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HUMAN FACTORS IN IVHS: AGE, DRIVING STRESS AND HEALTH

Final Report

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16. Abstract

This project consisted of three distinct empirical studies of the human and environmental factors that produce driving stress. The first investigation attempted to quantify individual differences in driver personality traits that make a driver more or less stress resistant. A psychometric methodology isolated four independent traits: time urgency, risk taking, hostility- anger, and cautiousness.

The second investigation explored the relationship between age related cognitive deficits and driving performance among a group of elderly drivers. Age related declines in information processing ability may affect an elderly driver's ability to deal with either typical traffic situations, or with IVHS innovations, or both. The research indicated that a measure of attention switching ability, and a cognitive inference- reading comprehension test predict driving ability in elderly subjects.

The third investigation consisted of a study of driver workload. The cardiovascular responses of drivers were measured under various real-world driving environments. The goal was to begin to provide a human factors perspective of surface street and freeway driving environments that can be used to shape the design and implementation of IVHS interventions. Phasic cardiovascular responses were found to detect workload changes that distinguish surface roads and freeways, amount of traffic congestion on freeways, and the impact of various "driving events" that occur during freeway driving.

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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.

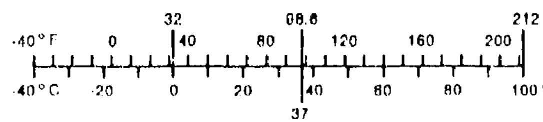
Symbol	When You Know	Multiply By	To Find	Symbol
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

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
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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SECTION 1 PERSONALITY AND DRIVING STRESS: CONSTRUCTION OF THE DRIVING STRESS SUSCEPTIBILITY SCALE (DSS)

I. INTRODUCTION

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 psychological and physiological perturbations 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 transactional stress models which emphasize that the individual's perceptions and interpretations of a situation determine whether that individual will experience the situation as stressful. Such interpretations are influenced by a number of factors, including specific personality traits of the individual. 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.

ne central objective of the current project involved the development of a psychometric instrument specifically designed to measure resistance to driving stress. The available literature indicates that existing measures of personality traits will only weakly predict individual differences in drivers' stress responses to traffic situations. We found that it was possible, however, to use available tests as models for the development of an instrument specifically designed to predict the degree to which a given individual would be resistant to the stress imposed by driving. We have called this instrument the *Driver Stress Susceptibility* scale (DSS).

The *DSS* is based on the assumption that resistance to driving stress is a individual difference variable that is specific to the stresses imposed by driving. It is not designed to predict response to stress in non-driving contexts; it should, however, be much more powerful than existing instruments in predicting stress responses to driving situations. The technical literature in the area of personality assessment indicates that relationships between personality variables and stress responses in a specific situation are strongest when the specific items that are used to measure the personality variable are written in such a way as to refer to the context in which the stress response will be measured.

The *DSS* was constructed using conventional test construction procedures. An item pool was generated based upon concepts suggested by existing instruments. That item pool was administered to a representative subject sample. Factor analytic procedures were employed to evaluate the dimensionality of the instrument and to insure high item-subscale correlations.

II. METHOD

A. Phase I: Generation and Analysis of Item Pool

A review of the general literature on the relationship between personality traits and stress was conducted in order to identify existing personality scales that could be adapted to our driving context. A number of personality traits were considered, including locus of control, sensation seeking, risk taking, Type A-B behavior, and anger/hostility. A preliminary version of the *DSS* was based upon items drawn from the following scales. Item content was modified whenever necessary to make the question relevant to the context of driving.

1. Sensation Seeking.

The Sensation Seeking Scale (Zuckerman, 1983) consists of 72 items designed to measure an individual's thrill and adventure seeking, experience seeking, disinhibition, boredom susceptibility, and general sensation seeking propensity. Individuals scoring high on this scale tend to be risk takers, adventurous, and tend to be more stress resistant than individuals scoring low on the scale. Questions from Form 4 of Zuckerman's Sensation Seeking Scale were selected and rewritten to refer to the driving situation (e.g. "I sometimes like to drive in situations that are a little frightening" or "I prefer drives on unpredictable roads"). Other questions from this instrument were left unchanged (e.g. "I would like to learn to fly an airplane").

2. Time Urgency: Type A Personality.

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. These traits characterize individuals who are likely to be competent drivers, but ones who are easily frustrated by delays.

The *Time Urgency and Perpetual Activation Scale* by Logan Wright and S. McCurdy measures several aspects of the Type A personality with a series of multiple choice questions. A number of these questions refer specifically to the driving ituation (e.g. -"In traffic I change lanes rather than staying in a slow one"). These driving-related questions were selected for inclusion in our instrument. Items from the *Behaviors in Traffic Questionnaire* (BIT), an adaptation of general Type A traits to the driving situation were also selected for inclusion on the *DSS*.

3. Hostility.

Questions from the *Buss-Durkee Hostility Inventory* were specifically adapted to the driving situation (usually with the simple addition of the phrase "while driving"). For example, the item "I lose my temper easily but get over it quickly" was changed to "I lose my temper quickly but get over it easily while driving." Hostility has been characterized both as a component of the Type A personality, and as an important variable in its own right. Individuals scoring high on hostility inventories tend to be easily stressed, and tend to have more stress related llnesses than do individuals scoring low on such inventories.

4. Risk Taking.

Questions from the *Willingness to Risk Questionnaire, Form A*, which specifically related to driving were selected for inclusion on the *DSS*. The format these questions (please circle (N)ever, (S)eldom, or (F)requently) required some minor revision to make them consistent with the ultiple response format of the other items on the DSS.

5. Anger.

Items from the *Novaco Anger Scale* that specifically related to driving were selected and rewritten to conform to the multiple respose format of the rest of the *DSS*. Such questions included items that measure the general tendency to become angry ("I lose my temper easily but get over it quickly while driving" or "When I drive I often feel like a powder keg ready to explode.") as well as anger in specific driving situations ("If someone annoys me while driving, I am likely to tell him what I think of him.").

6. Locus of control

Question from the Nowicki-Strickland *Adult Locus of Control* scale were adapted to a driving context. Such items included "When you successfully avoid an accident it is mostly luck" and "How well you do on a driving test depends on how much you prepare for it." Individuals who score high on a Locus of Control dimension ("Internals") tend to believe that they are responsible for events that happen to them. Individuals scoring low ("Externals") tend to attribute outcomes to chance or to luck. Generally, the literature indicates that Internals are significantly more stress resistant than are Externals.

In all, 125 questions were included on the first forn of the *Driving Stress Susceptibility* scale . These were all phrased so that they could be answered with one of three different five-point scales. One scale involved frequency responses and was anchored by "Almost always/Very frequently" and "Never." A second scale involved attitude assessments and was anchored by "Strongly agree" and "Strongly disagree." The third scale involved judgements of similarity of the self to general "I" statements and was anchored by "Very much like me" and "Very much unlike me."

B. Subjects.

542 students served as subjects in Phase 1 of this study.

C. Data Analysis.

The resultant data was submitted to an exploratory factor analysis. Factor analytic procedures included *Varimax* and *Promax*, with both orthogonal and oblique solutions.

III. RESULTS

A. *Phase 1: Principal Axis Factoring.*

Analysis with principal axis factoring and oblique rotation revealed a four factor structure. Examination of the items that loaded significantly on each factor allowed interpretation of this structure.

Factor 1 was labelled *Time Urgency*. A number of the items from the *BIT* and the *Time Urgency and Perpetual Activation Scale* loaded significantly on this factor. Individuals scoring high on this factor tend to drive fast, accelerate rapidly from stop signs, leave insufficient time to arrive at their destination, etc. Factor 1 designates individuals who would be easily stressed by traffic delays.

Factor 2 is a *Sensation Seeking-Risk Taking* dimension. 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.

Factor 3 is composed of questions pertaining to *hostility* and *anger* in driving situations and includes items from the Novaco scale and the Buss-Durkee hostility inventory. Individuals scoring high on this factor should be easily easily angered by a variety of driving situations. Since recurrent anger is a strong risk factor for a variety of stress related illnesses, individuals scoring high on this dimension should be epeatedly stressed by the driving situation.

Factor 4 seems to be a "*slow, patient, cautious*" factor. 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.

The use of an oblique solution resulted in significantly correlated factors. Table 1 below displays the degree to which each factor is correlated with other factors.

Factors	Factor 2	Factor 3	Factor 4
Factor 1 Time Urgency	.31	.36	-.13
Factor 2 Sensation Seeking		-.01	-.24
Factor 3 Anger, Hostility			-.18
Factor 4 Slow, cautious driver			

Table 1. Interfactor Correlations for the *Driving Stress Susceptibility* scale

Table 2 displays the percentage of total variance in subject responses that is uniquely accounted for by each factor.

Factor 1 Time Urgency	Factor 2 Sensation Seeking	Factor 3 Hostility	Factor 4 Slow, Cautious Driver
11.89	9.97	9.24	5.60

Table 2. Variance explained by each factor ignoring other factors

B. Phase II: Confirmatory Factor Analysis

Items for the four factors that emerged from the intitial exploratory analysis were selected and refined for inclusion in the second form of the instrument. Twelve items were retained for each factor. The decision to retain or drop a specific item was based on the magnitude of the item's loading on the factor, its subjective "fit," and its importance to the concept represented by the factor.

This revised instrument was administered to 530 individuals for purposes of confirming the four factor structure. The subject population was broadened in this confirmatory analysis; it included individuals older than those typical of an undergraduate population.

Preliminary analyses of this data indicate that the model fits adequately. The full set of analyses has yet to be completed. Information on respondents age and sex was collected along with the item responses in this testing wave, so it will be possible to see if the same measurement structure holds for males and females and for older and younger subjects. Invariance across these group distinctions will increase our confidence in the assertion that we have identified separate and distinct personality traits that exist both in our subject population and in the general population.

Initial and confirmatory factor analyses have yielded the following 48 item inventory:

C. *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 discribes 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.

IV. DISCUSSION

A. Factor 1: Time Urgency and The Type A-B Distinction.

The Western Collaborative Group Study, directed by Rosenman and Friedman, was the first longitudinal study to examine the relationship between behavior patterns and heart disease (Rosenman, Brand, Jenkins, Friedman, Straus, & Wurm, 1975). This line of research is important to the study of stress and driving because it highlights a personality disposition that (theoretically) causes different individuals to respond differently under stressful conditions. One commonly held position is that Type A behaviors may create and/or exacerbate stressful situations which in turn trigger physiological stress responses. If Type A individuals were found to have increased levels of stress in their lives, they could experience with more frequency, intensity, or duration, the hemodynamic and biochemical fluctuations associated with the physiological stress response. These fluctuations in turn could eventually result in physiological strain or damage.

Central to the list of behavioral characteristics Friedman and Rosenman used as indicators of Type A personality are "a consistent preoccupation with time and a sense of time urgency," and "intense concentration and alertness".

The Western Collaborative Group Study (1975) showed that heart attack victims displayed high levels of ambition, time urgency, loud and accelerated speech, and free floating hostility. The overall results showed that the Type A behavior pattern, assessed in healthy persons, was a significant predictor of coronary risk. Type A's were twice as likely as Type B's to develop coronary heart disease. From coronary arteriography, it was determined that Type A's had more severe levels of arteriosclerosis, possibly from the physiological responses associated with the Type A behavior pattern.

1. Hot reactors.

It has been widely reported that not all Type A individuals are at increased risk for coronary heart disease as a result of their behavior (Shekelle et al., 1985). Indeed some Type A individuals seem to thrive while manifesting behaviors related to time urgency, competitiveness, achievement orientation, and hostility. It has recently been speculated that Type A behavior exerts its harmful effects when combined with increased physiological reactivity.

Buell (1984) has suggested the term "hot reactors" to describe individuals who respond to physical or psychological stress with unusually high levels of physiological response. An early prospective study (Keys, Taylor, Blackburn, Brozek, Anderson, & Simonson, 1971) indicated that increases in diastolic blood pressure (characteristic of "hot reactors") predicted the appearance of coronary disease during a 23-year follow-up period. A more recent study (Sime, Buell, & Eliot, 1980) demonstrated that among individuals who have heart attacks, those who were hot reactors were most likely to have reinfarction within two years.

Given their high levels of emotionality and behavioral intensity, Type A individuals would appear to be hot reactors. However, studies have found only a modest correlation (approximately .30) between scores on Type A tests and physiological reactivity (Houston, 1983; 1986). Some individuals may exhibit typical Type A behavior and yet have modest physiological responses. Others may appear behaviorally as Type B individuals and yet be experiencing high physiological reactivity. Buell (1984) characterizes these latter individuals as discordant reactors because their surface behavior is discordant with their internal state. Because of the iscordance phenomenon it is impossible to determine if an individual is a hot or a cool cardiovascular reactor based on the person's surface behavior.

This literature clearly defines an individual difference variable that is relevant to the topic of driving stress. Drivers who are hot reactors and who respond cardiovascularly to traffic conditions would be expected to be at greater risk for cardiovascular disease relative to drivers who are cool reactors. Drivers who manifest Type A behaviors such as time urgency and hostility and are also hot reactors should be at the greatest risk.

2. Type A-B distinction and driving stress.

Stokols, Novaco, Stokols, and Campbell (1978) studied the effects of traffic congestion on stress responses. Previous studies had shown that people with Type A personalities showed more tension and hyperactivity than Type B's when performing for a low rate of reinforcement. This implies that Type A's would be more stressed by traffic situations (e.g. congestion) that require but do not reward vigilance. Type A's have been found to be more impatient and irritated when delayed by co-workers on joint decision making tasks. Type A's tend to strive harder to avoid loss of control ver their environment but will relinquish that control more apidly than Type B's when conditions are highly uncontrollable (Glass, 1977; Glass, Singer, & Pennebaker, 1977; Krantz, Glass & Snyder, 1974; Glass, Snyder and Hollis, 1974). Based on this information, it was hypothesized that Type A's would be more likely to show higher frustration levels and higher blood pressure levels than Type B's when driving in congested traffic conditions. Delays should also increase these measures of stress more for Type A's than Type B's.

Type A individuals were distinguished from Type B individuals using the measures of coronary prone behavior outlined by Rosenman, Friedman, and Strauss (1966). Traffic congestion was defined as stressors that impede progress between locations. Distance and duration of commute were the specific variables by which impedance level was determined. Both Type A's and Type B's were assigned to each of three groups: low, medium, and high impedance. Using both self-report and blood pressure measures as indicators of the stress response, the highest level of responding for Type B's was experienced by those Type B's in the high impedance condition. For Type A's, the medium impedance condition resulted in the highest stress response. Stokols & Novaco concluded that the degree of congruity between expectancies and travel constraints is the best predictor of stress response. In this study, Type A's relinquished control when conditions were highly uncontrollable; however, they became more stressed than Type B's when conditions were moderately controllable, as prior research had predicted. Conversely, Type B's were the most stressed by highly uncontrollable conditions. The evidence suggested that medium and high levels of traffic congestion differentially affect the level of physiological responses of people exhibiting Type A and Type B behavior.

B. Factor 2: Sensation Seeking - Risk-Taking.

Sensation seeking and risk taking are personality traits that are intimately connected with individual differences in chronic levels of arousal. Arousal is a major component of behavior which is physiologically indicated 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.

When an immediate response to the environment is required, these changes are normally highly adaptive. Chronic high levels of arousal may, on the other hand, lead to many types of psychosomatic illness such as ulcers, coronary heart disease, arthritis, and asthma (Kalat, 1984).

Because not all individuals interpret arousal in the same way, the comfortable level of arousal varies from person to person. Individuals scoring high on Factor 2 (Sensation Seeking - Risk Taking) 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). It has been hypothesized that individuals who prefer high levels of arousal (sensation-seekers) may be less affected by stressful events than persons who prefer lower levels of stimulation.

Persons innately predisposed to react to small changes in stimulus intensity with high arousal levels will tend to develop iow sensation seeking, low risk taking behavior patterns, and those predisposed toward lower arousal reactions tend to exhibit more adventuresome behavior patterns. Environmental stress may actually improve the performance of high sensation seekers and impair the performance of low sensation seekers.

The theoretical explanation for this difference involves three interrelated observations concerning arousal, sensation seeking, and performance. First, low sensation seekers persons tend to be more chronically aroused than are high sensation seekers. Second, there is a curvilinear relationship between arousal and performance; a person who is too little aroused will often fail to pay close attention to important features of the environment, while one who is too highly aroused will be too rigid, cautious, and nervous to perform adequately. Third, external stress raises a person's arousal level. Therefore, with a relatively unaroused high sensation seeker, environmental stress raises the arousal level, resulting in improved performance. With the already aroused low sensation seeker, external stress pushes the arousal level past the optimal point and results in poorer performance (Wakefield, 1979).

Risk taking shows a clear relationship with sensation seeking. Specifically, risk taking correlates with the venturesome aspects of sensation seeking and should act as a stress-buffer for those individuals possessing this trait.

1. Age differences in risk perception.

Accident statistics indicate that male drivers between the ages of 16 and 21 are involved in more fatal automobile accidents per year than any other group of drivers. One hypothesis about the cause of this high fatality rate is that young males misperceive the risks involved in driving. This concept is illustrated by Finn & Bragg (1986) who found that young males not only rated risky situations less dangerous than older males, but also felt less at risk if they were driving as opposed to being a passenger in a car driven by an age cohort.

Matthews, Morgan, and Andrew (1986) documented that male drivers in ages of 16-20 tended to view themselves as immune to the risks of driving. They also felt that their driving skills were as good or better than those of older drivers. Bragg et. al. (1985) gave young males (between the ages of 16-18) and older males (between the ages of 35 and 45) experience on a driving simulator. They found that young males rapidly became quite confident about their driving skills, while the older males were less quick to do so.

The literature indicates that older adults appear more cautious than younger adults in some contexts, but not all (Botwinick, 1984). Consequently, the relationship between risk- taking and stress remains equivocal and may best be understood in multivariate terms. A determination of the type of risk-taking or risk-avoidance behavior exhibited by individuals at various ages in specific contexts would be useful. Longitudinal studies would also be helpful in partitioning out the component of risk-taking behavior due to relatively stable personality constructs and the component due to developmental changes. Factor 2 of the *DSS* would be a useful research tool in this effort

2. Sex differences in risk perception.

The literature in this area generally indicates that males are more willing to take unknown risks than are females. Hudgens & Fatkin (1985) gave males and females repeated sessions on a computer game involving tank warfare. They found that in unknown or unpredictable ituations, women took fewer risks than did men, and also took longer to make a risky decision. Research on sex differences in risk perception has recently begun to focus on the role that sex hormones play in preference for risky behavior. Wilson (1975) has suggested that there are biological reasons why males should take more risks than females, and that male sexual hormones may actually cause males to engage in risky behavior. When norms are developed for Factor 2 of the *DSS* it will be possible to explore whether these generalizations apply to the context of driving.

C. Factor 3: Hostility - Anger.

Type A behavior refers to a syndrome of different types of behavior which can occur simultaneously in an individual. Research has been directed at determining the components of the behavior pattern that are most strongly related to heart disease. One line of research has indicated that only those characteristics concerned with hostility predict heart disease. For example, Cook and Medley (1954) found that scores on the HO scale were more predictive of heart disease than having a Type A personality. The HO scale is a list of 50 questions taken from the Minnesota Multiphasic Personality Inventory (MMPI). Men with high HO scores had, on average, 9 more arteriosclerotic blockages than did men with low HO scores. Additionally, HO scores predicted not only heart problems but deaths from any cause. Using the HO scale narrowed the list of risk factors to those associated with hostility, and using the HO scale allowed objective measurement of behavioral and personality characteristics, thus avoiding the problems of using the subjective structured interview to assess the behavioral characteristics involved in heart disease development.

Smith (1985) claims that the HO scale measures suspiciousness, resentment, frequent anger, and cynical mistrust of others. High HO scores are also associated with a less enthusiastic approach to life, the experience of more frequent and severe everyday hassles, and lower levels of satisfaction derived from everyday social contacts. People with fewer social contacts (via marriage, contacts with close friends and relatives, church membership, or membership in nonchurch groups) were 2 to 3 times more likely to die from any cause. Further refinement of the list of hostile characteristics showed that cynicism, hostile affect (or more specifically, anger), and aggressive responding are the most toxic aspects of hostility. These three characteristics together are better predictors of illness than the entire HO scale (Barefoot, et al. 1988).

Evidence that subjective feelings of hostility are associated with increased disease susceptibilty 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.

D. Factor 4: Slow, Cautious Drivers.

At first glance this factor would seem to be highly correlated (negatively) with the Time Urgency and Risk Taking factors. Inspection of Table 2 however, indicates that this factor accounts for variance in subjects' responses that the former factors do not. Slow cautious drivers are characterized by a preference for slow travel, patience, and a disinclination to take risks. The technical literature suggests that scores on this factor should be related to age and sex (c.f. section on risk taking above). It should be noted however, that this factor emerged from an analysis of the responses of college students. The relationship between this factor and stress resistance will be explored in validation studies of the *DSS*.

V. FUTURE DIRECTIONS: VALIDATION OF THE DRIVING STRESS SUSCEPTIBILITY SCALE

The next stage of development of this instrument will focus on validation. Once the measurement model has been confirmed, the question of whether the instrument actually measures traits that predict stress responses in the driving situation remains to be addressed.

A. Validation of the DSS with measures of subjective distress and physiological reactivity.

The *DSS* should predict individual differences in the stress response to driving situations. The validity of the instrument could be evaluated by correlating test scores with the physiological and psychological responses of drivers to stressful traffic situations. If significant validity is achieved, the test would constitute a valuable screening instrument for predicting individual differences in response to traffic stress. Further, it would be a valuable research tool for exploring the relationship between other variables (e.g. age, sex, experience, sensory loss) and driving stress susceptiblity.

B. Validation of the DSS as a moderator of the relationship between driving stress and health.

The *DSS* is conceptualized as a individual difference variable that moderates the relationship between driving stress and health. Validation studies should be conducted (similar to those conducted with other moderator variables) that evaluate the relationship between driving stress, personality, and health. Validation should consist of a longitudinal study of drivers who are exposed to high levels of traffic stress. Individuals scoring high on the *DSS* should experience more health problems than should individuals scoring low on the instrument.

The benefits of such a longitudinal study would be twofold. First, the relationship between traffic stress and health would be quantified. Although the current literature implies that traffic stress should impact physical health, that relationship has never been examined in a longitudinal study. Second, the study would establish the validity of an instrument that would predict which among a group of individuals exposed to traffic stress would develop health problems.

Individual differences among drivers may also predict variation in response to IVHS interventions. For example, drivers who are "time urgent" tend to be highly stressed by traffic delays and may benefit disproportionately by IVHS innovations that minimize congestion. On the other hand, drivers who are high on the "sensation seeking- risk taking" dimension may dislike giving up control of their vehicle or their route to an operator in a traffic control center.

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SECTION 2 AGE, COGNITIVE DEFICITS, AND DRIVING PERFORMANCE

I. INTRODUCTION

IVHS user services such as ATIS (Advanced Traveler Information Systems) have the potential to substantially increase the information presented to drivers while the driver is simultaneously attempting to navigate and to deal with the demands of traffic. This has raised questions for ATIS system designers and for human factors engineers as to whether ATIS systems and displays will overload the driver with information. This question is especially relevant for elderly drivers who may suffer diminished information processing abilities.

The general objectives of this project are to explore the relationship between age related cognitive deficits and driving performance among a group of elderly drivers. This research is relevant to the general topic of aging and driving competence. Age related declines in information processing ability may affect an elderly driver's ability to deal with either typical traffic situations, or with IVHS innovations, or both.

During the past three decades substantial research has 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 ability loss and accident history, citation history, or specific driving skill loss.

The research described below was designed to demonstrate a relationship between specific age-related measures of cognitive functioning and driving ability. The research evaluates the extent to which a measure of attention switching ability, and a cognitive inference-reading comprehension test predict driving ability in elderly subjects. This project is designed to yield information relevant to the following social 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?

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. Because of this, 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.

Cushman (1992) has noted that the cognitive changes that occur with aging range in severity from indiscernible, to minor (i.e., benign senescent forgetfulness), to frank dementia. Although cognitive impairment in older adults is in not inevitable, 10 to 15 percent of individuals at age 65 have some significant cognitive impairment. The percentage of the population that becomes impaired increases with age. There is relatively little information, however, that links specific cognitive deficits to the driving task.

A. The Aging Driving Population.

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, forthcoming) 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.

B. Accidents And The Elderly Driver

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).

These differences in *total* versus *per-exposure* accident rates have been the focus of discussion and conjecture. First, it appears that those drivers currently above age 65 reduce their own driving as they age, partially in recognition of increasing physical problems (Kosnik, Sekuler, and Kline, 1990). What is not clear is whether future generations of elderly drivers will want to, or be able to, reduce their driving to respond to declining skills.

Today, because of self-imposed limitations, the elderly are only represented in accident statistics in rough proportion to their share of the population. However, will future generations be as willing to perceive their limitations as those currently in older age brackets? As TRB Special Report 218 remarks, "That future cohorts of older drivers will curtail their driving as much as their earlier counterparts have appears unlikely: the average miles driven by those 65 and over has increased with each new major travel survey taken from 1969 through 1983." (TRB 218, 1988)

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).

Some studies have found that elderly drivers were more likely to be responsible for or cited as being at fault than younger drivers, although some argue that this is a result of *a priori* value judgments about older drivers (McKelvey and Stamatiadis, 1989). A 1986 Canadian study found that the increase in accident responsibility with increasing age over 65 was almost exponential (Rothe, 1990).

C. *The Aging Process and Driving Skills*

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 are:

1. Sensory capacity losses

Aging is associated with decrements in hearing (especially at higher frequencies), decrements in visual acuity, decrements in dynamic visual acuity, and frequently with increased sensitivity to glare. People with aural impairments lose a a basic alarm mechanism, the ability to hear proximate traffic. People with vision impairments lose depth perception, ability to read traffic control devices, and the ability to see small obstacles. Changes in the eye make older drivers increasingly less sensitive to shorter wavelength colors, such as cyan to deep blue, but enhance sensitivity to longer-wave length colors like orange and yellow. In addition all colors appear less vivid and bright. In traffic situations, these changes result in the loss of night vision (an 85 year old man receives, on average, only 40% of the light received at night by a 20 year old), the inability to see low-contrast targets, and increased sensitivity to glare.

2. Motor and psychomotor capacity losses

Decreases in reaction time can combine with general difficulties in movement (caused by pain or disuse) to create serious problems in high speed or complex traffic situations. Stiffness in the joints of the neck and shoulders may lead the older driver to less frequently make the head turning movements necessary to attend to relevant information to the side and rear of the vehicle.

3. Decline in information processing skills.

Decline in the mechanisms of the central nervous system 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. The most important changes may be those which affect attentional mechanisms.

D. The Relationship Between Skill Losses and Driving Safety

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; Witkin, 1969; Sivak, Kewman, & Henson, 1981; 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; Barrett et al., 1977).

Retchin, Cox, Fox, and Irwin (1988) have suggested that those drivers who are most likely to reduce their driving as a compensatory strategy are also those most impaired on motor and visual measures. However, self-imposed driving restrictions do not compensate for all areas of difficulty as evidenced by accident statistics (Rackoff and Mourant, 1979). Thus, when protective strategies fail, for any reason, older drivers become probable high-risk drivers. Since protective compensatory strategies require at least minimal awareness of impairment, those drivers whose cognitive impairment precludes such awareness are most at risk. It is not clear whether this increased risk might be largely due to primary cognitive impairment (e.g., impaired decision-making, reduced capacity) or due to a lack of insight into the need to restrict driving. However, it seems clear that the judgment, planning, and attentional capacities required for driving may be absent or compromised in a substantial percentage of older drivers. Currently, it remains an open question as to what degree of cognitive impairment, should restrict or preclude driving (Cushman, 1992; Ritchin et al., 1988).

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 1) between any of these functional problems and actual driving records, 2) between these functional problems and the comprehension of and response to complex driving situations.

Researchers who have attempted to link sensory 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)."

The failure to find a relationship between sensory capacity and driving skill may be due to the well documented ability of people to effectively compensate for age related decrements in sensory or cognitive abilities. There are, for example, several reports that indicate that well learned skills are retained despite age related declines in their presumed cognitive components. This phenomenon has been observed in chess playing (Charness, 1981; Pfau and Murphy, 1988), bridge (Charness, 1979), and transcription typing (Salthouse, 1984). Further, despite the age-related decline in visual acuity under low light conditions, a recent study (Kline, Ghali, Klein, and Brown, 1990) found no age related differences in the visibility distances for highway signs under day and dusk conditions.

E. Self-reported Problems of Older Drivers

During the initial phase of the present project, reports were collected from older drivers regarding those aspects of driving, particularly freeway driving, that they find most difficult and/or stressful. The freeway driving conditions most often cited by our sample of older drivers as difficult and/or stressful can be divided into three main categories. The first category consists of comments about the driver's *unfamiliarity* with the freeway system coupled with a lack of knowledge regarding how the system operates. Specifically, older drivers reported: (a) difficulty in correctly interpreting overhead roadway directional information, (b) being uncomfortable with road initiated lane changes, and (c) that having to navigate without the benefit of familiar landmarks was often stressful and confusing.

A second category of complaints involved problems related to driving at faster rates of speed such as: (a) having to make maneuvering decisions quickly, (b) being unable to compensate for being in the incorrect lane when a freeway divides into two or more major routes, (c) the difficulty of getting to an exit in time, (d) the difficulty of merging onto the freeway from an on- ramp, and (e) being required to make overly rapid lane changes.

The third category involves issues of attending to navigational and/or directional information. Expressly mentioned were: (a) having to deal with increasing levels of information presented along the route (e.g., names or numbers of exits, miles to exit), (b) delineators which redirect the flow of traffic by channeling drivers into unexpected detour lanes. (These are also often accompanied by reduced speed signs, flashing barricades, and/or flagpersons), and (c) variable message overhead signs issuing warnings or directions regarding weather conditions, traffic breaks, or road closures.

Our data thus indicated that older drivers avoid novel driving environments, such as freeways, because they lack knowledge of how the freeway system operates (e.g., road initiated changes, exits that appear to direct a driver in an unwanted direction), they have to make maneuvering decisions at a high rate of speed as opposed to being able to "get one's bearings while at a stop light", and having to attend to increasing levels of information which may also require a quick and specific response. Respectively, these categories are directly related to issues defined by the theoretical constructs of: (a) driving and the speed of mental operations, (b) attention and driving performance, and (c) age and fluid intelligence.

II. DRIVING AND THE SPEED OF MENTAL OPERATIONS

It has been suggested that many of the age differences in driving may be largely mediated by age-related reductions in the speed of executing simple processing operations (Salthouse, 1991). Several studies have reported that adult age differences in various measures of cognitive functioning are either moderately or substantially attenuated by statistical control of variables reflecting the speed of simple perceptual comparisons.

In the research described below we evaluate the relationship between age-related declines in perceptual comparison speed and driving competence. Perceptual comparison speed is a basic function that mediates both visual search ability and attention switching ability (cf. discussion of attention switching and driving ability below). The Trail Making Test from the *Halstead-Reitan Neuropsychological Test Battery* was chosen for assessing perceptual comparison speed. Because the visual search behavior of drivers becomes less efficient as early as 50 years of age, involvement in certain types of accidents may be related to the type of diminished capacity measured by the Trail Making Test.

The Trail Making Task allows evaluation of the extent that age effects the ability to make rapid, but relatively simple, responses in a perceptual comparison task similar to those arising during the course of driving on a freeway.

A. Task Complexity.

One line of research supporting the idea of age-related slowing in information processing is the task complexity effect. When older adults' mean reaction times to increasing task demands are plotted as a function of young adults' means in the same conditions, the result is typically a monotonically increasing function with a slope greater than 1.0 and a negative intercept (Salthouse & Somberg, 1982). The implication of this type of relation between young and older adults' reaction times is that the overall complexity of the task, rather than the processing demands of specific task conditions, is the most important determinant of age differences in performance.

III. ATTENTION AND DRIVING PERFORMANCE

One reason that unfamiliar traffic situations pose a problem for the older driver is that attentional capacities tend to decline with age. Because of the limited information processing capacity of the human brain, individuals are unable to process all of the information in their immediate surroundings; they must selectively attend to a restricted visual or auditory domain at any particular time. Age related declines in this ability may underlie many of the problems experienced by older drivers.

A. Focused Versus Distributed Attention

Driving presents a challenging situation in terms of attentional allocation. Not only is a great deal of information important for accurate navigation, but a substantial proportion of the particulars in the environment are irrelevant for the individual driver (e.g. freeway exit signs denoting offramps that a driver does not want to take).

Adult age differences in the performance of a variety of cognitive tasks, including visual search, have been attributed to an age-related decline in attentional capacities. This decline is typically discussed in terms of either a decreased availability of processing resources or a decreased efficiency of the selection of task-relevant information. One way to understand age deficits in attentional capacity is in terms of the distinction between *focused* and *distributed* attention. Focused attention refers to the extraction of information from a single display location while distributed attention refers to the extraction of information from a broader area. There is some evidence that suggests that performance on tasks requiring focused attention does not decline with age. For example, the ability to use a location cue during visual search, has been reported to be resistant to age-related decline (Hartley, Kieley, & Slabach, 1990)..

In contrast, distributed attention capacity definitely shows an age-related decline. For example, the estimated time required to process a nontarget letter and shift attention between display positions has been found to be significantly greater for older adults than for young adults. It appears that there is an age-related slowing in ability of a cue to facilitate subjects' decisions regarding individual displays. In driving, this would be analogous to older drivers requiring a longer search and processing time to shift attention from one target to another. For example, if an overhead directional sign contained information about several target locations (i.e., miles to the exit), older drivers would require more time to find the information most relevant to them.

Evidence supporting this hypothesis was reported by our sample of older drivers. They complained of being required to attend to too much information along the freeway and feeling that they didn't have a comfortable window of time to do it. Madden (1992) also found that increasing cue validity appeared to increase the difficulty of disengaging focused attention from the primary-cued location. In more behavioral terms, this means that older drivers would have more difficulty in switching from an expected target location and quickly scanning an area, if the target was not in the location they expected to find it in.

Given the age-related decline that occurs in the sensory processes underlying vision, limited display duration would impair search performance more for older adults than for young adults, which in turn would increase the amount of assistance that older adults would obtain from a location cue. Attention-shift reaction time is also longer in duration for older adults than for young adults.

It is possible that an age-related decline in visual acuity contribute to this age difference; the time required to process a single nontarget display item is one component of the estimated attention-shift reaction time. However, Madden (1992) found that the age difference in attention-shift reaction time remained significant even when group differences in visual acuity were taken into account.

B. Inattention and Driving Competence.

Generally, the kind of mistakes that older drivers tend to make often involve inattention (e.g., failure to yield or running stop signs). Assuming that such infractions are not attributable to willful disregard or recklessness, it would seem that older drivers experience more difficulty in noticing, and thus responding appropriately to, signs and signals. As Marsh (1960) has noted, the fact that older drivers tend to be more safety conscious, yet often ignore or misinterpret traffic signals, highlights the role that inattentiveness plays in creating vulnerability for the older driver.

Many of the driving situations older drivers most frequently describe as difficult and/or hazardous (e.g., backing up) have not been found to significantly correlate with actual driving problems as indicated by accident incidents (Panek and Fowler, 1969). Cushman (1992) has suggested that the risk situations which older drivers are less aware of, and thus less able to compensate for, are circumstances requiring attention, judgment, and general cognitive ability. Inattention is a type of risk factor that older drivers are unlikely to be aware of and are thus unlikely to be able to compensate for. In the studies described below inattention serves is used as a dependent variable. Several measures of cognitive deficits are used to predict the degree to which drivers can remain vigilant while behind the wheel.

C. Attention Switching Ability and Driving.

The fundamental constraint that underlies all the operations of attention is the limited information-processing capacity of the brain (Posner, 1989). Because of this constraint individuals are unable to process all of the information in their immediate surroundings; they must *selectively attend* to a restricted visual or auditory domain at any particular time. In order to process a large amount of information, individuals must rapidly switch their attention from one information domain to another.

The attentional demands imposed by driving are formidable. Driving is a simultaneous task paradigm in which the driver must attend to varying traffic conditions, attend to traffic control devices, and navigate. Consider the problem facing a driver who is trying to navigate to a particular address by using street signs. The driver must switch attention between other vehicles, pedestrians, traffic control devices (stop lights, lane markers, etc.) and street signs. If attention switching capacity is poor, the time spent locating and comprehending street signs will significantly detract from time spent monitoring the roadway. If attention switching capacity is very poor, the driver may choose not to monitor the peripheral visual field, or the rear view mirror, producing a kind of "tunnel vision."

Despite its apparent relevance, the literature concerning age and driving competency has yet to systematically explore the relationship between attentional skills or attention switching speed and driving ability.

D. Assessing Attention Switching Ability: The Trail Making Test.

The research described below employs the Trail Making Test as a primary measure of attention switching ability, and links performance on this test to performance on a driving simulator. This test, originally part of the Army Individual Test Battery, has enjoyed wide use as an easily administered test of general orientation and attention skills. Like most other tests involving motor speed and attention function, the Trail Making Test is highly vulnerable to the effects of both age and brain injury. The test is given in two parts, A and B. The subject must first draw lines to connect consecutively numbered circles randomly placed on one work sheet (Part A), and then connect the same number of consecutively numbered and lettered circles on another work sheet by alternating between the two sequences (Part B). The subject is urged to connect the circles "as fast as you can" without lifting the pencil from the paper. The test has demonstrated high test-retest reliability (r = .78) over six month intervals and is relatively resistant to practice effects (Lezak. 1983). Extensive T-score norms developed by Harley and his coworkers (1980) offer a sensitive set of norms for men aged 55-79.

As with any test in which response speed contributes significantly to the score, performance on the Trail Making Test declines with age. The nature of the decline can indicate underlying pathology. When the number of seconds taken to complete Part A is relatively less than that taken to complete Part B, the subject probably has difficulties in conceptual tracking or symbol interpretation. Slow performances on both parts point to the likelihood of brain damage. The slower performance of older subjects on this test is thought to be a result of deficits in frontal lobe functioning that are known to occur with age.

The Trail Making Test's utility goes far beyond the assessment of brain damage. Visual scanning and tracking problems that show up on this test indicate: (1) how well a subject responds to a visual array of any complexity, (2) how well he/she performs when following a sequence, (3) the ability to deal with more than one stimulus or thought at a time (Eson et al., 1978), or (4) how flexible he/she is in shifting the course of an ongoing activity (Pontius and Yudowitz, 1980). Staplin, Lococo, and Sim (1990) used the Trail Making Task to compare the speed, accuracy and flexibility of directed visual search among younger and older drivers. The authors noted that the argument that directed visual search processes play a central role in the effective use of traffic control devices is strong, and the Trail Making task provides a quick and clinically proven technique for making comparisons in this area of operator performance. As predicted, they found that there were substantial differences in the directed visual search capabilities of younger and older drivers with older drivers requiring significantly more time to complete the task.

IV. AGE AND FLUID INTELLIGENCE

Previous research on the relationship between cognitive ability and driving performance may not have been appropriately sensitive to the importance of familiarity. Age related cognitive deficits are most likely to influence new learning and performance in unfamiliar situations. The problem that older drivers have with unfamiliar driving situations may be understoood in terms of the distinction between "fluid" and "crystallized" intelligence. Fluid intelligence refers to a general processing ability and includes the ability to perceive relationships, deal with novel problems, and to acqire new knowledge. This is in contrast to crystallized intelligence which involves acquired skills and knowledge and the application of that knowledge to specific content in a person's experience (e.g., skills of a good auto mechanic, salesperson, or accountant).

Fluid processing typically reaches its peak well before the age of 20. Thus, a twenty-year-old may be more successful than a sixty-five-year-old at solving some problem that is unfamiliar to both of them, but the sixty-five-year-old will excel in solving problems in his or her area of specialization. The evidence to date shows minimal age differences in memory for familiar materials that may be found in the everyday environment. The performance of older subjects declines when the material is unfamiliar, incomplete, or irrelevant to the criterion task.

A. *Measuring Fluid Intelligence: The Woodcock-Johnson Psychological Test Battery.*

Fluid intelligence is directly related to that aspect of driving which requires individuals to: a) process spatial information, b) effectively comprehend a novel or unfamiliar roadway environment, or c) respond creatively and effectively to atypical driving situations. This ability is particularly important for operations such as interpreting highway symbol information, map reading and interpretations, understanding directional information, and maintaining or achieving a desired lane position in areas where road-initiated lane changes occur. A good deal of the relevant information presented along freeway routes requires recall of verbatim surface information for directional guidance. However, it is also often the case that part of the information may not be attended to, or seen, in time while driving. In addition, much of the information is novel for older drivers unaccustomed to freeway driving.

The *Woodcock-Johnson Psychological Test Battery* (WJPB) was used to test the ability to draw accurate inferences or interpretation from incomplete and novel information. The WJPB includes subtests which can yield important information regarding specific deficiencies. For example, these tests can reveal possible impairments in the perception and recall of visual patterns, motor difficulties in copying forms, limitations of short-term memory (STM), inability to handle abstract concepts, and many types of language disorders. For our purposes, we have chosen to use the subtests of letter-word identification and passage comprehension. The letter-word identification subtest provides a measure a measure of vocabulary level for individuals grade 10 to adult. Subjects are required to pronounce, out loud, 22 words increasing in difficulty (e.g., investigate...puisne). Subjects were not penalized for mispronunciations resulting from speech defects, dialects, or regional speech patterns.

The passage comprehension subtest requires subjects to correctly infer a missing word from a written passage ranging in length from a single sentence to several sentences in a short paragraph. Subjects read 23 passages increasing in difficulty. Subjects read each passage silently and were instructed to write a single word in the blank that they felt best completed the passage. They were encouraged to not spend more than 30 to 45 sec on each passage, but time was not a constraint.

Reliability estimates, or the stability of test scores over time, for ages 40 - 64 and 65+ years in a normal population range from .83 to .96. Generally, coefficients of .80 or higher are indicative of test stability (Woodcock, 1978). Woodcock (1978) presents good evidence of construct validity ranging from moderate to high (.75 to .90) for normal populations.

Predictive validity is the ability of a test to predict performance on some other measure of the same concept. The relationships between the Woodcock-Johnson and various other cognitive measures have been found to be moderately high to high (primarily, .60s to .80s), with the highest relationships reported for predictors of performance relating to reading, written language, and knowledge (Stein & Brantley, 1981; Woodcock, 1984).

V. MEASURING DRIVING PERFORMANCE

Performance on a driving simulator was used to evaluate a the impact of age-related cognitive deficits on a complex driving task. The driving simulator provides ecological validity in a context that does not place the subject at increased risk. In the following studies, the impact of age related cognitive deficits will be evaluated through subjects' performance on the driving simulator system designed by Systems Technology, Inc. (STI). Past research on vehicle dynamics and driver control behavior, driver decision making and divided/selective attention behavior and response to traffic control devices has been applied to the creation of control tasks and cognitive scenarios typical of real world driving.

A combination of vehicle dynamics characteristics and compensation for Computer Generated Imagery (CGI) transport delays have been employed to create an appropriate stimulus-response relationship between steering inputs and visual display motions. The composite vehicle dynamics/compensation characteristics have been carefully integrated so that steering sensitivity is appropriate over the full range from rest to top speed, and is not sluggish or oscillatory as is the case with many CGI based driving simulations. One of the key features of the driving simulation is its use of sound to give feedback to the subject. The program incorporates engine noise, tire screeches, sirens, and crash sound that are played in the background as the simulation continues. The engine noise includes both up and down shifting, and engine RPMs. The tire screech will occur if the vehicle is cornering too fast, and the siren sounds if there is a police officer present and the subject is caught speeding. Finally, if the subject hits another vehicle, or runs off the road, a crash will occur. The crash includes a cracking windshield and the sound of twisting metal.

VI. METHODS

A. Subjects

Fifty subjects between the ages of 55 and 87 were recruited from several senior centers in the greater Phoenix Metropolitan area. The mean age was 71.24 (SD=5.9). Twenty-six subjects were male and 24 were female. All subjects were informed that participation was voluntary and that they were free to withdraw from the experiment at any time.

B. Apparatus

1. Driving Simulation

The Systems Technology, Inc. Driving Simulator (version STISIM. 5) software was run on an IBM PC.

2. Neuropsychological Functioning

The Trail Making Test from the *Halstead-Reitan Neuropsychological Test Battery* was used as a measure of frontal lobe functioning and to assess perceptual comparison speed. Both Form A and Form B of the Trail Making Test were employed.

3. Verbal and Reasoning Ability

The letter-word identification and passage comprehension subtests from the *Woodcock-Johnson Reading Psychological Battery* were used as a measure of vocabulary level and the ability to draw accurate inferences from incomplete information.

4. Procedure

A driving events scenario was programmed on the simulator to allow examination of a variety of dependent measures under varying conditions. Subjects received instructions regarding the driving task before beginning the actual simulation. They were shown where the "rearview mirrors" were located and were asked to show the experimenter the appropriate response: making either a left or right turn signal and pressing the horn button. Subjects were also asked to test the brake and the gas pedal to make sure they were comfortable with the location. Everything appearing on the monitor (e.g., speedometer, car hood, etc.) was identified and explained to the driver before beginning the test drive. All subjects completed Part A and B of the Trails Making Test, the vocabulary test and the passage comprehension test. The order of these tests and the driving simulation task were counterbalanced.

5. Test Drive

The length of the drive was 28,000 ft. (5.3 miles). Data was collected every 0.1 sec beginning at 4500 ft. and ending at 5500 ft. This allowed the subjects to familiarize themselves with the simulator before any data was collected. Accidents were defined as steering too far off the roadway as to cause a crash and collisions were defined as actually hitting another vehicle or object.

6. Driving Simulation Variables

Data was collected on the following variables:

1. Age (Age)
2. Time to complete part A and B of the Trails Making Test (Trails A and Trails B)
3. Number correct on the vocabulary and passage completion test (Vocab and Passage)
4. Number of Accidents (Accidents)

5. Number of Collisions (Collisions)

6. Number of Pedestrians hit out of a possible two (Ped)

7. Number of Speed Exceedences defined as any time the driver exceeded the posted speed limit (Sp-Excd)

8. Number of Speeding Tickets defined as any time the driver exceeded the speed limit in the presence of a police officer (Sp-Tck)

9. Number of Traffic Light Tickets defined as any time a driver failed to obey a traffic control device in the presence of a police officer (Traf-Tck)

10. Average Speed and Variation of Speed (ft./sec) during data collection (Spd & Spd-Var)

11. Average Vehicle Curvature and Variation of Vehicle Curvature error (1/ft.) with respect to the road (Curv & Curv-Var)

12. Average Vehicle Heading Angle and Variation of Vehicle Heading Angle (radians) defined as heading error of the vehicle with respect to the road. (Angle & Angle-Var)

13. Average Lateral Lane Position and Variation of Lateral Lane Position (ft.) defined as vehicle lane position error. (Lane & Lane-Var)

14. Average Steering Wheel Angle (degrees) and Variation of Steering Wheel Angle (Steer & Steer-Var)

15. Average Acceleration due to throttle input (g's) and Variation of Acceleration (Thro & Thro-Var)

16. Average Deceleration due to braking (g's) and Variation of Deceleration (Brake & Brake-Var)

VII. RESULTS

The average time required to complete part A of the Trails Making Test was 35.55 sec (SD = 16.70). The average time for part B was 98.09 sec (SD = 63.48). Subjects correctly pronounced an average of 15.76 (SD = 5.21), or 71.6% of the words on the vocabulary test. On average, subjects correctly inferred 11.26 (SD = 3.67), or 48.9%, of the words on the passage completion test.

A. *Correlational Analysis*

Performance on Trails A and Trails B indicates the number of seconds required to complete the test; high numbers indicate poorer overall performance. Vocabulary and passage comprehensions scores on the WJPB indicate the number of correct responses; high numbers reflect better overall performance.

Table 1: Significant Correlations ($p<.05$) for each Driving Simulation Variable. If the absolute value of $r>.37$, then $p<.01$

VARIABLE	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Age				.31									
2. Trails A			.46	-.32		.29			.37				.39
3. Trails B	.31	.46		-.53	-.33	.62			.46				
4. Vocab		-.32	-.53		.62	-.56							
5. Passage			-.33	.62		-.38							
6. Accidents		.29	.62	-.56	-.38			.45	.31				
7. Collisions													.38
8.Pedestrians						.45							
9. Sp-Excd		.37	.46			.31				.53			.38
10. Sp-Tck									.53				
11. Traf-Tck													
12. Speed													
13. Spd-Var		.39					.38		.38				
14. Curve													
15. Curv-Var						.45		-.32				-.42	
16. Angle				-.34									
17. Angl-Var						.53	-.33						
18. Lane												.39	-.37
19. Lane-Var							-.41					.45	-.38
20. Steering													
21. Steer-Var						.39		-.44					
22. Throttle	.36	.33	.38	-.39		.47			.45			.47	
23. Throt-Var				-.47		.45			.34			-.35	.36
24. Brake													
25. Brk-Var												-.34	.34

Table 1 (continued)

VARIABLE	14	15	16	17	18	19	20	21	22	23	24	25
1. Age									.36			
2. Trails A									.33			
3. Trails B									.38			
4. Vocab			-.34						-.39	-.47		
5. Passage												
6. Accidents		.45		.53				.39	.47	.45		
7. Collisions				-.33		-.41						
8.Pedestrians		-.32						-.44				
9. Sp-Exced									.45	.34		
10. Sp-Tck												
11. Traf-Tck												
12. Speed		.42			.39	.45			.47	-.35		-.34
13. Spd-Var					-.37	-.38				.36		.34
14. Curve							.39					
15. Curv-Var			.41	.56			-.41	.90		.37	-.40	.59
16. Angle			.41				.32	.34	.36	.50	-.61	.42
17. Angl-Var		.56			.55	.70		.70	.32	.40	-.45	.30
18. Lane				.55		.74		.29				
19. Lane-Var				.70	.74			.41				
20. Steering	.39	-.41	.32					-.33	.30			
21. Steer-Var		.90	.34	.70	.29	.41	-.33				-.31	.44
22. Throttle			.36	.32			.30			.73	-.36	
23. Throt-Var		.37	.50	.40					.73		-.42	.36
24. Brake		-.40	-.61	-.45				-.31	-.36	-.42		-.76
25. Brk-Var		.59	.42	.30				.44		.36	-.76	

B. Factor Analysis

An exploratory factor analysis with Promax oblique rotation was performed through SAS on scores for the 25 variables. Principal components extraction was used prior to the rotation to estimate the number of factors, presence of outliers, degree of multicollinearity, and proportion of variance associated with each factor. With oblique rotation, proportions of variance must be obtained prior to rotation. Because factors were expected to be somewhat correlated, variability was also expected to overlap, and assignment of variance to factors is difficult after rotation. A small degree of multicollinearity was expected due to the fact that mean average scores as well as variance scores were used for some variables. No significant outliers were detected, and no data was deleted from the analysis.

A visual inspection of the scree curve indicated that five factors accounted for the majority of the variance in the data. Communality values tended to be quite high for all variables indicating that the factors were well defined by the variables. A cutoff of .35 was used for inclusion of a variable, and all 25 variables loaded on four of the five factors.

Considered together, the five factors accounted for 62.5% of the variance in driving performance (Factor 1 = 21.2%, Factor 2 = 14.2%, Factor 3 = 11.2%, Factor 4 = 8.6%, and Factor 5 = 7.3%). Table 2 indicates the loadings for each variable on a specific factor; variables are ordered and grouped by size of loading to facilitate interpretation. The following are interpretive labels suggested for each factor:

<u>Factor 1</u>: Controlling forward movement and stopping

<u>Factor 2</u>: Attending to lateral movement/position

<u>Factor 3</u>: Cognitive/Attentional problems & Accidents

<u>Factor 4</u>: Speed Control, Age, & Collision

<u>Factor 5</u>: Maneuvering Skills

Table 2: Factor Loadings for Driving Simulation Variables

Variable	*F1*	*F2*	*F3*	*F4*	*F5*	*Final Communality Estimates*	*Variance accounted for on Primary Factor*
Brake	-.90	-.10	.27	-.13	-.10	.763	.67
Angle	.85	-.08	-.02	-.13	.28	.687	.60
Brake-Var	.78	-.12	-.13	.16	-.23	.686	.60
Thro-Var	.61	.01	.27	.24	.25	.677	.47
Curve-Var	.54	-.01	.24	-.06	-.57	.910	.51
Lane-Var	-.04	.92	.01	-.11	.04	.863	.85
Lane	.03	.81	-.14	.09	-.07	.672	.65
Angle-Var	.37	.67	.25	-.08	-.09	.880	.61
Speed	-.54	.54	-.01	.19	.15	.556	.22
Collision	.13	-.45	.05	.35	-.05	.345	.19
Curve	.11	.39	-.08	.29	.28	.331	.13
Passage	.16	.13	.83	.16	-.07	.614	.54
Vocab	-.15	.18	.80	.01	-.26	.749	.64
Accident	-.01	.16	.69	.27	-.19	.697	.59
Trails B	-.24	.07	.68	.45	.00	.680	.45
Trails A	-.20	-.06	.47	.44	-.02	.418	.22
Sp-Exced	.04	-.11	.24	.71	-.32	.649	.47
Spd-Tck	.07	.02	-.19	.71	-.46	.584	.36
Spd-Var	.29	-.40	-.15	.62	.08	.677	.45
Thro	.37	.05	.27	.53	.32	.753	.44
Age	-.16	.19	.09	.50	.14	.341	.26
Pedestrian	-.27	-.29	.09	.27	.33	.312	.08
Steer	.22	.26	.05	-.08	.90	.826	.68
Steer-Var	.40	.32	.23	-.13	-.53	.872	.45
Traf-Tck	-.08	.17	-.14	.17	-.49	.266	.20

VIII. DISCUSSION

Factor 1 is related to the forward movement of the vehicle, and particularly to the variation in movement. Interestingly, curve variation and throttle variation, both variables on this factor, are also significantly correlated with accidents but not with collisions. This suggests that not only does Factor 1 represent movement, but that the amount of variation in control movements may be related to diminished ability to attend to all aspects of a complex task. Drivers who were steady in their movements (showed less moment to moment variation) had fewer accidents.

Interestingly, vocabulary scores on the *WJPB* were associated with Factor 1 performance, with high vocabulary being associated with better performance. Performance on the Trails test was uncorrelated with Factor 1 performance.

Factor 2 is indicative of lateral movement, and position of the vehicle on the roadway, rather than forward movement. Angle- Var is positively correlated with accidents, but together with Lane-Var is negatively correlated with collisions. The number of collisions variable loads negatively on this factor. Again, we see the different probable causal pattern for accidents and collisions. The negative loading for collisions on this factor could indicate that those individuals showing greater variance in the Lane, Angle, and Curve variables do so due to overcorrecting (and so avoid accidents), while for others the increased variance reflects inattention and road wandering.

Factor three refers to cognitive attentional variables and accidents. This cluster reflects the fact that good performance on the Trails test, on vocabulary measures, and on passage comprehension measures is associated with fewer accidents. The composition of factor 3, when combined with the specific correlations displayed above, provides strong support for our initial hypotheses: scores on measures of information processing ability are significantly related to driving performance. The correlation between age and time to complete part B of the Trail Making task directly parallels findings from previous studies indicating that sustained attention and concentration become more difficult with age (Cushman, 1992). Our data indicates that as attention and concentration become more difficult, accident rate increases.

Factor 4 defines a cluster related to speed control, throttle control, age and collisions. A subset of the drivers in this sample had difficulty in adequately controlling their speed while driving, especially when rounding turns. This factor indicates that these failures in speed control were associated with a tendency to drive the vehicle off the road (collisions). Failure in speed control was also associated with age, with poor performance on Trails A & B, and with poor performance on the WJPB vocabulary measure.

Factor 5 appears to be primarily related to maneuvering skills. Average steering rate is the only positive loading on this factor, while the variation associated with steering and vehicle curvature error have negative loadings. This suggests that the factor reflects accurate and controlled movement through the drive. Both Steer-Var and Curve-Var are positively correlated with accidents; the negative loadings for these variables supports the idea that controlled movement is associated with a reduction in accidents.

The general findings of this study supports the utility of the Trail Making Test and the WJPB as predictors of driving competence. As noted above, these tests measure a variety of cognitive abilities/deficits. Under the information load conditions of the present study, these measured cognitive deficits were related to a decline in driving performance. In the next phase of our research we plan to vary information load (task complexity) to more closely observe the relationship between cognitive deficit and information processing while driving. The present results further indicate the need for a more fine- grained analysis of cognitive deficits. The Trails test does, however, appear to hold promise as a general screening measure that is significantly related to driving ability.

Driving problems related to deficits in fluid intelligence were also evident in our sample. The performance measure for this variable, the Woodcock-Johnson, was significantly correlated with our other cognitive measure, The Trails Test, with accident frequency, and with specific driving performance measures (e.g. throttle control). Decreased levels of fluid intelligence was hypothesized to be responsible for the discomfort that older drivers reported when driving in unfamiliar situations. Age-related deficits in fluid intelligence were observed, and they were related to driving variables.

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SECTION 3 CARDIOVASCULAR MEASUREMENT OF DRIVER WORKLOAD

I. INTRODUCTION

A considerable number of research efforts (cf. Sadalla & Hauser, 1991) have been aimed at describing the demands placed on the driver by surface and freeway driving environments. Relatively few, however, have quantified the degree to which variation in these environments impacts driver workload. One reason for this may be the inherent difficulties involved in choosing objective measures of driving workload and tracking those measures through a complex, dynamic, real world driving environment. Despite such obstacles, research of this nature is critical in order to ensure that human limitations are not exceeded by the demands of IVHS technology and that innovations such as ATIS reduce rather than increase driver workload.

The studies presented in this technical report were conducted as part of an effort to describe the workload demands placed on drivers by varying driving environments. The goal was to begin to provide a human factors perspective of surface street and freeway driving environments that can be used to shape the design and implementation of IVHS interventions.

In these studies driver workload was objectively quantified by measuring moment to moment changes in the drivers' cardiovascular response as they drove through various environments. Cardiovascular responses were operationalized as the measure of workload because the cardiovascular system is the central energy transport system in the body; increases and decreases in cardiovascular activity reflect changes in metabolic demands. These demands result from physical work, cognitive work, or emotional response, and are typically a blend of all three.

The findings of Rutley and Mace (1970), Simonsen et al. (1968), and Wyss (1970), suggest that the influence from physical work in car-driving is negligible. Their data suggest cardiovascular response while driving primarily reflects the changing cognitive demands and changing emotional responses of the subject. Small transient changes in cardiovascular activity while driving presumably reflect the information processing demands placed upon the driver. Larger changes are likely the result of stimulation from the sympathetic branch of the autonomic nervous system. This system evolved to facilitate response to emergencies and as such is a physiological reflection of an individuals' subjective emotional state.

Cardiovascular response may thus be regarded as an objective quantification of the cognitive and emotional components of driver workload; one goal of the present research is to explore the degree to which such measures reflect changes in the driving environment. In order to be relevant to IVHS interventions, the following studies assessed the cardiovascular response of drivers in varied roadway environments. Drivers were monitored while driving on surface roads, freeway entrances and exits, and in two freeway environments, one in which they were restricted to a specified lane position, and one in which freeway position was unrestricted and left to the driver's discretion. The two freeway environments were chosen because one aspect of proposed IVHS interventions involves regulating the location and flow of vehicles in those environments.

This research was organized into three distinct studies. The first study explored the physiological impact of differences in road environments. Drivers were directed through a route that involved surface roads and freeways. On the freeway, subjects drove through a segment where they were unrestricted in terms of choice of lane or lane changes. During another segment of the freeway, drivers were required to remain in a specified lane. All drivers drove equal distances in lane 1, lane 2, and the HOV lane.

It was hypothesized that driver workload demands would be their lowest in the restricted freeway environment since drivers were only required to maintain their position in the flow of traffic. By the same rationale, it was predicted that the high occupancy vehicle (HOV) lane would place the fewest workload demands on drivers. Further, it was hypothesized that surface driving would be highest in workload demands because drivers not only were required to change lanes, but were also required to deal with the unpredictability of intersections, as well as traffic flow in two directions. Freeway entrances, because of the required merge with traffic, were hypothesized to be a high workload environment, and freeway exits, because of their scarcity of events, were predicted to be relatively low in workload demands.

The second study explored the cardiovascular consequences of traffic congestion in freeway environments. Congestion was operationalized in terms of the "level of service" (LOS) scale. LOS is quantified on the basis of the density of vehicles on the freeway with an LOS of 1 being the lowest vehicle density and LOS of 6 being the highest vehicle density. It was hypothesized that driver workload would increase as LOS increased.

The third study involved comparisons of various "driving events" that occur during freeway driving to determine whether phasic cardiovascular responses are sensitive enough to detect workload changes that occur in very brief time spans. This study examined and compared cardiovascular responses to events such as lane changes and vehicles moving in and out of the lane directly in front of the driver.

II. METHOD

A. *Subjects*

Thirty three subjects from the Arizona State University community volunteered to participate in this study and received $3.00 (for gas money) for their participation. Each subject drove his/her own vehicle in this study.

B. *Subject Preparation.*

As each subject arrived at the laboratory at their scheduled time, they were briefed in terms of the nature of the experiment. Each subject was then prepared for cardiovascular monitoring. Subsequent to surface skin preparation, 7 silver, 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.

C. *Procedure.*

Following calibration of the instrument, each subject was taken from the laboratory to their own vehicle and accompanied by an experimenter who rode in the passenger seat. The experimenter directed each subject on the appropriate route to follow and coded all pertinent experimental data. The total drive lasted approximately one hour. Subjects drove approximately 60% of the time on a freeway, and 40% on surface roads.

D. Data Coding.

Each subject drove on a prescribed route which included surface driving, unrestricted freeway driving (drivers were allowed to proceed, changing lanes at their own discretion), and restricted freeway driving (drivers were asked to enter and remain in a particular freeway lane). Multiple loops were made through the restricted freeway zone with a different lane required for each loop (the order of lane designations was counterbalanced across subjects). Finally, each subject returned by surface roads to Arizona State University.

Throughout the entire test route pertinent information was coded by the experimenter on a MS-DOS based portable laptop computer, programmed to receive one-letter codes and record time of occurrence to the nearest one hundreth of a second for the following information: 1) location -- surface, freeway entrance, freeway exit, lane in unrestricted freeway zone, lane in restricted freeway zone; 2) level of service (LOS) --experimenters were trained from Department of Transportation prototype photographs to estimate LOS during the freeway portion of the drive with an LOS of 1 being low congestion and an LOS of 6 being high congestion; estimates were made whenever the experimenter detected a change in LOS or every 30 seconds as prompted by a tone from the computer; 3) events -- lane changes, a vehicle moving in or out of the lane directly in front of the driver, and the driver applying the brake were coded on the freeway portions of the route. At the beginning of each subject's drive, the experimenter simultaneously depressed a key on the computer and an event marker button on the PR4 recorder to allow for subsequent synchronization of the cardiovascular data with the driving environment data.

Following completion of the test route, subjects returned to the laboratory, their electrodes were removed, and they were debriefed and asked to complete a post-experimental questionnaire.

E. Data Reduction.

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 the 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 hundreth of a second with the times stored in the data file coded on the notebook computer during each subject's drive. As a result data files were constructed which contained the following: 1)onset times and offset times for each of the location codes, corresponding mean IBI's for each respective time epoch, and a calculation of heart rate (HR) variability for that epoch (calculated as the standard deviation of the IBI's for that time epoch); 2) onset and offset times for LOS estimation, corresponding mean IBI's for each respective time epoch, and a calculation of heart rate (HR) variability for that epoch and 3) the time of occurrence of each lane change and driving event and corresponding instantaneous mean IBI for that event calculated by taking the IBI in which the event occurred as well as the prior and subsequent IBI and averaging those three beats. These master data files were then sorted in a variety of ways in order to provide the data required for the statistical analyses reported in the following section.

III. RESULTS AND INTERPRETATIONS

A. Study 1: Road Environments

Study one consisted of an analysis of the physiological consequences of driving through different roadway environments. The study examined drives on: (1) surface roads, (2) a zone of unrestricted freeway driving, and (3) a zone of restricted freeway driving in which subjects were asked to remain in a particular lane of the freeway. The restricted drive segment of freeway was repeated three times by each driver in order to compare the various (right, middle, and HOV) freeway lanes. Additionally, comparisons of each driving environment were made with freeway entrances and exits. All findings are the results of repeated measures ANOVAS.

1. Lane Comparisons:

1. In the restricted driving zone HR variability was significantly greater in the diamond lane versus lanes 1,2, and mid. $F(1, 27) = 21.68$, $p = .000$ (cf. Figure 1 below)

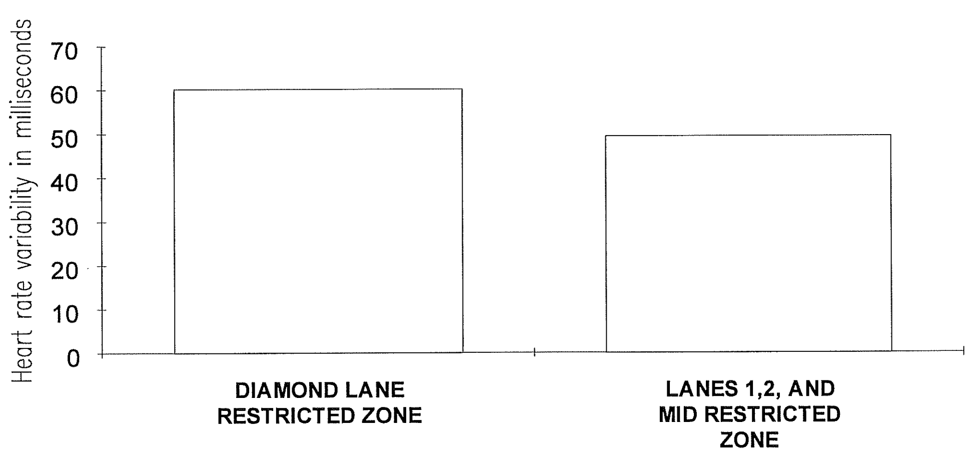

Figure 1: Comparison of heart rate variability for diamond lane restricted zone versus lanes 1,2, and mid restricted zone, $F(1,27)=21.68$, $p=.000$.

2. In the unrestricted driving zone HR variability was significantly greater in the diamond lane versus lanes 1,2,3, and 4. (cf. Figure 2 below)

HR variability is calculated as the standard deviation of interbeat intervals occurring during each driving condition. The meaning of differences in this variable have received a variety of interpretations, yet, conservatively, periods of higher HR variability can be interpreted as periods of time in which workload demands were comprised of more frequent extremes of workload. The above findings suggest that workload demands are more variable in the diamond lane whether in a restricted or unrestricted driving situation. This may reflect a scenario in which arousal is high upon entry into the diamond lane, but then decreases as one encounters fewer events in this lane. It may also reflect a scenario in which when events do occur in the diamond lane their effects are more salient and initiate greater shifts in arousal.

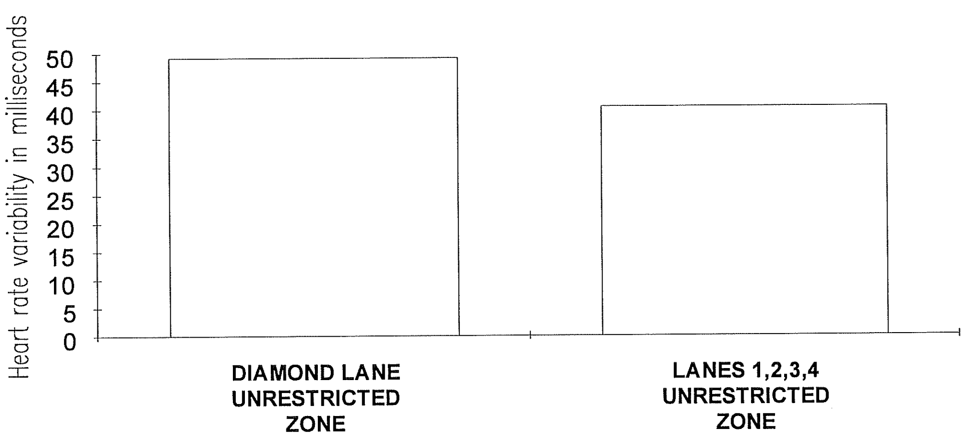

Figure 2: Comparison of heart rate variability for diamond lane restricted zone versus lanes 1,2,3, and 4 unrestricted zone, $F(1,32)=11.98$, $p=.002$.

2. Comparisons Between Surface Roads and Freeway Zones:

1. The mean interbeat interval was significantly shorter for periods of surface driving versus restricted freeway driving (c.f. Figure 3 below).

Since a shorter interbeat interval is the equivalent of a higher heart rate, these findings suggest that driver workload is greater when driving on surface roads than overall driving on the freeway when staying in one lane continuously, no matter what lane that may be. The fact that surface driving was equivalent to unrestricted freeway driving in terms of workload suggests that "stable freeway positioning" results in lower workload levels.

Figure 3: Comparison of mean IBI for surface roads versus all freeway lanes restricted zone, F(1,27)=17.59, p=.000.

2. HR variability was significantly greater for periods of surface driving versus unrestricted freeway driving. (cf. Figure 4 below).

HR variability was higher on surface roads than during unrestricted freeway driving. This is probably indicative of the fact that surface driving involves periods of relatively low demand, such as stopping at traffic signals, as well as relatively high demands, such as navigating busy intersections, while unrestricted freeway driving exerts more consistent workload demands on the driver.

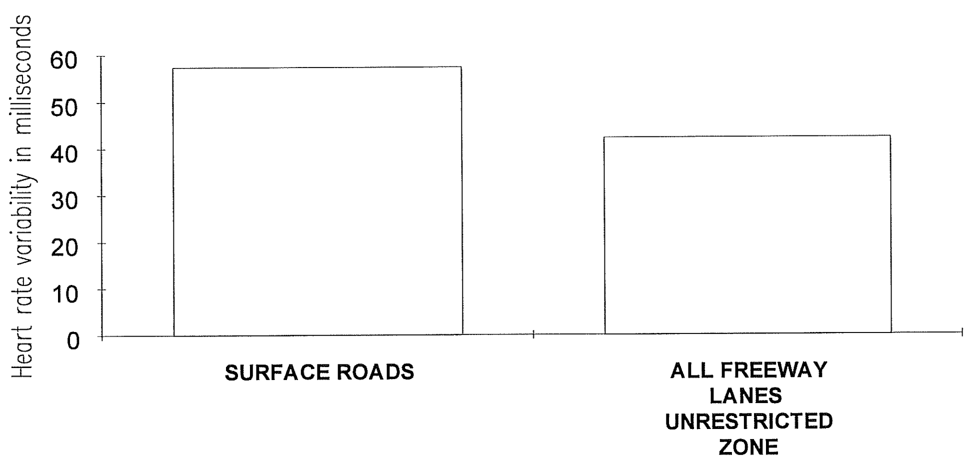

Figure 4: Comparison of heart rate variability for surface roads versus lanes 1,2, and mid restricted zone, F(1,32)=84.32, p=.000.

3. Comparisons Between Freeway Entrance and Freeway Test Zones:

1. The mean interbeat interval was significantly shorter while drivers were on the freeway entrance ramp versus overall restricted freeway driving (cf. Figure 5).
2. The mean interbeat interval was significantly shorter while drivers were on the freeway entrance ramp versus overall unrestricted freeway driving (cf. Figure 6).
3. Heart rate variability was significantly greater while drivers were on the freeway entrance ramp versus overall unrestricted freeway driving (cf. Figure 7).

These findings suggest that driver workload is greater while on the freeway entrance ramp than while driving on the freeway whether that freeway drive involves the restriction of remaining in one lane continuously or whether the driver is allowed to change lanes at discretion.

The HR variability findings are comparable to those found between surface driving and freeway zones. The fact that HR variability is greater on the freeway entrance ramp than during unrestricted freeway driving suggests that workload demands on the freeway, when navigation is left to driver discretion, remains relatively stable compared to the freeway entrance ramp which can be characterized as relatively low demand when the driver first enters the ramp but increases as merging onto the freeway draws nearer.

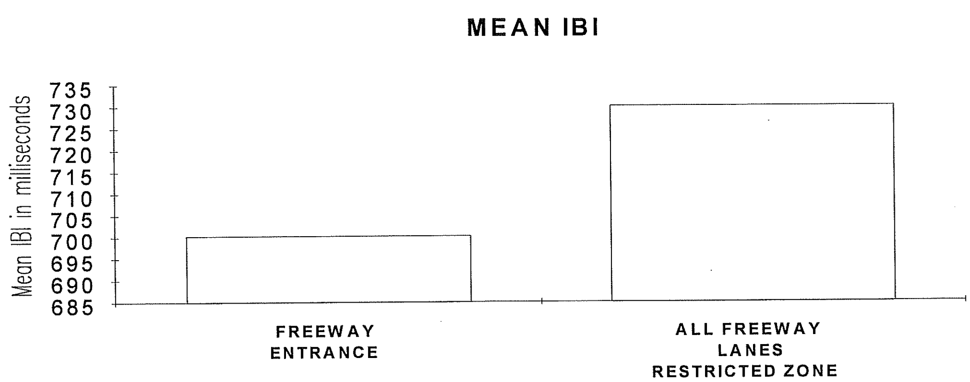

Figure 5: Comparison of mean IBI for freeway entrance versus all freeway lanes restricted zone, $F(1,27)=32.13$, $p=.000$.

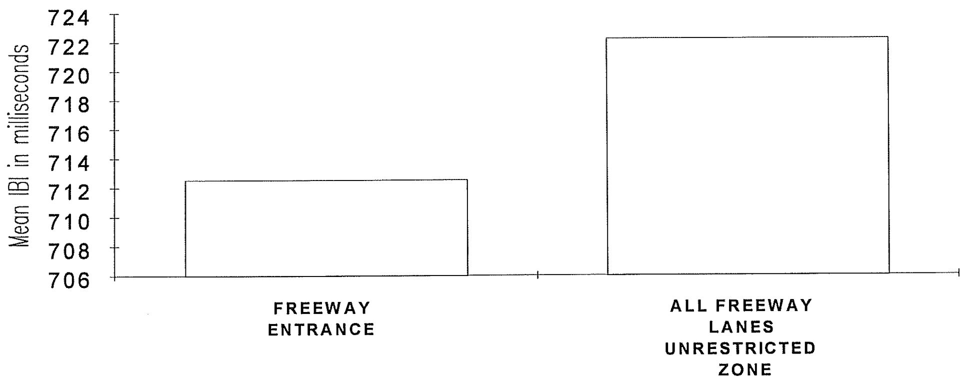

Figure 6: Comparison of mean IBI for freeway entrance versus all freeway lanes unrestricted zone, $F(1,32)=6.45$, $p=.016$.

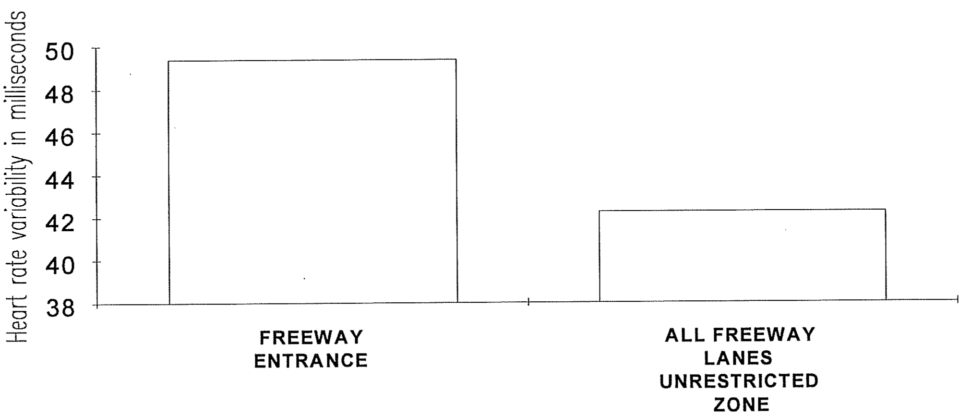

Figure 7: Comparison of heart rate variability for freeway entrance versus all freeway lanes unrestricted zone, $F(1,32)=25.92$, $p=.000$.

4. Comparisons Between The Freeway Entrance and Surface Roads:

1. The mean interbeat interval was significantly shorter on the freeway entrance ramp versus surface roads (cf. Figure 8)

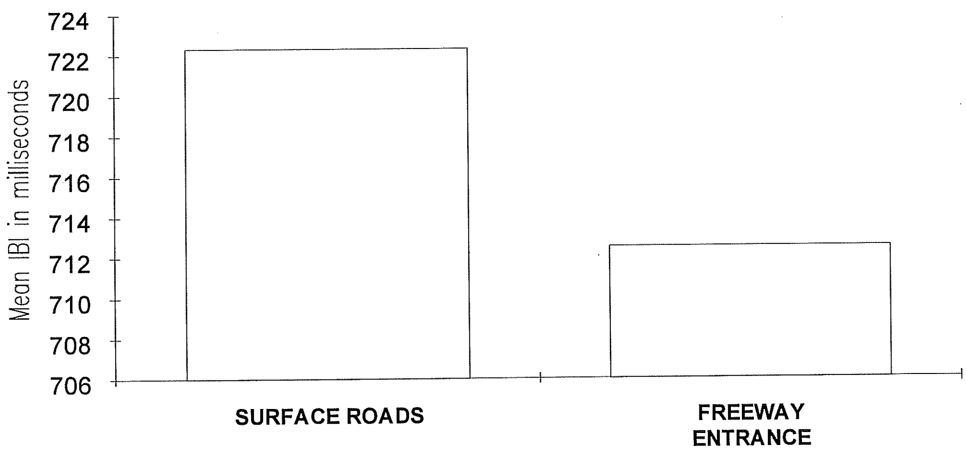

Figure 8: Comparison of mean IBI for surface roads versus freeway entrance, $F(1,32)=16.94$, $p=.000$.

2. HR variability was significantly less on the freeway entrance ramp versus surface roads (cf. Figure 9).

These findings suggest that driver workload is greater while on the freeway entrance ramp than while driving on surface roads. The fact that HR variability was greater on surface roads than on the freeway entrance ramp suggests that even though periods of relatively low and high demands may be experienced on the entrance ramp, such as early on the ramp and freeway merging respectively, these periods of relatively high and low demands encompass an even broader range on surface roads with extremes such as navigating busy intersections and waiting at a stop light respectively.

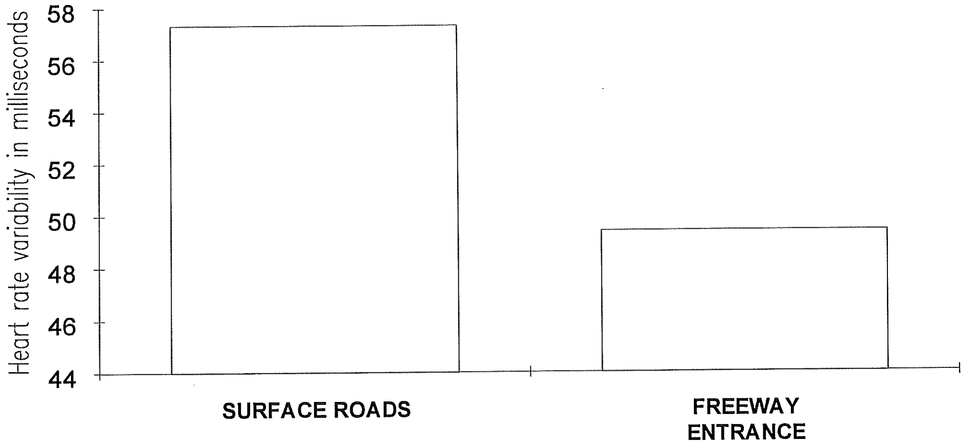

Figure 9: Comparison of heart rate variability for surface roads versus freeway entrance, $F(1,32)=22.29$, $p=.000$.

5. Comparisons Between The Freeway Exit and All Road Environments:

1. The mean interbeat interval was significantly longer while on the freeway exit ramp compared to the freeway entrance, unrestricted freeway driving, or surface roads.

While initial interpretation of this finding would suggest that driver workload reaches its lowest extreme while exiting the freeway, a review of the driving course in this study reveals that a traffic signal at the end of the freeway ramp resulted in long periods of time that drivers would sit stopped prior to entering surface road traffic. Since our coding procedure included this time as part of the freeway exit, it distorts whatever the actual freeway exit effect may be on drivers by contributing to an artificially long mean interbeat interval.

B. Study 2: Level of Service

Study 2 comprised an analysis of the cardiovascular consequences of traffic congestion. The independent variable was estimated freeway level of service. Experimenters were trained from Arizona Department of Transportation photographs that depict traffic congestion from level of service 1 (light) to level of service 6 (heavy) to estimate freeway level of service. Estimates were made whenever experimenters detected a change in congestion that would merit a new category or every 30 seconds as prompted by the coding computer. Since very light and very heavy traffic were not present for most drivers during this study, statistical analysis, using repeated measures ANOVAS, compared only levels of service 2,3, and 4 for significant differences.

1. Comparisons between Level of Service 2, 3, and 4:

1. The mean interbeat interval was significantly longer for level of service 2 versus level of service 3 (cf. Figure 10).

This finding indicates that workload increases as freeway congestion increases from level of service 2 to level of service 3. The fact that level of service 4 was not significantly greater than level of service 3 (indeed almost identical) suggests that plateaus in driver workload as a function of level of service may be present. Results from 3 individual subjects for whom more complete level of service data was available, suggest that level of service and driver workload may be positively correlated. Further data collection in more highly congested traffic will be necessary to determine the significance of this relationship.

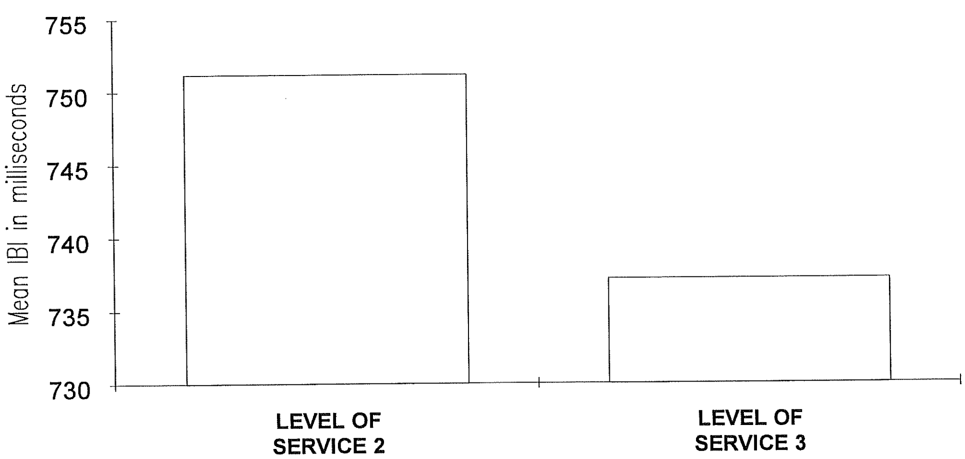

Figure 10: Comparison of mean IBI for level of service 2 versus level of service 3, F(1,21)=6.38, p=.020.

C. *Study 3: Driving Events*

This investigation consisted of an analysis of the impact of selected events that occur in freeway traffic environments. The study had three goals. The first goal was to determine whether events, when they occur in restricted and unrestricted freeway driving environments, vary in cardiovascular workload demands when compared with driving in the same environments when no events are occurring. The second goal was to determine whether the selected events differed from one another in terms of their impact on cardiovascular workload. The third goal was to determine whether there was physiological evidence of an orienting response from drivers at their time of event occurrence.

The selected events included vehicles that move in or out of the lane directly in front of the driver, the driver stepping on the brake pedal, and lane changes made by the driver. In order to determine cardiovascular workload demands for the various events, the individual heart beats during which events occurred, as well as the beats immediately prior and subsequent to that beat were averaged together. In order to determine cardiovascular workload demands for times when events were not occurring, a random sample of three beats, from the same driving condition in which the event occurred, was selected when no events were occurring. For example, if a vehicle moved in front of the driver while driving in the right most lane of the restricted driving zone, a random sample of three heartbeats would be selected from a time while the driver remained in that lane with no events occurring. If a lane change occurred, a sample of three random beats was selected during the time the driver spent in the lane prior to the lane change.

In order to compute means based on adequate frequencies of occurrences, vehicles moving in or out of the lane directly in front of the driver and occurrences of the driver stepping on the brake were combined for analyses and will be referred to as "driving events". Lane changes were treated as a separate category. In order to test for indications of an orienting response to driving events and lane changes, groups of heart beats surrounding these occurrences were analyzed. The orienting response has been demonstrated to elicit a phasic heart rate deceleration in response to stimuli which demand increased attention to the outside (sensory) environment. In order to test for the occurrence of the orienting response to driving events, the average of the three beats prior to the occurrence of the event (Pre), the average of the three beats during which the event occurred (Main), and the average of the three beats subsequent to the event (Post) were computed and compared. All findings are the result of repeated measures ANOVAS.

1. Event Analysis.

No significant differences in cardiovascular workload have yet been found in comparisons of driving events to the overall driving conditions in which they occurred. The data does not support the hypothesis that events such as vehicles moving in or out of the lane directly in front of drivers or applying the brake place either higher or lower demands on cardiovascular workload than does freeway driving in general. These conclusions are tentative and are based only on a preliminary analysis of our data set.

2. Lane Changes.

1. During restricted freeway driving, no significant difference was found in mean interbeat interval for lane changes versus overall driving.

2. During unrestricted freeway driving, the mean interbeat interval was significantly longer during lane changes versus overall driving (cf. Figure 11).

These findings suggest that the impact of changing lanes on cardiovascular workload may vary depending upon on the style of freeway driving in which the driver is involved.

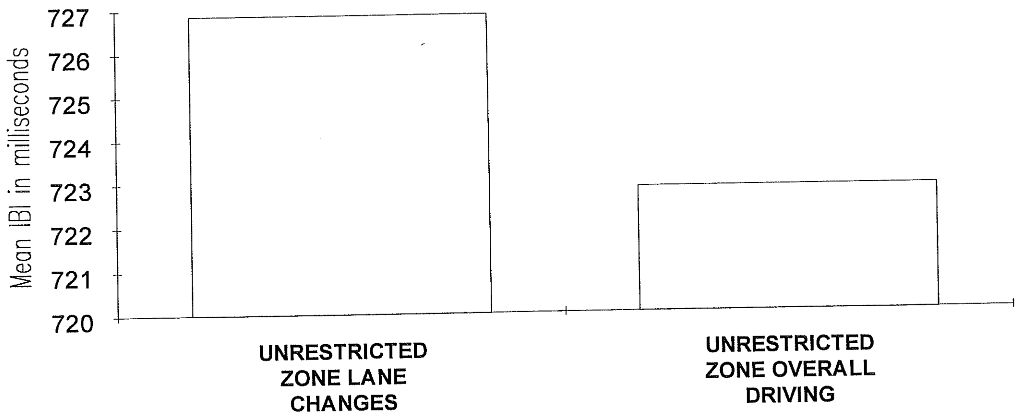

Figure 11: Comparison of mean IBI for unrestricted zone lane changes versus unrestricted zone overall driving, $F(1,32)=9.32$, $p=.005$.

3. Comparisons of Lane Changes With Other Driving Events.

1. During restricted freeway driving, no significant difference was found in mean interbeat interval for lane changes versus other driving events.

2. During unrestricted freeway driving, the mean interbeat interval was significantly shorter during lane changes versus other driving events (cf. Figure 12).

These findings suggest that the cardiovascular workload impact of changing lanes on the freeway relative to other driving events, such as vehicles moving in or out of the driver's lane or the driver braking, may depend on the style of freeway driving in which the driver is engaged. When driving in one lane for a continuous period of time and then changing lanes, the lane change does not appear to be more demanding than other driving events. However, when changing freeway position more frequently and at the driver's discretion, lane changing seems more stressful than other driving events as indicated by higher phasic heart rate at those times.

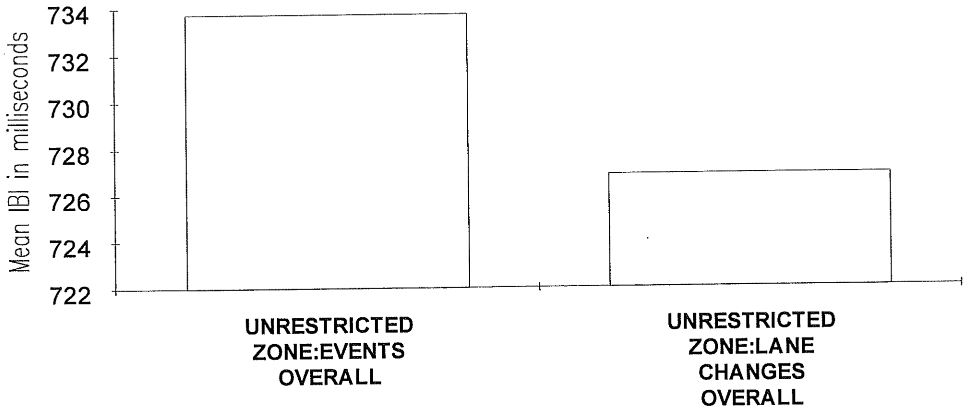

Figure 12: Comparison of mean IBI for unrestricted zone: events overall versus unrestricted zone: lane changes overall, F(1,32)=4.90, p=.034.

4. Comparisons Between Pre, Main, and Post Beats For Lane Changes.

1. During restricted freeway driving, the main mean interbeat interval was significantly longer than pre and post mean interbeat intervals (see chart 13).

2. During unrestricted freeway driving, the main mean interbeat interval was significantly longer than pre and post mean interbeat intervals (see chart 14). The finding of a phasic deceleration in heart rate while changing lanes, both during restricted and unrestricted freeway driving, suggests a physiological orienting response: a time of increased attention to the outside environment for important sensory information.

The data indicate that lane changes appear to be a significant category of driving events. During unrestricted freeway driving, lane changes place a higher demand on cardiovascular workload. Lane changes also appear to exert attentional demands consistent with the physiological orienting response in both restricted and unrestricted freeway driving, with the magnitude of the response differentiating it from overall driving on the freeway only in unrestricted driving style.

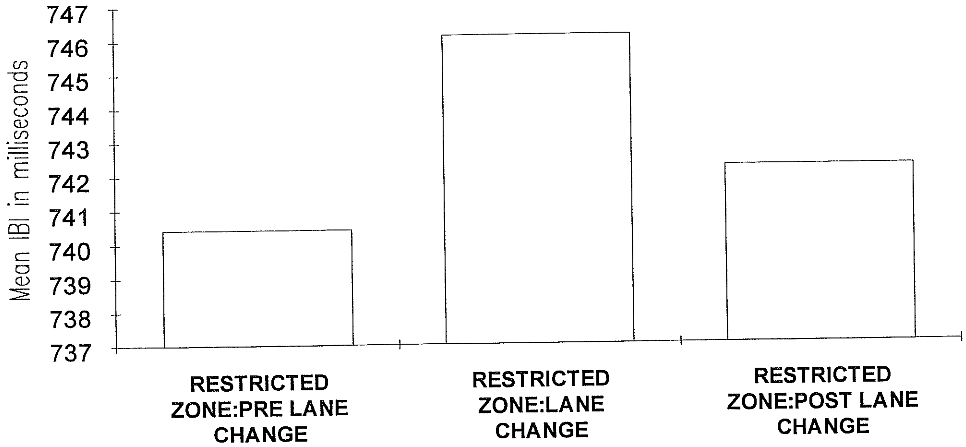

Figure 13: Changes in IBI as a function of lane changes in restricted zone, $F(1,32)=6.94$, $p=.013$.

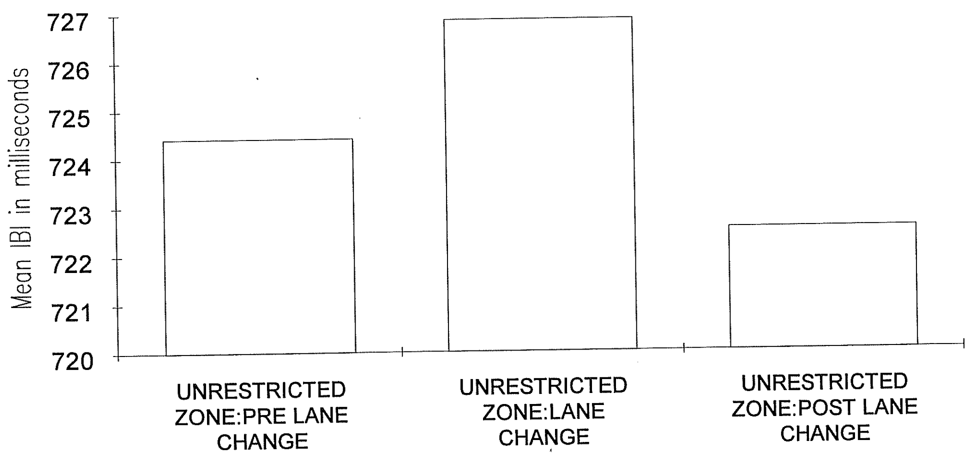

Figure 14: Changes in IBI as a function of lane changes in unrestricted zone, $F(1,32)=5.01$, $p=.032$.

IV. GENERAL DISCUSSION

The three studies discussed above were conducted as part of an effort to quantify driver workload in various driving environments. Workload studies are relevant to the evaluation of the impact of IVHS interventions on the driver. A primary objective of IVHS employments is to reduce traffic hazard and congestion exposure with a result of both safer and more efficient transport and decreased driving stress. The approach used in this investigation provides information which complements the analysis of freeway and surface systems in terms of variables such as vehicle density and point-to-point transit times. This human factors analysis assumes that IVHS interventions which reduce driving stress for the individual will result in a safer and more efficient system. When combined with research from the complementary strategy of measuring roadway system characteristics, IVHS implementation can be optimized to both distribute demands on roadway systems and decrease driving stress for individuals.

The overall goal of this investigation was to evaluate the utility of using cardiovascular measures of driver workload to distinguish between the impact of different driving environments and driving events. We found that both mean interbeat interval and heart rate variability proved to be sensitive to variations in driving environments in a variety of circumstances. These results supports the further use of cardiovascular measures in research designs seeking to study human factors dimensions of transportation issues.

The bulk of our initial hypotheses regarding the cardiovascular impact of driving environments, congestion, and driving events were supported. In the context of road environments, driver workload demands appear to be highest on freeway entrance ramps. Mean IBI was significantly shorter here than while driving on surface roads or during both restricted and unrestricted freeway driving. While driver workload demands may be highest on freeway entrance ramps overall, these demands do not appear to be constant as evidenced by greater HR variability on freeway ramps compared to unrestricted freeway driving. This is probably the result of relatively low demands upon entering the ramp contrasted with relatively high demands when merging with freeway traffic.

Differences in mean IBI indicate that driver workload is greater on surface roads than during restricted freeway driving. Taken with the fact that differences in mean IBI were not found between surface roads and unrestricted freeway driving, the evidence suggests that lower workload demands are associated with more stable freeway positioning and that IVHS interventions that encourage this may reduce workload demands on drivers.

The fact that HR variability was higher on surface roads than during unrestricted freeway driving is probably indicative of the fact that surface driving involves periods of relatively low demand, such as stopping at traffic signals, as well as relatively high demands, such as navigating busy intersections, while unrestricted freeway driving exerts more consistent workload demands on the driver.

This investigation found some evidence to support the notion that increases in traffic congestion on the freeway is associated with increases in driver workload. Mean IBI was greater for an LOS of 3 than an LOS of 2. This relationship may not be linear, however. Mean IBI was not greater for an LOS of 4 compared to an LOS of 3. Further investigation in this area is certainly warranted and in traffic environments which better provide a full range of LOS levels for statistical analysis.

In the context of events that occur during freeway driving, our data supported the notion that lane changes should be regarded as especially important. Lane changes placed greater workload demands on drivers than other driving events during restricted freeway driving (mean IBI was shorter for lane changes versus all other driving events). Further, the phasic decrease in mean IBI for lane changes (relative to the three beats prior and subsequent), provides physiological evidence for an orienting response. These findings imply that IVHS interventions which instruct drivers to change lanes may be either helpful or stressful to drivers, depending upon how the technology is implemented.

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