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INVESTIGATE THE EFFECTS OF DRIVING STRESS ON HEALTH

Final Report

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16. Abstract

This project concerned the relationship between age, cognitive deficits, and driving performance under varying workload conditions. Older and younger subjects were administered a battery of tests designed to assess information processing skills, and personality traits that were thought to underpin driving competence. Subjects then drove through a programmed course on a driving simulator. At different intervals during the drive subjects were required to perform subsidiary tasks of varying levels of difficulty. Dependent variables included measures of driving performance, heartrate measures, and subjective stress measures. Data indicated that workload manipulations affected driving performance, physiological responses and subjective stress indices of both older and younger drivers. The relationship was in many instances mediated by age, cognitive skills, and personality factors.

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METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	2.54	centimeters	cm
ft	feet	0.3048	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	6.452	centimeters squared	cm^2
ft^2	square feet	0.0929	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
mi^2	square miles	2.59	kilometers squared	km^2
ac	acres	0.395	hectares	ha
		MASS (weight)		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		VOLUME		
fl oz	fluid ounces	29.57	millimeters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.0328	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3

Note: Volumes greater than 1000 L shall be shown in m^3.

Symbol	When You Know	Multiply By	To Find	Symbol
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

These factors conform to the requirement of FHWA Order 5190.1A

*SI is the symbol for the International System of Measurements

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
yd	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
yd^2	kilometers squared	0.39	square miles	mi^2
ha	hectares (10,000 m^2)	2.53	acres	ac
		MASS (weight)		
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1000 kg)	1.103	short tons	T
		VOLUME		
mL	millimeters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
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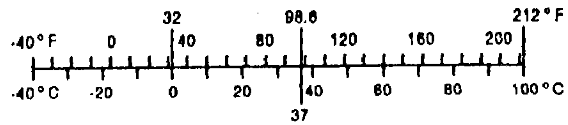

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INTRODUCTION

TRAFFIC CONGESTION

Ground transportation plays a central role in the economic life of every industrialized country. To a large extent, the efficient movement of people, goods, and services depends upon an increasingly intricate system of automobiles, trucks, and roadways. In the United States the utility of this form of transportation has been undergoing continuous and serious degradation as a result of traffic congestion. During the past few decades the increase in traffic congestion has been significant and unprecedented. In 1975, for example, 41 percent of the travel on urban freeways during peak hours occurred under congested conditions; in 1983 that number rose to 55 percent.

Traffic congestion is associated with a number of well documented costs. These include: (1) increased fuel costs, (2) loss of time, (3) monetary losses associated with increased accident rates, and (4) losses to businesses whose clients are discouraged by congestion. In 1987 urban freeway congestion was estimated at 1.2 billion vehicle-hours of delay per year (Lindley, 1987). Vehicle delay on freeways has been predicted to increase by over 400 percent between 1985 and 2005; surface streets are likely to see an increase in vehicle delay of over 200 percent (Maring, et. al., 1987) Approximately 2 billion hour per year are currently wasted in U.S. due to traffic congestion, and it has been estimated that by year 2005 there will be a 500% increase in the number of hours caught in traffic. Projections of current accident rates suggest that there will be one traffic fatality per minute on the world's roads by the turn of the century (Hancock, et.al., 1993).

Intelligent vehicle highway systems

One potential remedy for the traffic congestion problem, advocated by transportation planners in the United States, Europe, and parts of Asia, involves the use of technological innovations which increase the capacity and safety of currently available roadways. These solutions, generically known as IVHS (intelligent vehicle highway systems) or ITS (intelligent transportation systems) rely on technologies which use advanced sensor, computer, communication and control technologies for regulating the flow of vehicles along roads and highways.

One promising method for the reduction of congestion involves improving the route-choosing and route-following techniques used by drivers. The subset of IVHS technologies aimed at this problem are known as ATIS (Advanced Traveler Information Systems) or more simply as Traveler Information systems. They are based on the rationale that a significant proportion of the variance in traffic congestion can be attributed to driver error in route selection and in navigation. One analysis of driver route choices, for example, indicated that errors in trip planning and route following account for approximately 20 percent of total miles driven, and approximately 40 percent of total time spent driving (King, 1986).

Central to many Advanced Traveler Information Systems is the provision of an invehicle computer which is linked to a Traffic Management Center. The intent of onboard navigational devices is to reduce both congestion and the overall burden on the driver by simplifying the process of choosing and following a route. Such systems have the potential to provide the driver with a considerable amount of data including : optimal path from current location to destination, current status of the roadway, current weather conditions, en route advisories, information about roadway incidents, non-traffic related information such as traveler service providers or parking information, current vehicle location, alternate route selection, real time route guidance information, and invehicle signing regarding recommended speeds, notification of an upcoming curve, or warning about incipient hazards.

Simpler ATIS technologies involve the use of variable message signs which can be positioned on the roadway and which can be programmed to update the driver with much of the same information that can be provided via an onboard computer. At this juncture it should be noted that ATIS systems, almost by definition, provide additional information for a driver to process.

IVHS and Information overload.

It is clear that ATIS technology has the potential to substantially increase the information presented to drivers while the driver is simultaneously attempting to navigate and deal with the demands of traffic. This has raised questions for ATIS system designers and for human factors scientists as to whether ATIS systems and displays will overload the driver with information (c.f. Walker et. al., 1990). There is some evidence that even simple tasks can reduce driving ability if they compete for the drivers attention. One study for example, investigated the effect of using cellular telephones on drivers' ability to remain centered in their lane. (Zwahlen et. al, 1988). Subjects were required to enter long-distance telephone numbers while driving. The authors estimated that given 12 ft. lanes, approximately 2 percent of drivers would leave their lane while making a call; given 10 ft lanes, this number would rise to almost 12 percent. The results imply that even this relatively simple and well practiced activity adds sufficiently to the demands of the driving task such that driving performance may be impaired.

As the above example illustrates, onboard systems or variable message signs may compete with other elements of the driving task. Consequently use of a guidance device may impose additional demands which could offset the benefits of assisted navigation. Driving in traffic is a task which inevitably makes substantial demands on the driver's attentional capacity. Drivers are currently confronted with a multitude of traffic control devices displaying regulatory, warning and guidance information. They must maintain the vehicle's position in traffic, monitor controls and instrumentation, observe the actions of other drivers, and sort through a collage of other information and visual distractions while trying to interpret the traffic control messages. For example, on an approach to a freeway interchange, current standards would permit more than thirty separate destination messages on ten separate sign installations within less than two minutes driving time. Drivers cope with this challenge in different ways, ranging from ignoring most of this information to employing unsafe and disruptive driving tactics.

THE RESEARCH PROBLEM

From the drivers standpoint, most ATIS innovations will increase the amount of information that must be processed while driving. Technology such as variable message signs, automated collision warning systems, or -in-vehicle navigation systems have the potential to create information processing problems , especially for drivers with diminished information processing capabilities. The research described below is based on the assumption that ATIS tends to add to the information processing demands of the driving task; and at some level of increase, additional information may cause an unacceptable deterioration in driving safety.

This project explores the relationship between cognitive deficits that occur with age and driving performance under varying workload conditions. Both driving performance and the physiological reactions of younger and older drivers are assessed. The research is designed to yield information concerning the relationship between cognitive skills (or deficits), personality variables, and the ability to function in the complex multi-tasking environment that characterizes driving an automobile. The model that guides this project is depicted in Figure 1 below.

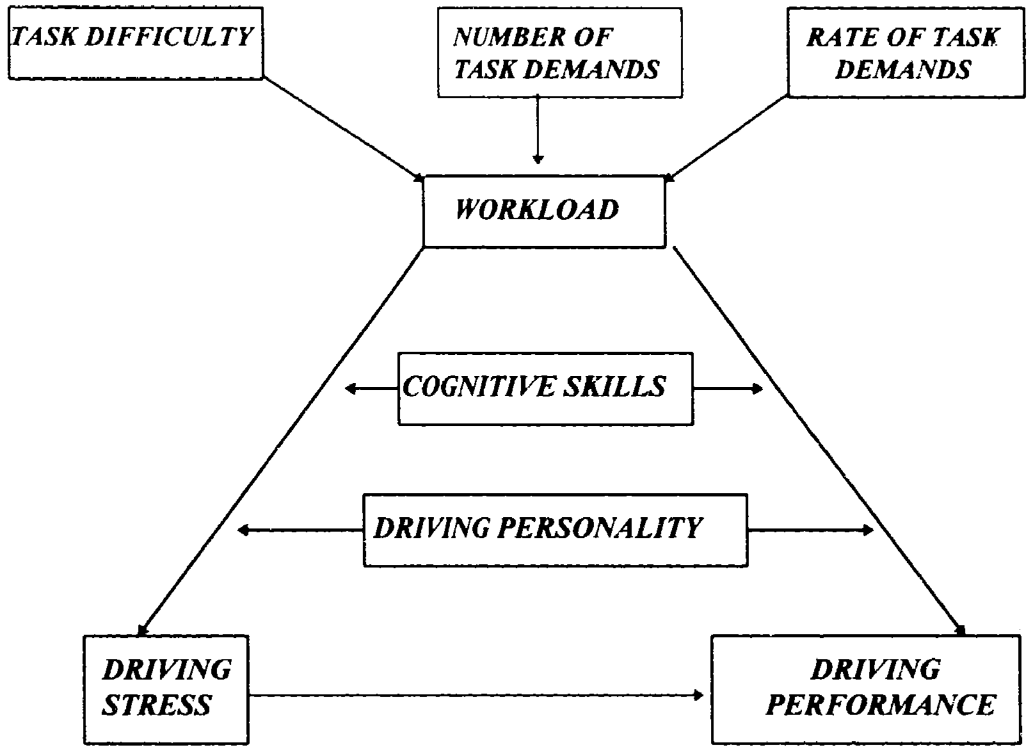

Figure 1. Relationship between Workload, Cognitive skills, Personality, Driving Performance and Driving Stress

The primary focus of this research was to explore the impact of workload variables on driving performance and driving stress in younger and older drivers. There was also a secondary focus to the research. During the past three decades empirical studies have documented perceptual, cognitive, and motoric deficits that accrue with age. During the same period numerous studies have shown that drivers over age 65 tend to incur more driving citations and tend to be involved in more accidents per mile driven than younger drivers. Although it seems reasonable to suppose that the increased risk associated with driving for elderly drivers is in some way related to sensory-cognitive deficits associated with age, research has yet to document any specific linkages between sensory-cognitive deficits and accident history, citation history, or specific driving skill loss (Staplin, et. al., 1990).

OLDER DRIVERS.

The present research compares the performance of elderly drivers with that of younger drivers under varying workload conditions. The elderly are an ideal test population for studying the impact of information overload on driving performance. They constitute a rapidly increasing proportion of the driving population. They are most likely to exhibit sensory and cognitive deficits that would make driving more difficult or more stressful, and they are over-represented in accident data. Any intervention that either helps (or is not detrimental to) the performance of the "worst case" is likely to be advantageous for the entire population.

Aging, cognitive deficits, and driving.

The issue of age and driving competency becomes more pertinent as a result of changing demographics of the driving population. The elderly are the fastest growing segment of society; almost 27 million people or 12% of the U.S. population are over 65 today and the Census Bureau estimates that by the year 2020 almost 18% of the population will be elderly. The elderly are increasingly more likely to depend on the private car for their mobility. Rosenbloom (1993) has shown that the elderly took more trips in a private vehicle in 1990 than they did in 1983 or 1977; over 91% of all trips in rural areas and over 87% of all urban trips by the elderly were taken in a private car in 1990. Further, analyses of long-term demographic trends show that by 2020 almost 75% of the elderly will live in suburban or rural areas where alternatives to the car are non-existent.

The increasing dependence of the elderly on the private car has been associated with a significant increase in the number of elderly men and women with driver's licenses since 1950. Today there are over twenty one million drivers in the U.S. over 65; roughly 94% of men and 75% of women 60-69 have licenses. Since the traditional gap in licensing rates for men and women has largely disappeared for younger cohorts, elderly women in the future will be as likely to drive as elderly men. For example, in 1951-1956 only 8% of women over 70 were licensed to drive; by 1990 70% of women over 70 had licenses.

Given their growing dependence on the car, it is important to question how the elderly fare as drivers, since skill losses and performance decrements often come with age. Most of the literature shows a clear pattern: elderly drivers have *fewer accidents per capita* than younger drivers but far *more accidents per exposure*. These trends generally produce a characteristic U-shaped curve which indicates greater accident involvement by younger and older drivers (Brainn, 1980; TRB 218, 1988, Maleck and Hummer, 1986).

The literature also shows other clear trends: older drivers are far more likely to be involved in multi-vehicle accidents and these accidents are typically caused by failing to yield, turning improperly, or ignoring stop signs and traffic lights (Brainn, 1980; Yanik, 1985; Garber and Srinivasan, 1991). Both North American and European studies show that elderly drivers are more likely to have accidents in intersections, in urban areas, and in daylight and they are more likely to be killed in all accidents (OECD, 1985, Viano, 1990, Evans, 1988, Hauer, 1988). A 1986 Canadian study found that the increase in accident responsibility with increasing age over 65 was almost exponential (Rothe, 1990).

Why do the elderly 1) experience higher accident rates per exposure, and 2) experience certain types of accidents more frequently than younger drivers?

The most important impairments found among elderly people-- those which have the most impact on their ability to manage as drivers result from a decline in the mechanisms of the central nervous system Information processing deficits cause many elderly to respond poorly to new situations and to do poorly when information load is high, when demands are made upon comprehension abilities, or when they are required to integrate symbolic information.

Previous research has recognized the importance of decision- making, judgment, awareness, ability to draw correct inferences from incomplete information, and even personality traits as factors that are related to driver safety. For example, significant correlations have been reported between test-course driving skills and measures of choice reaction time, timed visual discrimination, eye movements during driving, and performance on visual search tasks (Mourant, 1979; Shinar, 1978). Measures that reflect general attention, selective attention, attention-sharing and decision- making, such as choice reaction time and dichotic listening have also been related to driver performance (Kanneman, Ben-Ishae, & Lotan, 1973; Mihal & Barrett, 1976).

Cognitive-perceptual deficits associated with aging have the potential to affect different phases of the driving task and may ultimately explain higher accident rates among the elderly. However, few researchers have examined the relationship between these functional problems and the comprehension of, and response to, complex driving situations.

Researchers who have attempted to link sensory, cognitive, or motor capacity losses to accident rates *have surprisingly found little correlation*. Staplin and Lyles (1991) note that, in spite of numerous documented declines with advancing age in sensory - perceptual skills, cognitive functions, and the speed of psychomotor responses involved in driving, "safety researchers have yet to account for differential accident experience in terms of performance deficits on critical driving tasks." The literature concerning the relationship between impaired vision and older adults' risk for accidents has recently been examined; it was concluded that "research to date has failed to establish a strong link between vision and driving in the elderly (Owsley et al., 1991)."

Age related deficits in simultaneous processing

Although age related deficits in motor performance have been observed for some time, Welford (1985) noted that only three decades ago it was commonly assumed that age differences in performance were due to sensory and motor deficits. He suggested that "it was one of the first tasks and achievements of psychological research on aging to establish that central changes are involved and are often more important than peripheral ones."(p. 339).

The literature indicates that older adults are less able than younger adults to carry out separate cognitive process simultaneously, even in the context of a single task (McDowd, et al., 1991). A representative study in this area by Kay (described by McDowd et al 1991) indicated that older adults perform less well than young adults on a task requiring the subject to switch attention from input to storage to response. Subjects had to press one of a set of twelve keys depending upon which of a set of stimulus lights were illuminated. In conditions of greater difficulty, subjects had to remember and respond to previously presented lights. Older subjects performed as well as younger subjects on the concurrent task, but performed more poorly on the more difficult memory tasks. These results may be interpreted as due to impaired memory processes or as impaired ability to carry out the multiple processes of perception, memory, and response simultaneously.

Measuring cognitive deficits

The research described below was designed to demonstrate a relationship between specific age-related measures of cognitive functioning and driving ability. All subjects were administered a battery of cognitive measures which included: two tests of verbal working memory, one measure of visual working memory, one measure of scanning ability and one measure of higher order reasoning. Three of these tests also yield a measure of cognitive speed. Memory, scanning ability and cognitive speed are known to decline with age.

The research should yield information relevant to the following issues: (1) what deficits in cognitive functioning associated with aging indicate that an individual ought to restrict their driving? (2) what deficits in cognitive functioning indicate that a driver would be challenged by the information processing requirements of ordinary driving? (3) what deficits in cognitive function predict that drivers will be challenged by the information processing requirements of complex, high workload driving situations?

It is essential to develop measures of sensory, cognitive, or motoric ability that strongly predict driving performance. Age, in itself, is a poor predictor variable. Individuals can be found in any age group whose performance on both ability tests and driving tests exceeds the performance of average individuals in any younger age group. Although cognitive impairment in older adults is in not inevitable, 10 to 15 percent of individuals at age 65 have some significant cognitive impairment. Because of the great variability in competence among older age groups, age clearly ought not be used as a criterion for limiting driving. Additionally, humans have the ability to compensate for many sensory, cognitive, or motoric losses. It is thus necessary to discover those sensory-cognitive deficits that are difficult to compensate for and which strongly predict deficient driving performance. Currently, it remains an open question as to what degree of cognitive impairment should restrict or preclude driving (Cushman, 1992).

WORKLOAD

The origin of the concept of workload may be found in the measurement of human capacity to perform physical work. When cognitive and perceptual variables are of interest, the term refers to mental workload. Workload is assumed to increase as demands increase. Common ways to increase workload include increasing the difficulty of tasks, adding, simultaneous tasks, or by adding environmental stressors such as noise. Low to moderate increases in workload may not produce an impact on observable performance, because the operator can compensate by increasing the effort (i.e., devoting a greater share of cognitive resources) expended on the task. At some point however, increases in workload result in decreases in performance, and from that point on additional load results in additional performance decrements.

Controlled vs. Automatic processing.

Shiffrin and Schneider (1977) emphasized the distinction between controlled and automatic processing that is relevant to issues regarding workload and driving. Controlled processing is subjectively more effortful, makes heavier demands on attention capacity, and tends to show little improvement with practice. Automatic processing is relatively effortless, is less affected by capacity limitations, and tends to improve with practice.

Most of the purely psychomotor demands of ordinary driving have been highly practiced and become automatized. Control movements such as steering, braking or manipulating the clutch of an automobile make few demands upon the attentional capacity of experienced drivers.

Under normal driving conditions experienced drivers should have considerable capacity to perform secondary tasks. To the degree that secondary tasks are also automatized (and do not use the same central processing mechanisms as driving) they may not add significantly to workload.

Driving and the parallel versus serial processing distinction.

A great deal of empirical attention has been paid to questions concerning the amount of information that a human can attend to and respond to at any given time. In executing a skill such as driving, cues arising from body (kinesthetic information), from the automobile (control panel information) from the immediate external environment (traffic, pedestrian information) must be integrated with stored experience and with higher-order decision making functions relating to navigation. As noted above driving inherently requires the rapid attention switching between several sources of information, and the simultaneous performance of several tasks (e.g. maintain appropriate speed, avoid obstacles, navigate, maintain car in lane, etc.). Adding additional tasks may overload processing capacity such that neither the driving task or the additional task may be carried out efficiently.

This observation is based on the common view that processing by the human brain, at least with respect to the upper levels of a control hierarchy, consists of routing information through a single channel of limited capacity. When a person is overloaded performance impairments are observed on a primary task, on the secondary task, or on both tasks. The secondary task decrement has been used in the assessment of various stressors, such as noise or fatigue, and has also been used to reveal impairments which would not be apparent in the scores for the main task performed alone.

When the demands imposed by one task become excessive, or when two tasks require the same perceptual, cognitive, or response mechanisms, it becomes impossible to perform the tasks "in parallel". Some sort of serial switching between tasks becomes required. For example, it is possible to simultaneously drive and listen to the radio, but much less possible to drive and read. Since the latter two task both make use of a common visual scanning mechanism, some sort of serial switching back and forth between tasks is required if they are to be performed concurrently.

There are several characteristics that have been found to account for the tactics people use when switching back and forth between two tasks, or between two channels. One characteristic has to do with the statistical properties of the environment. When the environment is rapidly changing, as when a car is driving around a curve, sampling increases and other things being equal, that task is accorded priority. Another property has to do with well know human departures from optimal sampling. When events are quite frequent, humans sample them less often than is optimal, and when they are quite rare, humans sample more frequently than is optimal (Wickens, 1989). Memory factors may also influence attention switching tactics. Consider the case of a driver alternating attention between a forward field of view and the rear view mirror. Part of the decision to sample information from the rearview mirror may depend in part on how well the driver can remember what was seen previously.

Finally, it should be noted that there may be some cost involved in switching from one task to another. There is some switching time necessary to disengage from one task and engage in another. In the case of older drivers, the time required to disengage from the forward field of view, attend to the rear view mirror, interpret what is seen in the mirror and return to monitoring the forward field of view may be excessive (due to losses in attention switching speed). In such instances, monitoring of the rear view mirror (as well as side view mirrors, or in-vehicle displays) may be substantially decreased.

Workload manipulations

Different methods of manipulating workload have been used in empirical studies of the impact of workload on driving competence. The present investigation employs three methods which have been found effective in previous research: (1) task difficulty manipulations, (2) the addition of simultaneous visual tasks, and (3) the addition of simultaneous cognitive tasks. Each loading technique was designed to allow a variable level of difficulty. This created an interactive effect of the individual techniques that yielded a substantial range of workload conditions.

Task Difficulty.

One method of increasing driving workload is to increase the difficulty of vehicle control. Intuitively, maintaining vehicle control is easier on straight roads than on curves, easier when the vehicle is traveling slower as opposed to faster, and easier when lanes are wide as opposed to narrow. The research literature supports such intuitions. For example, on narrow roads, or approaching bridges, the frequency of driver's steering movements increases, presumably to maintain stricter control of the vehicle's position within the lane (Walker et. al., 1990). Road curvature affects vehicle's position within the lane (Walker et. al., 1990). Road curvature affects workload more directly; the sharper the curve, the more corrections per unit time are required to avoid lane encroachment (Noy, 1989).

Simultaneous Visual Tasks.

Events that compete for visual attention increase driving workload. For example, Wierwille et. al. (1987) found that under conditions of high traffic density, drivers tended to increase the proportion of visual attention directed toward the forward view, and to "narrow" the scope of attention to the center of the roadway. High traffic density created a kind of "tunnel vision" by making demands on the drivers' attentional capacity; drivers had little "spare capacity", and thus decreased the frequency with which they checked rear and side view mirrors and glanced at dashboard displays. Noy (1989) conducted an experiment in which subjects drove through a series of curves in a driving simulator; an auxiliary visual search task was presented during the drive. Viewing ratio (percentage of time spent looking at the auxiliary display) was dependent on the sharpness of the curves negotiated (primary task difficulty). Further, driving performance was degraded by the auxiliary task.

Simultaneous Cognitive Tasks

Simultaneous tasks requiring cognitive resources have been used to increase driver workload Several studies have employed numeric tasks such as mental addition tasks in various forms. For example, Brown and Poulton (1961) required "average" drivers and "advanced" drivers with special training to perform simultaneous mental addition tasks while driving a route which included both a residential area and a business district. Task errors increased progressively from residential to business district conditions, and accelerator pedal responses increased under higher load condition. Their results suggested that the numeric task increased workload, and that greater load decreased performance both on the number problems and on the driving task.

Workload measurement

Three general classes of subject responses have been used to empirically measure moment-to-moment or task-to-task variation in workload. These classes include: (1) subjective ratings of effort, stress, annoyance, or work (Damos, 1988), (2) performance-based assessment techniques that are based on the assumption that primary task or secondary task performance declines as workload increases (Jex, 1988; Wickens, 1989), and (3) physiological workload assessment techniques (Meshkati, 1988). Each of these techniques was employed in the present research.

<u>Driving performance measures</u>

Performance-based approaches to workload assessment include primary-task measures and secondary task measures. The fomer assess workload by examining some aspect of the subject's ability to perform a required task. In the present case the primary task involves measures of performance on a driving simulator under varying levels of difficulty, and vary amounts of secondary task load. The assumption is that spare or reserve processing capacity (capacity not demanded by the primary task) can be allocated to the performance of secondary task.

The performance measures used in this study have been demonstrated to be sensitive to workload in published research and in previous research in our laboratory (c.f. Sadalla et.al., 1993). Measures of average lane positioning and variability of lane positioning have been found useful in discriminating workload related to visual attention and psychomotor demand. (Walker, et. al. 1990) Speed measures, such as the deviation from a required speed, or speed variability have also been used successfully (Brown & Poulton, 1961; Wilson & O'Donnell, 1988) and were employed in the present study.

Physiological measures

Physiological indices related to cardiac, eye, and brain function have been employed to assess levels of workload, operator effort, or resource expenditure. There are a number of advantages to the use of physiological measures for assessing workload. One advantage that is especially important in multi-task paradigms is that physiological indices (e.g., measures of heart rate) do not require the operator to consciously generate additional responses. A second advantage that can be important in multi-task environments is that most physiological measures allow for continuous data recording. Multi-task environments can generate rapidly changing workloads that may reach extremely high or extremely low levels depending upon whether the various tasks make concurrent demands upon the subject. Under such conditions it is advantageous to have a continuous measure, rather than a discrete measure which may lack the temporal sensitivity to detect rapid changes in subject response.

Heart rate.

Heart rate measures have frequently been used to assess workload in multi-task settings, most commonly on either flying tasks or simulated flying tasks. Heart rate variables have been shown to distinguish workload levels associated with a variety of flying situations including (c.f. Wilson and Eggemeier 1991): landing, gradient of approach to landing, refueling in the air, using autopilot to land, and flying combat missions. From the standpoint of the current research it is important to note that heart-rate measures have also been shown to be sensitive to simulated flying situations including: simulated instrument landings, normal phases of simulated flight, and learning to fly a simulator.

Heart rate measures have also been used to measure workload in driving contexts. Taggart et al (1969) measured cardiac response to driving in normal subjects, cardiac patients and race car drivers. Normal drivers and cardiac patients both showed transient heart rate increases to various driving events. Helander (1975) showed that hear rate measures reflected driving difficulty. Heart rate and heart rate variability have been shown to reflect small transient changes in driving difficulty on both freeway and surface road situations (Sadalla et al 1993).

Each of the workload measures, as well as loading techniques, are presented in detail in the Methods section of this report.

PERSONALITY FACTORS, DRIVING PERFORMANCE, AND DRIVING STRESS

An extensive body of literature documents substantial individual differences in the response to the same external sources of stress (cf. Sadalla & Hauser, 1991). This literature is based on the dual premises that different individuals are more or less resistant to stress and that these differences in stress resistance may be traced to personality variables (Endler & Edwards, 1982; Prokop, 1991). Some individuals are highly sensitive to external sources of stress and respond both psychologically and physiologically with minimal provocation. Other individuals are relatively stress resistant and show minimal performance losses or physiological reactivity even when under conditions that arouse strong reactions in the average person. Applied to the context of driving, this literature suggests that some individuals should be relatively immune to the stresses and strains imposed by difficult traffic situations, while other individuals might display an extensive stress response to identical driving conditions.

Our conceptualization of driving stress is based on stress models which emphasize that the individual's interpretations of a situation, cognitive skills, and personality traits determine whether that individual will experience the situation as stressful. Personality traits are defined as stable dispositional factors that consistently influence behavior in a variety of situations. In the present research we are concerned with traits that influence behavior in a variety of driving situations

In this research we employ the *Driving Stress Susceptibility* scale (*DSS*). This scales was developed during previous research to identify components of a "driving personality" that are associated with stress responses to particular driving situations. In the present research, the validity of this instrument will be evaluated by correlating subtest scores with the driving performance and physiological responses of drivers to under different workload conditions. The test yields scores on four different personality dimensions: time urgency, risk taking, anger-hostility, and patient-cautious.

Time Urgency

Individuals who are "time urgent" (impatient, in a hurry, on a tight schedule) are likely to be frustrated and stressed by traffic congestion. Time urgency is a central component of a trait known as the Type A personality. The Type A-B distinction has received much attention as a risk factor in coronary disease. Type A men tend to have 2-3 times the rate of heart disease as Type B men who are matched for traditional risk factors (e.g. age, weight, blood cholesterol, blood pressure, etc.). A prototypical Type A individual is time urgent, competitive, highly alert, and easily angered.

Individuals scoring high on the DSS time urgency factor tend to drive fast, accelerate rapidly from stop signs, leave insufficient time to arrive at their destination, etc.. They respond positively to questions such as -"In traffic I change lanes rather than staying in a slow one". This trait defines an individual difference variable that is relevant to the topic of driving stress. Time urgent individuals are likely to drive faster than average, to accelerate and decelerate rapidly, to be practiced at multi-tasking while driving, and to be easily frustrated by traffic delays.

Risk Taking

Individuals scoring high on this factor like to drive, are not easily frightened, and like risk and excitement in the driving situation. The factor includes specific statements about driving ("I'm almost never frightened while driving" or "I think I would enjoy the sensations of driving very fast down a steep mountain road.") and general statements about risk taking and preference for excitement ("I would like to learn to fly an airplane."). Individuals scoring high on this factor should be relatively stress resistant in difficult or dangerous driving situations, but might be stressed by routine or monotonous driving tasks.

Risk taking is a personality trait that is intimately connected with individual differences in chronic levels of arousal. Arousal is a major component of behavior which is characterized by increases in sympathetic nervous system activity, such as increases in heart rate, blood pressure, epinephrine secretions, muscle tension, sweating, and electrical conduction of the skin, breathing rate and pupillary dilation. Individuals scoring high on the risk taking scales tend to seek out and enjoy higher levels of arousal or sensation. Preference for high levels of stimulation is also associated with willingness to take risks and with preference for different and/or unusual complex experiences (Zuckerman, 1983).

Low risk takers tend to be more chronically aroused than are high risk takers, and tend to respond to external stress with greater physiological response. We might therefore expect that low risk takers will be more physiologically reactive than high risk takers under the stressful conditions of high workload.

Anger-Hostility

Evidence that subjective feelings of hostility are associated with increased disease susceptibility has clear implications for the study of driving stress. Hostility is a common emotional reaction while driving. In one study (Turner, Layton, & Simons, 1975) 12% of the men and 18% of the women sampled reported that at times they could "gladly kill another driver." Lesser feelings of hostility are doubtless even more common. Individual differences in hostility reactions while driving are thus likely to predict some of the variance in health reactions to traffic conditions, with drivers who experience more hostility at relatively greater risk. In the context of the present research we expect drivers who score high on this dimension to show greater degrees of physiological reactivity under high workload (frustrating) conditions than will drivers who score low on this dimension.

Patient-Cautious

Individuals scoring high on this factor rarely hurry, dislike speed and dislike other drivers who speed. These drivers change lanes infrequently and tend to drive below the speed limit. These drivers should be relatively stress resistant in most driving contexts. They may, however, prove to be stressed by those situations that require rapid decision making or rapid maneuvering. Although this factor was derived from a factor analysis of data from younger drivers, it is expected that our older driver cohort will score higher on this factor than will the younger drivers. Further, we expect high scores on this trait to be associated with greater performance deficits under high workload divided attention conditions.

METHOD

SUBJECTS

73 voluntary subjects were divided into two groups based on age. Thirty eight subjects ranging in age from 19 to 45 years were classified as the younger sample of drivers, while 35 subjects ranging in age from 58-87 years were classified as the senior sample. The mean age for the senior drivers was 71.81 (SD = 7.44). The mean age for the younger drivers was 24.55 (SD = 5.91). Young drivers were recruited from the Arizona State University campus, and senior drivers were recruited from the Gilbert Senior Center in Gilbert, Arizona. All subjects were licensed and current drivers.

COGNITIVE BATTERY

The cognitive test battery described below was developed to test several aspects of cognitive functioning that are known to be correlated with age and the types of motor performance required for driving. (Sadalla et. al., 1993). Complete subject instructions for each test are given in the Procedure section of this document.

Word Span Test

The word span test represents part one of two tests designed to measure memory capacity. This test consisted of 237 monosyllabic words with a word frequency of at least 10 (Kucera & Francis, 1967). This word frequency was chosen in order to optimize the level of recognizability and familiarity for all words used. The 212 words were then divided into two equal groups (word decks 1 and 2) for the purpose of counterbalancing with the sentence span test described in the following section. Five series of three, four, five, six, and seven words were placed in the center of blank 4 X 6 cards for presentation. A 14 point font was used for printing the words. The subject is required to remember as many words as possible after each series. Words can be recalled in any order with the exception that the last word given is not recalled first.

Sentence Span Test

The sentence span test is part two of two tests designed for measuring working memory capacity. Two-hundred eight unrelated English sentences, 13 to 16 words in length, were placed in the center of blank 4 X 6 index cards. Sentences were one to two lines in length and were printed with a 12 point font. Words selected from the word span test were placed at the end of each sentence following the appropriate punctuation. The cards were arranged in five sets each of 2, 3, 4, 5, and 6 sentences. Blank cards were inserted to mark the beginning and end of each set. Both the Word Span test and the Sentence Span test were constructed based on the work of Daneman & Carpenter (1980, 1983). Subjects are required to recall the terminal words given after each series with the same exception of not giving the last word presented first.

Trail Making Test

The test is given in two parts, A and B. The subject must first draw lines to connect the consecutively numbered circles placed on worksheet A, and then connect the same number of consecutively numbered and lettered circles on worksheet B by alternating between the two sequences. The subject is urged to connect the circles as quickly as possible without lifting the pencil from the paper. Part A of this test consists of 26 consecutively numbered circles appearing in random order on a single page of standard paper. Part B consists of circles containing the letters A through M, and circles containing the numbers 1 through 13 appearing in random order on a single page. This test was originally part of the Army Individual Test Battery.

Digit Symbol Test

The digit symbol test consists of a series of different angular lines (i.e., symbols) separated by boxed enclosures and which correspond to a series of numbered digits (see Appendix C). Because this is a timed test, subjects are given a sample test to orient them to the procedure before beginning. Each subject has 90 seconds to write down the corresponding number for each boxed symbol.

Similarities Test:

This test consists of 15 paired words describing various objects or. Subjects are required to give an explanation regarding how the two words are similar in representation. Correct responses are indicated by the most specific term that represents the salient features of each word. One sample word-pair is given before actual testing and the subject is informed of the correct response. No time limit is imposed for this test.

PERSONALITY BATTERY

Personality traits related to driving were measured by the *Driving Stress Susceptibility (DSS)* scale. This survey measures four traits related to the likelihood that a driver will be stressed by various events encountered while driving. The four factors measured are: (1) time urgency, (2) risk taking, (3) anger - hostility, and (4) patient, cautious driving.

The Driving Stress Susceptibility Scale.

On the following pages you will find a series of statements. Read each statement and decide whether or not it describes you. Then indicate your answer, using the scale below, on the answer sheet provided. Answer every statement even if you are not completely sure of your answer. Please use a #2 pencil to mark your answers.

A. Very much like me

B. Somewhat like me

C. Neither like nor unlike me

D. Somewhat unlike me

E. Very much unlike me

1. In traffic I change lanes rather than staying in a slow one.
2. I prefer being a passenger in a car to driving a car.
3. I would be very angry if my car was stalled at a traffic light and the guy behind me kept blowing his horn.
4. When driving around town I wait until the last minute to leave and therefore must move with haste to avoid being late.
5. I like driving on freeways.
6. If people yell at me while I am driving, I yell back.
7. I would like to drive or ride on a motorcycle.
8. I speed up when two lanes of traffic converge, assuming the people in the other lane will either slow down or keep the same speed.
9. I often worry about being injured in a traffic accident.
10. On a clear freeway, I drive at or a little below the speed limit.
11. I catch myself estimating the number of minutes it will take me to get to my appointment so I can leave at the last minute and still be on time.
12. I'm almost never frightened while driving.
13. I lose my temper easily but get over it quickly while driving.
14. I will run a red light, especially if it has just turned red.
15. I would like to learn to fly an airplane.
16. I would get extremely angry if I needed to get somewhere quickly, but the car in front of me was going 25 mph in a 40 mph zone and I couldn't pass.
17. I change my route of travel on streets depending on whether or not I hit a red light. (i.e., If I come to a red light and I can turn right and go a different route instead of wait through the red light, I will.)
18. I get upset at drivers who do not signal their driving intentions.
19. I prefer drives on unpredictable roads.
20. When a car cuts in front of me, I ease up to give them all the room they need.
21. I feel that speeding vehicles create more of a safety hazard than slow moving vehicles.

22. When I am in a traffic jam and the lane next to mine starts to move, I stay in my lane since I figure that my lane will be moving soon too.
23. If the road is tricky, I would prefer to let someone else drive.
24. I would like to test drive new cars.
25. When a traffic light turns green and the car in front of me doesn't get going, I don't mind waiting for a while until it moves.
26. I am not at all angered when I am driving along at 45 mph and the guy behind me is right on my bumper.
27. I will pass another car on a blind hill or sharp curve.
28. I figure that drivers who follow me too closely are in a hurry, so I give them a chance to pass and go on their way.
29. When I am on a busy freeway, I allow entering vehicles to merge in front of me although I have the right-of-way.
30. I must confess that driving on freeways frightens me.
31. I look at stoplights and try to time my driving so that I won't have to come to a complete stop.
32. I like to try new roads that I have never driven before.
33. I would be furious if I walked out to the parking lot, and I discovered that my car had been towed away by the police.
34. At an intersection where I have to yield the right-of-way to oncoming traffic, I speed up to avoid having to yield.
35. I get extremely irritated when I am traveling behind a slow moving vehicle.
36. I work on something up until the last minute, allowing just enough time to go to the next place where I am headed.
37. I like to make quick departures from stop signs.
38. I ease through yellow lights or edge forward when waiting for a green light.
39. I would not be angry at all if I got in my car to drive to work, and the car wouldn't start.
40. I would like a job which would require a lot of driving.
41. I sometimes like to drive in situations that are a little frightening.
42. I feel that most people drive too fast.
43. I would be very angry if the person whose car is next to mine in the parking lot swung open his door, chipping the paint from my car.
44. I am always patient with other drivers.
45. I think I would enjoy the sensations of driving very fast down a steep mountain road.
46. I am often irritated by slow drivers who don't let me pass them.
47. I believe that the speed limit on freeways and interstate highways should be lowered.
48. I would be furious if someone ripped off my automobile antenna.

APPARATUS

Cardiovascular recording and analysis equipment.

This system consists of a 486 IBM compatible computer with a 400 MB harddrive, laser printer, VGA monitor, cassette tape playback Unit, 2 Turbo Processor Boards, and a Graphics-to Processor Interface Card. The system also includes three portable cardio-holter monitors each capable of recording EKG for up to 24 hours. The monitors are small, may be worn on waist belts, and do not interfere with activities such as driving or flying.

The essential element of the system is the software developed by Motora which is capable of analyzing 14 different parameters of cardiovascular response. This allows the evaluation of cardiovascular response to task situations of either short or long duration. The system is designed to record and analyze physiological stress responses.

Upon arriving at the laboratory each subject was briefed on the nature of the experiment. The subject was then prepared for cardiovascular monitoring. Subsequent to surface skin preparation, 7 silver-chloride disposable electrodes were attached to the skin using a standard chest configuration to collect three channels of electrocardiogram (EKG) activity. The electrodes were fastened to leads which carried their input to a Mortara Instruments PR4 holter recorder. The PR4 is a small device which is strapped around the waist and records the electrical potentials of the heart on a cassette tape for later laboratory analysis.

Each subject's physiological data tape was analyzed on a Mortara Instruments MK5 cardio-holter analysis system. The MK5 digitizes the EKG electrical signal and detects each R-wave. The R-wave is indicative of the hearts ventricular contraction when blood is thrust into the arterial system for circulation. By detecting each R-wave and computing the elapsed time between consecutive R-waves, a beat-to-beat calculation equivalent to instantaneous heart rate is achieved. This measurement is referred to as the interbeat interval (IBI) and is the reciprocal of heart rate (longer IBI's indicate slower heart rate and shorter IBI's indicate faster heart rate).

Depression of an event marker button on the PR4 recorder results in a high frequency pulse being placed on the physiological data tape. The MK5 identified this pulse, enabling the cardiovascular data to be synchronized to the nearest one hundredth of a second with events occurring during the simulated drive.

Driving Simulator

The Systems Technology, Inc. Driving Simulator (version STISIM 5.0) software was run on an IBM PC. STISIM is a PC based interactive simulator designed to represent a range of psychomotor, divided attention and cogntive tasks involved in driving. The simulation includes vehicle dynamics, visual and auditory displays, and a performance measurement system. Driving tasks and events are programmable with a Scenario Definition Language that allows specification of an arbitrary sequence of tasks, events, and performance measurement intervals.

The vehicle dynamics model allows for specifiable steering and speed control characteristics meaningful to the driver. Steering dynamics include understeer which properly changes steering sensitivity as a function of speed. Speed control dynamics consist of an automatic transmission with a specifiable number of gears, throttle acceleration and deceleration limits, and an unstable speed divergence that can be used to set the workload of the speed control task. Auditory feedback is provided for engine speed. Tire limits account for a maximum cornering capacity and stopping deceleration. Auditory screeches are associated with exceeding the tire limits during cornering and braking.

The visual display scene is presented on a conventional 19 inch computer monitor. The visual scene includes a roadway, horizon scene, side view mirrors, intersections, traffic control devices and interacting traffic. The display scene may be specified.

DRIVING SCENARIOS AND TASK STRUCTURE

Driving Segment 1.

Roadway design

Driving segment one was 19,800 feet (3.75 miles) in length. Data collection began at 1100 feet. The drive consisted of 24 equal segments; 12 straight roadways and 12 curved roadways.. Segments 1 - 3 were straight, 4 -7 were curved, 8 - 15 were straight, 16 - 23 were curved, and the final segment 24 was straight. Eighteen "gong" sounds were produced throughout the drive. These occurred in segments 1, 2, 4, 5, 6, 8, 9, 10, 12, 13, 14, 16, 18, 19, 20, 21, 23, and 24.. Each curve was programmed with the following parameters: (1) the curve initially appeared 500 feet away from the subject, (2) the distance from the very start of the curve up to the maximum curvature (i.e., lead-in distance) was 250 feet, (3) the maximum curvature continued for a longitudinal distance of 300 feet, (4) the distance from the end of maximum curvature to the end of the curve (i.e., lead-out distance) was 250 feet, and (5) the maximum curvature used was defined by a circle with a radius of 667 feet..

Attention switching task

The task performed during this segment was designed to explore the subjects' ability to maintain velocity and lane position while performing subsidiary tasks that required looking away from the road. Subjects were instructed to look away from the monitor toward a display immediately to their right whenever cued by a "gong" sound. This display consisted of either a printed word (Stop, Yield, Merge, Hill) or a highway sign-symbol corresponding to these words..

Facsimiles of four roadside signs were constructed from the Arizona Driver License Manual. The signs employed were: Stop, Yield, Merge, and Hill. Signs were approximately 4" by 4" in size. The names of the signs, whether printed below the sign or appearing without the sign, were printed in a 48 point font. In a practice phase each subject was familiarized with the sign-symbols, so there was no ambiguity concerning the meaning of each unlabeled sign.

This task consisted of three levels of difficulty, each of which was compared to a control condition. In the control condition subjects simply looked toward the display board, but did not make a response. Condition 1 (identification) simply required subjects to identify the sign or to read the printed word. In Condition 2 (same format) the subject was presented with either two sign-symbols, or two words, and had to state whether or not they referred to the same sign. Subjects were instructed to respond "match" or "no match." In Condition 3 (different format) subjects were presented with a printed word and a sign-symbol and had to state whether or not they referred to the same sign.

Conditions 1,2, and 3 represent increasing levels of task difficulty. Condition 1 simply required subjects to decipher a single sign or printed word. Condition 2 simply required a comparison of two symbols or two words. Because condition 3 required subjects to decipher and compare the meaning of two different symbols, it should make the most demands on central processing mechanism.

Driving Segment 2: Low Workload

Driving segment 2, was 26,500 feet (5 miles) in length. A total of 18 signs (9 target saying *Rightville* and 9 non-targets were displayed throughout the course of the drive. A total of eight "low-difficulty" mathematical questions were asked at approximately every third sign. Four symbols (left or right triangle and left or right horn) appeared in either the left or right "rear-view window" on the upper side of the computer screen. Subjects were instructed to signal in the appropriate direction with the turn signal on the driving simulator when they saw one of the four symbols. If the target sign "Rightville" appeared, they were instructed to push the green horn bottom on the simulator as quickly as possible.

Low workload was defined as a drive which consisted of turns with minimal curvature (turns defined by a circle with a radius of 1111 feet). The roadside signs that subjects had to respond to whenever they saw the word "Rightville" had only one word. The simultaneous math problems were easy single digit problems.

Driving Segment 3: Moderate workload.

Segment three was identical to segment two except for the following: (1) the curves were tighter (defined by a circle with a radius of 667 feet), (2) the roadside signs had two words on them, requiring more reading before a response could be made, and (3) the simultaneous math problems were more difficult.

Driving Segment 4: High workload

Segment four was identical to segment three except for the following: (1) the curves were tighter (defined by a circle with a radius of 500 feet), (2) the roadside signs had four words on them requiring more reading before a response could be made, and (3) the simultaneous math problems were the most difficult.

Driving Segment 5: Sustained attention task

Segment five consisted of a ten minute drive on a straight road. The segment contained one low difficulty curve and one sign. The sign did require subjects to respond. The purpose of this segment was to explore subjects ability to remain vigilant and to concentrate on driving when there were few task demands.

DEPENDENT VARIABLES

Two classes of dependent variables were employed in this study: physiological measures of workload and measures of driving performance. The driving performance variables are described in the results section below. The principal method for assessing driving workload or driving stress involved measuring the cardiovascular reaction of drivers to different driving segments programmed on the driving simulator.

Interbeat interval and heart rate variability.

The Mortara Instruments MK5 cardio-holter analysis system was used to generate a record of cardiovascular response for each subject. The MK5 digitized the EKG electrical signal for each R-wave. The R-wave is indicative of the heart's ventricular contraction when blood is thrust into the arterial system for circulation. By detecting each R-wave and computing the elapsed time between consecutive R-waves, a beat to beat calculation equivalent to instantaneous heart rate was achieved. This measurement was referred to as the interbeat interval (IBI) and is the reciprocal of heart rate (longer IBI's indicated slower heart rate and shorter IBI's indicated faster heart rates).

Depression of an event marker button on the PR4 recorder resulted in a high frequency pulse being placed on the physiological data tape. The MK5 identified this pulse, enabling the cardiovascular data to be synchronized to the nearest one one-hundredth of a second. As a result, data files were constructed which contained corresponding mean IBI's and calculations of heart rate (HR) variability for each measure (e.g., divided attention task, accuracy and speed of response of roadside signs) contained within each of the five driving segments.

PROCEDURE

Subjects participated in two one-hour sessions on two consecutive days; day A and day B. Day A referred to subjects participation in completing the cognitive test battery and Day B referred to subject participation on the driving simulator including physiological monitoring. Subjects were randomly assigned to day A or day B.

Day A:

On day A subjects completed the cognitive test battery and the Driving Stress Susceptibility Scale. In addition, demographic information and driving histories were obtained.

DAY B

EKG set up

On the second day of participation, the experimenter presented a brief overview of what was to take place during this phase of the experiment. Subjects were then taken to a partitioned area and asked to remove the top portion of their clothing for an electrocardiogram (EKG) placement. A standard 3-channel hook-up was used with electrode stress loops taped to the subject.. All electrode sites were placed over bone, as much as possible, to prevent muscle artifact noise.

Driving simulation practice phase

After subject's were seated at the simulator, the experimenter checked to make sure that the accelerator and brake were at an appropriate distance for subject comfort. Each relevant aspect of the simulator (e.g., turn signal, green button for divided attention task, horn, etc.) was identified for the subject and they were asked to point, or touch, each object and repeat the name.

Subjects were informed that they would be given a practice run before the actual test. There were four parts to the practice run, similar to the actual test, and each with somewhat different instructions. The practice run was administered in order to have each subject as familiar with the operation of the simulator as possible The first part of the practice drive was a straight section of roadway. Subjects were told to get a "feel" for how the simulator responds to the movement of the steering wheel and pressing on the accelerator. They were told to drive in the right lane just as they would in everyday driving, and to try and keep their speed at 45 miles per hour throughout the entire drive. During this straight section, a plane, with a printed banner saying "STRAIGHT" appeared on the screen. Subjects were informed that the plane would reappear during the course of the drive indicating a change in roadway conditions and/or experimental instructions. A curved section of roadway appeared next prompted by the banner "CURVES". Subjects were told to continue driving in the right lane and prompted to keep their speed up to 45 miles per hour. When the third banner, "GONGS" appeared, subjects were told to turn their head to the right and look away from the screen each time they heard a "gong" sound from the simulator and to maintain speed and position. The fourth banner, "SIGNS" was followed by the instructions to look for signs along the roadway while driving. If a sign said "Rightville" the subject was told to press the green button on the simulator as quickly as possible while maintaining speed and position. If a sign appeared, but did not say "Rightville" they were told NOT to press the green button. Subjects were corrected as needed on each of five signs that appeared during the course of the practice simulation, and prompted to maintain their speed and lane position as necessary. There was a six minute rest period between the practice run and the actual driving simulator testing. This was done in order to return the subject to a baseline heart rate and to prevent any residual physiological effects from being included in data collection for the actual testing.

Driving simulation test phase

The actual testing phase on the driving simulator was comprised of a total of five driving segments. Subject numbers were programmed into the simulator prior to driving. The order of driving runs 2 through 4 was randomly assigned by the computer. Driving segment 1 was always first; driving segment 5 was always last.

RESULTS AND DISCUSSION

DATA REDUCTION AND PREPARATION

Measurement of Driving Performance

The STI driving simulator recorded 14 driving performance variables every tenth of a second. Six measures were dropped from this analysis because their mean or variability values were essentially zero. The remaining eight variables which were subjected to analysis included: mean and variability of acceleration, mean and variability of lateral lane position, mean and variability of speed, and mean and variability of steering wheel position. Acceleration was measured in g's, lateral lane position was measured relative to the center-point of the roadway, speed was measured in feet per second, and steering wheel position in terms of degrees.

__Factor analysis of driving performance variables.__

A principal components factor analysis with oblique rotation was conducted on the eight driving performance variables; data from the low workload driving segment was used in this analysis. Examination of the scree plot suggested that a four factor solution was appropriate. Factor score coefficients were generated using the regression method for each of the three driving stress levels. Factor score coefficients were used to create four composite indices of driving performance. The factor scores and the components of each composite variable are depicted in Table 1 below.

	Speed Variability	**Position Variability**	**Absolute Speed**	**Absolute Position**
Acceleration Mean	**.318**	**.039**	**-.204**	**-.016**
Acceleration Variability	**.359**	**-.168**	**.160**	**.014**
Lane Position Mean	**-.005**	**-.009**	**-.001**	**.998**
Lane Position Variability	**.004**	**.527**	**-.086**	**.039**
Speed Mean	**-.088**	**-.019**	**- .724**	**-.002**
Speed Variability	**.357**	**.127**	**.140**	**.004**
Steering Mean	**-.194**	**.020**	**.351**	**.000**
Steering Variability	**.048**	**.573**	**.116**	**-.026**

Table 1. Factor Score Coefficients Used to Create Driving Performance Composites

The primary components of Factor 1, the *Speed Variability* composite, are acceleration mean, acceleration variance, and speed variance. The primary components of Factor 2, the *Position Variability* composite, are variability of lateral lane position and steering variability. The third factor, *Absolute Speed*, is defined largely by a single dependent variable, average speed, and the negative sign for this coefficient implies that this measure is reverse scored (high numbers indicate slow speeds). Similarly, the fourth factor, *Absolute Position*, is also defined primarily by a single dependent variable, the mean of lateral lane position.

Measurement of Cognitive Abilities

Scores on the five cognitive tests (word span, sentence span, digit symbol, trails test, and similarities test) were submitted to a principal components analysis with oblique rotation for the purpose of creating a smaller number of composite cognitive measures. Examination of the scree plot indicated that a three factor solution would be appropriate, and thus three factor scores were generated for each subject using the regression method. The factor score coefficients used to create these composites are depicted in Table 2 below.

	Verbal Working Memory	**Visual Scanning Ability**	**Fluid Intelligence**
Word Span	**.610**	**.091**	**-.066**
Sentence Span	**.520**	**-.093**	**.088**
Digit Symbol	**-.005**	**-.631**	**.043**
Trails Test	**.023**	**.526**	**.046**
Similarities	**-.007**	**.009**	**-.999**

Table 2. Factor Score Coefficients Used to Create Cognitive Ability Composites

The first composite, *Verbal Working Memory*, consists mainly of the two linguistic memory span tasks. The second composite combines the digit symbol and trails tests into a measure which we have labeled *Visual Scanning Ability*. This is a complex skill that involves the ability to remember a target and to rapidly find that target from among a set of foils or distractors. It should be noted that these tests reward rapid responses and that numerically high scores on this composite variable indicate low levels of ability. The third composite, *Fluid*

Intelligence, is essentially a reconstruction of normalized scores on the similarities subscale of the Wechsler Adult Intelligence Scale (WAIS).

Measurement of Subjective Stress

Responses to the four questions about perceived levels of stress during the driving task were analyzed using a principal components technique with oblique rotation to examine the underlying factor structure. The scree plot suggested a two factor solution, and factor scores were computed using the regression method. The factor score coefficients used to generate these composites are given in Table 3 below.

	Driving Stress	**Driving Annoyance**
Annoyance	**-.030**	**.938**
Difficulty	**.293**	**.231**
Pressure	**.390**	**-.054**
Stress	**.417**	**-.130**

Table 3. Factor Score Coefficients Used to Create Subjective Stress Composites

The first composite combines the task difficulty, pressure, and stress items into a single general measure of self-reported stress in the driving task. The second measure is primarily an indicator of annoyance with the driving task.

Age, Cognitive Deficits, and Driving Stress Susceptibility

The forty-eight items of the *Driving Stress Susceptibility Scale* were divided into four subscale scores. These subscale scores were generated by forming simple averages of four sets of item scores as suggested by factor analyses in prior studies (c.f. Sadalla, et. al., 1993). The four subscales measure *Time Urgency*, *Anger*, *Risk Taking*, and *Patient-Cautious* behavior, and in the driving situation.

In order to facilitate analysis, scores on the cognitive and personality variables were ranked and sorted into high, moderate, and low categories for each measure. Cross-tabulation of age by these cognitive and personality variable levels revealed that in six of the seven cases, the distribution of scores was not identical for the older and younger age groups. In general, the older cohort tended to have disproportionately large numbers of individuals in:

(1) the lower cognitive span categories (Chi-$Square_2$=15.40, p<.001),

(2) the poorer visual scanning ability categories (Chi-$Square_2$= 46.000, p<.001),

(3) the lower anger categories (Chi-$Square_2$=11.689, p<.01),

(4) the higher patient-cautious categories (Chi-$Square_2$=16.756, p<.001),

(5) the lower time urgency categories (Chi-$Square_2$=20.244, p<.001).

The cell frequencies depicting these relationships are presented in Tables 4, 5, 6, 7, and 8 below.

	Under 45	Over 65
Low Working Memory Scores	**5**	**19**
Mod Working Memory Scores	**18**	**17**
High Working Memory Scores	**16**	**8**

Table 4. Age and working memory ability. Cell entries refer to number of subjects in each age and ability category.

	Under 45	Over 65
High visual scanning ability	**23**	**1**
Mod visual scanning ability	**16**	**9**
Low visual scanning ability	**0**	**24**

Table 5. Age and visual scanning ability. Cell entries refer to number of subjects in each age and ability category.

	Under 45	Over 65
Low Anger Scale scores	6	18
Moderate Anger Scale scores	15	8
High Anger Scale scores	18	8

Table 6. Age and score on the Anger subscale of the DSS. Cell entries refer to number of subjects in each age and personality type category.

	Under 45	Over 65
Low scores on Patient-Cautious	22	4
Moderate scores on Patient-Cautious	10	13
High scores on Patient-Cautious	7	17

Table 7. Age and score on the Patient-Cautious subscale of the DSS. Cell entries refer to number of subjects in each age and personality type category.

	Under 45	Over 65
Low Time Urgency Scores	4	19
Moderate Time Urgency Scores	16	11
High Time Urgency Scores	19	4

Table 8. Age and score on the Time Urgency Subscale of the DSS. Cell entries refer to number of subjects in each age and personality type category.

Because of the selection of age ranges in this study, general regressions of age on cognitive and personality variables would not be able to accurately determine the effect of age on such variables beyond the grouping effect. Regressions *within* each age group show no significant effects of age on cognitive and personality variables except in the case of visual scanning ability. For this composite, there is no significant effect of age in the young cohort, but there is a positive association between such scores and age in the older cohort ($b=.048$, $t_{30}=2.21$, $p<.05$). This indicates that, in the group of individuals over age 65, increasing age is related to decreases in visual scanning ability.

WORKLOAD MANIPULATION

Three simulated driving segments were created specifically to involve different levels of driver workload. Workload was manipulated in three different ways: number and sharpness of curves, amount of material to be scanned on roadside signs, and difficulty of math problems presented aurally to the driver during the drives. The low workload condition had 6 curves of where the maximum curvature was defined by a circle with a radius of 1111 feet. The medium workload condition had 10 curves of where the maximum curvature was defined by a circle with a radius of 667 feet, and the high workload condition had 18 curves whose maximum curvature was defined by a circle of 500 feet. Thus the higher workload conditions had more curves and contained curves which required more extensive turning of the vehicle.

Information on roadside signs.

The amount of information on roadside signs varied with workload condition. Subjects were required to read signs which appeared onscreen alongside the road and to respond by touching a horn button if they saw a roadsign that said "Rightville." Signs were designed to resemble freeway offramp signs. In the low workload condition, only one name was on each sign. In the medium and high workload conditions, each sign listed 2 and 4 city names respectively.

Simultaneous Math Problems.

Subjects were also required to respond to math problems that were presented during the driving task. The difficulty of these problems varied according to workload condition. The math problems that were read aloud to the driver involved either subtracting multiples of 10 (low workload condition), subtraction of two numbers that did not involve "borrowing" (medium workload condition), and subtraction involving "borrowing" (high workload condition).

Workload manipulation checks.

Self-reported stress levels.

The workload manipulations described above were found to affect the self-reported stress levels of subjects. The self-reported *driving stress* composite and the *driving annoyance* composite were subjected to repeated measures ANOVA with Helmert contrasts. Results (depicted in Tables 9 and 10 below) indicated that Stress and Annoyance were higher in the two higher workload conditions than in the low workload condition, $t_{72} = -10.82$, $p < .001$ and $t_{72} = -7\text{-}87$, $p < .001$. Also, stress and annoyance were higher in the high workload condition than in the medium workload condition, $t_{72} = -7.98$, $p < .001$ and $t_{72} = -5.74$, $p < .001$.

	Mean	S. D.
Workload 1	**.00**	**1.00**
Workload 2	**.46**	**.96**
Workload 3	**1.34**	**1.14**

Table 9. Effect of Workload on driving stress. $F_{2,71} = 75.42$, $p < .000$

	Mean	S. D.
Workload 1	.00	1.00
Workload 2	.37	.95
Workload 3	1.00	1.20

Table 10. Effect of Workload on Driving Annoyance $F_{2,71} = 39.26$, $p < .000$

These results clearly indicate that the workload manipulation affected the subjective experience of stress.

Physiological assessment of workload

A repeated measures ANOVA was conducted for each of the 2 indicators of physiological stress. The within subject factor, workload, was highly significant for the heart rate variable, $F_{2,68} = 6.57$, $p< .01$. It was found that only 1 of the 2 contrasts (testing the difference between Workload 3 vs. Workload 2) was significant in this case. The 754.10 mean interbeat interval (IBI) in the high workload condition was smaller than the 764.10 mean IBI in the moderate workload condition. Means and standard deviations of IBI for each workload condition are depicted in Table 11 below.

	Mean	S. D.
Workload 1	763.1	138.1
Workload 2	764.1	146.3
Workload 3	754.1	142.4

Table 11. Effect of workload on mean interbeat interval (reciprocal of heartrate).

Data from Table 11 indicate that heart rate varied with changes in workload. Increasing workload from condition 2 to condition 3 significantly increased heart rate. No differences in heart rate variability were found in the different workload conditions.

Performance on roadside sign task.

Reaction times in response to the target word for the three conditions were analyzed using a repeated measures analysis of variance with Helmert contrasts. The overall effect of workload was significant, and the contrasts revealed that reactions were significantly faster in the low workload condition than in the medium and high workload conditions ($t_{72} = -8.29$, $p < .001$). Reaction times were also faster in the medium than in the high workload condition ($t_{72} = -3.85$, $p < .001$).

A similar type of repeated measures ANOVA was performed on the number of target signs missed and the number of non-target signs responded to in each workload condition. There were more "misses" and "false alarms" in the medium and high workload conditions than in the low workload condition ($t_{72} = -3.27$ and -2.98, p's < .01. There were also more "misses" and "false alarms" in the high workload condition than in the medium workload condition ($t_{72} = -2.74$ and -2.60, p's < .01 and .05, respectively). Table 12 below presents the means and standard deviations of these variables.

Variable	Low Workload		Medium Workload		High Workload	
	Mean	SD	Mean	SD	Mean	SD
Reaction Time	3.62	1.45	3.99	1.38	4.24	1.43
Misses	0.26	1.14	0.34	1.19	0.64	1.29
False Alarms	0.08	0.32	0.18	0.48	0.36	0.65
# Math Problems Correct	7.07	1.36	6.15	1.81	3.89	2.19

Table 12. Means and Standard Deviations of Visual Search and Math Problem Variables for Different Workload Conditions.

__Performance on Math Problems.__

A repeated measures ANOVA with Helmert contrasts was performed on the number of math problems answered correctly (out of a possible 8) in each of the three workload conditions. More math problems were answered correctly in the low workload condition than in the two higher workload conditions ($t_{72} = 11.13$, $p < .001$). Also, more math problems were answered correctly in the medium workload condition than in the high workload condition ($t_{72} = 10.24$, $p < .001$).

DRIVING PERFORMANCE

Workload manipulations and driving performance

The data obtained from the driving simulator task indicated that higher levels of workload are associated with more variability of position in lane, better average position in lane (lane centering), less variability in speed, and slower absolute speeds. The means for the composites scores (reflecting speed variability, position variability, absolute speed, and absolute position) in each of the three workload levels are reported in Table 13 below. The composites were created such that the lowest stress condition would have a mean of zero and a variability of 1. Therefore, the means and variances of conditions 2 and 3 are judged relative to condition 1.

	Speed Variability		Position Variability		Absolute Speed		Absolute Position	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Low Workload	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00
Medium Workload	-3.21	1.12	2.15	1.34	6.35	1.27	-0.06	0.96
High Workload	-1.30	1.22	7.13	2.18	3.73	1.27	-0.26	0.91

Table 13. Means and Standard Deviations of Driving Performance Composites for Different Workload Conditions

A repeated measures ANOVA with Helmert contrasts was conducted for each of the four composite driving performance measures: absolute speed, variability of speed, absolute lane position, and variability of lane position.. In all four cases, the overall effect was highly significant (for variability of position, $F_{2,71} = 864.01$, $p <.001$; for absolute position, $F_{2,71}=298.25$, $p<.001$; for variability of speed, $F_{2,71} = 584.72$, $p < .001$; and for absolute speed, $F_{2,71}= 715.44$, $p <.001$)

The data displayed in Table 13 also indicate that there was more variability of road position in the moderate and high workload conditions than in the low workload condition, and there was more variability in the high than in the moderate workload condition. Secondly, the average absolute speed was slower in the moderate and high workload conditions than in the low workload condition, and average absolute speed was slower in the high than the moderate workload condition.

In contrast to the data on variability of lane position, workload manipulations appeared to decrease speed variability. There was less speed variability in the moderate and high workload conditions than in the low workload condition; there was, however, more speed variability in the high than in the moderate workload condition.

Divided attention task difficulty and driving performance

The difficulty of the divided visual attention task imposed during segment 1 of the drive was expected to influence driving performance. As noted in the introduction, driving inherently requires the rapid attention switching between several sources of information, and the simultaneous performance of several tasks (e.g. maintain appropriate speed, avoid obstacles, navigate, maintain car in lane, etc.). Adding additional tasks may overload processing capacity such that neither the driving task or the additional task may be carried out efficiently. The simultaneous visual attention task was expected to be disruptive because it uses the same central processing visual mechanisms as does driving, and at higher levels of difficulty also requires the use of decision making mechanisms. This manipulation also most closely simulates ATIS technologies and their potential impact on driving performance.

When a driver is overloaded with information, driving performance may be impaired, secondary task performance (in this case the ability to read and comprehend incoming information), may be impaired, or both may be impaired. In the present study the difficulty of the secondary divided visual attention task, was found to affect driving speed,. variability of driving speed, lane centering, and variability of lane centering.

Driving speed

There was a main effect of straight versus curved roads; subjects drove more slowly on curved roads than on straight roads ($F_{1,72}=687$, $p< .000$). There was a main effect of secondary task demands ($F_{3,70}=1086.89$, $p<.000$). There was also a significant interaction between secondary tasks and the straight versus curved road condition ($F_{3,70}=6525.75$, $p<.000$).

When subjects performed tasks that made considerable demands on their visual attentional capacity (same format and different format conditions) while driving on curves, they drove slower than when they performed the same tasks while driving on straight roads ($t=-62.30$, $p<.001$) This finding indicates that the attentional demands of driving on a curved road interacted with the attentional demands of performing the secondary task. Table 14 below depicts the impact of the simultaneous visual attention task on driving speed.

Roadway shape	control Mean SD	identification Mean SD	same format Mean SD	different format Mean SD
straight	13.45 (.75)	1.58 (1.78)	-9.18 (1.59)	2.34 (1.47)
curved	-.81 (1.04)	-4.21 (1.70)	16.69 (1.11)	7.89 (1.68)

Table 14. Means and standard deviations of absolute speed for different experimental conditions. High numbers indicate slower speeds.

Speed variability

We also expected that the attentional demands of a secondary task would impair subjects' ability to maintain speed control. This hypothesis was supported by the data. The experimental manipulations of straight vs. curved roads, and different types of secondary tasks influenced the variability of driving speed. Table 15 below depicts the means and standard deviations for speed variability.

Roadway shape	control Mean SD	identification Mean SD	same format Mean SD	different format Mean SD
straight	-7.39 (.86)	-.60 (.72)	5.08 (.79)	-1.24 (1.18)
curved	.41 (.72)	2.68 (1.93)	-8.99 (1.57)	-4.29 (1.44)

Table 15. Means and standard deviations of speed variability for different experimental conditions.

Speed variability can be thought of as due to two factors. Subjects vary speed because of inattention. Therefore when their attention is diverted by a secondary task, we expect to see increased deviation from prescribed speed and more speed variability. On the other hand, speed variability is also due to error correction. Subjects who constantly readjust their speed to match the speed limit will show more speed variability then will subjects who maintain a constant but inappropriate speed.

Our data indicate that there was a main effect of straight versus curved roads ($F_{1,72}$=313.31, p <.000), a main effect of secondary task ($F_{3,70}$=466.92, p< .000), and a significant interaction ($F_{3,70}$=6680.41, p<.000). Under control conditions there was less speed variability on straight sections of roadway than there was on curved sections of roadway. However, when subjects were confronted with secondary tasks, the relationship changed.

There was less variability of speed under control conditions than under the combined attention switching conditions (t=-27.82, p<.001). Within the attention switching conditions, there was more speed variability in the identification tasks than in the matching tasks (t=28.59, p<.001), and there was more speed variability when the matching task involved the same format than when it involved different formats (t=10.14, p<.001). The interaction between secondary task demands and straight versus curved roadways was in part due to the fact the combination of roadway curvature and highest task demands produced very little speed variability (t=49.77, p<.001), possibly indicating an inability on the part of overloaded drivers to make error corrections.

__Variability of lane position__

Variability of lane position was also expected to vary as a function of the difficulty of the secondary task. Mean and standard deviation for this variable under different experimental conditions are presented in table 16 below.

Roadway shape	control Mean SD	identification Mean SD	same format Mean SD	different format Mean SD
straight	1.69 (0.86)	1.90 (1.44)	0.83 (0.97)	1.71 (1.17)
curved	2.54 (1.02)	1.53 (1.12)	3.61 (1.12)	2.69 (1.57)

Table 16. Mean and standard deviations of variability of lane position under varying conditions of roadway shape and simultaneous task difficulty.

There was a main effect of task ($F_{3,70}$=23.06, p<.001) which was due to the fact that there is more variability of position in a combination of the same and different format matching tasks than in the identification task (t=-7.33, p<.001), indicating that increased attention switching demands may require larger amounts of position correction when attention returns to the roadway. There is a main effect of roadway curvature ($F_{1,72}$=546.45, p<.001) such that there is more variability of position on curves than on straight-aways. Additionally, these two variables interact with each other ($F_{3,70}$=565.17). The difference in position variability between the identification task and a combination of the same and different format matching tasks only occurred on curved sections of roadway (t=-20.33, p<.001).

Absolute lane position

The difficulty of the divided visual attention task was expected to influence the subjects' ability to maintain the vehicles position in the center of the lane. Means and standard deviations for absolute lane position, as a function of roadway shape and the difficulty of the secondary task, are presented in table 17.

Roadway shape	control Mean	control SD	identification Mean	identification SD	same format Mean	same format SD	different format Mean	different format SD
straight	.09	(.03)	.06	(.04)	.05	(.02)	.06	(.03)
curved	.01	(.04)	.05	(.04)	.04	(.04)	.05	(.03)

Table 17. Mean and standard deviation of absolute position within the lane under varying conditions of roadway shape and simultaneous task difficulty.

There was a main effect of task ($F_{3,70}$=21.25, p<.001). This was due to better lane centering in the identification condition than in the combination of same and different format matching conditions ($t=3.33$, $p<.01$) and better lane centering in the different format condition than in the same format condition ($t=-7.19$, $p<.001$). There is also a main effect of roadway curvature ($F_{1,72}=-17.45$) which indicates better lane centering on straight than on curved sections of roadway. Finally, these variables interact with each other ($F_{3,70}=417.85$, $p<.001$) to show that the effects of straight vs. curved sections of roadway are due primarily to differences in the control (no attention switching) condition.

Personality and driving performance

Only one personality subscale had a significant effect on driving performance. The Time urgency subscale was related to both variability of speed and absolute speed. Those who scored high on time urgency showed less variability of speed and had higher average speeds overall.

Self-reported stress and driving performance

Results indicated that those individuals who experienced greater amounts of driving annoyance had more variability of roadway position than those who experienced smaller amounts of annoyance. Those individuals who experienced greater amounts of driving stress had more variability of road way position and slower absolute speeds than those who experienced smaller amounts of stress.

In separate analyses, absolute position, variability of position, absolute speed and variability of speed were regressed on the driving annoyance and driving stress composites. The unstandardized beta weight associated with driving annoyance in the variability of position analysis was significant at the .001 level ($b = 1.23$, $t_{217}=6.66$). Similarly, the beta weight associated with driving stress in an analysis of roadway position variability was also significant at the .001 level ($b = 1.45$, $t_{217}=8.59$). The effect of driving stress on absolute speed was also found to be significant in a regression analysis ($b = 0.47$, $t_{217}=2.83$, $p < .01$). It should be noted that this analysis does not take into account the repeated measures information in the data set and treats the repeated observations as independent.

Cognitive deficits and driving performance

<u>Verbal short-term memory</u>

Low scores on cognitive span (a composite score reflecting performance on two measures of short-term memory for words) were associated with poorer driving performance. Subjects with poorer short-term memory were less able to maintain position within the lane (they show more variation in lane position). The MANOVA indicated a main effect of cognitive span ($F_{2,70}=5.00$, $p<.01$) on lane position variability. The means for variability of lane position by cognitive span were:

Cogspan score	**Lane position variability**
Low	**2.59**
Medium	**1.71**
High	**1.91**

Table 18. Relationship between Cogspan score (a composite measure of short-term memory for words) and lane position variability. High scores indicate greater variability.

<u>Visual scanning ability</u>

The data also indicated that visual scanning ability (performance on the Trails Test and the Digit Symbol Task) affects a number of driving performance variables. There was a main effect of visual scanning ability on variability of speed ($F_{2,70}=4.27$, $p<.05$); speed became less variable as visual search ability improved.

Cognitive deficits, task difficulty and driving performance

There was an interaction between the composite measure of verbal short term memory and task difficulty which predicts variability of lane positioning ($F_{6,134}$=2.20, p<.05). Individuals with poor short term memory for words show more variability of position under conditions that demand visual search and attention switching. Subjects with better short-term memory show less variability of lane position when performing simultaneous visual search tasks. The means indicating variability of lane positioning in different experimental conditions are displayed in table 19 below.

CogSpan Score	Roadway Shape	Control	Identification	Same format	Different format
Low	Straight	2.15	2.43	1.35	2.33
Low	Curved	2.87	1.87	4.16	3.54
Medium	Straight	1.38	1.54	0.53	1.30
Medium	Curved	2.24	1.21	3.26	2.23
High	Straight	1.56	1.74	0.63	1.51
High	Curved	2.52	1.53	3.43	2.32

Table 19. Effect of short-term memory ability and roadway curvature on variability of lane position under different types of divided attention tasks. High scores indicate more variability of lane positioning.

THE EFFECTS OF AGE

Age and driving performance

Age group was a significant predictor of absolute speed and of speed variability. The data indicated that older drivers tended to drive more slowly through our tasks than did younger drivers ($F_{1,71}$=12.87, p<.001), and the older drivers maintained a steadier speed (i.e., they show less speed variability) than did the younger drivers ($F_{1,71}$=14.25, p<.001). Older drivers also showed more position variability than did younger drivers ($F_{1,71}$=22.06 , p<.001).

Age, task demands, and driving performance

As noted above there was a main effect of age on driving speed; older drivers tended to drive more slowly than younger drivers. In addition, there was a main effect of task demands on driving speed. All subjects tended to drive more slowly as task demands increased. Further, the relationship between age and driving speed was found to interact with task demands ($F_{3,69}$=5.24, p<.01. As task demands increased, older subjects tended to slow down more than did younger subjects.

Age, task demands, and cardiovascular response

Both younger and older subjects showed an increase in heartrate (a decrease in interbeat interval) as task demands increased. The data analysis indicated a three way interaction between age, task, and roadway curvature ($F_{3,66}$=5.72, p<.01). Heartrate increased in the attention switching conditions relative to the control conditions on curved roadways, and this effect was greater for younger subjects than it was for older subjects. This finding replicates previous studies of cardiovascular response to driving situations (cf. Sadalla, et. al., 1993) which indicate that older drivers show *less* cardiovascular response to driving events than do young subjects.

less

ANALYSIS OF CARDIOVASCULAR DATA

Workload, divided attention task demands and cardiovascular response

Our data indicated that both roadway shape and the difficulty of a simultaneous visual task produced changes in heart rate. Table 20 below presents mean interbeat interval for different experimental conditions.

Roadway shape	control Mean	control SD	identification Mean	identification SD	same format Mean	same format SD	different format Mean	different format SD
straight	765.26	140.68	737.30	141.85	762.38	139.68	767.20	140.26
curved	768.61	139.27	758.75	138.34	756.65	138.13	758.84	140.66

Table 20. Means and standard deviations of interbeat interval for different experimental conditions. High numbers indicate slower heartrate.

There was a main effect of type of task ($F_{3,67}$=18.85, p<.001). This was due to the fact that interbeat intervals are longer (heart rate is slower) in the control condition than in a combination of the three attention switching conditions (t=$_{6.92}$, p < .001). Further, interbeat intervals are shorter (heart rate is faster) in the same format condition than in the different format condition (t=-3.58, p < .001). There is also a main effect of roadway curvature ($F_{1,69}$=26.12, p<.001) such that interbeat intervals are shorter (heart rates are faster) on curved than on straight sections of roadway. Additionally, these two variables interact with each other ($F_{3,67}$=12.49, p <.001). The interaction is due to the fact that interbeat intervals get shorter with increasing task demand only on curved sections of roadway (t=6.05, p<.001).

Cognitive abilities, task demands, and cardiovascular response

Visual scanning ability (measured by the Trails Test and the Digit Symbol Test) interacted with task demands and road curvature to influence heart rate. Subjects with poorer ability tended to show higher heart-rates under conditions where the roadway was curved and the secondary task demands were high. The data indicated a three way interaction between measures of visual scanning ability, task demands, and road curvature for interbeat interval ($F_{6,128}$=2.53, p<.05). No difference between control and attention switching conditions were found for straight sections of roadway. On curves however, interbeat intervals are shorter (heartrates are higher) in the attention switching conditions than in the control condition, and this difference becomes more pronounced with decreases in visual scanning ability. Heart rate means reflecting this interaction are displayed in table 21 below.

Visual Scanning Score	Roadway Shape	Control	Identification	Same Matching	Different Matching
Low	Straight	729.5	734.7	730.3	735.1
Low	Curved	739.4	726.5	722.5	727.2
Medium	Straight	762.2	761.9	758.3	762.2
Medium	Curved	765.6	754.9	752.3	752.1
High	Straight	806.1	807.5	800.6	806.5
High	Curved	802.5	796.8	797.4	799.6

Table 21. The effect of attention switching ability, roadway curvature, and difficulty of the divided attention task on mean interbeat interval (reciprocal of heartrate). High scores indicate longer interbeat intervals and lower heartrates.

Personality and cardiovascular reactions to workload.

ANOVAs performed on cardiovascular data revealed an effect of time urgency on the length of interbeat intervals ($F_{2,67}$=3.11, p=.051). Both the linear and quadratic contrasts were significant (for the linear effect, t=2.24, $p<.05$; for the quadratic effect, t=-2.04, $p<.05$), indicating that, in general, IBI decreases (heart rate increases) as time urgency increases; however, those individuals in the "moderate" time urgency category had the shortest IBIs (fastest heart rates). Data are displayed in table 22 below.

Time urgency score	Interbeat interval mean
Low time urgent	813.83
Mod Time urgent	715.30
High Time urgent	755.91

Table 22. Relationship between time urgency score on the DSS and interbeat interval mean.

Personality, task demands, and cardiovascular response

Measures of Time Urgency from the DSS interacted with task demands and roadway curvature to produce an effect on subjects' heartrates. Subjects scoring high on the Time Urgency subscale of the DSS displayed an increased heartrate under conditions of high task demands and curved roadways. No differences were found for straight roadway conditions. Data are displayed in table 23 below.

Time Urgency Score	Roadway Shape	Control	Identification	Same format	Different format
Low	Straight	821.9	824.8	812.6	821.0
Low	Curved	818.9	815.9	809.6	813.6
Medium	Straight	719.3	720.6	719.2	723.1
Medium	Curved	723.1	711.6	712.9	714.6
High	Straight	758.3	760.3	759.0	761.1
High	Curved	767.9	752.5	751.0	751.9

Table 23. The effect of time urgency (measured by the DSS), roadway curvature, and difficulty of the divided attention task on mean interbeat interval (reciprocal of heartrate). High scores indicate longer interbeat intervals and lower heartrates.

PERSONALITY TRAITS AND SELF REPORTED STRESS LEVELS

Four subscales were created from the 48 DSS items based on factor analyses conducted in previous research. These subscale scores were divided into low, medium, and high categories, and these were entered as predictor variables in repeated measures ANOVAs of the two self-reported stress composites. Two personality trait dimensions, measured by the "patient-cautious" and risk-taking" subscales of the DSS were found to be related to subjective experiences of stress and annoyance. Those individuals who scored high on the " patient-cautious" subscale of the DSS scored lower on the driving annoyance component of the subjective stress measure than did those who scored low on this subscale. Individuals who scored high on the risk subscale experienced less driving stress than those who scored high.

The main effect of the slow, patient, cautious subscale was significant for driving annoyance, $F_{70,2} = 3.40$, $p < .05$. The main effect of the risk subscale was significant for driving stress, $F_{70,2} = 4.51$, $p < .05$. Means are depicted in tables 24 and 25 below.

DSS subscale score	Driving annoyance
Low Patient- Cautious Score	0.81
Moderate Patient- Cautious Score	0.15
High Patient- Cautious Score	0.37

Table 24. Mean scores on driving annoyance measures for subjects scoring low, moderate and high on the Patient-Cautious subscale of the DSS.

DSS risk taking score	Driving stress
Low Risk-Taking Score	**1.00**
Mod Risk-Taking Score	**0.56**
High Risk-Taking Score	**0.28**

Table 25. Mean scores on driving stress measures for subjects scoring low, moderate and high on the risk taking subscale of the DSS.

SUSTAINED ATTENTION TASK

A number of the results reported below were generated in the context of a series of factorial ANOVAs with one between subjects age, cognitive ability, or personality variable crossed with a within subjects "segment" factor. The segment factor had three levels (designated 1, 2, and 3) which followed each other sequentially in time. These were represented by a series of two Helmert contrasts (segment 1 vs. the average of segments 2 and 3, and segment 2 vs. segment 3). The between subjects variables with more than 2 levels were represented by two orthogonal polynomial contrasts (linear and quadratic).

Age and driving performance under sustained attention conditions

T-tests performed on driving performance measures averaged over the entire sustained attention driving segment showed no age effects. However, this type of analysis suffers from a lack of power due to large inter-subject variability. Analyses that systematically remove such variance (analyses involving within-subject factors) are superior in this regard. Main effects of age on two driving performance variables did emerge from a within-subject x between subject analysis involving comparisons between 3 different segments of the sustained attention task (as described above). It was found that older individuals showed more variability of position than younger individuals ($F_{1,71}$=12.83, p<.01), and the older drivers tended to drive through the sustained attention task more slowly than younger drivers ($F_{1,71}$=4.95, p<.05). Means for the two age cohorts for these two driving performance variables are provided in table 26 below.

Driver Age	Variability of Position	Absolute Speed
Under 45	-1.00	-0.62
Over 65	-0.76	-1.05

Table 26. Driver age, variability of position, and absolute speed under sustained attention conditions.

Cognitive abilities and cardiovascular response under sustained attention conditions

No effects of cognitive ability variables were found in a series of between subjects ANOVAs, but a main effect of fluid intelligence (similarities subscale score) was found in the higher powered context of a within x between subjects analysis. This effect showed that higher levels of fluid intelligence were associated with higher amounts of variability in interbeat intervals.

Score on Similarities subscale	Interbeat interval variability
High Fluid Intelligence	9262.61
Mod Fluid Intelligence	3736.12
Low Fluid Intelligence	2472.96

Table 27. Relationship between fluid intelligence and heart rate variability during sustained task.

Personality traits and cardiovascular response under sustained attention conditions

A between subjects ANOVA revealed an effect of time urgency on the average length of the interbeat interval, $F_{2,67}$=3.28, p<.05. In general, interbeat intervals were shorter (heart rates were higher) for those individuals with higher levels of time urgency, but the shortest interbeat intervals (fastest heart rates) were found for those subjects in the moderate time urgency category.

DSS time urgency score	Interbeat interval mean
Low time urgency	830.35
Mod time urgency	735.40
High time urgency	769.49

Table 28. Time urgency and interbeat interval means under sustained attention conditions.

Time and driving performance under sustained attention conditions.

The sustained attention task consisted of a (rather monotonous) straight drive with no distractions that lasted approximately 10 minutes. One question of interest involves whether subjects will show decrements in performance (due to inattention) over time. In order to explore this question three segments of the sustained attention task were selected for comparison. These were ordered according to time (i.e., segment 1 occurred earlier in the drive than segment 2, and segment 2 occurred earlier in the drive than segment 3). Analysis of this within subjects variable revealed no differences in any of the 4 driving performance measures across the three segments. Moreover, no interactions between the segment variable and any of the age, cognitive, or personality variables emerged.

METHODOLOGICAL ISSUES.

The results obtained in the present research must be qualified in relation to several aspects of the research design. First, it should be noted that the driving task employed in this study was simulated. Simulator performance is likely to be different from real world driving performance because the consequences of a mistake are dramatically different.. Further, driving the simulator is a substantially different psychomotor task than is driving a real car (for example, subjects are likely to drive off the road more frequently in one hour of simulator performance than they would in a lifetime of driving). The simulator employed in this study employed a standard 14" monitor and thus presented a dramatically reduced field of view. No navigational tasks were required of the subject, which further reduced the complexity of the task.

Second, the subjects in the study were under intense scrutiny while driving. The experimenter sat next to the subject during all phases of the driving task leading to the possibility that demand characteristics influenced subject's driving behavior. The extent to which results obtained under such conditions would generalize to normal driving are unclear. It is likely, for example, that subjects showed less tendency to speed, or to vary speed than they would under normal driving conditions. It seems likely that the difference between older and younger subjects in driving speed would be greater in real world conditions than was observed in this study.

A related topic concerns the fact that drivers were hooked-up to a cardiovascular recording apparatus. The physical impact of having electrodes attached to the chest, and the psychological impact of knowing that one's cardiovascular system was being carefully monitored may easily have affected driving performance, physiological stress reactions, or both.

Third, neither the younger drivers nor the older drivers who served as subjects in this study constitute a random sample drawn from the driving population. The younger subjects were primarily college students who volunteered for the study in exchange for extra credit in a college course. They therefore should represent the upper range of both cognitive ability and conscientiousness. The older drivers were volunteers from the Gilbert Senior Citizens Center. It was our impression that the older subjects who volunteered were more confident of both their mental skills and their driving ability than were members of the Senior Citizens Center who did not volunteer. The older subjects may have been more cognitively competent, more curious, more adventurous and less conservative than the general older population.

SUMMARY AND CONCLUSIONS

The data obtained in this study generally supported the model depicted (c.f. Figure 1) in the introduction to this report. Increases in driver workload (by making the roadway more difficult and by adding simultaneous tasks) affected the driving performance, the physiological responses, and the subjective stress estimates of both older and younger subjects. Workload, driving performance, and stress reactions were interrelated, and the relationship was in some cases mediated by cognitive skills and personality factors.

Workload.

The most important effects of workload concerned the impact on driving performance. High workload conditions were associated with poorer lane positioning and slower speeds. When the workload manipulation involved a task that required subjects to briefly look away from the monitor, driving speed decreased, speed variability increased, lane positioning was degraded, and variability of lane positioning increased. These results clearly have implications for ATIS systems that employ in-vehicle computers and computer monitors. Since the magnitude of this effect was a function of the difficulty of the divided attention task, the precise impact of a given ATIS invention cannot be estimated. The present research suggests, however, that devices that require a driver to remove eyes from the road and process information, will tend to degrade driving performance.

Cardiovascular reactions.

Both roadway shape (number and radius of curves) and the difficulty of a simultaneous task influenced the cardiovascular reactions of subjects. Increasing the difficulty of the driving task or of the simultaneous task increased heart rate. It should be noted however, that these increases were small in scale. No subjects in this experiment experienced tachycardia, or any exaggerated physiological stress reaction. We did find that the cardiovascular system responds to changes in mental workload in a predicable way and may be used as an indirect measure of workload level.

It is important to note that that the hypothesized relationship between cardiovascular stress reactions and driving performance was *not* observed in this study. Cardiovascular data did not predict any of the driving performance variables. The most plausible explanation of this (absence of a relationship) is noted above. The levels of cardiovascular activation observed in this study were too low to have a disruptive effect. Whether such small changes in cardiac response would be observed in a real world study of driving and divided attention (with substantially different consequences for making an error), requires further research.

Cognitive abilities interacted with task demands to produce an impact on subjects' cardiovascular response. Under conditions of high task difficulty, subjects with poor visual scanning abilities showed higher heart rates than did subjects with good visual scanning ability. This finding highlights the importance of measures of visual scanning ability in the multi-task environment of driving. Subjects with good visual scanning skills are able to rapidly search a visual domain and to identify targets within that domain. This skill should allow increased awareness of the driving situation, and more reserve capacity to perform subsidiary tasks. If the secondary tasks require looking away from the roadway and back again, subjects with good visual scanning skills should be less stressed by the task. Our data generally support these hypotheses.

Time urgency was also associated with cardiac response. Subjects who scored high on the time urgency subscale of the DSS displayed an increased heartrate under conditions of high workload (the combination of curved roadways and difficult secondary task demands). This finding is consonant with literature that suggest that time urgent individuals have a greater tendency to respond to external stress with increased cardiac output (cf. Sadalla, et. al., 1993).

Driving performance

As noted above workload manipulations had the most significant impact on driving performance. Driving performance was also affected, however, by personality factors, self reported stress levels, and by cognitive skills/deficits. The time urgency subscale was related to both variability of speed and absolute speed. Those who scored high on time urgency showed less variability of speed and higher speeds overall. Subjects who reported higher levels of driving annoyance and driving stress showed poorer lane positioning and slower overall speeds than did subjects who were not annoyed or stressed. It is noteworthy here that the subjective stress indices were more predictive of driving performance than were the more objective physiological indices.

Verbal short term memory and visual scanning ability also influenced driving performance. Subjects with good short term memory showed less variation in lane positioning; subjects with good visual scanning ability showed better ability to maintain speed control. Measures of short-term memory interacted with task difficulty to affect variability of lane positioning. Subjects with cognitive deficits in this area showed more variability of lane positioning under high task difficulty conditions than did subjects with good short term memory.

The effect of age

In general, older subjects drove more slowly and displayed more position variability than did younger drivers. They also tended to maintain a steadier speed than did younger drivers. When faced with the additional demands of subsidiary tasks, older drivers tended to slow down significantly more than did younger drivers. Interestingly, older subjects showed less cardiovascular response to difficult driving conditions than did younger subjects; they appear to be less physiologically labile than the younger cohort. The relationship between task difficulty, cardiovascular output, and task performance in older subjects clearly merits further study.

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