Intersections eventually chosen for the study were edited from the original tapes. The sequence of intersection appearance was chosen based on a method of random ordering. The final version of the tapes contained participant instructions (Appendix A), three practice intersections, and 14 test intersections. The 14 test intersections included two intersections in each of the following categories: flashing amber signal, flashing red signal, traffic signal displaying red, traffic signal displaying green, traffic signal changing green-amber-red, stop sign, and no sign/signal facing the driver's approach. Each of the intersections was a four-way crossroad intersection. The edited tapes of each intersection employed the following sequence: a 30-second dark period, a 15- to 23-second visual approach to an intersection, and a 70-second exposure to a taped rating scale. The entire tape, including recorded instructions, was approximately 40 minutes in length.

The three edited angles of view were played back to the participants using three VHS video-recorders (JVC Model HR-D142U), each connected to one of three rear-screen projection systems with 114 cm diagonal screens (Mitsubishi Model VS-459-R). The participant viewed the screens seated in a driving console, located 142 cm from the center of the middle screen. The two side screens were positioned at angles corresponding to those of the cameras which taped the scenes, covering 120 degrees. A rendering of the simulation area is provided in Figure 2.

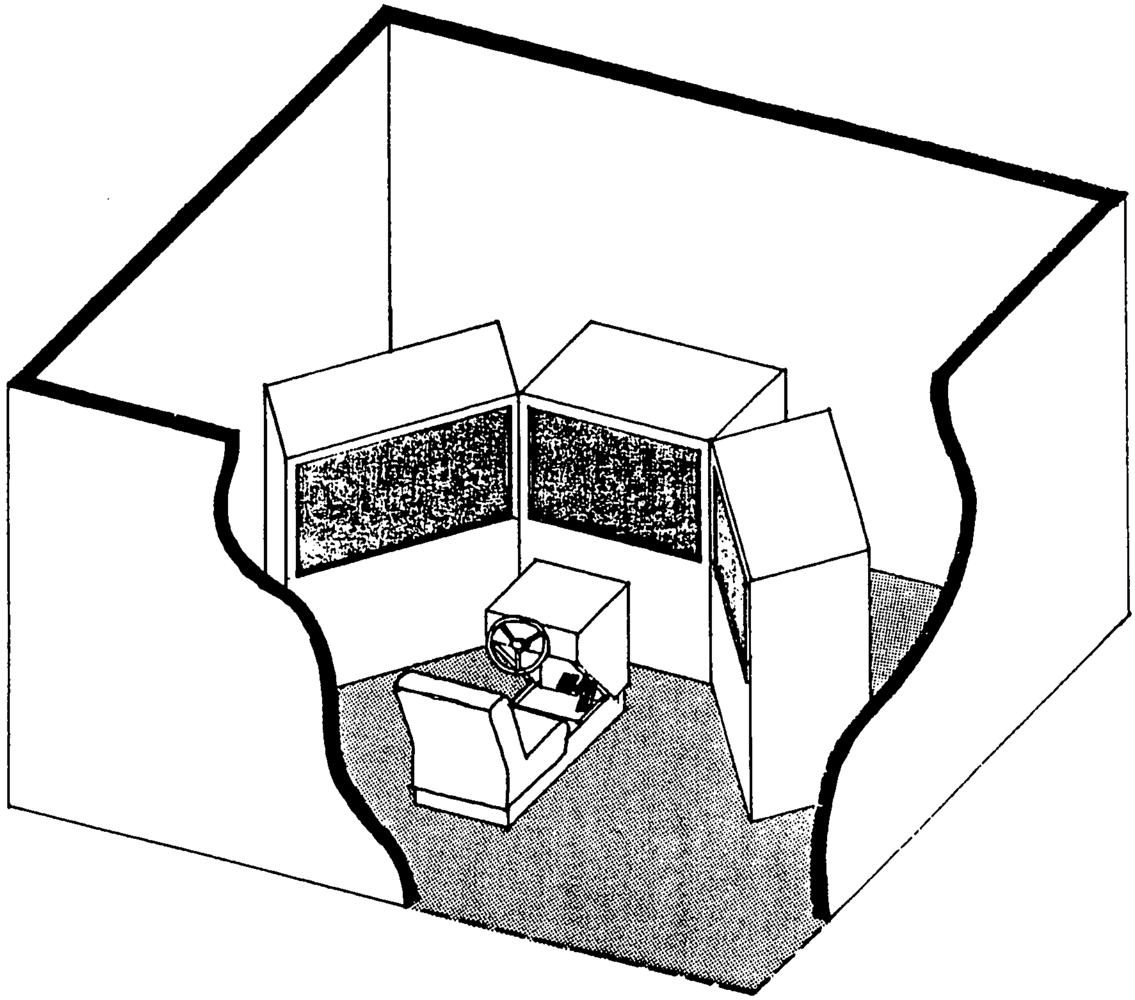

Figure 2. Intersection Simulation Area With Display Screens And Console.

Additional equipment in the simulation included a video camera used to tape head turns, Gould ECG and Biotach modules (Model 11-4143-01) used to collect heart rate responses, and a MFE multi-channel strip-chart recorder used to record heart activity and responses from the brake and accelerator pedals of the driver console.

Materials

Driver Questionnaire. A 40-item questionnaire was completed by each participant (Appendix B). The items addressed general background information, health background, vision and hearing ability, driving history and behavior (accidents, violations, mileage, typical driving conditions, and ratings of various traffic conditions).

Spielberger State/Trait Anxiety Scale. The 40-item State/Trait Anxiety Scale (Spielberger, 1983) was completed by each participant soon after arriving at the testing location. The first 20 items of the scale (State Anxiety) were immediately readministered after the simulation.

Embedded Figures Test. The individual version of the Embedded Figures Test (Witkin et al., 1971) was administered to each participant. The test includes 12 simple figures with corresponding complex figures. The task involves locating the simple geometric shape within the complex figure after the simple figure has been removed. The object of the task is to solve it as quickly as possible. A score is computed for each subject based upon the average number of seconds to solution. A high score indicates the characteristic of field dependency, while a low score reflects field independency.

Reaction Time Test. A Lafayette Instrument Visual Choice Reaction Timer (Model No. 63035) was used to measure simple and choice reaction times. The device provides the subject with four lights and one buzzer, with buttons below each stimulus. To measure simple reaction time participants were told to rest their index finger on the far right button. Their task was to depress the button as soon as the light directly above it appeared. For the choice reaction time, subjects were directed to respond in the same manner, but utilizing both right and left index fingers. Subjects were provided five practice trials for each of the two tasks. The practice trials were followed by 20 test trials. Each stimulus presentation was preceeded by a "Ready" signal. This signal varied from one to three seconds before the stimulus light. Each participant's score was the median of the 20 responses.

Benton Visual Retention Test. The Benton Visual Retention Test (Benton, 1974) was individually administered to each subject. The test is designed to measure short-term visual memory. Ten cards, containing one to three geometric shapes, are displayed to the examinees for 10 seconds. After each card is removed the examinee's task is to draw the figures. Two scores are generated by this test, number correct out of 10 and an error score based on approximately 40 potential errors.

Visual Abilities. Visual abilities were measured with the aid of a Bausch & Lomb Master Ortho-Rater (Catalog No. 71-21-40-65). The standard procedures, described in the instruction booklet, were followed in measuring visual acuity, vertical and lateral phoria, color vision, and lateral visual field. All subjects were requested to wear any corrective lenses they would normally wear while driving.

Depth Perception. Depth perception was measured with a Lafayette Depth Perception Apparatus (Model No. 1702). This apparatus involves discrimination of the displacements of two vertical bars, viewed through a small window from a distance of 15 feet. Each subject was given five trials from which an average was computed for the degree of error (cm scale).

Subjective Rating Scale. A subjective rating scale was designed for use in rating the workload of the intersection scenes (Appendix C). The anchors used for this scale were based on suggestions by Meister (1985). The rating scale was designed to be presented to the subject immediately after each intersection. The scale contains five statements, to which the participant was instructed to rate his/her level of agreement/disagreement from 0 to 6.

Procedure

Participants were initially pre-screened over the telephone to make certain they met the minimum criteria for participation in the study, and to provide each with details regarding the general nature of the research and their participation.

Upon initial contact at the testing location, the general purpose of the research was again outlined, and each participant was allowed to sign an informed consent form (Appendix D). The schedule of payment was also explained to each participant. A conditional bonus of $10.00 for completing the simulator driving portion of the study within a "sensible" time frame (predetermined by the researcher) was also discussed.

After the introductory period, each participant was given the general background questionnaire to complete. This questionnaire was followed by the Spielberger State/Trait Anxiety Scale.

Next, participants were administered the Embedded Figures Test, the reaction time test, and the Benton Visual Retention Test, in that order.

A third set of measures involved visual screening, which assessed visual field, visual acuity, phoria, color vision, and depth perception.

All three sets of measures required 60 to 90 minutes to complete. Afterwards, each participant was allowed a 10 minute break.

Upon returning from break, each subject was introduced to the simulation and had heart rate electrodes attached. As the participant adjusted to the surroundings and heart rate stabilized (requiring approximately 15 minutes), the equipment and simulation were explained. Each participant was then presented the taped instructions explaining the nature of the simulation (reprinted in Appendix A).

As stated previously, the tapes contained five minutes of instructions, followed by three practice intersections, and finally the 14 test intersections. Subjective responses to each intersection were made during a 70-second period after each intersection scene, and were recorded on tape for later scoring. A video camera, mounted over the participant's head, not only recorded the verbal responses (dependent variable of subjective workload) but also taped the dependent variable of head turns as the subjects watched each scene.

The four remaining dependent variables: heart rate, choice of pedal response, final pedal decision latency, and number of pedal choice changes, were recorded on a multi-channel chart recorder.

After the final intersection, the participant filled out the Spielberger State Anxiety Scale. This was followed by debriefing and each subject being paid $40.00.

Results

The original overall design of the study was a 3 (Age Group) x 2 (Gender) x 7 (Traffic Control Design) mixed-effects model, with subjects nested in age group and gender, S(Age x Gender) x TCD. However, complications in taping intersection scenes altered the inclusion of the intersection variable. It was not possible to tape intersections without confounding variables (e.g., approach speed, level of cross traffic, length of scene). Therefore, the resulting MANOVA and ANOVAs involved a 3 (Age Group) x 2 (Gender) factorial design. For these analyses, the six dependent variables, for each subject, were computed from the average response of the subject across all 14 test intersections. In order to compare the relative workload of the seven traffic control designs, additional MANOVAs and follow-up ANOVAs were computed for each individual intersection.

Dependent Variables

The six dependent variables for workload included four performance response measures (pedal response errors, the number of seconds from the last pedal response to the intersection, the number of pedal response changes made approaching each intersection, and the number of head turns made during the entire intersection scene), one subjective response measure (rating scores for each intersection), and one physiological response measure (heart rate reactivity).

Pedal Response Errors. The task for each participant in the simulation was to observe the intersection ahead, determine if the intersection required coming to a stop or allowed the driver to go through the intersection, and to indicate their decision by depressing either the brake (indicating "stop") or the accelerator (indicating "go through"). Each subject was told that they could change their pedal response as often as needed, to try to make sure that their final response was correct, to try to make their correct response as early as possible, and that a bonus of $10.00 was contingent upon completing the 14 intersections within a generous time limit (to encourage speed). In truth, there was no time limit and all participants received the bonus.

For each of the 14 intersections, subjects were scored "1" or "0", depending on the accuracy of their final pedal response. The pedal errors were averaged across the 14 intersections to produce each subject's entry in the Age x Gender data analyses.

Number of Seconds from Intersection for Final Pedal Response. By counting backwards from the mark on the strip-chart which indicated the point where the intersection was reached to the pen deflection that corresponded to the subject's final pedal response, it was possible to obtain an index of how early the participant decided on a final response. It was possible to measure this to one-tenth of a second. Again, for the Age x Gender analyses, an average time was computed across the 14 intersections for each subject.

Number of Pedal Response Changes. As stated above, each participant was encouraged to respond rapidly and accurately. It was therefore possible that subjects that were having problems processing the information would make a large number of pedal response changes. Again, these responses were averaged across the 14 intersections to yield an index for the Age x Gender analyses.

Head Turns During Approach. A video camcorder was unobtrusively suspended from the ceiling, above the driver's console. This provided a video tape of each subject's head turns. The tape was viewed at a later date at which time each head turn of five degrees or greater was scored. The total number of head turns was averaged across the 14 intersections for the Age x Gender analyses.

Subjective Workload. As stated previously, there was a 70-second period immediately after each intersection when the subject was presented the scale on which to rate the workload of the intersection (Appendix C). This scale was presented visually and auditorily. The participants were requested to rate the five statements verbally, using the numbers 0 to 6. These verbal responses were recorded for later scoring on the same video tape as the head turns. The ratings for the five statements were added to produce a total score for each intersection. These ratings were averaged across the 14 intersections to yield the subjective workload index for the Age x Gender analyses.

Heart Rate Reactivity. Heart rate electrodes were attached to the left and right upper chest and upper left abdominal area of each subject. The heart rate recordings utilized for this study occurred at two specific intervals for each intersection. One heart rate measure was taken for the final five seconds of each intersection. This was considered to be the period which would reflect a reaction to the intersection scene. The second heart rate measure was taken for a five second period during the 30-second dark period between each intersection scene. This second set of heart rate measures functioned as a baseline to which each of the reactive (phasic) heart rates could be compared. Because of the individual differences in normal heart rates it is advisable to compare an individual's reactive heart rate to their own baseline. A method similar to the one empolyed, has been suggested by Ben-Shakhar (1985). The result of this method is that heart rate reactivity is quantified in standard score units. The baseline heart rates are used to compute the mean and standard deviation for computing the standard scores for the reactive heart rates. The 14 standard scores for each subject were averaged to provide an overall heart rate reactivity index in the Age x Gender analyses.

Phase One Analysis

Data analysis was accomplished in three major phases. The initial phase of the analysis began with a multiple analysis of variance (MANOVA). The MANOVA was used to examine the relationships of the two main effects, independent variables (age and gender), to the six dependent variables, which represent workload. Next, univariate ANOVAs were computed for each of the six dependent variables.

Based upon Wilk's Criteria, the MANOVA indicated significant main effects for age, $F(12, 122) = 4.76$, $p < .0001$; and gender, $F(6, 61) =$

3.33, $p < .0066$.

ANOVAs, computed separately for each of the six dependent variables, indicated three had significant relationships with age: response errors in brake/accelerator use, number of seconds from intersection when last pedal response was made, and heart rate reactivity. Both response errors in pedal use and heart rate reactivity indicated a significant gender effect. In all three ANOVAs, the age/gender interactions failed to reach significance. However, since the most extreme scores were predicted for young males (18-30) and older females (62-74), the six age-by-gender groups were compared for significant differences. Tables for each of these three ANOVAs are provided in Appendix E. Follow-up Tukey HSD tests for significance are reported below. The three dependent variables which failed to achieve a significant age or gender effect were pedal response change, head turns, and subjective workload.

Pedal Response Errors. The ANOVA for pedal response errors indicated a significant effect for age group, $F(2, 66) = 8.56$, $p < .0005$, eta squared = 0.189; and gender group, $F(1, 66) = 5.33$, $p < .0240$, eta squared = 0.059. Tukey's HSD tests for significance were computed to compare age groups and gender groups, using an alpha value of .05. The test for age group indicated that the youngest group (18-30) made significantly fewer errors than either of the two older groups. Means, based upon the percentage of scenes with incorrect final pedal responses, from youngest to oldest groups, were 0.018, 0.086, and 0.110. The Tukey HSD test for gender group indicated that males made fewer errors than females (0.050 vs. 0.093).

A Tukey HSD test (alpha = .05) for the six individual, age by gender, cell means indicated that young males and young females (18-30) made significantly fewer errors than females in the 40-52 and 62-74 age groups (Figure 3).

Seconds from Intersection. The ANOVA for the dependent variable of seconds from the intersection when the last pedal response was made indicated a significant effect for age group, $F(2, 66) = 17.27$, $p < .0001$, eta squared = 0.327. However, the gender group effect failed to reach significance at the alpha level of 0.05, $F(1, 66) = 3.75$, $p < .0572$, eta squared = 0.035. Tukey's HSD tests for significance were computed to compare age groups and gender groups, using an alpha value of .05. The youngest age group (18-30) responded significantly earlier than the two older groups. The means, from youngest to oldest group were 10.877, 9.214, and 8.464 seconds from the intersection. Males also made earlier responses than females (9.851 seconds vs. 9.186 seconds).

A Tukey HSD test (alpha = .05) for the six individual, age by gender, cell means indicated that young males and young females (18-30) displayed significantly earlier pedal responses than did females in the 40-52 and 62-74 age groups. In addition, the young males also made earlier responses than the oldest group of males (Figure 4).

Heart Rate Reactivity. The ANOVA for the dependent variable of heart rate reactivity indicated a significant effect for age group, $F(2, 66) = 14.04$, $p < .0001$, eta squared = 0.278; and gender group, $F(1, 66) = 4.75$, $p < .0328$, eta squared = 0.047. Tukey's HSD tests for

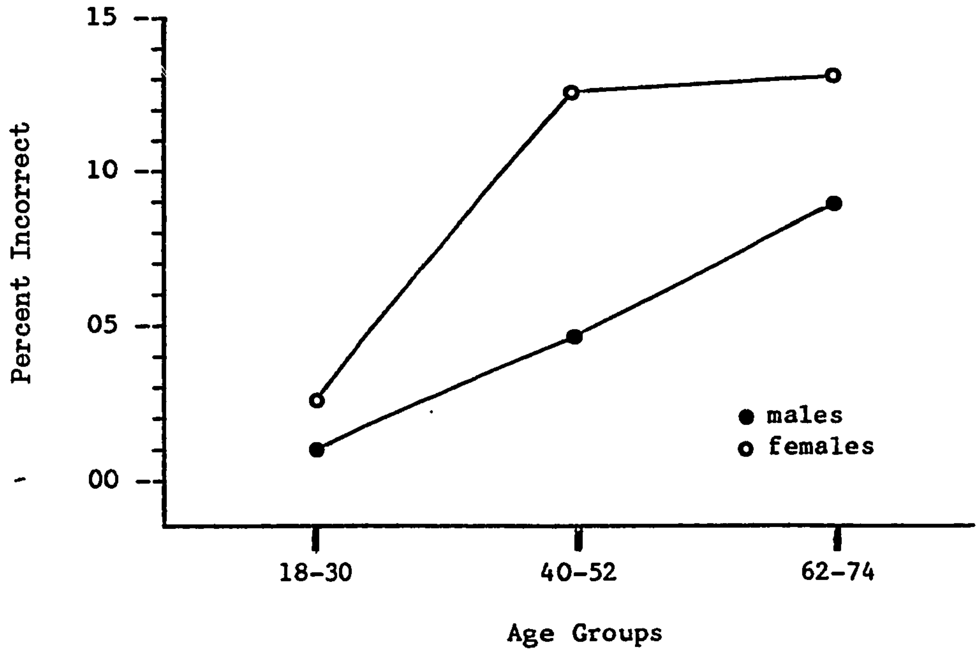

Figure 3. Percentage of Intersections With Incorrect Final Pedal Response.

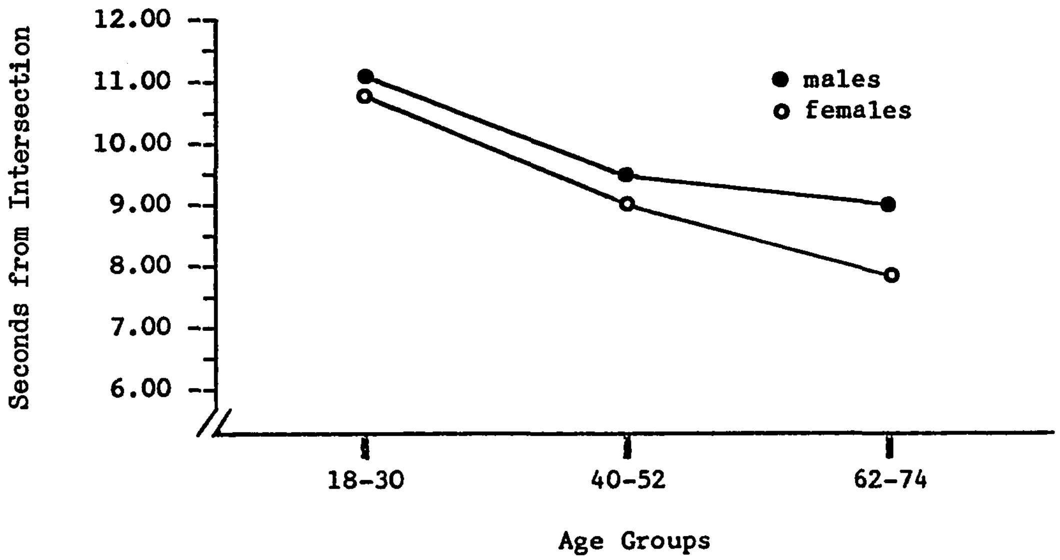

Figure 4. Average Number of Seconds from Intersection When Final Pedal Response Was Made.

significance were computed to compare age groups and gender groups, using an alpha value of .05. The youngest age group (18-30) displayed significantly less reactivity, as compared to the two older groups. The mean reactivities, in standard score units, from youngest to oldest group, were 0.099, 0.713, and 1.194. Males also displayed significantly less reactivity than females (0.484 vs. 0.853 standard deviations).

A Tukey HSD test (alpha = .05) for the six individual, age by gender, cell means indicated that young males and young females (18-30) were significantly less reactive than females in the 40-52 and 62-74 age groups, and males in the 62-74 age group. In addition, 40-52 year-old males displayed significantly lower reactivity than did 62-74 age group females (Figure 5).

Phase Two Analysis

In a second phase of the data analysis, an attempt was made to assess the effect of the type of traffic control device. As stated earlier, the orignial research design was a 3 x 2 x 7 mixed-effects model. It was obvious from observations of the video tapes that each of the two intersections, sharing a common device type, contained uncontrolled differences (e.g., visibility conditions, amount of cross traffic). This made it inappropriate to combine the 14 intersections by device type. Therefore, a direct comparison was made for the 14 intersections with a 3 x 2 x 14 mixed-effects MANOVA. As might be expected, the MANOVA yielded a significant "Intersection" effect, $F_{(78, 4681)} = 23.78$, $p < 0.0001$ (Wilks' Criterion). The age group and

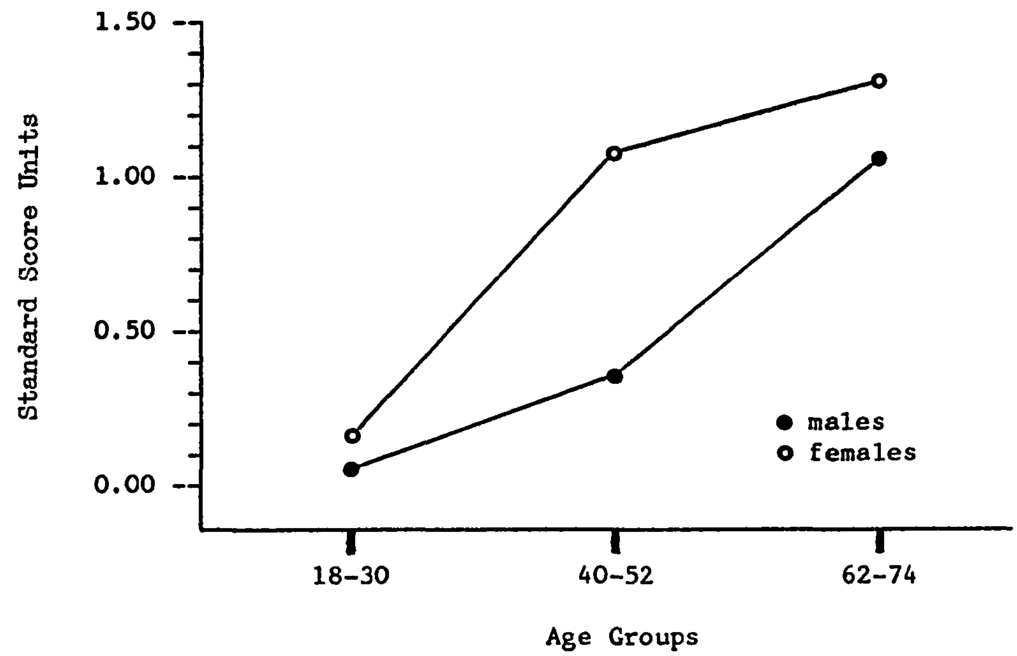

Figure 5. Average Change in Heart Rate (HR), from Resting HR to Intersection HR (HR Reactivity), in Standard Score Units.

gender effects were both significant, as previously indicated in the first phase of the data analysis. Additional significant effects were obtained for the following interactions: Age Group x Intersection, $\underline{F}$ (156, 4982) = 1.82, $\underline{p} < 0.0001$; and Gender x Intersection, $\underline{F}$ (78, 4681) = 1.35, $\underline{p} < 0.0219$. The three-way interaction was not significant. The ANOVAs for each of the six dependent variables indicated significant intersection effects, with all six reporting $\underline{p} < .0001$. These significant effects are considered to be the result of uncontrolled parameters of the intersections. There is no point in further analysis of these differences.

However, some indication of the relative workload of the various device types may be obtained by computing separate MANOVAs for each of the 14 intersections. The design for each MANOVA was the same as that used in the phase one MANOVA, where each subject's six dependent measures were averaged across all 14 intersections, a 3 x 2, factorial design. The MANOVAs were followed by univariate ANOVAs.

Of the six dependent variables, serving as operational definitions of workload, seconds from the intersection when the final pedal response was made, and heart rate reactivity, served as the variables which were most discriminating among the groups. Of the 14 intersections, 13 yielded a significant age effect for "seconds from intersection", with youngest drivers consistently making earlier responses than the oldest drivers. Heart rate reactivity yielded a significant age group effect for 10 of the 14 intersections. On all intersections, young subjects displayed much less reactivity than the older drivers.

In order to determine the relative difficulty of the seven device types, the number of significant age group effects for the dependent variables of pedal response error, seconds from intersection when last response was made, and heart rate reactivity, were totaled from the two ANOVAs of the intersections displaying the same traffic control device. Table 1 displays the total number of significant age group differences, out of a possible six, for the seven types of intersections.

The trend indicates that the flashing red and changing signals caused the most age-related workload. The open intersection was next, followed by the flashing amber signal, green light signal, and stop sign. The least stressful intersections were those containing a red light signal.

One is cautioned from inferring too much from this crude analysis, especially since visual quality of the video-tape used may have played a role in creating stress, due to the difficulty related to searching for various visual cues.

Phase Three Analysis

The final phase of the data analysis began with the computing of Pearson Product Moment Correlations between all the variables under study. Fourteen of the variables of most interest are displayed in the correlation matrix in Table 2. It should be noted that the dependent variables of pedal response error, seconds from the intersection when final response was made, and heart rate reactivity, were all significantly interrelated.

Table 1. Significant Differences Between Age Groups On Three Dependent Variables for Two Intersections With the Same Traffic Control Device Type.

Intersection Type	No. of Significant Differences
Flashing Red Signal	5
Changing Signal	5
Open Intersection	4
Flashing Amber Signal	3
Green Light Signal	3
Stop Sign	3
Red Light Signal	2

Based upon hypothesized relationships between the subject variables and the workload dependent variables, stepwise multiple regressions were performed on the three significant dependent variables. The predictor variables, in the first regressions, included age and gender, along with a series of variables from the information processing model. A list of the 21 predictor variables employed is presented in Appendix F. The results of these regressions are discussed below under separate headings for the three dependent variables. The regressions are also reported in Table 3.

A second set of stepwise regressions was computed omitting the age and gender variables, and utilizing only variables more directly related to information processing. These variables included visual acuity (far) with correction, depth perception, lateral visual field, field dependency, short-term visual memory, and simple reaction time. Most of these processing variables indicated significant Pearson Product Moment Correlations with the age variable (Table 2). Older drivers generally had poorer visual acuity, degraded depth perception, smaller visual fields, increased field dependency, degraded visual memory, and slower simple reaction times.

The stepwise regressions were computed using the stepwise technique in the 1982 version of the SAS User's Guide: Statistics, (SAS Institute, pp. 101-110). In the method of regression employed, variables are added one at a time to the model. For a variable to be added to the model, the F statistic for that variable must be significant at the "SLENTRY" level of 0.15. After a variable is added to the model, the stepwise method considers all the variables currently in the model and deletes any variable that does not yield an F value

Table 2. Correlation Matrix of Age, Sex, Information Processing, and Simulator Response Variables, (n = 72).

		1	2	3	4	5	6	7	8	9	10	11	12	13
1	Age													
2	Gender	NS												
3	Far Acuity	.570	NS											
4	Depth Per.	NS	NS	.397										
5	V. Field	-.500	NS	.360	NS									
6	Field Dep.	.403	.304	.426	NS	NS								
7	V. Memory	-.462	NS	-.269	NS	NS	-.453							
8	V. Memory	.500	NS	.384	NS	NS	.506	-.896						
9	Simple RT	.380	.237	.299	NS	NS	.341	NS	NS					
10	Choice RT	.320	.262	.344	NS	NS	.324	NS	.251	.711				
11	RT Diff.	NS	NS	NS	NS	NS	NS	NS	NS	.439	.320			
12	Ped. Err.	.384	.243	NS	NS	NS	.348	-.234	.259	NS	.320	NS		
13	Sec. Int.	-.564	NS	-.343	NS	NS	-.250	NS	NS	NS	-.250	NS	-.353	
14	HR React.	.526	NS	.422	.260	NS	.424	NS	.326	NS	NS	NS	.448	-.417

Table 3. Stepwise Multiple Regressions for Pedal Errors, Seconds from Intersection, and Heart Rate Reactivity.

Outcome Variable	Regression 1 (X = 21)		Regression 2 (X = 7)	
	Variable	R Sq.	Variable	R Sq.
Pedal Errors	Age	0.1425	Field Dependency	
	Gender		Total	0.1210
	Trait Anxiety			
	Total Accidents			
	Driving Anxiety			
	Visual Field			
	Total	0.3255		
Seconds from Intersection	Age	0.3110	Visual Acuity (Far)	
	Gender		Depth Perception	
	Depth Perception		Total	0.1761
	Total	0.3832		
Heart Rate Reactivity	Age	0.2767	Field Dependency	
	Driving Anxiety		Visual Acuity Far	
	Gen. Health Status		Total	0.2507
	Field Dependency			
	Depth Perception			
	State Anxiety			
	Total	0.4445		

significant at the "SLSTAY" level of 0.15. After this check is performed, and the required deletions are made, another variable can be added to the model. The stepwise process ends when none of the variables outside the model has an *F* value significant at the "SLENTRY" level of 0.15 and every variable in the model is significant at the SLSTAY level of 0.15, or when the variable to be added to the model is a variable just deleted from it. The results of both stepwise regressions are displayed in Table 3.

Pedal Response Errors. In the first regression, involving 21 potential predictor variables, pedal error scores were best predicted by the following six variables: age, gender, trait anxiety (Spielberger scores), total accidents in driving history, driving anxiety level (item 40, questionnaire ratings), and lateral visual field. Together, these variables produced a R-square value of 0.3255, $F(6, 64) = 5.15$, $p < 0.0002$. The regression equation indicated higher error rates for older drivers, females, and individuals scoring higher on anxiety trait, a larger number of accidents, lower self-ratings of driving anxiety, and larger visual fields.

Age accounted for the largest amount of the variance in this regression. The R-square value of age alone was 0.1425, $F(1, 69) = 11.46$, $p < 0.0012$.

The second regression, on pedal errors, included a smaller set of predictor variables, ones more directly related to information processing. These variables included visual acuity (far) corrected, depth perception, lateral visual field, field dependency, short-term visual memory, and simple reaction time.

The stepwise regression on pedal errors indicated only one significant predictor, field dependency, with a R-square value of 0.1210, $F(1, 70) = 9.63$, $p < 0.0028$.

Seconds from Intersection. In the first regression for the dependent variable of the number of seconds from the intersection when the final pedal response was made, the same 21 predictor variables were utilized. Distance from the intersection (in seconds) when the final response was made was best predicted by three variables. Again, age and gender accounted for a majority of the variance. The third variable included in the equation was depth perception. The R-square value was 0.3832, $F(3, 67) = 13.88$, $p < 0.0001$. The values indicated that earlier final pedal responses were generally made by younger drivers, males, and persons with poorer depth perception.

As indicated previously, age accounted for the largest amount of variance, with a R-square value of 0.3110, $F(1, 69) = 31.14$, $p <$ 0.0001.

The second regression utilized the same six predictor variables, as used for pedal errors. The regression on seconds from the intersection indicated two significant predictors, visual acuity (far) and depth perception, together yielding a R-square = 0.1761, $F(2, 69) =$ 7.37, $p < 0.0013$.

Heart Rate Reactivity. In the first regression for the dependent variable of heart rate reactivity, the original 21 predictor variables were again used. Heart rate reactivity was predictable from six variables: age, driving anxiety scores (item 40, questionnaire ratings), general health status (self-report), field dependency, depth perception, and state anxiety scores. The R-square value was 0.4445, $F(6, 64) = 8.54$, $p < 0.0001$. Higher reactivity was produced by older drivers and drivers with higher driving anxiety ratings, poorer general health status, strong field dependency, poorer depth perception, and lower state anxiety scores (Spielberger scale).

As in both of the previous regressions involving 21 predictor variables, age accounted for the largest amount of variance, with a R-square of 0.2769, $F(1, 69) = 26.42$, $p < 0.0001$.

Again, in the second regression six predictor variables were employed. The regression for predicting heart rate reactivity yielded two significant predictors for the model, field dependency and visual acuity (far). Together, these variables provided a R-square value of 0.2507, $F(2, 69) = 11.54$, $p < 0.0001$.

One can see from the second set of stepwise procedures that performance on the intersection simulation is predictable (to some degree) by only a limited number of the more direct information processing variables employed in the study: field dependency, visual acuity (far), and depth perception.

Discussion

The simulator performance results followed a trend evident from demographic accident statistics for intersections, with more intersection errors found among elderly drivers. An increase in heart rate reactivity displayed by the older participants suggests that these individuals experienced a higher workload than their younger counterparts. The longer decision latencies by the older drivers appeared to support the conclusion of increased workload, resulting in delayed decision-making for the final pedal response.

The most surprising aspect of the study was the decrement in performance and signs of increased workload found among the 40-52 year old females. Recent accident statistics have indicated the presence of a sharp increase in intersection accidents among females in the over 65 age category, but there have been few indications that the information processing workload may increase at the much earlier age.

Looking at the three dependent variables of pedal response errors, seconds from the intersection when the final pedal response was made, and heart rate reactivity; a consistent trend appears for overall responding and responses to each of the 14 test intersections. The response pattern of the youngest group consistently indicates the least amount of experienced workload. Contrary to findings by Hagen (1975), the performance of young males and females is nearly identical on all dependent variables.

After the youngest groups, the highest levels of performance were displayed by the 40-52 year-old males. Somewhat more degraded in their overall performance were the 40-52 year old females and the 62-74 year old males, whose performances were relatively similar. The group displaying the highest levels of workload were the 62-74 year old females.

A few comments should be made regarding the failure of three of the dependent variables (subjective workload, headturns, and pedal changes) to reach significance. The problem with subjective workload appears to be related to idiosyncratic use of the scale by the various subjects. Some individuals used a wide range of responses. Others used a very narrow range of the scale, some reporting the same rating throughout the simulation. This use of a narrow range of the scale may be attributed to the fact that none of the taped scenes involved near collisions. In the scenes used for the present study, the intersections were all typical crossroad traffic scenes.

One possible explanation as to why head turns failed to indicate significant differences among the groups appears to be that there were two patterns of head turning behavior. One pattern of head turning appeared to be an indication of workload, turning the head to obtain more information regarding the intersection. However, as has been found with steering wheel reversals (MacDonald & Hoffmann, 1980), some individuals under high workload "freeze", gripping the steering wheel and staring straight ahead, rather than turning their heads to collect more information.

The other pattern of headturns observed in some participants was to make a pedal response and then to sit back and study the scene, turning to look at the side screens. Therefore, we end up with a situation in which some individuals, experiencing higher levels of workload, may turn their head more and others turn their head less, while still others, experiencing very little workload, turn their head a great deal.

Failure by the dependent variable of pedal changes to display significance is largely due to a low number of changes made by the participants, most participants making no pedal changes.

In addition to the age and gender effects, for the six workload dependent variables, results of the correlations and regressions indicate that several information processing variables are related to simulator performance. There are a large number of significant correlations between age and the other variables under study. Among older drivers there was poorer corrected far vision, reduced peripheral visual field, a greater amount of field dependency, poorer short-term visual memory, and slower simple and choice reaction times.

One variable which surprisingly failed to demonstrate a significant correlation with age was cognitive processing reaction time. This variable was created by subtracting each subject's median simple reaction time from their median choice reaction time. Both simple and choice reaction times were positively correlated with age (simple RT, $r = 0.380$; choice RT, $r = 0.320$). After a further review of the related literature, this failure to find a relationship is believed to be the result of the simplicity of the choice reaction time task used in this study. Had a complex reaction time task been employed, it is believed that this correlation would have been significant.

Although an attempt was made to create a valid simulation of the intersection situation, the criterion-related validity of this simulation has yet to be studied. Caution should be exercised in generalizing these findings to the design of intervention strategies. Studies which have attempted to measure the relationships between simulator performance and actual driving performance have reported conflicting results, some yielding significant relationships and others finding little or no relationship between simulator performance and driving ability (Harano et al., 1975; Edwards et al., 1977; Blaauw, 1982).

Possible interventions to reduce the workload for older drivers at intersections may include increased utilization of 4-way stop signs, the use of longer sight distances, increased use of permissive left turn signalization, removing much of the roadway clutter near intersections, and increasing the size of the lenses of the traffic signal.

It is doubtful that specialized training for older drivers will have a great effect on intersection accidents. Many older drivers appear to have already changed their driving styles to compensate for decrements in information processing, as evidenced by their driving at slower speeds and avoiding night driving (Petrocine, 1979). There have been some attempts to improve perceptual skills by practice and training (Johnson, Flinn, & Tyer, 1979), but the effectiveness of such interventions for older drivers has not been clearly demonstrated. Reducing the amount of information that must be processed at the intersection appears to be one of the most appropriate interventions for increasing the safety of the intersection.

One interesting observation regarding the older subjects was that of the strong relationships between corrected visual acuity (far) and the variables of age and workload. When subjects were measured for visual acuity, they were allowed to use their corrective lenses. Many of the older subjects did not have 20/20 vision when wearing their glasses or contact lenses. Some of the older subjects reported not wearing their glasses because they felt they did not really need them in order to drive safely. It would therefore follow that some decrements in performance might be reduced if drivers would keep their corrective lenses updated and accurate, and if they would consistently wear the corrective devices.

There are several further lines of research suggested by the current study. First, is the need to establish an estimate of criterion-related validity. The intersections chosen for this research were all local intersections in Northern Virginia. It would be relatively simple to measure subjects in both the intersection simulator and at the same roadway intersections, on the same set of dependent variables, to establish a form of concurrent validity.

One consideration for future studies concerns subject selection. Most of the participants in the present study reported very few, if any, vehicular accidents. Selecting individuals with poor driving records would likely have increased many of the predictive relationships between information processing variables and simulator performance. This would also have allowed for stepwise multiple regressions to predict accident involvement. It is difficult to establish predictive validity without a group of high-accident subjects.

A second approach to the study of information processing at intersections is to investigate the responses of participants as they wait to pull into the intersection. This had been part of the original proposal for the current research, but time and resources prevented its inclusion. The simulator used in the current research could be utilized by turning the side cameras 90 degrees from the straight-ahead position.

An additional predictor variable is also recommended for use in future studies. Based upon a task analysis of the driver at intersections, a measure of the individual's ability to calculate closing gaps of approaching traffic appears needed in order to add a critical information processing variable for the research.

In conclusion, the present research indicates that the performance decrements found among older drivers at intersections (apparent from accident statistics) can be demonstrated in the simple driving simulator designed for this research. There are numerous processing abilities that are likely responsible for these decrements in performance. Visual abilities and perceptual style appear to be among the variables most clearly involved in the age-related increases in accidents at intersections. As predicted in the original hypotheses, highest levels of workload were demonstrated by older drivers, by female drivers, and by drivers at red flashing traffic signals.

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Appendix A

Instructions to Participants

Hello, you are about to be shown a series of driving situations in which you will view the scene from the perspective of a driver in a vehicle. Please sit and hold the steering wheel as if you were driving. The three screens in front of you will provide a wide field of view of approaching intersections. Just before each scene begins you will hear a voice announcing the scene. As soon as the scene begins you will be faced with a decision to either stop or proceed through the approaching intersection. Press the brake pedal to indicate your decision to stop at the intersection. Press the accelerator pedal to indicate your decision to go through the intersection. You will see the scene gradually slow from 30 miles per hour to a stopped position at the intersection, irregardless of your response. Please do not respond until you think you know the correct choice. Incorrect choices will be followed by a loud horn at the end of the scene. The following scene represents a driver making an incorrect choice. Watch this typical intersection scene. (A scene is shown of an incorrect decision, followed by a horn blast).

An additional $10.00 is available to those individuals who finish the intersections within a generous time limit. It is therefore to your benefit to indicate your choice of response to each intersection as soon as you think you are correct. Incorrect choices will result in being given a maximum time score for that particular intersection and hearing a horn blast. You may, however, change your choice of entering or stopping at each intersection by pressing the appropriate pedal at any time before you reach the intersection. You may change your choice as often as you like so continue to study the intersection until it ends. Of course, the longer it takes you to make your final correct choice the closer you will come to passing the maximum time limit allowed to receive the $10.00 bonus. However, the time limit is generous, with most previous participants receiving the bonus.

After your vehicle comes to a stop at the intersection your side screens will go dark. A rating scale with 5 items concerning the intersection will appear on the middle screen for 70 seconds. A voice will ask you to rate the intersection for each of the five items. When the voice pauses for each item you will have 10 seconds to say your response aloud. The response will be tape recorded.

The rating scale will be followed by a 30 second pause, with all three screens empty. Near the end of this 30 second break you will hear a notice that the next scene will soon begin.

This cycle, of intersection scene -- rating scale -- pause, will repeat for each intersection until all intersections have been viewed. This will take approximately 45 minutes.

Before you begin with the actual study scenes, we would like to provide you with 3 practice intersections. Do not worry about remembering all these instructions. By the time you have finished the third practice intersection you will be familiar with the tasks. After the second practice intersection there will be a brief pause for you to ask any questions you may have.

Now lets begin ...(20 second pause)... Practice Intersection Number 1 ... (5 second pause)...

Appendix B

Driver Questionnaire

I. Identification

1. Name: ________________
2. Date of Birth: __________
3. Sex: (circle one) M F
4. Occupation: ___________
5. Level of Education: (check one)

___ did not complete high school
___ completed high school
___ some college
___ completed 4 year degree
___ completed a graduate degree

II. Health Background (General)

6. Height: ____ 7. Weight: ____

8. Overall Health Status: (circle one)

poor below average average above average very good

9. Check any which apply to your current health (within the past year):

___ diabetes
___ high blood pressure
___ respiratory problems
___ general cardiac problems
___ general circulatory problems
___ partial or occasional paralysis
___ recurrent back pain (at least once per month)
___ recurrent headaches (at least once a month)
___ sleep disorder
___ seizures
___ dizziness or loss of balance

Explain briefly, including any medications for the above problems:

____
____
____

III. Vision and Hearing

10. What is your <u>uncorrected</u> vision? 20/____

11. What is your <u>corrected</u> vision? 20/____ (N/A if not corrected)

12. Do you wear: (check each which apply)

___ glasses ...... what percent of the time? ____%

___ contacts ..... what percent of the time? ____%

		Circle	One
13.	Do you need correction to see clearly at a distance?	Yes	No
14.	Do you need correction to see clearly up close?	Yes	No
15.	Do you wear glasses or contacts while driving?	Yes	No
16.	Do you experience problems seeing at night when driving?	Yes	No
17.	Do bright lights bother you when driving at night?	Yes	No
18.	Do you experience color vision problems?	Yes	No
19.	Do you see double images at times?	Yes	No
20.	Do you experience tunnel vision at times?	Yes	No
21.	Do you suffer from glaucoma?	Yes	No
22.	Do you have a problem with cataracts?	Yes	No

23. Describe briefly any changes in visual abilities you have noticed over the years: ______________________________

____

24. Do you experience any hearing loss or related problems? Yes No

If yes, explain: ______________________________

____

25. Do you experience motion sickness when you are a vehicle passenger?

___ always ___ frequently ___ occasionally ___ seldom ___ never

IV. Driving History and Behavior

26. At what age did you receive your <u>first</u> drivers license? ______

27. How many moving traffic violations have you received in the past 5 years? ______ (include any for "driving under the influence")

For what offenses: ______________________________

____

28. Since receiving your first license, in how many traffic accidents have you been the responsible driver?

_____ minor (no injuries requiring emergency medical attention and vehicles are all drivable)

_____ major (either an injury requiring medical attention or at least 1 vehicle requiring towing)

29. Since receiving your first license, in how many traffic accidents have you been the driver <u>not at fault</u>?

_____ minor (no injuries requiring emergency medical attention and vehicles are all drivable)

_____ major (either an injury requiring medical attention or at least 1 vehicle requiring towing)

30. How many miles do you drive in a typical year? ______ miles

31. How many miles do you drive in a typical week on:

-- interstate highways or expressways ______ miles
-- rural roads and highways ______ miles
-- city or neighborhood streets ______ miles

32. Do you drive a personal car as the primary driver (you put at least 50% of the miles on the vehicle)? (circle one)

Yes No

33. How often do you drive at night? (check one)

___ daily
___ several times per week
___ once a week
___ less than once a week, but occasionally
___ never

34. Does your drivers license restrict your driving in any way? (circle one)
Yes No If so, how? ______________________________

35. In what state are you licensed to drive? ______________________

36. What speed do you typically drive on interstate highways, when traffic is light? _____ mph

37. How does your speed in most driving situations compare to that of other drivers? (check one)

___ much slower ___ little slower
___ same ___ little faster ___ much faster

38. What percent of your driving are you alone in the vehicle? ____ percent

39. What percent of time do you wear a seatbelt while driving? ____ percent

40. How uncomfortable are you driving in the conditions below? (circle 1-4)

	Comfortable	Mildly Uncomfortable	Moderately Uncomfortable	Extremely Uncomfortable
Heavy rain	1	2	3	4
Light rain	1	2	3	4
Snow/ice	1	2	3	4
Rush-hour conjestion	1	2	3	4
Familiar country road	1	2	3	4
Unfamiliar country road	1	2	3	4
Local city streets	1	2	3	4
Streets of unfamiliar city	1	2	3	4
Busy intersection	1	2	3	4
Left turn at busy intersection	1	2	3	4
Night driving in city	1	2	3	4
Night driving on expressway	1	2	3	4
Night driving on country road	1	2	3	4

Appendix C

Subjective Rating Scale for Each Intersection

Rate the last road scene by saying your answers aloud,

using the numbers 0 to 6.

0	1	2	3	4	5	6
Substantially Disagree	Moderately Disagree	Perhaps Disagree	Neutral	Perhaps Agree	Moderately Agree	Quite Agree

1. It was **complex**, compared to typical intersections.
2. It was **confusing**, regarding the appropriate action to take.
3. It was safely handled with **a lot of effort**.
4. I felt **anxiety** choosing the correct action to take.
5. I felt **uncertain** that my choice of action was correct.

After the second group of intersections the subjects saw similar slides, except the highlighted words were changed to: simple, clear to understand, very little effort, calm, and certain.

Appendix D

Record of Informed Consent

This form relates to your participation in a research project sponsored by the Federal Highway Administration. Please read the following information and sign below if you give your consent to participate in the study.

Part 46, Subtitle A to Title 45 of the Code of Federal Regulations, relating to the protection of human subjects in research, requires your informed consent for participation in a Federal Highway Administration study. Section 46.103 (c) gives the following definition:

> "Informed consent means the knowing consent of an individual or his legally authorized representative so situated as to be able to exercise free power of choice without undue inducement or any element of force, fraud, deceipt, duress, or any other form of constraint."

The subject matter of this research study concerns driver behavior at intersections. It is being conducted by Monty G. Grubb, under the supervision of Truman Mast, Ph.D., in the Traffic Systems Division of the Federal Highway Administration.

All information collected during the research will be confidential. Only Mr. Grubb will be able to associate your identity with the information collected.

The following events will take place during your participation:

1. You will be given several tests - some related to your visual abilities and others to measure how you mentally process information.

2. You will be asked to fill out a questionnaire which relates to your health and driving history.

3. You will observe video taped scenes of driving situations and be asked to make certain driver responses to the scenes.

4. During your observation of the video tape 3 small electrodes will be taped to your upper body to measure your heart rate. This will be done as discretely as possible.

The study is expected to take 2.5 to 3 hours to complete. You are free to withdraw your consent and discontinue your participation at any time. However, you are strongly encouraged to complete the study.

The study pays 30 dollars (based upon a $10 per hour rate) for completion. In addition, a 10 dollar bonus is available for completion of the video taped scenes within a generous time limit.

Participants electing to terminate participation before all portions of the study are completed will be paid at a rate of 10 dollars per hour (with all participants receiving a minimum of $5).

I hereby agree that the basic elements of the study, described above, have been examined to my satisfaction, and that I consent to participate as a subject in the research.

____
Name (please print)

____
Researcher

____
Signature Date

Appendix E

Analysis of Variance Tables

Analysis of Variance for Pedal Response Errors.

Source	SS	df	MS	F	p	eta^2
Age	0.1101	2	0.0551	8.56	0.0005	0.1893
Gender	0.0343	1	0.0343	5.33	0.0240	0.0590
Inter.	0.0129	2	0.0064	1.00	NS	
Error	0.4243	66	0.0064			
Total	0.5816	71				

Analysis of Variance for Seconds from Intersection.

Source	SS	df	MS	F	p	eta^2
Age	73.1699	2	36.5849	17.27	0.0001	0.3266
Gender	7.9404	1	7.9404	3.75	0.0572	0.0354
Inter.	3.0960	2	1.5480	0.73	NS	
Error	139.8353	66	2.1187			
Total	224.0416	71				

Analysis of Variance for Heart Rate Reactivity.

Source	SS	df	MS	F	p	eta^2
Age	14.4487	2	7.2244	14.04	0.0001	0.2777
Gender	2.4447	1	2.4447	4.75	0.0328	0.0470
Inter.	1.1913	2	0.5956	1.16	NS	
Error	33.9498	66	0.5144			
Total	52.0346	71				

Appendix F

Predictor Variables in First Stepwise Multiple Regression

Age

Gender

Health Status

Number of Traffic Violations in Past Five Years

Total Number of Accidents, Entire Driving History

Relative Speed Typically Driven

Percent of Time Seatbelt Used When Driving

Driver Anxiety in Various Road Conditions

Spielberger Trait Anxiety

Spielberger State Anxiety (Immediately After Simulation)

Field Dependency Score (Embedded Figures Test)

Choice Reaction Time

Processing Reaction Time (Choice minus Simple RT)

Visual Memory (Visual Retention Test, Number Correct)

Visual Memory (Visual Retention Test, Total Errors)

Visual Phoria (Horizontal)

Visual Phoria (Vertical)

Visual Acuity Far (with correction)

Color Vision

Visual Field (based on left visual field score)

Depth Perception (Lafayette Instrument)

Autobiographical Statement

The author, Monty G. Grubb, was born in Salisbury, North Carolina, on December 3, 1950. In 1969 he entered college at East Carolina University, located in Greenville, North Carolina. Here he received an AB degree in 1973, and a MA degree in 1975, both in psychology. Graduation was followed by additional graduate work at the University of North Carolina at Greensboro. From 1976 to 1980 he was employed as a psychologist, for the state of North Carolina, in Kinston, North Carolina. During 1980 to 1982 he worked as a psychologist for Southeastern Mental Health Center, located in Wilmington, North Carolina.

In 1982, Mr. Grubb was admitted to the Doctorate program in Industrial/Organizational Psychology at Old Dominion University, Norfolk, Virginia, where he received the PhD degree in 1987. While persuing the degree, he was involved in research with the Norfolk Bureau of Paramedical Rescue Services, the Navy Personnel Research and Development Center (San Diego), and the Federal Highway Administration (Department of Transportation, Washington, D.C.). As a graduate student, Mr. Grubb received both teaching and university fellowships. In 1985, he was awarded a one year Federal grant to conduct human factors research concerning driver information processing. He has presented papers and produced technical reports on such topics as occupational stress, the benefits of employee fitness programs, techniques of assessing employee performance, and vehicle operator workload.