ARIZONA DEPARTMENT OF TRANSPORTATION

REPORT NUMBER: AZ92-366

PSYCHOLOGICAL AND PHYSIOLOGICAL CONSEQUENCES OF DRIVING STRESS

Final Report

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November 1991

Prepared for:
Arizona Department of Transportation
206 South 17th Avenue
Phoenix, Arizona 85007
in cooperation with
U.S. Department of Transportation
Federal Highway Administration

Technical Report Documentation Page

1. Report No. AZ92-366	2. Government Accession No.	3. Recipient's Catatlog No.
4. Title and Subtitle Psychological and Physiological Consequences of Driving Stress		5. Report Date November 1991
		6. Performing Organization Code
7. Author(s) Edward K. Sadalla and Edwin Hauser		8. Performing Organization Report No. CART-1991-1
9. Performing Organization Name and Address Center for Advanced Research in Transportation College of Engineernig and Applied Sciences Arizona State University, Tempe, AZ 85287		10. Work Unit No.
		11. Contact or Grant No.
12. Sponsoring Agency Name and Address **ARIZONA DEPARTMENT OF TRANSPORTATION** **206 S. 17TH AVENUE** **PHOENIX, ARIZONA 85007**		13. Type of Report & Period Covered Final Report 5/91 - 12/91
		14. Sponsoring Agency Code

15. Supplementary Notes

Prepared in cooperation with the U.S. Department of Transportation, Federal Highway Administration

16. Abstract

This project consisted of a review of the literature in subject areas related to driving stress, aging, and health. This document contains:

1. A comprehensive review of the literature concerning the impact of driving on the health, behavior, and subjective well-being of drivers.

2. A comprehensive review of the literature on the cognitive and perceptual consequences of aging that is relevant to driving tasks and driving stress.

3. The identification of personality and lifestyle dimensions which contribute to driver susceptibility to stress.

Recommendations for research in each of these subject areas is suggested.

17. Key Words Driving stress, aging, health, personality.	18. Distribution Statement Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161	23. Registrant's Seal

19. Security Classification (of this report) Unclassified	20. Security Classification (of this page) Unclassified	21. No. of Pages 171	22. Price

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INTRODUCTION

In recent years behavioral scientists have extensively researched the impact of the urban environment on the physical health and the subjective well being of residents. A sizable body of literature now exists which documents potentially harmful consequences of such urban variables as population size, population density, ambient noise, air quality, and residential design. This research falls under the heading of "urban stressors" and is used by urban planners and architects to guide planning and design decisions. Despite the recent profusion of research in this area, certain aspects of the urban environment have received relatively little empirical attention.

Among the most important of these neglected topics concerns the effect of driving conditions on the health and well being of drivers and their passengers. An adequate understanding of these factors is vital when we consider that the automobile is a central part of the daily life of most urban and suburban residents, as well as the primary mode of transportation for nearly 90% of the U.S. labor force (Novaco, Stokols, and Milanesi, 1990). In addition, in major metropolitan areas the proportion of automobile commuters ranges from 85% to 93%. With increasing traffic congestion in such areas, commutes are becoming longer, more demanding, and more stressful. In one study of transportation related problems (Quinn & Staines, 1979), 33% of the respondents characterized their driving problems as "sizable" or "great." In another 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."

These startling figures indicate the substantial role that driving plays in the daily lives of modern Americans. As greater numbers of people come to rely on automobile transportation, driving conditions are becoming more congested. This means that daily commutes become longer and more difficult, placing increasing demands on the individual driver. A partial resolution to these problems involves the development and implementation of IVHS (Intelligent Vehicle-Highway System). Early developments will include driver information advisory services, a prototype of an ADIS (Advanced Driver Information System), as well as traffic control mechanisms such as freeway ramp metering. However, because automobile travel is such an integral part of modern life, understanding how current and future driving stressors affect the individual is an important concern.

Specifically, it is important to evaluate the impact of road design and traffic variables on levels of "driver stress." Driver stress is a term which refers to the cumulative negative physiological, psychological and behavioral reactions which occur as a consequence of driving. These reactions, while sometimes less immediate and less visible than monetary and time losses, should nevertheless be considered during the design of a transportation system. Some such consequences are thought to include accident rate, short and long term health problems, and driver conflict.

This paper discusses the existing literature relating to driver stress and its physiological and psychological effects. However, before specifically discussing stress in the driving situation, it is necessary to discuss different ways of conceptualizing stress as a general phenomenon.

STRESS MODELS

The concept of "stress," as it applies to human beings, is <u>polysemic</u>; it refers to a diverse set of concepts and phenomena. The term itself originated in the field of engineering, where it refers to a measure of force per unit area. The resulting temporary or permanent change in the structure of the object is termed "strain." In this usage, the distinction between the external forces and their effect is quite clear. However, when the word "stress" is applied to human beings, the distinction quickly becomes blurred. Humans, in contrast to physical objects, are not passive elements within their environmental system. Rather, people actively perceive, interact with, and alter their surroundings. To be useful in this context, a model of stress must encompass a number of different aspects, including external stimuli, the individual's perceptions, physiological and psychological responses, and coping mechanisms. Further, the model must explain how these elements interact with each other to form an adaptable system. Historically, theories of stress have not emphasized such an integrated viewpoint. Cox (1978) describes three approaches that previous researchers have used in defining stress: response-based, stimulus-based, and interactional models.

<u>Response-Based Stress Models</u>

Response-based approaches to studying stress place considerable emphasis on the individual's response to disturbing environmental features. The primary focus of attention is on specifying the particular pattern of physiological or behavioral changes which may be taken as evidence that an individual is, in fact, under pressure from an external source.

This approach to stress was first proposed by Hans Selye (1956). Selye noted that a number of different kinds of environmental stressors produced a similar pattern of physiological responses. These responses represented the organism's preparation for defense. Selye believed that the nature of the stress response was essentially identical regardless of the type of stressor or even, within reason, the species of the organism. He called this common pattern of physiological reactions the General Adaptation Syndrome. With continued exposure to the stressor, the stress response proceeds through three identifiable stages: alarm, resistance, and exhaustion. The alarm phase involves the initial "fight or flight" reaction, in which the organism prepares itself physiologically for the activity that will be necessary for survival. This state of physiological arousal cannot be maintained indefinitely, and if exposure to the stressor is continued, the organism will enter the resistance phase. In this phase, the organism adapts to the stressor, and many of the physiological changes associated with the alarm reaction are reduced. Further prolonged exposure to the stressor may lead to the exhaustion phase, in which the organism's ability to adapt to the stressor is lost, and the organism may collapse and/or die.

One weakness of this sort of approach to studying stress is that classifying any stimulus that produces a typical "stress response" pattern of physiological changes as a stressor may lead to including conditions that are not experienced as particularly stressful, such as passion, exercise, and surprise, under our definition of stress inducing situations (McGrath, 1970). Another important weakness of response-based approaches is the fact that there are considerable individual differences in responses to stress. Two people presented with the same noxious stimulus do not react identically. One may experience a sharp rise in heart rate while the other does not. Moreover, a single person presented with the same stimulus on two different occasions may react differently each time. Also, all symptoms of the "syndrome" do not always appear together. The problem inherent in response-based definitions of stress, then, is the lack of a consistent correspondence between the external stressor and the individual's immediate internal state. These approaches leave no room for response variability, and such variability, in fact, is frequently reported in studies of individuals in "stressful" situations.

Stimulus-Based Stress Models

Stimulus-based approaches to stress describe the concept in terms of the characteristics of environments that are considered stressful. Stress is conceptualized in terms of external forces present in the environment that may act upon the individual, a usage very closely related to the original engineering terminology. The emphasis in this framework is to enumerate the conditions that can be accepted as stressors. These include excessive information processing demand, noxious environmental stimuli, perceived threat, disrupted physiological function, isolation, group pressure, and frustration.

The main problem with such an approach again lies in the area of individual differences. A high demand situation, for example, may be stressful for most, but not all, people. Stimulus-based stress models cannot account for these variations in what different individuals find stress inducing. Also, this type of framework tends to encourage the development of a number of different stress theories that each cover only one distinct class of stimulus conditions, leading to a fragmented, and relatively impoverished, understanding of the stress phenomenon (McGrath, 1970).

<u>Transactional Stress Models</u>

The third approach to conceptualizing stress combines aspects of the response-based and stimulus-based definitions with an emphasis on the perceptions and interpretations of the individual. Cox suggests that stress can be most adequately described as "part of a dynamic system of transaction between the person and his environment." Such transactional or interactional models (e.g., Cox, 1978; McGrath, 1976; Lazarus, 1966) place a good deal of importance on the perceptual-cognitive processes of the individual. Human beings are not purely objective evaluators of their environments. Each person has his or her own unique perspective which colors the interpretation of reality. People differ in personality and have different histories. Any given environmental feature is not experienced identically by any two people. Moreover, individuals' abilities to cope with the environment, and their own perceptions of these abilities, also differ. With such variation in perceptions and abilities, it is not surprising to discover significant individual differences in stress responses.

The crucial element in transactional theories is a cognitive appraisal process (Lazarus, 1966). The basic idea of cognitive appraisal is that the stress inducing qualities of an event are dependent on the individual's perception and interpretation of that event. Thus different people in the same situation may experience it very differently. One way of conceptualizing this process is to view cognitive appraisal as a point at which an individual compares his perceptions of environmental demand with his perceptions of his abilities to cope. Environmental demand can produce stress only when the individual anticipates that he or she will be unable to adequately cope with it without endangering other goals. Stress will arise when there is a "mismatch" or "imbalance" between the perceptions of situational demand and coping ability. Figure 1 (from Cox, 1978) shows how cognitive appraisal plays a key role in a transactional model of stress.

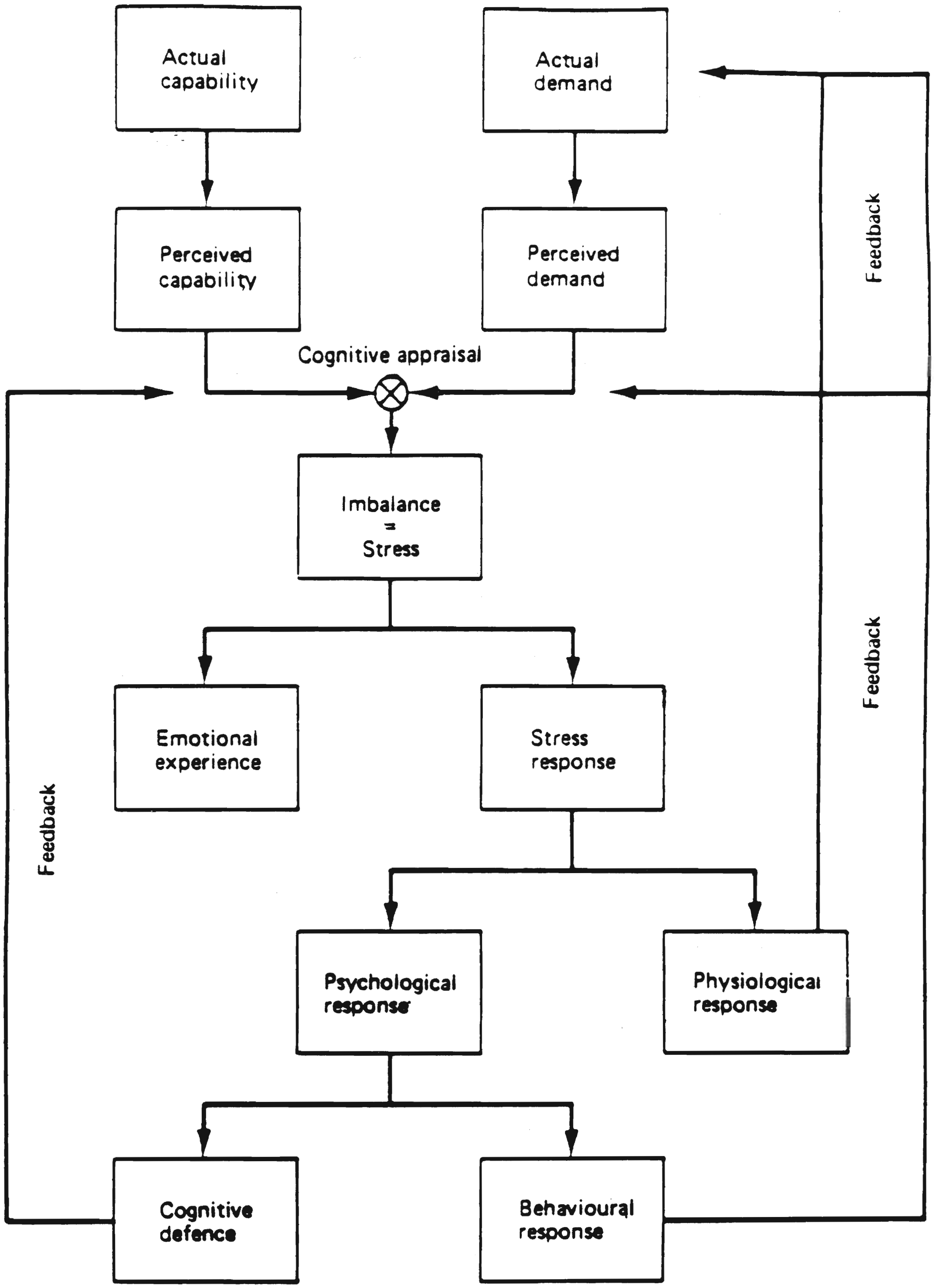

Figure 1. A transactional model of stress (Cox, 1978).

Every situation places demands on the individual. These are represented by the "actual demand" box in the model. These demands may include physical, attentional, or information processing requirements of the external situation, or they may be internally generated by the individual's physiological or psychological needs. However, the individual does not objectively assess the level of demand present in a given situation, but, instead, he or she views the situational demands through the filter of prior experience, with the result that the "perceived demand" in any given situation is unique to each individual experiencing it.

Each individual has a certain ability to adapt to the situation, based on his or her physical, mental, emotional, and behavioral capabilities. However, these abilities are not perceived objectively, but are also viewed through the filter of prior experience and personal belief. These actual and perceived abilities are represented by the "actual capability" and "perceived capability" boxes in the upper left of the model. The next step involves a comparison of the levels of perceived demand and perceived capability.

If, at this point, perceived capability falls below perceived demand, stress will result. It is important to remember that this comparison step involves perceived, rather than actual, levels of capability and demand. According to this model, a person whose actual level of capability is, in fact, insufficient to deal with the situation that he confronts but who has evaluated his abilities as adequate will not experience stress until such a point that feedback from the environment (lack of successful change) causes him to reevaluate his coping abilities and reappraise the demand-capability comparison as imbalanced and stressful. Similarly, a person who underestimates his or her own abilities will experience stress in a situation that he or she could, in fact, handle effectively. The operation of these perceptual processes, then, allows for a wide range of individual differences in stress responses.

When a given individual does experience stress, it involves both an emotional experience and a specific stress response. These two processes are not as easily separable as the model would suggest. The distinction is made, however, to emphasize the differences between the subjective experience of stress and its more objectively quantifiable physiological and psychological effects. The next stages of the model involve cognitive and behavioral attempts to cope with the stressor. If such responses are successful, the event is reevaluated as non-stressful and further coping behaviors are unnecessary. This benign reappraisal may be the result of cognitive restructuring or an objective change in the environment caused by an overt behavioral coping response. If reappraisal processes still indicate an imbalance, the individual continues to experience stress and continues to make attempts at coping.

The overall form of the model is a continuous loop, and this form is important in that it emphasizes the interaction between individual and environment. This process is even clearer in the simplified transactional model provided by McGrath (1976). This model is shown in Figure 2 below.

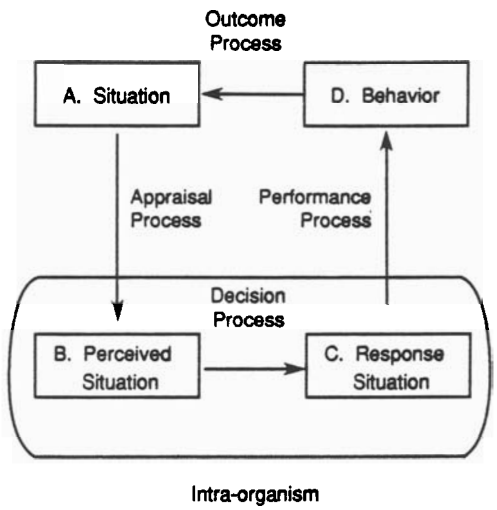

Figure 2. A simplified transactional model (McGrath, 1976).

It indicates that a situation (A), is appraised by the individual, resulting in a perceived situation (B). This is then used as the basis for a decision (C), which is carried out with certain behavioral responses (D). This behavior has an impact on the situation, which is then reappraised, beginning another cycle.

In the Cox model, the loop involves several different feedback mechanisms (cognitive, physiological, and behavioral) and is slightly more complicated than the McGrath model, but the same sort of reasoning applies. Feedback from any system can be sufficient to allow reappraisal of the person-environment interaction, which may, but need not, then be considered non-stressful.

TYPES OF STRESSORS

Two very different types of stressors have been investigated by researchers concerned with the effects of stress on humans. One line of research involves the effects of major life events on the health and well being of the individuals who experience them. Holmes and Rahe (1976) have developed an instrument to measure the number of stressful life events than an individual has experienced, and these are weighted according to the severity of the change. Events such as death of a spouse, divorce, marriage, retirement, pregnancy, and change in employment are included on this scale. Relationships have been found between the number of stressful life events and a variety of physical and psychiatric disorders. The attention of other researchers has centered on the relatively minor hassles that individuals encounter in the course of their everyday activities rather than on major life changes. Events such as losing a wallet and arguing with a teenage child may be placed in this category. The number of such events that an individual experiences is also correlated with physical and psychological health, and, in fact, the relationship is stronger for these daily hassles than for major life events.

The stress induced by driving may be classified as a daily hassle. Since driving is a very frequently and regularly encountered stressor, it is important to be able to understand the effects that driving has upon the health and well being of driver, and to be able to specify features of the driving system that may be modified to reduce this negative impact.

Driving Stress

The stress involved in driving is not attributable to any single source. Rather there are several aspects of driving that may each contribute to the experience of driving stress (Robertson, 1988). The driving task, the set of operations that are required to keep a vehicle on the road and avoid accidents, is only one potentially stress inducing aspect of the driving situation. The transport task, with the goal of getting from point A to point B within a certain period of time, is another potential stressor. Additionally, the environment inside the vehicle and the external environment can greatly affect the level of stress experienced by the driver. Selye (1976) echoes this point, stating that the "stressor potentiality" of driving is due to a combination of concentration, anxiety, physical discomfort of maintaining the same position for an extended period of time, boredom, vehicle vibration, noise, and many other possible factors. Robertson (1988) reports a commuting stress study by Costa et al. (1983) that found that the discomforts experienced by automobile drivers included such diverse concerns as the fear of being late (reported by 14% of the drivers in their sample) and the fear of being involved in an accident (reported by 61%).

Even within the driving task, there may be several different factors which contribute to the experience of driving stress. Gulian et al. (1989) and Synodinos and Papacostas (1985) have conducted factor analyses that indicate the existence of several different dimensions within the general concept of driving stress. Gulian et al. adopt a transactional approach to driver stress and conceptualize it as a set of responses associated with the perception and evaluation of driving as demanding and dangerous, relative to the individual's driving abilities. They suggest that driving stress might be experienced on two different levels. Specific events which tax the driver's ability may produce immediate, situational-level stress. Additionally, long-term repeated exposure to such events may have cumulative physical and psychological effects. It is emphasized that a number of factors extrinsic to the driving situation, such as the quality of one's family life and employment situation, may interact with driving stress if these influences affect driver's appraisal of road incidents.

Gulian et al. have developed an instrument to measure driving stress. The Driving Behavior Inventory (DBI) includes 97 questions about demographics; car use; accident history; health, personal, occupational, and domestic problems; mood, emotions, and attitudes toward driving, traffic situations, and road users; and coping strategies and behavioral responses to general and specific traffic situations. Respondents are asked such questions as "When in a hurry do you tend to drive near the car in front of you?" and "Would you say that other drivers drive too fast?".

Factor analyses of the DBI show two possible factor structures, with one and five factors respectively. This indicates that, depending on the specific type of analysis performed, the DBI is either measuring a singular construct or a combination of five different constructs. Eighteen of the 33 items designed to highlight driver stress reactions load >.40 on the single factor in the simpler solution. The five factor solution is as follows:

Factor	% Variance
I. Driving Aggression	15.5%
II. Irritation When Overtaken	7.6%

III. Driving Alertness 6.4%

IV. Driving Dislike 5.0%

V. Frustration When Failing to Overtake 3.7%

This solution suggests that driver stress may be made up of a combination of five different dimensions (driving aggression, irritation when overtaken, driving alertness, driving dislike, and frustration when failing to overtake), each of which contributes uniquely to the level of stress experienced by any given driver. A replication of the analysis with a second sample provided similar results. The two possible factor structures found in the second study, and a list of the questionnaire items that make up each factor can be found in Figure 3.

Items	Loading
'Driving Aggression': Contribution to Total Variance: 14·1%	
Driving usually makes me feel aggressive	0·60
I tend to overtake other vehicles whenever possible	0·57
When irritated I drive aggressively	0·48
When I try but fail to overtake I am usually frustrated	0·48
Driving a car gives me a sense of power	0·46
I think it is worthwhile taking risks on the road	0·42
'Dislike of driving and related anxiety': Contribution to Total Variance: 6·9%	
I am worried to drive in bad weather	0·58
I am always ready to react to other drivers' unexpected manoeuvres	0·56
Driving usually does not make me happy	0·53
In general I do not enjoy driving	0·52
Driving usually makes me feel frustrated	0·48
I feel confident in my ability to avoid an accident	0·48
I am more anxious then usual in heavy traffic	0·48
I am more tense on new than familiar roads	0·47
I am usually patient during the rush hour	0·42
'Driving Alertness': Contribution to Total Variance: 6·4%	
I am on the alert on a difficult road	0·81
I increase concentration on a difficult road	0·74
Slow moving vehicles are a traffic hazard	0·55
I am always ready to react to other drivers' unexpected manoeuvres	0·42
An accident is always possible because of other drivers' poor judgement	0·41
'Irritation when Overtaken': Contribution to Total Variance: 4·8%	
I feel bothered when overtaken at a junction	0·64
I feel angry when overtaken at a junction	0·62
I feel anxious when overtaken at a junction	0·58
'Overtaking Tension': Contribution to Total Variance: 3·5%	
I do not feel indifferent when overtaking another vehicle	0·64
I feel satisfied when overtaking another vehicle	0·62
I feel tense when overtaking another vehicle	0·46
'General Driver Stress': Contribution to Total Variance: 15·7%	
I am annoyed to drive behind slow moving vehicles	0·70
When I try but fail to overtake I am usually bothered	0·66
When I try but fail to overtake I am usually frustrated	0·66
I am usually patient during the rush hour	0·53
When irritated I drive aggressively	0·52
Annoyed when traffic lights change to red when I approach them	0·52
I do not feel indifferent when overtaking another vehicle	0·50
In general I mind being overtaken	0·49
Driving usually makes me feel aggressive	0·48
Driving usually makes me feel frustrated.	0·48
I am more tense on new than familiar roads	0·47
I lose my temper when another driver does something silly	0·46
I feel tense when overtaking another vehicle	0·43
Driving a car gives me a sense of power	0·43
I feel bothered when overtaken at a junction	0·43
I feel satisfied when overtaking another vehicle	0·40

Figure 3. Factor structure of the DBI (study 2) and items loading on each factor (Gulian, 1989).

Gulian et al. believe that driver stress is a "compound function of factors intrinsic (traffic conditions) and extrinsic (personal life) to driving" (1988). To test this idea, analyses were carried out to determine which categories of questionnaire responses could be used to predict reported driving stress levels. Variables not related to driving, such as life stresses and age, are predictive of four of the five previously identified driving factors, as well as the general driving stress factor identified in the single factor solution. Specifically, higher life stress was associated with higher driving stress, and increasing age was associated with increased dislike of driving. The relationship between life stress and driving will be further discussed in the next section of the paper.

Synodinos and Papacostas (1985) also conducted a factor analysis of driving behaviors. Their instrument is called the Behaviors in Traffic (BIT) questionnaire. It consists of 26 five-point response scales which measure time-urgent behavior in traffic situations. Factor analyses of the BIT reveal four factors that account for 43% of the variance in responses. The factors can be labelled as ursurpation of right-of-way, freeway urgency, externally-focused frustration, and destination-activity orientation.

These two factor analytic studies show that driving stress is not a singular concept. It is made up of a number of different frustrations that have in common only the fact that they all occur in the driving situation. The finding that driving stress can be predicted by non-driving variables has a further implication for our model. If individual difference variables such as age and life stress can affect driving stress levels, the experience of driving stress cannot be a direct function of the road and traffic environment. Rather, for these type of mediators to operate, driving stress must be a function of the environment <u>plus</u> the individual. This connection occurs at the level of perception and interpretation, and a model of driving stress should concentrate on this interface. Transactional stress models, with their emphases on individual perception and cognitive appraisal, focus specifically on these processes and thus may be the best models for explaining driving stress. Two researchers, Gstalter and Helander, have proposed models of the driving situation (but not of driving stress specifically) that incorporate elements of transactional models.

Gstalter (1985) has proposed a theoretical approach to the driving situation that takes the form of a continuous loop: the objective traffic situation is perceived by the individual on the background of his or her personal experiences. The individual then compares this perceived situation with his or her perceptions of the coping possibilities. This comparison results in a subjective level of confidence in one's ability to control the situation. This leads to decisions between possible actions, and the action itself leads to a change in the objective situation, thus closing the loop. Gstalter further speculates that the cognitive-emotional parts of the comparison process will decrease in importance as the actions associated with the driving task become more practiced and essentially automatic.

Helander (1975) has also proposed a model of the driving system that emphasizes the interactions between the driver, the vehicle, and the environment. According to this model (Figure 4, below), the properties of the environment are embodied in the concept called environmental complexity. This includes the static environmental features, such as the road surface and surroundings, and dynamic environmental features, such as one's own car and the other traffic on the roadway. The driver perceives this environmental complexity, not objectively, but through processes that are influenced by one's personal attitudes, motivation, and knowledge.

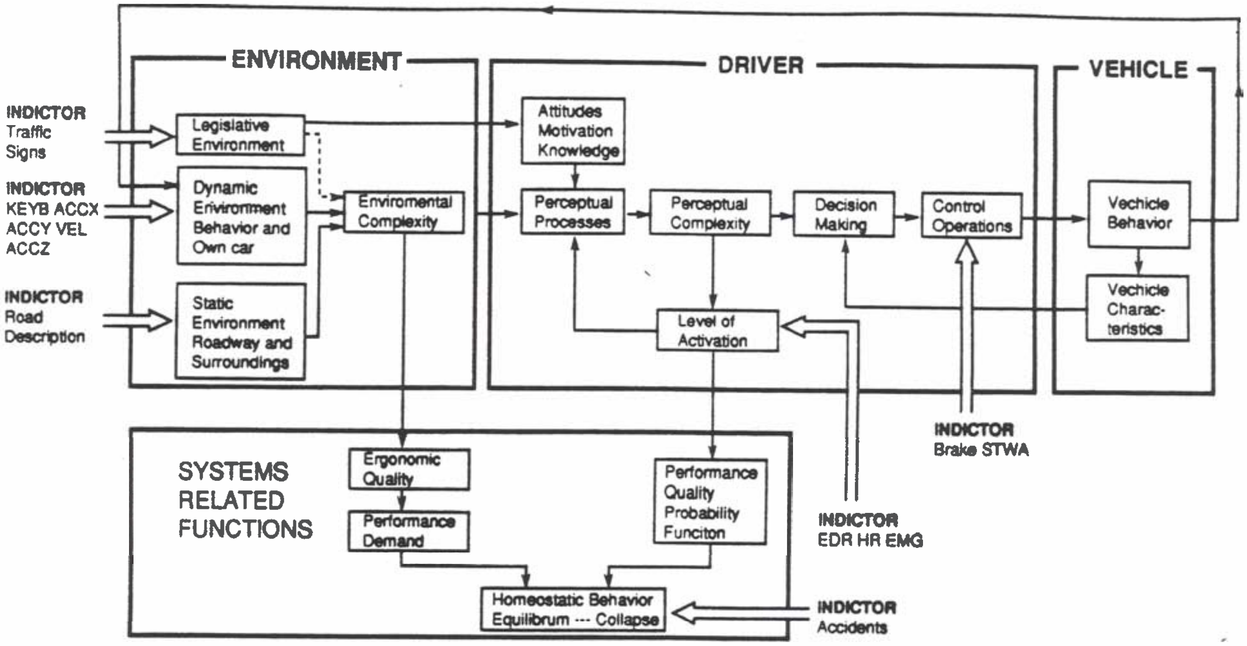

Figure 4. A model of driver, vehicle, and road system interactions in the driving situation (Helander, 1975).

Perceptual complexity, the driver's interpretation of environmental complexity, describes the total influence of the environment on the driver. The level of perceptual complexity determines the activation level of the driver. Activation level can be measured through physiological correlates such as heart rate and galvanic skin response. Activation level, in turn, affects performance in terms of vehicle control operations, which affect the external environmental situation.

Neither of these two models directly deals with the idea of driving stress, but it is apparent at what point such a concept would enter each scheme. In Gstalter's model, the perceived situation is compared with perceived coping possibilities to arrive at a subjective confidence level. If the perceived situational demand exceeded coping abilities at this comparison point, stress would result. In Helander's model, perceptions of environmental complexity influence the driver's activation level. A high activation level is a necessary prerequisite for the experience of stress.

It is at this point, then, that the concept would enter into the model.

We can combine features of these two models to create a useful model of driving stress. From Gstalter we can borrow the cognitive appraisal process in which the perceived driving situation is compared to perceived coping abilities. From Helander we can borrow an emphasis on the interaction between the driver and the road system and on the influence of non-driving variables such as attitudes and motivation on the perception of the environment.

This driving stress model is shown in Figure 5 below. The level of

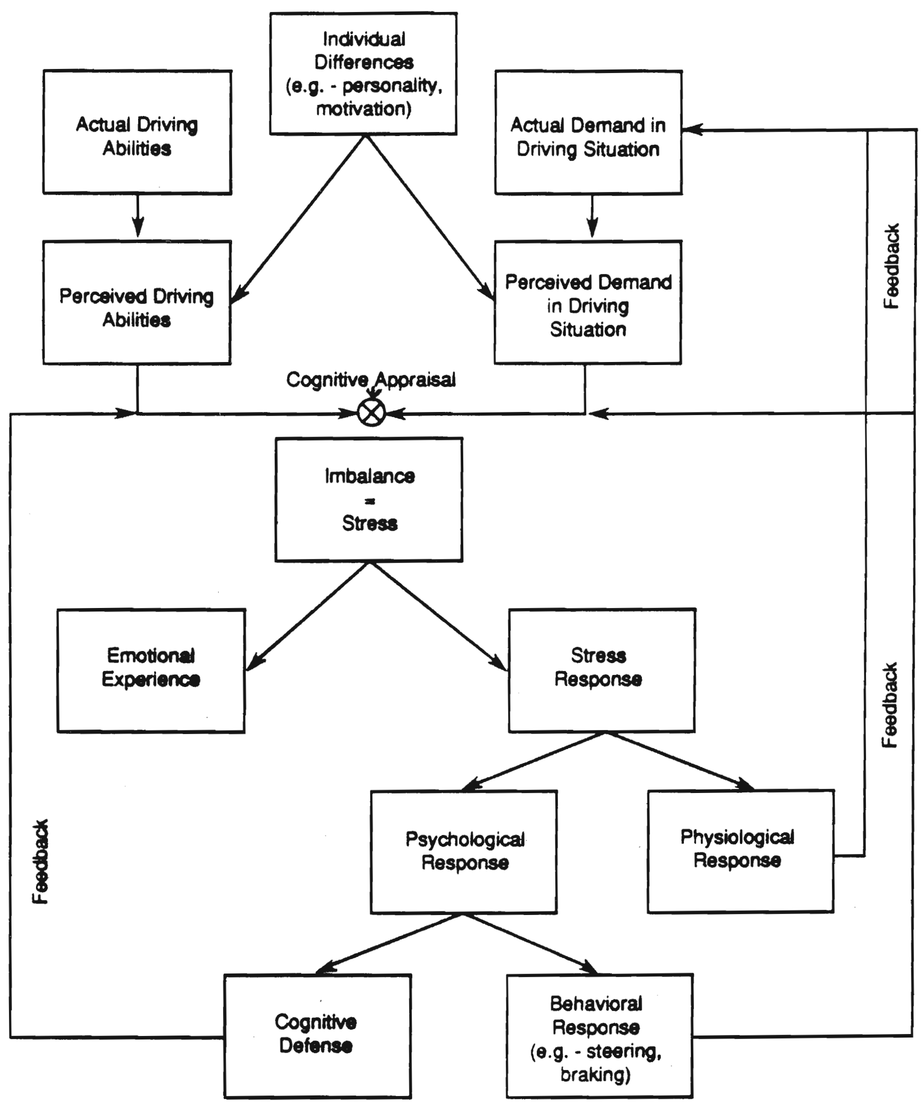

Figure 5. A transactional model of driving stress.

demand in the perceived driving situation, which is a function of the actual situation and of other non-driving variables, is compared with the level of perceived coping abilities, which is a function of actual abilities and other individual difference variables. If coping abilities are judged to be inadequate to deal with the immediate situation, stress results. This involves both a subjective emotional response and specific psychological and physiological changes. Active attempts to cope with the stressors in a driving situation are primarily behavioral (steering, increasing or decreasing speed, etc.). However, it is possible that cognitive strategies might also be used in some driving situations (e.g., when other road users will not allow the driver to change lanes). These coping responses change the situation, which is then reappraised. If the overall situation is still stressful, the cycle continues.

The immediate psychological and physiological effects of driving stress, however, are only part of its total effect. Continued exposure to driving stresses also has a cumulative effect on the individual. Since this model shows how driving stress is produced, rather than enumerating all of its possible consequences, these long-term effects are not specifically indicated. However, driving stress may produce long-term changes in the health and subjective well being of the driver. These effects are not limited to the driving process, but may affect other aspects of the individual's life, such as work productivity and residential satisfaction.

Stressful Life Events and Driving

It has been previously mentioned that life event stress is associated with high levels of driving stress (Gulian et al., 1989). Life event stresses have been the subject of many studies, most of which have been concerned with the connection between life changes and illness. It has been suggested (Selzer and Vinokur, 1975) that the influence that these stressors have on the individual might include changes in mental functions that directly influence behavior. Specifically, life event stress might affect mental functioning in such a way that driving behavior changes and the likelihood of accidents increases. An accident clearly represents a situation in which situational demands exceeded coping abilities, and thus accidents may be viewed as extreme examples from the range of driving stress situations. If Selzer and Vinokur are correct, life event stress may reduce an individual's behavioral coping ability or alter the cognitive appraisal process in such a way that driving stress is increased, resulting, in the most extreme situations, in increased accident rates.

Experimental evidence supports this line of thought only indirectly. Rather than evaluating the coping abilities and mental processing skills of individuals with different levels of life stress, studies have typically been limited to comparing the life stress levels of individuals who have had an accident with those who have not had an accident. For example, Brown and Bohnert (1968) report that 80% of their sample of 25 drivers who were involved in fatal accidents had been under serious stress prior to the accident, while only 18% of a matched sample of 25 drivers who had not been in an accident reported being under such stress.

Selzer (Selzer, Rogers, and Kern, 1968; Selzer, 1969; Brenner and Selzer, 1969) has conducted a similar study. He compared 96 drivers who had been at fault in fatal accidents with a matched control group who had not been in an accident. Fifty-two percent of the fatal accident group had experienced recent social stress while only 18% of the controls reported similar events. The types of stresses reported included serious and disturbing conflicts with significant others, the death or serious illness of a loved one, vocational difficulties, and financial problems. Interpretation of this result is complicated by the fact that the fatal accident group also exhibited a higher rate of psychopathology, including alcoholism, paranoia, depression, and suicidal thoughts, than the control group. If the alcoholics in the fatality group are excluded from the analysis, rates of psychopathology do not differ between the two groups, but those drivers in the fatality group still reported significantly more life stresses than the controls (42% vs. 18%).

A slightly different sort of investigation was conducted by McMurray (1970). Accident and violation rates of individuals involved in divorce proceedings were compared to average population levels. Subjects were grouped into four categories (male plaintiff, female plaintiff, male defendant, and female defendant) for analysis. During the seven year period covered by the driving record, the accident rates for those people involved in divorce proceedings were from 43 to 82% higher than the average rates. Violation rates were 78% to 195% higher. Similar results were found for the one year period associated with filing the divorce petition (from six months before to six months after the filing of the document). For all four of the groups studied, the period of greatest accident and violation activity was the first three months after filing the divorce petition (see Figure 6, below). The types of violations for which the

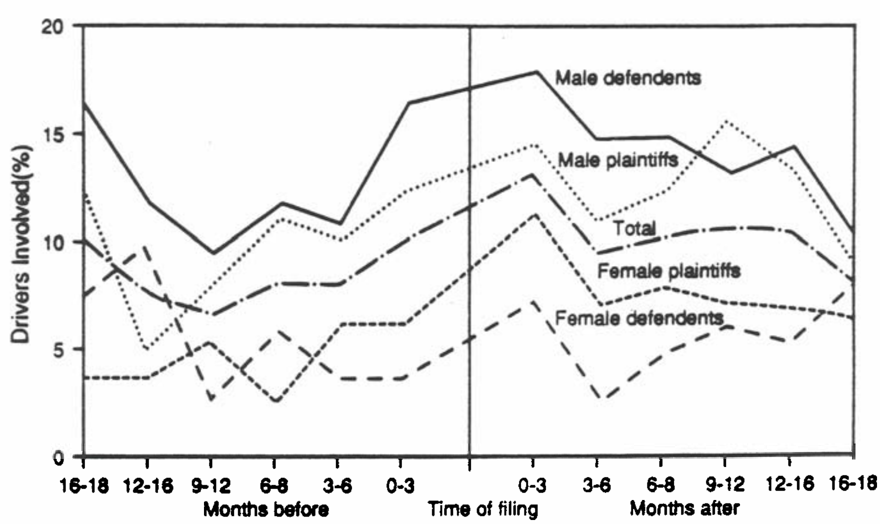

Figure 6. Percentage of drivers involved in accidents and violations before and after filing for divorce (McMurray, 1970).

divorce group were cited differed from the average types of violations in the population. Fewer serious violations (those requiring mandatory license suspensions) were found in the divorce group, but minor violations involving speeding, failure to yield, and failure to stop occurred more frequently in the divorce group than in the population at large.

These studies do suggest that driving stress, as evidenced by accident and violation rates, is greater in individuals who have experienced recent significant life stresses than in those who have not. One group of drivers in which this relationship may prove to be particularly strong is the elderly driving population.

DRIVING STRESS AND THE ELDERLY

The driving population of the United States is aging. In 1988, only 11.3% of the population was over 65 years of age. This group is expected to increase to 16.9% by the year 2000, and by 2030, over 20% of the population will be over 65 (U.S. DOC., 1981, 1984). Figure 7, below, shows these changes graphically. The number of licensed drivers within the

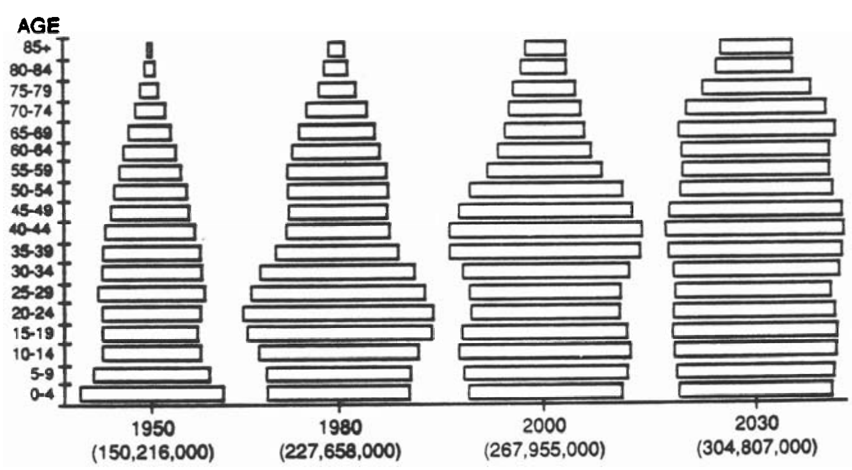

Figure 7. Age distribution of the U.S. population, 1950-2030 (Transportation Research Board, 1988).

elderly group is also increasing. Elderly drivers will make up a larger percentage of the driving population, and, therefore, the problems that elderly drivers may have with stress in the driving situation are particularly important.

It is a fairly well established fact that elderly drivers are involved in a disproportionately large number of traffic accidents. In particular, elderly drivers tend to be involved in miltivehicle accidents to a greater extent than other drivers (McKelvey and Stamatiadis, 1989). Given that an elderly person is involved in an accident, there is an 83.1% chance that it is a multi-vehicle accident. The corresponding figure for the total driving population is 75.4%. Crashes involving older people are most likely to occur on non-Interstate arterial roads (62%) in urban areas (81%) (Overend, 1986).

McKelvey and Stamatiadis (1989) consider accident data in terms of a relative accident involvement ratio. The proportion of vehicle-miles travelled for each age group is compared to the proportion of accidents for that age group. If the ratio is greater than 1.0, the group is considered overinvolved in accidents for their exposure level. The ratio of percentage of accidents to percentage of vehicle-miles of travel is 1.09 for older drivers, 2.22 for younger drivers, and 0.72 for middle-aged drivers.

Another metric for comparing relative accident involvement for various age groups involves a comparison between the percentage of accidents in which the driver is at fault and the percentage of accidents in which the driver is an innocent victim. This measure shows that drivers between 60 and 69 years of age have a relative accident exposure ratio of 1.01. Those 70 to 74 have a ratio of 1.32, and those over 75 have a ratio of 1.89. For comparison, the ratios for drivers under 25 and from 25-59 are 1.20 and 0.86 respectively.

The absolute number of driver fatalities decreases with age (Figure 8)

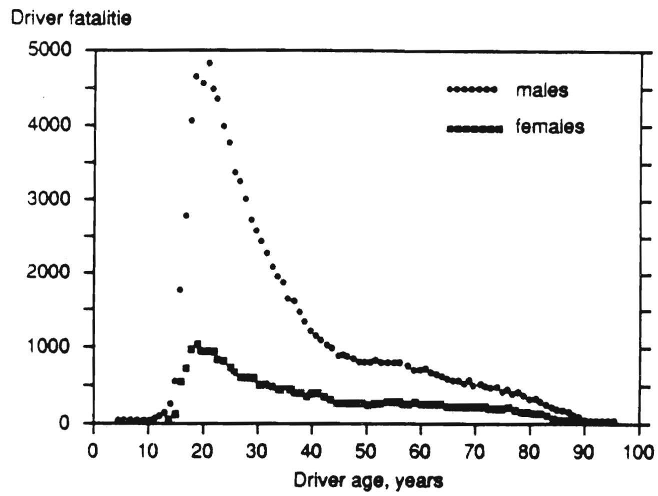

Figure 8. Number of driver fatalities, 1981-1985 (Evans, 1988).

but the number of driver fatalities per million population increases significantly for males, and slightly for females, after age 70 (Figure 9) (Evans, 1988).

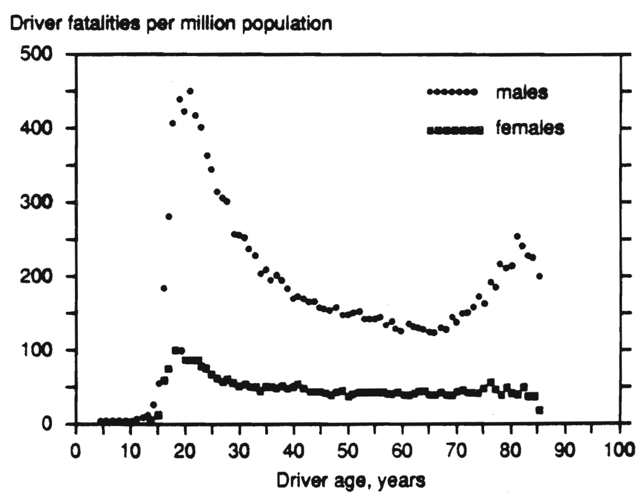

Figure 9. Driver fatalities per million population, 1981-1985 (Evans, 1988).

The number of driver fatalities per million licensed drivers evidences a similar increasing trend (Figure 10),

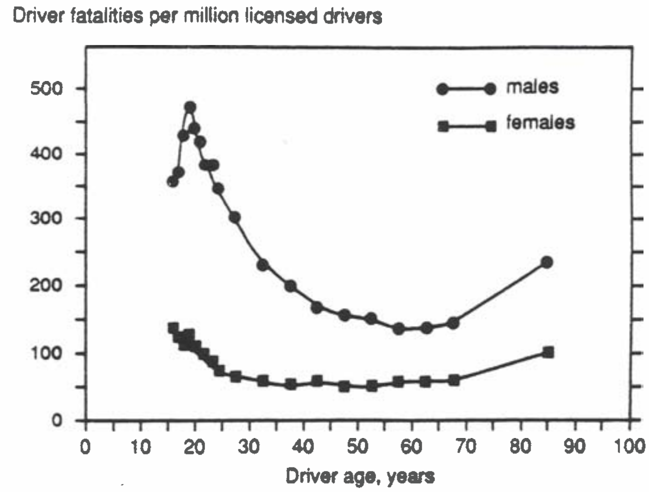

Figure 10. Driver fatalities per million million licensed drivers, 1983 (Evans, 1988).

as does the number of driver fatalities per unit distance of travel (Figure 11).

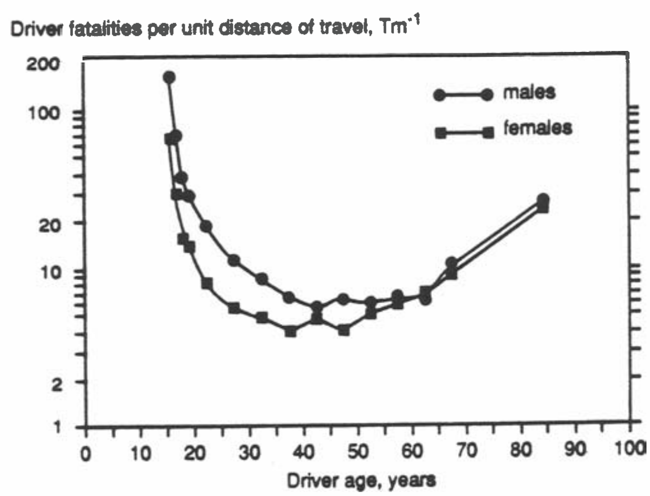

Figure 11. Driver fatalities per terameter (1 Tm = 621 million miles) of travel, 1983 (Evans, 1988).

Evans suggests that the increases in driver fatalities may, in fact, be due to the fact that a crash of given serverity is more likely to prove fatal to an elderly driver than to a younger driver. It is possible to compute "equal severity ranges," and the number of involvements in crashes in the severity range necessary to kill an 80 year old male shows no upward trend after age 70 (Figure 12).

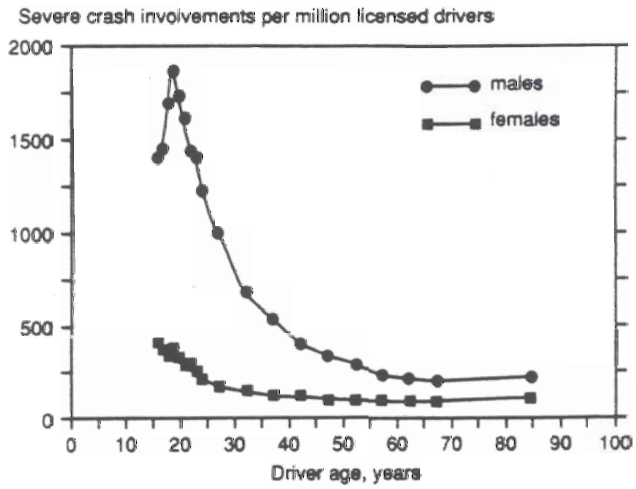

Figure 12. Estimated driver involvements in crashes of sufficient severity to kill 80-year-old male drivers per million licensed drivers (Evans, 1988).

In terms of involvements per unit distance, the upward trend is still evident, but it is smaller than that found in the non-adjusted data (Figure 13).

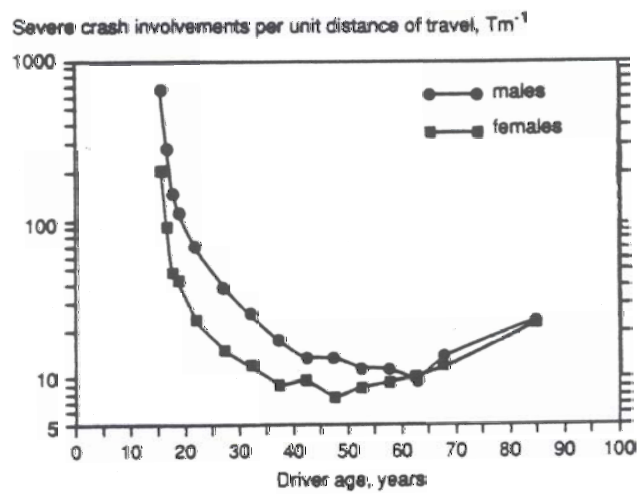

Figure 13. Estimated driver involvements in crashes of sufficient severity to kill 80-year-old male drivers per terameter (1 Tm = 621 million miles) of travel (Evans, 1988).

It should be noted that in no case did the accident involvement of elderly persons exceed that of very young drivers. In all cases when the risk at age 65 exceed that at age 40, the increased risk is primarily bourne by the driver.

Selzer and Vinokur (1975) suggest that life event stress can account for the high accident rates of elderly drivers. Old age may be accompanied by a great many different life stresses, including retirement, a drop in income level, alienation or isolation from children, illnesses and injuries, and the deaths of friends and relatives. Experiencing such stresses may place a great demand on the individual's mental coping resources, leading to a decline in performance on driving, and perhaps many other, tasks.

Research has shown that the life events included in most standardized measures are, in fact, experienced less frequently by older people than by younger and middle-aged adults. However, these age groups also differ in the type of events experienced. Though older adults report fewer life events, they also report greater unhappiness and more intrusion on their lives as a result of those events (Chirboga and Dean, 1978).

There is another reason to expect that elderly drivers may be especially susceptable to driver stress. The interactionist model suggests that stress occurs when perceived demands exceed perceived capabilities. The fact that some actual abilities decline with age leads one to expect that the amount of stress induced by a given situation may be greater for an elderly driver than for a younger driver. Deteriorating vision, in particular, may make the driving task more difficult for the older driver. Both static and dynamic visual acuity decline with age, making the discrimination of detail of both stable and moving objects more difficult. Older persons also tend to experience a narrowing of their visual field and often develop greater sensitivity to glare. Cognitive changes that accompany aging, including changes in attentiveness, estimation skills, and speed of information processing, may further complicate the driving process. These deficiencies create problems for elderly drivers in situations that force the aged driver to keep pace with traffic, requiring the quick and efficient processing of a great amount of (primarily visual) information (for example, at complex intersections) (Planek, 1971).

In fact, many older individuals are aware of their deficits in these areas, and they may often try to compensate for such difficulties. Forty percent of people 55 and over report difficulty seeing at night. Thirty-two percent report difficulties in merging and exiting in high speed traffic, and 27% report difficulty in reading traffic signs (Transportation Research Board, Special Report 218). Elderly individuals recognize that they have problems in a number of driving areas, including turning at intersections and driving under adverse conditions (Cooper, 1990). To cope with these difficulties, elderly individuals may decide not to drive at night, or in rain or snow. They may scale back the number of trips that they take, or decide to drive only within a certain well-known area. However, this type of coping behavior is not always effective, in part because some the specific situations in which elderly drivers do, in fact, perform inadequately are not recognized by the elderly individuals as problem areas. Elderly individuals are more likely to admit to relatively minor problems (such as disobeying traffic control devices) rather than to much more common violations such as failure to yield.

Finally, there is one more reason to suspect that older drivers may be particularly prone to driving stress. Elderly people may have more pronounced stress reactions, in terms of cardiovascular output and other physiological responses, than younger individuals (Chebotarev and Korushko, 1987). These researchers suggest that "a considerable decrease in adaptive capacities [may be] observed with aging."

PHYSIOLOGICAL MEASUREMENT OF DRIVING STRESS

The immediate effects of driving stress that have received the most attention from researchers are physiological changes. Physiological responses to stress involve two types of reactions: specific and non-specific. Specific physiological reactions occur only because of the unique nature of the stressor. Non-specific physiological reactions occur in response to most, if not all, stressors. Reactions to temperature extremes illustrate this distinction: intense heat produces profuse sweating while cold produces shivering, but reactions to both temperature extremes involve increased adrenocorticoid activity. In this case, shivering and sweating are specific effects that are elicited only by certain kinds of stimuli. Increased adrenocorticoid activity is a non-specific effect that occurs in response to a very wide range of stressors. Specific effects may, on occasion, modify the non-specific effects.

Since the physiological response pattern that characterizes driving stress is not particularly well documented, we should most appropriately concentrate on investigating the non-specific stress response associated with this activity. The essential factor in any stress response is sympathetic nervous system (SNS) activation. The SNS is one of the two branches of the autonomic nervous system. The sympathetic branch is primarily responsible for preparing the body for "fight or flight" when confronted with a dangerous situation. The SNS innervates most major organs. Sympathetic activity generally involves increasing cardiovascular output and decreasing digestive function. Under stressful conditions, the sympathetic system is responsible for increasing heart rate, dialating the bronchi in the lungs, and interrupting digestion. The opposing branch of the autonomic nervous system, the parasympathetic system (PNS) innervates most of the same organs, but has an opposite effect on their functioning.

The PNS slows heart rate, constricts the bronchi, and promotes digestion. Thus the level of functioning for many organs depends on the level of activation of both the sympathetic and parasympathetic systems.

Some physiological reactions, however, are entirely controlled by the SNS. These singularly controlled reactions include sweating, the secretion of hormones from the adrenal glands, constriction of the blood vessels, and piloerection ("goose bumps"). These reactions are the exclusive province of the SNS. The parasympathetic system plays no part in controlling these physiological functions.

Physiological reactions to stressors are also produced by a somewhat more circuitous route than direct SNS activation. It was mentioned above that the SNS innervates the adrenal glands. These glands lie at the superior poles of the kidneys. The adrenals consist of two effectively independent parts, the medulla and the outer cortex. The splanchnic nerve of the SNS controls the release of catecholamines (adrenalin and nonadrenaline) from the chromaffin cells of the adrenal medulla. Adrenalin increases heart rate and cardiovascular output and increases the rate and depth of respiration. Adrenalin also mobilizes glucose as a source of energy. Noradrenaline is also associated with increases in respiration rate, and this catecholamine is involved in blood pressure control through changes in peripheral resistance.

The adrenal cortex secretes three types of steroid hormones, including the glucocorticoids cortisol and corticosterone. These hormones also have catabolic (preparation for fight or flight) effects on the body. The release of these hormones is governed by the level of adrenocorticotropic hormone (ACTH) in the blood. ACTH is secreted by the anterior lobe of the pituitary gland, and its release depends, in turn, on the release of corticotropin-releasing factor (CRF) from the hypothalamus. There are, then, several simultaneously operating systems that affect physiological reactions to stress, which may produce complimentary or contradictory effects on various bodily organs.

Experimental studies of the physiological indexes of stress typically involve the measurement of only a few variables. These include a number of cardiovascular variables (heart rate, electrocardiograph patterns, heart rate variability, and blood pressure), galvanic skin response, and levels of catecholamines and corticosteroids.

Many of these indexes are electrophysiological measures. The fundamental principle involved in such measurements is that a difference exists in the concentration of charged ions in cells and in the surrounding fluid. The cells are, therefore, polarized. When a nerve cell operates, it depolarizes as ions flow across the cell membrane. This change of electrical potential can be measured if a group of cells are all working synchronously. These differences can be detected by electrodes on the surface of the skin, where they are amplified and recorded. The placement of the electrodes determines which set of potentials is recorded. The electrocardiogram, which measures the changes in electrical potential of the heart muscle is the most common example of this sort of measuring device.

The potential differences in a beating heart have a characteristic waveform that corresponds to the systematic polarization and depolarization of different areas. This waveform, when recorded with a carefully specified standard electrode placement, is depicted in Figure 14.
The maxima and minima of the waveform are labelled in a standard fashion. Typical findings in stress-related studies show changes in the size of the T wave or in the S-T segment under stressful conditions.

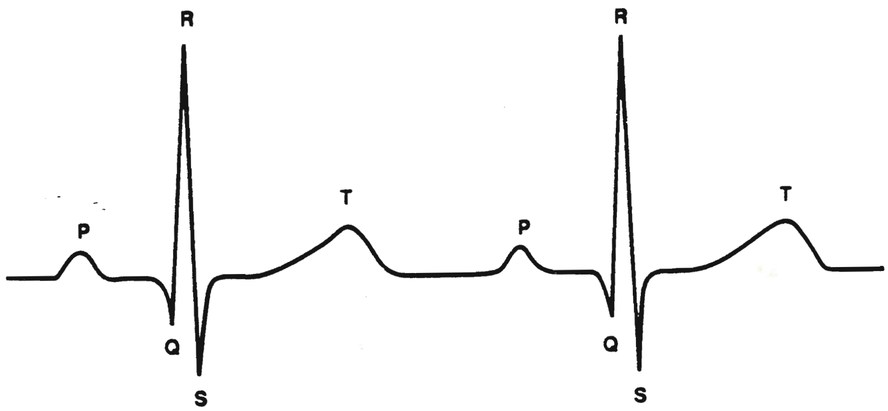

Figure 14. The ECG waveform (adapted from Robertson, 1988).

The ECG may also be used to determine heart rate. Heart rate is defined as the frequency at which the heart beats, and it is typically expressed in beats per minute. One way to determine heart rate is to count the number of waveforms present on the ECG tracing for a given time period. A more sensitive measure of heart rate is the instantaneous heart rate, which is the reciprocal of the interbeat interval, which is the time elapsed between successive identical points of the ECG.

Heart rate variability refers to how evenly and steadily the heart beats. This measure is typically expressed in terms of the standard deviation of instantaneous heart rate over some specified period of time. Other measures of HRV involve the calculation of coefficients that take the effect of heart rate on heart rate variability into account. A third way of measuring HRV involves spectral analysis. Any periodic waveform may be analyzed to determine the frequency and amplitude of its sinusoidal components. In applying spectral analysis to HRV, a series of beats is considered as a single waveform, and the variability in heart rate is detectable as a very low frequency component.

Blood pressure is the amount of pressure exerted upon the inner surface of blood vessels, expressed in millimeters of mercury (mmHg). Diastolic pressure is the amount of pressure on the vessel wall when the heart contracts, and systolic blood pressure is the amount of pressure on the vessel wall while the heart muscle is relaxed. Measurements of blood pressure can be made externally, using a sphygmomanometer, or, more accurately, using a catheter placed inside a blood vessel. Blood pressure typically rises in stressful situations.

Another physiological measure that is frequently employed in studies of stress responses is galvanic skin response (GSR). This measure is also known as skin conductance response (SCR) and electrodermal response (EDR). Typically, a pair of electrodes is used to measure the level of electrical resistance of the skin. Conductance is the reciprocal of resistance. A drop in resistance (increase in conductance) occurs in response to stressful stimuli. Several different measures of GSR can be used, including basal levels of skin conductance, relative increases in response to specific stimuli, and measures of relative increases averaged over some unit of time.

Levels of catecholamines and corticosteroids can also be used as indicators of stress. Catecholamines may be measured by analyzing blood plasma, but analyses of adrenalin and noradrenaline levels in urine are more common. Corticosteroid levels are determined by measuring the urinary levels of certain substances which result from the breakdown of these compounds.

PHYSIOLOGICAL CHANGES ASSOCIATED WITH DRIVING

The next section of text is essentially a catalog of a large number of studies that have examined physiological variables in the driving situation. If driving is, in fact, an environmental stressor, driving tasks should be accompanied by a certain set of general physiological responses very similar to those evoked by other stressful stimuli. The physiological changes that we would expect to find in a driving situation include cardiovascular changes (heart rate increases, blood pressure increases, changes in heart rate variability and in electrocardiographic patterns), changes in GSR level and frequency of response, and changes in the blood plasma and urinary levels of certain chemical substances (most notably catecholamines, such as adrenalin and noradrenaline, but also corticosteroids).

It should be emphasized, however, that the physiological changes that occur when driving may be due to a number of different factors. For example, McDonald (1984) lists three possible interpretations of the heart rate changes that typically accompany driving: physical, attentional, and emotional. Driving does require some physical effort, both in maintaining posture and in control movements such as steering and braking, and physical effort is known to affect many physiological indexes in the same way that stress does. Driving also requires increased attention, which is known to be accompanied by heightened physiological arousal. The emotional stress of driving is not easily separable from either of these two factors, and it could be argued that the attentional and emotional explanations should not be disentangled from each other, particularly when discussing anxiety generating high traffic situations. It is not clear whether high task demand causes anxiety, or if the attentional mechanism and the emotional mechanism are both activated simultaneously and independently by the same features of the environment.

For the sake of clarity, the studies are grouped together according to the type of comparisons made (e.g., driving vs. non-driving, well illuminated vs. poorly illuminated conditions) and, in areas that have generated a large number of investigations, by the type of physiological index employed in the study.

Driving/Non-Driving Comparisons

A number of different studies have compared the levels of various physiological indexes under driving and non-driving conditions. Usually, a measurement of a physiological variable is made while the subject is resting, and then this baseline level is compared to the level of the variable during or just after the driving task. Any difference between the two is considered to be caused by the driving.

Heart Rate. Heart rate is typically higher while driving than while resting. For example, Wyss (1970) found that the average heart rate of 84 subjects increased from a resting level of 71 +/- 8 bpm (beats per minute) to 90 +/- 11 bpm while subjects drove their own cars over a number of different routes. Taggart, Gibbons, and Somerville (1969) found that 91% of normal subjects exhibited a heart rate increase while driving their own cars in heavy traffic in the vicinity of Picadilly Circus and Trafalgar Square in London, an area with which all subjects were familiar. When 24 subjects with coronary heart disease (CHD) drove the same route under similar conditions, 21 showed heart rate increases over the resting level. The highest reported heart rate for the normal group was 155 bpm; the highest reported heart rate for the CHD group was 180 bpm.

Taggart, Gibbons, and Somerville also studied race car drivers during competition. This sort of situation may exaggerate the kind of stresses present in more typical everyday driving tasks, thus making the specific physiological changes involved easier to identify and examine. During the 15 minute period before the start of the race, all 10 of the drivers showed heart rates of 150-180 bpm. By the start of the race, heart rates had climbed to even higher levels (180-210 bpm) and were maintained at these extremely high levels throughout the 20 minute event.

Bellet, Roman, Kostis, and Slater (1969) studied 65 normal subjects and 66 subjects with CHD. A variable increase in heart rate while driving was found in both groups. A 2 1/2 hour drive caused a significant heart rate increase in some, but not all, of the subjects. The highest recorded heart rate level was 145 bpm among the normal subjects, 155 bpm among the CHD subjects.

A Japanese study found that heart rate increased above resting levels in four subjects during a 29.3 km drive along a common road in Tokyo (Ohkubo, 1976). An experiment using police drivers as subjects reported a brief initial rise in heart rate at the beginning of a 30 mile drive (Hunt, Dix, and May, 1968).

There seems to be fairly broad agreement that driving increases heart rate in normal individuals and in those with heart disease. Robertson (1988) cites a number of additional studies that further support this position. Dupis (1965) found that heart rate was 15-27 bpm higher than resting levels during the first 10-20 minutes of a drive. Hashimoto (1967) found heart rate increases (of different magnitudes) on highways, town, and mountain roads. Heart rate is also elevated while driving on a closed track (Michaut, Pottier, Roche, and Wisner, 1964). Michaut et al. reported that heart rates were, on average, 26 bpm higher than resting levels at the beginning of a three hour drive. This rate decreased to 17 bpm above resting levels as the drive progressed.

Heart Rate Variability. Measurements of heart rate variability can also be obtained from heart rate recordings. The pulse rate is not perfectly stable; differences between the length of successive interbeat intervals can be detected and studied. Wyss (1970) reported that heart rate during driving shows irregular but continuous variations from +/- 8-10% to +/- 50% of the preceding value within 6-8 to 30-50 seconds. That is, the heart rate continually changes, speeding up and slowing down constantly during the driving situation. When compared to resting levels of heart rate variability, Plant (1969) reports that the standard deviations for heart rate were considerably higher when driving than when parked.

Blood Pressure. Another cardiovascular measure that may be affected by driving is blood pressure. In general, blood pressure increases are found in subjects that experience stressful situations. However, blood pressure seems to be remarkably stable while driving. Bevan (1969) found only very small changes in blood pressure (systolic -3 mmHg, diastolic +3 mmHg) when periods of driving were compared to the five minutes immediately preceding them. Differences of this magnitude are statistically insignificant. Littler, Honour, and Sleight (1973) report similar results. Their data show that arterial blood pressure remains remarkably stable in normal subjects and hypertensive subjects throughout a journey. No differences were found between the blood pressure levels at the beginning and the end of a drive. Transient periods of raised pressure were recorded (usually related to such episodes as overtaking), but these quickly returned to baseline levels. It seems that specific driving events may lead to increases in blood pressure, but driving itself does not.

Electrocardiograph Changes. The stress of driving may also cause changes in the electrocardiograph tracings of individuals with coronary heart disease, and, under certain extreme conditions, similar changes have been detected in normal individuals.

Bellet, Roman, Kostis, and Slater (1968) tested 65 normal subjects and 66 subjects with documented coronary heart disease. The ECG tracings of the normal subjects during driving were essentially identical to the ECG tracings recorded under resting conditions. However, significant ECG changes while driving were found in 11 (16.7%) of the 66 CHD subjects. The most common change was S-T segment depression, which was found in six of the subjects. This type of change is often seen in CHD patients, and it can be the result of either physical exertion or mental stress. The driving conditions in this study were not overly difficult: subjects drove familiar cars during daylight hours in their normal manner. Since the driving task in the study was very similar to the subjects' everyday commute, these researchers concluded that this type of ECG change occurs quite frequently in CHD patients, probably on a daily basis. Hoffman (1963) reports the same sort of ischemic changes in drivers with coronary disease.

Taggart, Gibbons, and Somerville (1969) compared resting and driving ECG tracings of 32 normal subjects and 29 heart patients (most with CHD). Of the 24 subjects with CHD, S-T changes occurred in 13 (54%). These changes were gross in 6 (25%). Moreover, S-T depression and flattening of the T waves were recorded in three of the normal subjects. At a later time, the normal subject with the most striking S-T changes was injected with atropine to produce the level of tachycardia (accelerated heart rate) that she had experienced while in the driving situation. No S-T changes occurred until "a sudden severe fright was administered." This suggests that the ECG changes found when driving are due to anxiety produced by the driving situation.

The subjects in the Taggart, Gibbons, and Somerville study were required to drive in dense, fast-moving traffic in the vicinity of Trafalgar Square and Picadilly Circus in London. Their driving task was certainly more demanding than that in the Bellet, Roman, Kostis, and Slater study. It is this difference in task difficulty that probably accounts for the fact that ECG changes were found in normal subjects in only one (Taggart, Gibbons, and Somerville) of the studies. Light traffic conditions may produce ECG changes in subjects whose circulatory systems are compromised. Under heavier traffic conditions, the same sort of changes begin to occur in those with normal circulatory systems. A 1965 study conducted by Hoffman provides further evidence for this interpretation. Hoffman's study showed S-T depression and a flattening of T waves in healthy persons during city driving, typically considered a very demanding task.

Another situation that has been found to produce S-T and T wave changes in normals is long distance driving. Burns, Baker, Simonson, and Keiper (1966) recorded the ECG of four normal drivers who each drove from 200 to 2600 miles over a period of one to four days. T wave changes were seen in three of the subjects. In a later investigation (Simonson, Baker, Burns, Keiper, Schmitt, and Stackhouse, 1968), a fifth subject was added. This subject also showed a lowering of the T wave after prolonged periods of driving (300 miles). These changes were very similar to those seen in the same subject during rush hour traffic conditions.

Littler, Honour, and Sleight (1973) found no S-T or T wave changes in normal, hypertensive, or CHD patients, but they acknowledge that the particular lead system that they employed in their study may have been unable to detect such changes.

Galvanic Skin Response. Mean GSR rates during driving are 50 times as great as those obtained when subjects were resting in a quiet room (Taylor, 1964). Hines (1986) reports a study in which a biofeedback monitor was used to measure GSR. The frequency of a pulsed tone rose with increased stress. Even when the driver had had sufficient time to become accustomed to the monitor, there was a rise in tone upon starting the engine.

Catecholamine Levels. Another non-cardiac measure that can be used as an indicator of stress is the level of urinary catecholamines produced while driving. Bellet, Roman, and Kostis (1969) found that mean levels of catecholamine excretion during two hours of driving were significantly higher than those found during two hours of resting in the laboratory for both normal subjects and those with CHD. Higher levels of hydroxycorticosteroids were also found in both groups during the driving period. The approximately 80% increase in catecholamines is quite consistent with the 100% increase reported by Schmid and Meythaler (1964).

Taggart, Gibbons, and Somerville (1969) measured plasma catecholamine levels in 3 men with CHD and one normal woman immediately after a drive through city traffic and again several days later (presumably not immediately after a drive). The changes that they found were generally insignificant and inconsistent. However, similar comparisons of adrenalin and noradrenaline levels in racing drivers showed that post-race levels of noradrenaline were elevated in all 10 cases, and in some drivers the post-race level was 20 times that of the resting sample. Post-race levels of adrenalin were elevated in only one of the ten drivers.

Road Type Comparisons

Certainly not all types of driving are equivalent in producing these physiological indications of stress. We have already discussed the fact that driving in dense city traffic or for long periods of time produces ECG changes in normal subjects that do not occur under less difficult driving conditions. Different types of roads tend to produce different amounts of stress, and thus differences in heart rate, GSR, etc. should be detectable.

Heart Rate. Hoffman and Schneider (1967) have conducted a study that compares heart rate levels on various types of roads. They express their results in terms of the percentage of 600 healthy drivers that experienced a heart rate increase of a certain level (20% or 40% above resting levels) under each condition. For example, none of the drivers in their sample experienced a heart rate increase of 20% or greater during highway driving in low density traffic. During urban driving, however, 28% of 600 healthy drivers produced HR increases of 20% or more, and increases of 40% or more were found in 8%. This result is supported by Berger, Bliersbach, and Dellen (1976) who also report that increased heart rates indicate that greater stress is experienced on city roads than on highways. Hashimoto et al. (1967) found that highway driving produced a 6-9% increase in HR over resting levels. Driving on town and mountain roads produced increases of 15-18%. Probst (1976) reports that well constructed highways with low density traffic produce less cardiovascular stress than twisting roads with heavy traffic.

Wyss (1970) compared six different combinations of road types and conditions. He found that the smallest increase in HR occurred during highway driving. Town driving produced larger increases, and driving up- and down-hill produced even larger increases in HR.

Robertson (1987; 1988; Robertson and Goodwin, 1988) examined the heart rates of six subjects who drove a route which included four different types of roads: dual carriageway, major rural road, minor rural road, and urban roads. For these six subjects, minor rural roads showed the least change from resting HR levels, followed by the major rural road, and the urban road, with the dual carriageway showing the greatest increase in HR. This result, a substantial increase in heart rate for highway driving, does not agree with those reported above. An additional sample of another six subjects shows a pattern that is more consistent with previous literature. This second set of rankings, from lowest to highest heart rate, is: major rural road, dual carriageway, and minor rural and urban roads.

Blood Pressure and Electrocardiograph Changes. Other measures of cardiovascular activity have not received as much attention in regard to differences produced by different types of roads. Wyss (1970) did include blood pressure and electrocardiographic measures in his study of town, motorway, and up-and down-hill driving, but no significant differences were found.

Galvanic Skin Response. GSR has also been compared for various road types. Brown and Huffman (1972) found that mean GSR was significantly higher for business district, expressway, and residential driving than for rural highway driving. The measure of GSR that the researchers employed was a relative one. The recorder was adjusted so that a startle response produced a 2 cm deflection of the pen. The measure that was used to compare the different roadways was the average number of 1/2 cm or greater pen deflections per minute.

Michaels (1960) investigated differences in tension induced by two urban routes, a major arterial to and from downtown Washington and a roughly parallel alternate route that ran through a primarily residential area. The average magnitude of GSR was approximately the same for both routes, but 30% fewer responses per minute were generated on the alternate than on the major arterial.

A later study (Michaels, 1962) differentiated between different types of expressway design in terms of the amount of tension generated while travelling on each. The four expressway designs selected for study were (1) an interstate route designed to current interstate standards, with a design speed of 70 mph, (2) a 15 year old parkway with a design speed of 50 mph and less rigorous standards in terms of curvature and grade than are presently acceptable, (3) a 10 year old urban freeway with a design speed of 70 mph and fairly modern curvature and grade, but with substandard acceleration and deceleration lanes, and (4) an expressway with less rigorous standards of curvature and grade than are currently acceptable, only partial control of access, crossovers at the median, at-grade intersections, and access to a frontage road. The magnitude of GSR per unit time measure indicated that for each of the six subjects studied, the highway built to interstate standards generated less tension than the other three highways. When a mathematical correction accounting for volume differences was applied to the data, the lowest level of tension caused by interferences with other drivers is found on the urban freeway, followed by the interstate route, parkway, with the highest tension levels found on the freeway with only partial control of access. When tension responses generated by road design features were analyzed, tension is lowest on the urban freeway, followed by the parkway, the freeway with only partial control of access, with the interstate route generating the most tension. This sort of finding is probably due to the fact that drivers regulate their speed by monitoring traffic conditions, and when traffic interferences are reduced by highway designs that restrict access, drivers increase their speed to a point where feedback from road design features provides information about performance. Data that compare the expressway, a parallel 4 lane highway without control of access or grade separation, and an urban arterial show that the 4 lane highway produced 1.7 times tension, and the arterial produced 3.34 times as much tension as the expressway.

A third study by this researcher (Michaels, 1965) compared the Maine Turnpike, a major expressway, with US 1, a parallel non-controlled access highway. Data from nine test subjects show that US 1 generated more tension (in terms of magnitude of GSR per minute) than the turnpike for all subjects, though the average amount of tension varied considerably between subjects. The range in reduction of tension among this group was from 22-61%, with an average reduction of 46%. Figure 15 shows these tension differences for each driver.

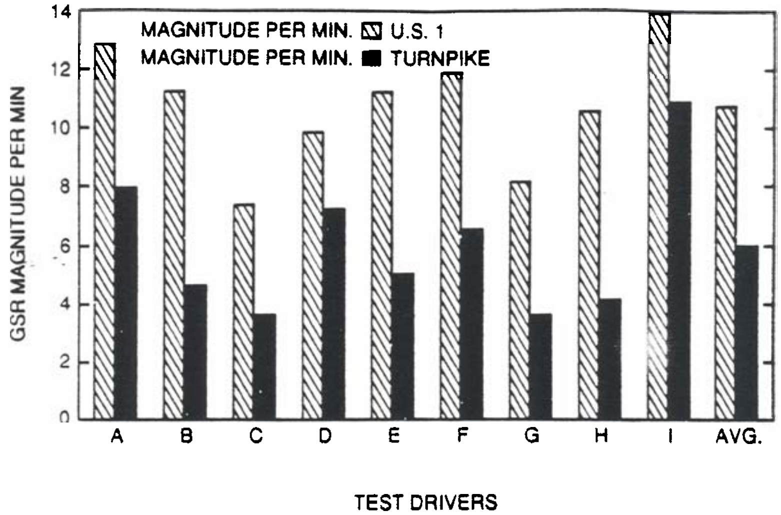

Figure 15. Mean tension generated on the Maine Turnpike and US 1 for each test triver (Michaels, 1965).

Taylor (1964) conducted a study that compared percentage change in GSR as drivers traversed a 21 mile route that contained 40 homogenous sections of different road conditions, including winding country roads, urban streets, and an expressway. The GSR rate, in nominal response units per minute, was, for the most part, quite stable across the different road sections. Some significant relationships, such as higher GSR rates for road sections containing road junctions than for immediately adjacent sections, were identified, but a constant GSR rate was maintained throughout most conditions. The researcher explains this by postulating that GSR may function as a pacing mechanism. A driver may have a certain level of tension that he or she is willing to tolerate. If road conditions impose a greater or lesser amount of tension, the driver will adjust speed accordingly.

Catecholamine Levels. Berger, Bliersbach, and Dellen (1976) report that levels of catecholamines indicate that greater stress was experienced on city roads than on highways.

Road Design Elements

Certain road elements have been shown to have a direct relationship to physiological indicators of stress. For example, Babkov (1975) reports that heart rate is higher on entering and leaving a curve than on straight sections of roadway. Also, as the radius of a curve decreases and lateral force on the car increases, GSR levels increase, as shown in Figure 16.

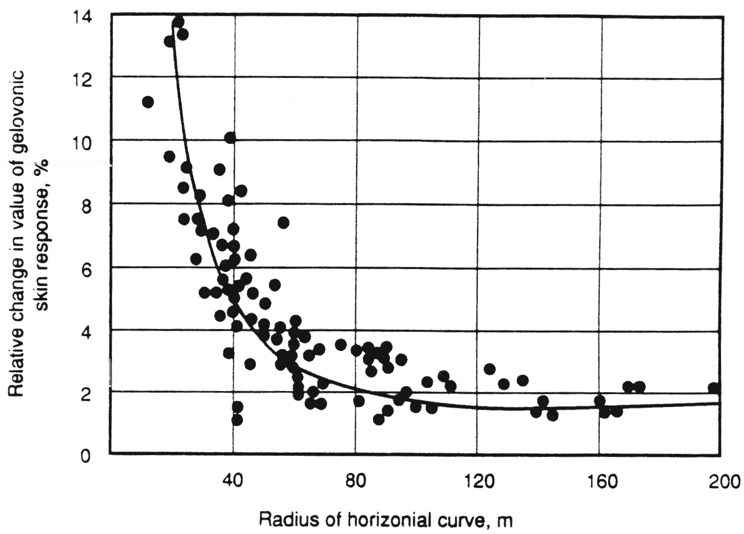

Figure 16. GSR changes associated with curves of varying radii (Babkov, 1975, reprinted in Robertson, 1988).

Engels (1978) has found that heart rate is higher on left hand bends than on other sections of roadway for those drivers who are accustomed to driving on the right.

Michaels (1962) notes that, among highway interferences, the most tension inducing are changes in pavement characteristics, followed closely by the tension induced by the negotiation of curves.

Hills also seem to be associated with increased levels of stress. Wyss (1970) found higher average heart rate levels while driving up and down hills than while driving on level town roads and expressways. Helander (1975) reports that downhill grades which require use of the brake are associated with increased levels of stress as measured by heart rate and GSR.

On-ramps also seem to be particularly stressful. Platt reports a study that showed that drivers' heart rates increase significantly during ramp entry to a freeway. Rutley and Mace (1972) investigated drivers' heart rates at different parts of road junctions. Subjects in this study drove along a motorway, exiting and reentering at each junction. Each junction consisted of five parts: pre-off-ramp, off-ramp, roundabout, on-ramp, and post-on-ramp. HR changes were expressed as percentages of a reference level which was defined as the lowest average value (bpm) obtained for that subject for any part of any junction on that run. Results show that HR rises when drivers negotiate a motorway interchange. The average percentage heart rate over the reference level for each road section can be found in Figure 17.

Part of junction.	Mean HR rise %	SD (of HR means for each subject)
Pre-off ramp	6.9	4.4
Off ramp	7.5	5.9
Roundabout	12.4	6.0
On-ramp	12.7	8.4
Post-on ramp	5.4	4.6

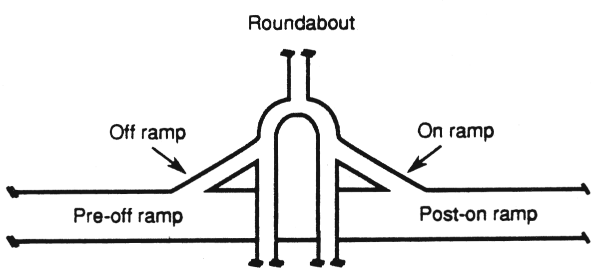

Figure 17. Mean percentage heart rate increase at different junction parts (Robertson, 1988).

The rank order of these changes is as would be expected from a subjective estimate of each segment's difficulty. The mean percentage increases for roundabouts and on-ramps are significantly greater than the values for the other junction segments. Rutley and Mace point out the fact that some of the HR increases found in this study are of the same magnitude as those evoked by simulated driving and weight lifting tasks requiring the same amount of muscular effort. Therefore, it is likely that at least part of the HR increase found at motorway junctions is due to the physical effort of performing the required turning maneuvers, but the fact that the largest HR change was found for the on-ramp, a segment requiring very little physical effort, suggests that at least some of the heart rate increases found in this study were due to mental effort or emotional factors.

Segment Difficulty Comparisons

Many studies have found that heart rate and other physiological indicators of stress tend to increase with the "difficulty" or "complexity" of the driving situation.

Heart Rate. Egelund (1983) compared heart rate and heart rate variability measures for nine drivers who traversed a 30 km route that included 19 segments representing a variety of traffic situations. The 19 road segments were placed in "complicated" or "uncomplicated" categories. The uncomplicated segments were those that placed a low demand on the driver, since they were straight roads with few and clear intersections and low traffic density. The complicated segments, however, were urban roads with multiple "incalcuable" intersections, road divisions, or highway acceleration entries, and thus placed a high demand on the driver. Segment complexity was found to be related to heart rate and a spectral analysis measure of heart rate variability. The researcher concluded that heart rate and heart rate variability both indicated aspects of mental load, heart rate in a direct, and heart rate variability in an inverse relationship. Purely arithmetic indexes of heart rate variability showed no relationship to complexity or mental load.

Dupis (1965) reports that increases in driving task difficulty related to road and traffic events such as sudden stops, acceleration, overtaking, and dangerous curves, are associated with heart rate increases of up to 45 bpm. Becker, Schwibbe, Ahlbrecht, and Steufgen (1971) found that the difficulty of a given situation was closely related to the pulse rate or its increase. Hunt, Dix, and May (1968) found that heart rate increases among highly experienced drivers were associated with particularly hazardous road segments.

Galvanic Skin Response. Cleveland (1961) found that more complex paths through an intersection generated more tension responses (GSRs) than did simpler paths through the same intersection. Helander (1975) reports that peaks in EDR activity are typically obtained at spots of increased task demand.

Accident Rates. Kaiser (1975) reports a highly significant relationship between pulse rate and accident rate on various sections of roadway. Low pulse rates were noted on road sections where the accidents were not related to driver error. Robertson (1988) also investigated the connection between accident rates and heart rates, but no significant relationship was found. However, this latter study did not separate accidents due to driver error from accidents precipitated by other causes, which may account for the inconsistency.

Taylor (1964) found that where the number of side turnings is greater, the risk of accident is greater, and the GSR experienced per mile of travel is also higher. Thus the distribution of GSR closely follows the distribution of accidents, but the causal connection in this relationship is unclear. Babkov (1975) reports an increase in GSR at accident "black spots," and suggests that the increased emotional strains of drivers at these locations were related to the high number of accidents. Helander (1975) found that the EDR of drivers who traversed a test route covaried with the rate of single car accidents that occurred in the same direction the test car was travelling.

Traffic Volume

Michaels (1962) found that the relationship between GSR and traffic volume is quite linear up to about 2400 vehicles per hour in two lanes, at which point the rise in tension appears to increase exponentially, up to a maximum tested value of 3600 vehicles per hour in two lanes. The measure of GSR used in this study was magnitude of GSR per unit time. This relationship is shown graphically in Figure 18.

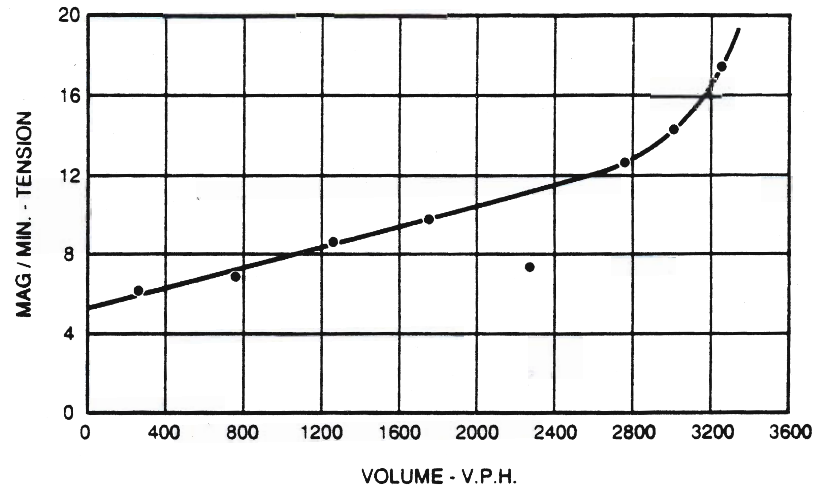

Figure 18. Effect of traffic volume on tension responses (Michaels, 1962).

Taylor (1964) reports that traffic conditions have no effect on the rate of GSR. Traffic conditions at peak and off-peak travel times produced no differences in the number of GSR responses per minute.

Traffic Events

Many experimenters have attempted to find a link between individual galvanic skin responses and specific traffic events, and most have been successful. Michaels (1960) compared traffic events on a major urban arterial and on an alternate route, as well as the tension responses generated on each route. A list of 8 traffic events was developed, and the eight kinds of interferences on this list accounted for 95% of all agents causing a change in test vehicle speed or placement. This list included parking maneuvers, marginal pedestrians, instream moving, transit loading platforms, pedestrians instream, turning vehicles, merging and crossing vehicles, and traffic signals. Approximately 15% of the traffic events observed generated no response from the driver. A traffic event was recorded once every 24.7 seconds on the arterial and once every 34.9 seconds on the alternate route. Since 85% of the traffic events generated GSRs, there was a tension inducing event once every 29.2 seconds on the arterial and once every 41.4 seconds on the alternate.

Additionally, each route was analyzed individually to determine what types of traffic events generated the greatest magnitude of GSR response. For the arterial, the highest magnitude of GSR response was generated by turning, followed by crossing and merging, traffic control devices, instream pedestrians, moving vehicles, parking, loading platforms, with marginal pedestrians generating the smallest tension responses. On the alternate route, the largest GSR was generated by crossing and merging, followed by opposing vehicles, traffic control devices, turning, moving vehicles, instream pedestrians, marginal pedestrians, with parking generating the smallest GSR. The events that generate the largest GSRs are those events in which the rate of change of location of the conflicting vehicles is at a maximum. With humans' limited accuracy in speed estimation and angular closing rate and limited time for such decisions, these situations have a high degree of unpredictability and may reasonably be the most threatening.

The later Michaels study (1962) comparing expressway designs also involved traffic events. Four traffic events, instream vehicles, merging or crossing vehicles, exiting vehicles, and pedestrians, and four design variables, gradient, curvature, pavement changes, and shoulder objects, were recorded. On expressways, two interferences, instream traffic and negotiation of curves, account for approximately 70% of all driving interferences. 90-95% of all traffic interferences are instream conflicts. On the urban freeway, over half of all interferences were caused by traffic; only about 25% of the interferences on the interstate were caused by traffic. On routes with uncontrolled access, marginal conflicts are more frequent (30% vs. 10% of traffic interferences) than on controlled access interstates.

Torres (1971) found a positive linear relationship between the number of traffic events and accumulated log conductance change in skin resistance. Surti and Gervais (1967) ranked traffic events on a freeway and a surface street in term of the magnitude of tension response and the frequency of such responses. Longitudinal friction, traffic events encountered along the direction of motion (roughly comparable to Michaels, 1962, instream conflict) accounted for the greatest percentage of the total responses for the freeway as well as the street route. The magnitude of response is thought to be an indicator of the difficulty of the driver's required decision making process. The traffic event rankings for the freeway and the surface street, in term of magnitude and frequency of response are given in Figures 19 and 20.

Freeway		Surface Street	
Rank	Event	Rank	Event
1	On-ramp merging (Event No. 3)	1	Signals and stop signs (Event No. 7)
2	Longitudinal friction (Event No. 1)	2	Longitudinal friction (Event No. 1)
3	Shoulder incidents (Event No. 5)	3	Parking (Event No. 5)
4	Off-ramp diverging (Event No. 4)	4	Pedestrians (Event No. 6)
5	Change in horizontal or vertical alignment (Event No. 2)	5	Left turn (Event No. 4)
		6	Right turn (Event No. 3)
		7	Change in horizontal or vertical alignment (Event No. 2)

Figure 19. Traffic and geometric events ranked according to degree of difficulty of driver decision process (magnitude of GSR) (Surti and Gervais, 1967).

Freeway		Surface Street	
Rank	Event	Rank	Event
1	Longitudinal friction (Event No. 1)	1	Longitudinal friction (Event No. 1)
2[a]	Change in horizontal or vertical alignment (Event No. 2)	2	Signals and stop signs (Event No. 7)
3[a]	On-ramp merging (Event No. 3)	3	Change in horizontal or vertical alignment (Event No. 2)
4	Off-ramp diverging (Event No. 4)	4	Pedestrians (Event No. 6)
5	Shoulder incidents (Event No. 5)	5	Parking (Event No. 5)
		6	Right turn (Event No. 3)
		7	Left turn (Event No. 4)

[a]Based on a magnitude distribution, Event No. 3 ranked 2 and Event No. 2 ranked 3 for the freeway; remaining events had ranks identical to frequency distribution.

Figure 20. Traffic and geometric events ranked according to frequency of tension responses (Surti and Gervais, 1967).

Hulbert (1957) developed a four category system for coding traffic events that grouped events as actual interruptions (of the ideal path of the driver), possible interruptions, actual infringements, and possible infringements. Ninety-one percent of the recorded GSRs were associated with one of these four types of traffic situations. Actual interruptions of the path accounted for most of the responses, but 23% were due to only potential interruptions, and 62% of these involved no recorded action on the part of the driver.

Helander (1975) coded 25 types of traffic events encountered by 75 subjects driving a 23.7 km stretch of rural road. Sixteen of these occurred often enough to be analyzed statistically. These traffic events were rank ordered in terms of electrodermal response and brake pressure. The most stressful events recorded in this study were (1) cyclist or pedestrian + meeting other car, (2) other car passes in front of own car, (3) multiple events, (4) own car passes other car, and (5) leading car diverges. The rank ordering of the complete list can be found in Figure 21, below.

Rank Order	EDRC Traffic Event	Traffic Event Code	Number of Events	BRAKE Traffic Event Code
1	Cyclist or pedestrian + meeting other car	23	28	23
2	Other car merges in front of own car	40	47	40
3	Multiple events	2	163	2
4	Own car passes other car	60	3 590	30
5	Leading car diverges	30	207	20
6	Own car passes other car + car-following	61	126	61
7	Cyclist or pedestrian	20	839	21
8	Other car passes own car	50	157	11
9	Meeting other car	3	1 535	3
10	Cyclist or pedestrian + car-following	21	65	1
11	Car-following	1	13 049	70
12	Car-following + meeting other car	11	353	0
13	No event	0	112 630	50
14	Parked car + car-following	71	64	71
15	Parked car	70	742	10
16	Meeting other car	10	50	60

Note: $r_s = 0.71$; $p < 0.001$.

Figure 21. Rank orders of traffic events based on magnitude of electrodermal response and brake pressure (Helander, 1975).

Heart rate responds instantly to certain traffic events that may be termed "critical situations" (Simonson et al., 1968). Increases of up to 45 bpm have been found in traffic situations requiring sudden stops, overtaking, or dangerous curves (Dupis, 1965). Hoffman and Schneider (1967) report that 42% of 600 healthy drivers produced a heart rate increase of 20% or more over resting levels during critical situations. Fourteen percent produced increases of 40% or more.

<u>Speed and Pace Comparisons</u>

Suenaga et al. (1965) have found that forced-pace high-speed driving causes cardiovascular changes. In their study, two cars drove from Fukuoka to Moji on the national highway. The driver of one car was allowed to select his own pace and drove according to traffic conditions. The driver of the second car was directed to drive as fast as possible, subject only to the speed limit. Subjects who drove in the normal manner showed no differences in blood pressure after the drive, and their heart rates remained stable throughout the driving period. However, the heart rates of drivers of the "runaway" car increased from the start to the end of the drive, with levels highly elevated above the normal rate. Heart rate was, on average, 15 bpm higher in the high speed, forced-pace condition than in the normal speed, self-paced condition. Post drive systolic and diastolic blood pressure were both elevated as well. Blood pressure did not return to normal levels until 45 minutes after the drive.

Zeier and Baettig (1977) have found that circulatory stress is higher at high speeds than at low speeds. Hoffman and Schneider (1967) report that heart rate is unaffected by speed when subjects drive at different speeds on a motorway. It is likely, however, that the speeds in this latter study did not significantly challenge the capacities of the subjects. Dupis (1965) reports that high-speed driving produces heart rate increases of 6-7 bpm over and above the already elevated driving levels. Robertson (1988), however, found no significant correlation between mean speed over a road section and any heart rate variable. The road sections in this experiment were of very different types, and subjects were allowed to vary their speed accordingly, so it is likely that they adjusted their velocity to maintain a steady rate of tension, and thus heart rate.

Seydal (1974) reports a negative correlation between speed and GSR. This work used different traffic environments, and one can surmise that the roads on which subjects travelled at the highest speeds were specifically designed to minimize demand on the road user (e.g., limited access highways), and those roads on which subjects travelled at lower speeds had a significantly higher frequency of tension inducing events. A similar sort of explanation is used by Taylor (1964) to explain the lack of a significant relationship between GSR and speed. He postulates that drivers pace themselves by monitoring the frequency of their GSRs, reducing speed when necessary to keep their overall tension level constant.

Driving Maneuvers

Clayton et al. (1971) report that four class 1 (expert) police drivers showed an increase in heart rate during more active patrol periods involving such actions as stopping a moving vehicle and making emergency U-turns on a highway.

Probst (1976) reports that overtaking another vehicle is stressful. Hunt, Dix, and May (1968) found that two of three inexperienced drivers showed an increase in heart rate while overtaking another car, and all showed heart rate increases while being overtaken. Littler et al. (1973) found short periods of raised arterial pressure during driving related to such episodes as overtaking.

Helander (1978) found that EDR was related to such activities as overtaking, being overtaken, and meeting pedestrians or cyclists. In general, those activities associated with the use of the brake as considered stressful, especially for inexperienced drivers. The exceptions to this general rule are passing maneuvers, which do not require brake use. Helander (1975) also reports that short sight distances are stressful.

Illumination Comparisons

Brown and Huffman (1972) report that GSR rates are lower during night driving conditions than during daylight driving conditions. However, it is unclear whether other factors, such as speed and traffic volume, also varied between the two conditions and could have possibly been responsible for the unexpected direction of this relationship.

Cleveland (1961) found than only 80% as many tension responses (GSRs) are produced under illuminated conditions when compared to the same intersection when unlighted. The magnitude of the GSRs under the lighted condition is also only about 80% of that generated under unilluminated conditions. Michaels (1960) compared the tension responses of drivers on urban streets during peak, off-peak, and night driving conditions. In some, but not all, cases, driving during peak periods produced greater magnitude of response per minute, and the data for night driving typically followed the pattern for peak period runs. Taylor (1964) reports that the presence or absence of darkness (and/or peak hour traffic) has no observable effect on mean GSR rate.

Weather Comparisons

Platt (1969) reports an investigation in which a single subject was monitored for physiological changes while driving under adverse conditions. While driving in a strong wind and with light blowing snow covering the roadway, this driver, who had a normal heart rate of 80-85 bpm, reached heart rate levels of 150 bpm (max), and the standard deviation of the heart rate (a measure of heart rate variability) was also high. These changes occurred even though speed was reduced to just 47 mph.

Neumann et al. (1978) report a study of the effects of heat and noise on physiological functioning of drivers. The "non-stress" condition in this study was defined as a temperature of 76 degrees F and a sound intensity of 55 dBA, while the "stress" condition involved a temperature of 90 degrees F and a sound intensity level (road and car noise) of 78 dBA. Subjects drove for two hours and forty-eight minutes under each of the two conditions. In the high temperature noisy condition, heart rate, GSR, and systolic and diastolic blood pressure were all higher than in the moderate temperature, moderate noise condition. Mackie and O'Hanlon (1977) conducted a similar study of heat stress. Again, significantly higher heart rate and greater heart rate variability were found in the high temperature condition.

Weir and Allen (1972) report that a lateral wind (gusting) caused an increase in heart rate from 75 to 80 bpm.

Transmission Comparisons

It is unclear whether driving a car with automatic transmission, which could be argued to decrease the amount of effort required of the driver by the driving task, results in lower stress levels than driving a car with manual transmission. Zeier (1979) found that the rate of adrenalin excretion, skin conductance activity, heart rate, and heart rate variability were significantly higher when driving a manual than when driving an automatic. However, Seydal (1972) reports that no differences in HR levels were found in his study comparing manual and automatic transmissions. Unfortunately, details of Seydal's investigation are unavailable, and it is not possible to resolve this contradiction without further data.

Experience and Skill Comparisons

Helander (1976) notes that young drivers have psychomotor capabilities that are superior to those of older adults, yet the injury rate for drivers under the age of 20 is at least twice that of 30 year olds. This appears to be an effect of experience, since increased fatality rates are obtained for the first 5 years of driving, regardless of the age at which the license is first acquired. Helander believes that GSR is a valid measure of the mental effort involved in driving.

Helander has found that the most important vehicle control variable for predicting the physiological response of inexperienced drivers were those involving longitudinal control (braking, acceleration, and velocity). For experienced drivers, however, the most important predictors were those involving lateral control of the vehicle (steering wheel angle). More frequent EDRs were recorded in experienced than in inexperienced drivers.

Stikar, Hoskovec, and Biehl (1972) have found that expected events produce different physiological responses in experienced and inexperienced drivers, but that unexpected events produce similar reactions. Unexpected skidding causes increases in HR for both experienced and inexperienced drivers, but when skidding is expected, experienced drivers show less stress.

Hoffman and Schneider (1967) report that a lower proportion of experienced than inexperienced drivers showed large HR increases in urban traffic. Ohkubo (1976) has found that the heart rate increase (over resting levels) that accompanies driving is more pronounced in unskilled than in skilled drivers.

Hunt, Dix, and May (1968) had six police drivers, three of whom were considered expert and three of whom were inexperienced, drive a 30 mile course. The mean heart rate for the experienced group (82 bpm) was lower than that of the inexperienced group (93 bpm). In situations involving "competitive conflict" between drivers, all of the less experienced drivers showed heart rate increases, while the experienced drivers did not. In response to unexpected incidents, the experienced group again showed less change. The range of interbeat intervals was used as a measure of heart rate variability, and this index showed a smaller range for experienced than for inexperienced drivers.

Brown and Huffman (1972) compared two groups of drivers: those with good driving records and those with poor driving records. The good record group was made up of 16 men who had had no accidentsor moving violations during the previous four years. The poor record group consisted of 16 men who had had two or more accidents and two or more moving violations during the same time period. The good record group had significantly lower mean rates of galvanic skin response. Drivers with poor records, then, show greater arousal. It is unclear whether this high level of physiological reactivity makes them bad drivers, or whether an inability to successfully deal with the driving situation (or perhaps some other factor) causes both the poor record and the physiological response.

Preston (1969) compared the galvanic skin responses of drivers with high and low insurance premiums on town and country roads. The high insurance group did not differ from the low insurance group in the magnitude of GSR, but the ratio of town GSR to country GSR for this group showed that the high insurance group was more reactive. It is suggested that when driving in town, most GSRs are generated by other drivers, but on country roads, such responses are generated by the driver's own behavior. Thus driving on the open road will be more affected by individual differences in the amount of risks a group of drivers takes.

Taylor (1964) found that a subject's driving experience was a consistent source of variation in GSR rate. Those drivers with less experience typically show higher GSR rates. This is shown in Figure 22.

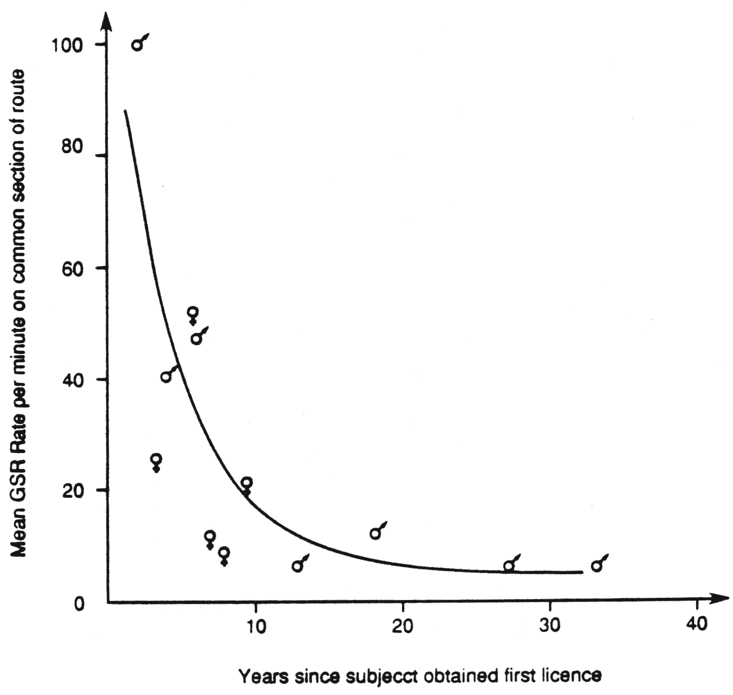

Figure 22. Subjects' mean GSR rates and amount of driving experience (Taylor, 1964).

Taylor speculates that travelling at the expected speeds on the roadway may be accompanied by a higher level of anxiety in inexperienced drivers.

Passenger Reactions

Simonson et al. (1968) report that the heart rate responses of the driver and passengers in a driving situation are nearly identical. These researchers speculate that this may be because the passenger and the driver often share the same emotional stress situation. Dupis (1965) also reports that the heart rate of passengers tends to mimic that of drivers.

Zeier (1979) found that passenger responses (heart rate, GSR, and heart rate variability) were essentially identical to driver responses in a car with automatic transmission, but passenger levels of these variables were significantly lower than driver levels in a manual. In both situations, passenger levels of muscle tension (EMG from the frontals muscle) are significantly lower than those of the driver. Torres (1971) reports that GSR is higher in drivers than in passengers.

Littler et al. (1973) found that, for the most part, arterial pressure of an individual riding in a car was similar to the pressure found when that individual was driving a car. However, in this study driving did not produce significant pressure changes, so the implication is that blood pressure also remains stable in passenger situations.

Road Markings

Babkov (1974) found that change in electrical resistance of the skin was related to road edge treatment. When edge lines were added to a section of roadway, less EDR was generated. Lower EDR was found on mountain roads with concrete edge barriers than on mountain roads without such barriers.

Interpretation of Physiological Changes

Based on evidence such as that presented above, McDonald (1984) has evaluated three possible interpretations of the physiological changes that typically accompany driving: physical, attentional, and emotional. He finds the physical explanation inadequate, based on a study by Wyss. Wyss (1971) investigated the oxygen pulse (the relationship of oxygen consumption to metabolic rate) to determine whether the heart rate increases found during driving were due to strictly physical causes. His results show that the heart rate changes produced by physical effort in the driving situation are insufficient to account for the levels of increase that are typically found. Additionally, heart rate increases have been found in situations where no control operations were necessary (Hoffman and Schneider, 1967). Wyss proposes that the causes for these heart rate increases may be primarily emotional rather than physical. This explanation is supported by researchers like Taggart et al. (1967; 1969) who have found that the cardiovascular changes that take place while driving are associated with emotional responses, such as anxiety or fear. The attentional hypothesis is also probably a valid explanation for some of the physiological changes, since task demand level (road complexity) is positively associated with physiological response level (Helander, 1976).

A number of different researchers have mentioned that physiological indicators of stress might be used by the individual as a sort of "pacing mechanism." Michaels (1962) suggests that the tension induced in driving may represent a means by which a driver may stabilize his or her system. Feedback allows the driver to determine the upper limit to his or her control of the driving situation. When traffic conditions are such that the driver is subject to considerable stress, he will slow down. When traffic is not a factor, he uses road design characteristics to obtain performance information. Helander (1976) lends support to this interpretation by pointing out that comparisons between speed limits and velocities show that the road environment, rather than the speed limit, restricts driving speed. Motorists adapt to road conditions rather than conforming to indicated speed regulations.

Gstalter (1985) similarly notes that when a situation is very demanding, drivers react with more cautious behavior, typically reducing speed. This further supports the idea of a pacing mechanism, though it is not clear whether this refers to a physiologically based pacing system, or one based on the level of information present in the immediate environment.

Taylor (1964) suggests specifically that GSR is used as a pacing mechanism while driving. Any given driver has a level of emotional tension or anxiety that he or she is willing to tolerate. If the driving situation that the driver is in generates a level of tension above this threshold, the driver will adjust his or her speed in order to bring the frequency of tension responses back down to an acceptable level. Robertson (1988) also supports a "pacing" type of explanation for the frequent failure to find a relationship between heart rate and speed. If the driver is allowed to self-select responses to the driving environment, the drivers could select an optimum speed for the conditions and would be able to maintain a constant arousal level.

CUMULATIVE EFFECTS OF DRIVING STRESS

The physiological effects of driving stress discussed in the previous section are temporary effects of the immediate environment. There is, however, another major aspect of driving stress, the cumulative effect of prolonged exposure to stressful driving situations.

Health

Perhaps one of the most important impacts of driving stress is the effect of driving on the health of the driver. Unfortunately, the effect has not been directly investigated. However, two studies, one involving the effect of commuting stress on the worker and one relating physiological stress indicators to health, can provide a basis for making predictions as to the possible impact of driving stress on health.

Taylor and Pocock (1972) have conducted a study of commuting stress and health. Their emphasis was on whether the number of absences from work was related to the length of each worker's daily commute. Employees of two large organizations were surveyed about their commutes. Each commute was described in terms of stages, parts of journeys in which neither the method of transport nor the vehicle was changed. The workers' daily commutes could include walks, rail transport, bus transport, and automobile transport. The commutes ranged from 12 minutes to 2 1/2 hours, with a median duration of one hour. The average number of stages was 2.84, with the majority having between two and four stages, with one or two by public transport. This information was then compared to the number of certified and uncertified work absences of each individual employee.

The results of this study show that the number of stages in a journey was an important factor in sickness absence. Those employees with one or two stages in their daily commute had fewer absences than those with more. The duration of the journey was important only for those individuals whose commutes were over an hour and a half long. The use of a car as the primary means of transportation was also associated with higher rates of absence.

Mulders et al. (1982; 1988) have investigated the link between driving and health in a population of professional bus drivers. The average rate of absenteeism for bus drivers in The Netherlands is twice the Dutch industrial mean. Six out of ten drivers retire early for reasons of medical disability.

Twelve subjects were selected from the population of bus drivers. Six of these were chosen for their high rates of illness absences, and six were chosen for their low rates of absence over the previous year. The high sickness group had each had five or more short absences within a years time, and the low sickness group had had two or fewer absences over the same period. Urine samples were collected from these six subjects for catecholamine analysis.

Both groups showed higher catecholamine levels after a period of work than after a rest period. The high and low sickness groups did not show differences in catecholamine levels on a day off. However, the high sickness group showed significantly higher elevations of adrenalin and noradrenaline (from resting baseline levels) than the low sickness group after a day at work. This suggests that differential physiological reactivity is associated with differential illness rates.

A later study of the same population used a similar method but incorporated a medium sickness group. As expected, the physiological reactivity (catecholamine levels) of this group fell in between that of the low sickness and high sickness groups after a day at work. No differences between the groups were found on a day off. A third study has replicated this finding. The researchers conclude that a strong link exists between increased neuro-endocrine reactivity and the early stage of progressive health impairment. Because of the design of the study, no stronger (causal) inferences could be made.

Well Being

Stokols, Novaco, Stokols, and Campbell have conducted a series of studies that explore the effects of routine exposure to traffic congestion on mood, physiology, and task performance of automobile commuters (1978; Novaco, Stokols, Campbell, and Stokols, 1979; Stokols and Novaco, 1981; Novaco, Stokols, and Milanesi, 1990). The central concept in their work is impedance. They define this term as "any circumstances that ... interfere with one's movement between two or more points." Thus impedance refers to a specific group of stressors (e.g., traffic congestion, traffic signals, intravehicular conditions) to which commuters are regularly exposed. Impedance is a form of behavioral constraint that specifically impedes the movement between two points. The greatest degree of impedance from traffic congestion would be experienced while travelling large distances slowly; the smallest degree of impedance would be experienced while travelling short distances quickly.

One hundred employees of two large industrial firms in Irvine, California were selected to participate in the initial study from a pool of over 300 volunteers, and these individuals were classified into groups based on the distance and duration of their daily commute. These measures were believed to be indicative of the amount of impedance encountered by each commuter. The subjects were classified into one of five groups based on the distance and duration of their daily commute. Those subjects whose commute fell within the bottom 25% of the distributions of distance and time were classified as low-impedance. This group consisted of 27 people who travelled less than 7.5 miles in less than 12.5 minutes on their way to and from work. Those subjects whose commute fell into the middle 30% of the time and distance distributions were classified as medium-impedance. There were 22 individuals who travelled between 10 and 14 miles in 17-20 minutes in this group. Those subjects whose commutes fell into the top 25% of the time and distance distributions were classified as high-impedance. There were 36 individuals in this group, and they travelled between 18 and 50 miles, spending 30 to 75 minutes on the commute.

The three groups discussed above were made up only of people whose commutes were consistent in terms of time and distance (i.e., if distance was high, time was high; if distance was medium, time was medium, etc.). Two additional groups were also formed. The first of these consisted of six people who travelled a short distance in a medium amount of time. The second consisted of nine individuals who travelled a medium distance in a long period of time.

The results of this study show that higher levels of impedance are associated with greater perception of traffic congestion as an inconvenience and lower levels of commuting satisfaction. High impedance subjects also rated themselves as more tense and nervous than did low impedance subjects.

These researchers found no main effect of the impedance variable on blood pressure when the analysis was confined to the three groups described above. However, correlational analyses of the entire sample show that distance, duration, and speed of the commute are all positively related with both systolic and diastolic blood pressure readings.

The ecological framework of this research emphasized that the effect of driving stress on individuals would not be uniform, but would interact with various individual difference variables. These researchers found an interaction between the Type A-B distinction and the impedance variable. The Type A-B distinction refers to a personality dimension: Type A individuals are very concerned with time related deadlines and tend to seem "driven;" Type B individuals are more relaxed and easygoing. Medium impedance Type A subjects had higher systolic blood pressure and greater performance deficits on a puzzle task than did Type B subjects. This pattern was reversed in the high impedance condition, and no differences were found in the low impedance group.

The subjects who participated in the initial study were contacted eighteen months later in an attempt to assess coping behaviors that had been used to deal with commuting stress, health changes, employment satisfaction, residential quality, and feelings about the commute. Eighty-two of the initial 100 subjects were contacted.

Among high impedance subjects who were contacted eighteen months after the primary phase of the study, 62% of those individuals who reported high satisfaction with their travel arrangements had made efforts to alter their commute (e.g., by joining carpools or substituting public transit or walking for automobile driving) while only 20% of the low satisfaction individuals had made such attempts. Among all subjects, those who had high scores on a summary coping index were more satisfied with their travel situation when contacted eighteen months after the initial study than they had been originally. The pattern was reversed for those subjects who had low scores on the coping index.

The follow up study also introduced a new twist to the concept of impedance. The initial time and distance defined measure was termed physical impedance. This was contrasted with a new measure of impedance, subjective impedance, which was generated from a large set of self-report items pertaining to perceived constraints in driving. Subjective impedance was found to be related to evening mood and reports of chest pain, but not with other health measures. Physical impedance was related to job satisfaction, illness-related work absences, and colds and flu. Commuting satisfaction, a subjective measure, was significantly related to job change.

Another group of researchers, Schaeffer, Street, Singer, and Baum (1988), has developed an alternative index of impedance as a measure of commuting stress, which is operationalized in terms of speed. In their study, subjects were divided into two groups, with those driving over 20 mph classified as low impedance and those driving under 20 mph classified as high impedance. Higher levels of impedance were associated with higher systolic and diastolic blood pressure and significantly poorer performance on a proofreading task. No differences were found on measures of heart rate and self-reported hostility or anxiety.

All of the drivers in this study were further classified into high and low control groups. Most stress research finds that individuals who can exert some degree of control over their environment are less susceptable to the effects of stress. In this study, carpool vs. single drivers was used as the primary measure of control, and the presence or absence of alternative commuting routes was used as a secondary measure. Within the high impedance group, low control (carpool) drivers showed significantly higher systolic blood pressure readings than did high control (single) drivers on all three days of the study. Being a carpool driver was positively correlated with diastolic blood pressure on days 2 and 3, and with higher heart rate on days 1 and 2. Single drivers were significantly more hostile and anxious after their commutes than were carpool drivers. Drivers who had a choice of commuting routes performed more poorly on behavioral tasks than did those who had only a single possible route to work. These results do not clearly indicate what effect control, as it is operationalized in this study, has on the experience of driving stress.

The results of these kinds of studies, then, indicate that driving does have a negative cumulative effect on the individual. Stress related physiological changes, health problems, unpleasant moods, performance deficits, and job dissatisfaction have all been shown to be related to the amount of stress in the individual's driving situation.

SUMMARY AND RECOMMENDATIONS

Stress is most usefully defined as a mismatch between an individual's perception of the demand present in a situation and that individual's perception of his or her own ability to cope with the demand. In the driving environment, stress is a function of the road and traffic environment and of the individual. The stress related to driving does not arise from a singular source; rather, a number of features of the driving situation can induce stress. Driving stress has immediate physiological effects and cumulative effects on health and psychological well-being. Research in this area has typically shown that:

(1) Immediate changes in heart rate, heart rate variability, electrocardiographic patterns, galvanic skin response, and urinary levels of catecholamines are associated with the driving situation. Individuals show considerably more physiological indicators of stress while driving than while resting. Road type, specific road elements (such as curves and on-ramps), the difficulty or complexity of the driving situation, and specific in-traffic maneuvers (such as passing, merging, being overtaken) have been shown to elicit higher levels of physiological stress in drivers. These stress responses are due primarily to increased attentional and decision making demands that such situations impose on the driver, and to the emotional responses that are evoked.

(2) Individuals differ greatly in their experience of driving stress. Not everyone shows the same patterns of physiological changes when confronted with a stressful situation. Not everyone finds a certain situation stressful. Some of these differences are specific to each unique individual, but other differences are systematic. For example, experienced and skilled drivers typically experience less stress in the driving situation than do less experienced drivers.

(3) The literature suggests that driving has cumulative effects on both the health and well-being of the individual. However, the extent and severity of these effects has not been well established. Only a few studies have been conducted in this area, and the data that they have generated are not sufficiently coherent to allow confident inferences about these effects to be made.

In light of the current state of empirical evidence on the topic of driving stress, several suggestions can be made as to specific areas of study that require clarification or elaboration. All of these recommendations involve verification of the assumptions and implications of the transactional model of driver stress.

Recommendations

1. Classification of driving situations in terms of their stress producing potential. Previous research on driving stress has employed small numbers of subjects (in many cases as few as six or eight drivers) to explore the impact of a single driving variable (e.g., being overtaken). Because of the use of small N, single variable designs, the literature consists of a number of isolated and often contradictory findings. The existing literature does not therefore provide a way to calibrate the relative stress producing potential of either roadway design variables or of traffic congestion variables.

Such calibration is essential for effective intervention. Transportation design and planning would benefit from more precise knowledge of both the situations that elicit stress, and their relative impact on different types of drivers. The transactional model of stress suggested above provides an appropriate guide for the execution of this research. The model requires that summary measures of the task demands posed by different driving situations be developed. For example, it requires quantification of the relative degree of difficulty between freeway driving and surface street driving. It requires quantification of the relative demands of congestion versus unimpeded driving. Such measures should be perceptually based and should quantify the difficulty of various driving tasks for different groups of drivers.

The transactional model also requires that the psychological and physiological impact of various driving situations be measured. This quantification of the relative stress producing properties of different driving tasks is conspicuously absent from existing literature. Current literature only suggests that some traffic events produce stress. Little is known about the <u>extent</u> or the <u>duration</u> of traffic induced stress. Virtually nothing is known about the impact of a given driving situation on different types of drivers.

2. <u>Exploration of the relationship between aging and driving stress</u>. The elderly are the fastest growing segment of society; almost 27 million people or 12% of the US 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 (1988) has shown that the elderly took more trips in a private vehicle in 1983 than they did in 1977; over 91% of all trips in rural areas and over 87% of all urban trips by the elderly were taken in the private car. Further, analyses of long-term demographic trends indicate that by 2020 almost three quarters of the elderly will live in suburban or rural areas where alternatives to the car are non-existent.

Despite the importance of the subject, the relationship between aging and driving stress has yet to be empirically explored. The transactional model of stress indicates that perceived stress is a function of both external events and drivers' resources. The literature concerning the perceptual and cognitive consequences of aging (cf. Section II of this report) indicate that the information processing resources demanded by driving tend to deteriorate with advancing age. This suggests that as drivers age they should become more physiologically and psychologically stressed by traffic situations. This hypothesis, however, has yet to be empirically verified. Research in this area should attempt quantification of both the roadway design variables and the traffic situations that impose relatively greater stress on elderly drivers.

3. <u>Investigate the long-term cumulative impact of driving stress on both</u>

younger and older drivers. Because no longitudinal studies have been conducted, the hypothesis that driving stress leads to measurable changes in health is conjectural. Despite the evidence that driving is a stressor, and that stress negatively influences health, specific linkages between driving and health have rarely been documented. It therefore remains possible that driving produces a minimal long term impact on health. It is possible that people easily adapt to driving stress. It is possible that only a subset of the driving population is at risk. It is possible that the "cost" of traffic congestion and other traffic variables in terms of physical and psychological pathology is small. Without empirical study these and related questions cannot be answered. Large scale longitudinal studies are required that compare different groups (including the elderly) and different driving task demands while health is evaluated. Research should involve both prospective and retrospective research designs.

4. Explore the mechanisms that mediate the relationship between driving stress and health changes. Implicit in the concept of stress is that excessive stress, relative to an individual's capacities, induces illness. The support for this hypothesis comes from studies of the physiology of neuroendocrine systems and of the immune system (cf. Section III below). Research on driving stress requires research on both stress-health outcomes and on the mediators of those outcomes. To date, there exists fragmentary evidence that driving stress has an impact on cardiovascular health. No studies of immune system response to driving stress have been conducted. Further research on both of these topics is required if the relationship between driving stress and health is to be clarified.

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II. Perceptual and Cognitive Consequences of Aging: The Impact on Driving Ability and Driving Stress

More than ever before, a significant proportion of the driving population is reaching middle age and beyond. In fact, the percentage of older drivers is increasing steadily in the United States. In 1984, 25% of the licensed drivers were 55 years of age and over. By the year 2000, the projection is 28% and will be 39% by 2050 (Koltnow, 1985). When we consider an American population that is aging, it is important to address the needs and concerns of the older driver within a societal context. Today's older Americans are healthier, wealthier, and more mobile than were previous generations. Most older Americans are licensed drivers and take most of their trips by automobile. In addition, mobility, especially by automobile, is essential to the lives of older Americans. However, America's roadway system, including its roads, signs, vehicles, licensing, and training was designed for healthy 25-year-olds, not for older drivers (Research & Development, 1989). As this trend continues, it becomes vitally important to establish the characteristics affecting the elderly driver not only in terms of highway design and transportation systems, but also in reference to the the perceptual and cognitive changes that take place with aging.

Although it has been well documented that performance on various measures of cognition, vision, complex reaction time, and other driver-related skills deteriorates with age, older drivers show the greatest variability of any age group in performance on these tasks, and this deterioration rises at an accelerating rate with increasing age. This group of drivers also show the greatest within-subject variability. Consequently, it becomes important to consider the functional age of elderly drivers rather than their chronological age. Staplin, Lococo, and Sim (1990) state that the "study of functional capacity in experimental aging research may be broken down in terms of sensory/perceptual, cognitive, and psychomotor performance, while emphasizing that the boundaries between functions are not always sharply defined" (p.4).

In fact, the earliest and most widespread changes that affect the aging driver are vision changes. For example, the onset of presbyopia (a form of farsightedness occurring after middle-age) may make it difficult for drivers even in their mid-40's to perceive controls and displays within near vision. In addition, a gradual reduction in visual acuity, contrast sensitivity, and lens light transmission which initially manifest in the early 50's may affect driving performance. Changes in color perception may determine how well the control displays appear because certain colors seem to have better definition than others. Steady declines in the visual field may impede the older driver's view of the road. Adaptation to the dark becomes prolonged. Low lens light transmission and a sensitivity to glare from oncoming traffic or from light reflected in rearview mirrors has been cited as the most significant reason why older adults reduce their driving at night (Research & Development, 1989).

Presently, there is no uniform standard for the minimal vision required to obtain a driver's license. Forty-one states do require 20/40 visual acuity, but some of these waive the standard with a recommendation from an optometrist or ophthalmologist; other states use 20/70 as their criterion; others have still weaker standards. Furthermore, present vision testing measures only static visual acuity, yet driving skills require perception of a dynamic environment. Low contrast acuity and other visual factors such as peripheral vision are not taken into account.

PERCEPTUAL CONSEQUENCES OF AGING

The question of which visual attributes are required for satisfactory driving performance is debatable. Measures of driving performance which consider the useful field of view, peripheral and central angular movement, movement in depth, contrast sensitivity, sensitivity to glare, dynamic visual acuity, and low luminance performance should be likely candidates (Research & Development, 1989). These features may be among the most relevant because drivers are often unaware that their vision is deteriorating in these respects.

Consequently, the visual parameters within which satisfactory driving performance in elderly drivers is possible need to be adequately assessed. Staplin, Lococo, & Sim (1990) suggest that categories of visual performance related to driving safety should include spatial vision (e.g., acuity and contrast sensitivity), temporal vision (e.g., flicker fusion/image persistence) color vision, visual field size, and dark adaptation. They also indicate that binocular depth perception (steropsis) is important to vehicle handling effectiveness, but that sensory dysfunctions in this area can often be interpreted in terms of more "basic" deficits, and are usually not discussed separately. However, an examination of the research in these basic areas is important to allow for comprehensive integration and understanding of the processes involved in the aging process.

Spatial vision differs from object vision not only in terms of utilizing two separate visual pathways which extend from the primary visual receiving area in the occipital lobe, but also in that the pathways serve two different functions. As the name implies, object vision (reaching the temporal area of the brain) is vital for identifying objects. Spatial vision (reaching the parietal region in the brain) is crucial for locating objects. Both processes are examples of higher-order visual functioning that goes far beyond the analysis carried out by feature detectors in the primary visual receiving area. The end result of object vision processing is information about an object's physical properties that facilitate the identification of the object when seen from different viewpoints and in different areas of space. The end result of spatial vision processing is information about the object's location. It is believed that integration of these two types of information takes place within subcortical (limbic areas) and cortical (frontal lobe) regions of the brain (Goldstein, 1989).

Staplin, Lococo, and Sim (1990) suggest that the functional assessment of spatial vision performance relative to driving tasks depends on factors such as level of illumination and target size. Related to this idea is visual sensory processing which involves spatial frequency contrast sensitivity, a basic capacity of the visual system required for all spatial perception and a possible source of driving impairment.

Static Acuity

Spatial vision is often determined on the basis of static or dynamic visual acuity. Static visual acuity refers to the ability of the visual system to resolve small details in the environment. Visual acuity is most often measured with the aid of charts such as the Snellen chart or the Bailey-Lovie Chart. Ferris, Kassoff, Bresnick, and Bailey (1982) suggest that two features of the Bailey-Lovie Chart make it particularly good for research purposes. Specifically, letter size decreases from line to line in 0.1 logarithmic steps, and the same number of letters are on each line. This allows letter acuity to be expressed in terms of log minimum angle resolved (logmar).

There are variations of these tests, but all of them are constructed to measure the smallest visual angle at which an object can be correctly identified. In general, acuity can be predicted from measures of high spatial frequency contrast sensitivity, though the opposite is not true (Staplin, Lococo, & Sim, 1990). Up to ages 40 to 50, little change in acuity has been noted, but after this time a marked decline is observed. By ages 60 to 70, without correction, poor vision is the rule rather than the exception (cf. Chapanis, 1950; Weymouth, 1960; Richards, 1972; Botwinick, 1984). Specifically, the Framingham study has shown that about

10 percent of men and women between the ages of 65 and 74 have acuity worse than 20/30, compared to roughly 30 percent over the age of 75. Three classes of pathology (cataract, retinopathy, and glaucoma) were found in 10.4, 37.1, and 88.2 percent of those with moderate to severe visual loss in the 52 to 64-, 65 to 74-, and 75 to 85-year-old age groups, respectively (Kahn et al., 1977). In fact, Pitts (1982) attributes the majority of the late decline in acuity to four pathologic factors (i.e., cataract, senile macular degeneration, other retinal pathology including diabetic retinopathy, and glaucoma) implying that only a small loss can be attributed to slow "normal aging."

Illumination. The majority of older individuals, however, do not suffer from visual pathology and maintain good to fair corrected visual acuity. Shinar (1977) reported that average acuity was 20/30 at age 65, but dropped significantly to 20/70 for those over age 65. Kline and Schieber (1985) suggest that much of the slight to moderate loss in static visual acuity accompanying normal aging appears to be due to changes in the optic media of the eye. Senile miotic changes of the pupil and opacification of the lens and vitreous body tend to decrease retinal illumination and markedly increase the intraocular scatter of light. These factors result in a three fold reduction in the light reaching the retina between the ages of 20 and 60 (Weale, 1961). This results in a "sun-glasses" effect which becomes exacerbated under conditions of low or poor illumination. However, a conflict arises. Older people need lots of illumination, yet high illumination can make for glare, especially among those who have cataracts or who are developing them. To at least partially compensate for this effect, Upchurch and Bordin (1986) note that overhead guide sign illumination is dependent upon the positioning of fixtures (particularly tilt angle) with respect to the sign. This can dramatically affect a drivers ability to adequately see and respond in terms of both foot-candles of illumination and lighting uniformity. Some non-illuminated, reflectorized background signs may also be able to help counteract the effects of low or poor illumination and could be considered as an alternative to illumination in some instances.

Staplin, Lococo, and Sim (1990) also correctly note that assessments of visual performance under nighttime conditions should be assessed against the nature of the night driving task. Because even at night, most visual information is processed by the cone, or daylight, system, artificial lighting which raises the illumination allows reading and tracking functions to be possible. The peripheral rod, or nighttime, visual system is primarily responsible for alerting and orienting drivers to weaker signals in the environment. Drivers with reduced sensitivity to peripheral signals will require brighter stimuli to elicit proper visual attention. In fact, Staplin, Lococo, and Sim (1990) indicate that individuals with reduced sensitivity may require traffic control device stimuli that are between 10 to 100 times brighter (depending on the color) in order to be perceived in the periphery than a person without reduced sensitivity. Consequently, while internally illuminated signs may not be a serious problem under these conditions, objects depending on a reflected light for driver detection will fall closer to the elevated cone thresholds. A summary of operationally-significant, age-related visual detection performance decrements is presented in table 1.

Table 1. A qualitative assesment of relative decrements experienced by older versus younger drivers in target detection under designated (nighttime) driving conditions.

	Horizontal Target			Vertical Target (obstacle)			Vertical Target (reflectorized)		
Glare Condition	clear	rain	fog	clear	rain	fog	clear	rain	fog
No opposing traffic	moderate	Severe	moderate	severe	severe	slight	moderate	slight	slight
Opposing traffic on multi-lane roadway*	Severe	extreme	moderate	severe	severe	moderate	moderate	moderate	slight
Opposing traffic on two-lane roadway	extreme	worst case	Severe	extreme	extreme	moderate	severe	severe	moderate

* Opposing traffic streams are seperated by at least 12 feet.

Declines in static acuity with target illumination can be observed for all age groups, but the loss in visual sensitivity becomes significantly accelerated in aged individuals (e.g., Guth & McNelis, 1969; Sturgis & Osgood, 1982). (See Figure 1).

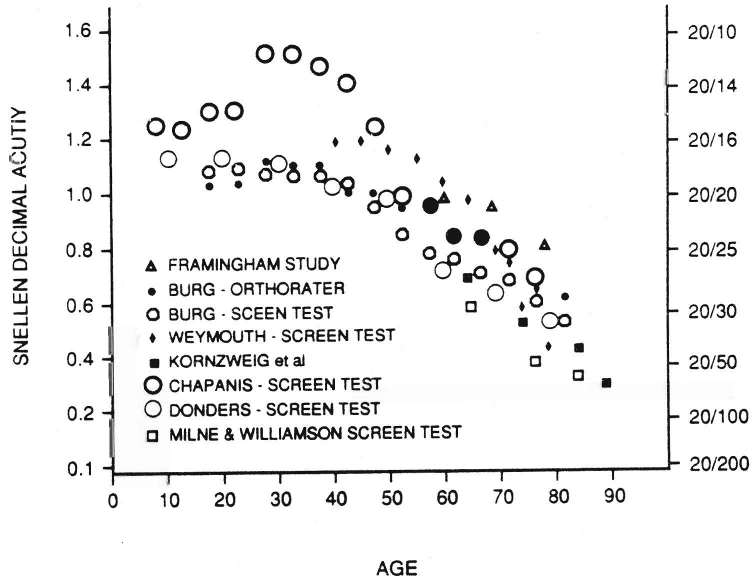

Figure 1. The composite of visual acuity as it changes with age based upon eight investigations. Acuity is based on the best corrected eye. (From D. G. Pitts, The effects of aging upon selected visual functions. In handbook of the psychology of aging. New York: Van Nostrand Reinhold, 1985).

Familiarity. Although the detection and recognition of symbol signs and other relevant features of traffic control is a multistaged task, it is necessarily first dependent upon visual acuity. Allen, Parseghian, and Van Valkenburgh (1980) report a number of studies which have determined the minimum visual angles for various types of perception. It has been shown that detail can be resolved down to 1/2 to 1 minute of visual angle by persons with 20/20 visual acuity, but that recognition of detail may not be dependent on degree of visual acuity alone if the symbol or word is a familiar one (Jacobs, Johnston, & Cole, 1975).

Smith and Weir (1978) have also shown that the minimum visual angle for detail is about 1 minute of arc, and that high recognition occurs for orientation of arrowheads whose maximum dimension was 8.6 minutes of visual angle with symbol detail on the order of 1 minute of arc. The proposal that recognition is dependent on visual acuity and familiarly has received further support from findings related to the recognition of symbol signs. Jacobs, Johnston, and Cole (1975) have reported that symbol signs give roughly twice the recognition distance of equivalent sized alphabetic signs. However, Allen, et al. (1980) point out that equivalent symbol stroke was typically greater than letter stroke.

More recently, Staplin, Lococo, and Sim (1990) conducted a study to assess the differences in drivers' ability to read unique word combinations and complete messages on regulatory, warning, and guide signs at a glance as a function of character size (subtended visual angle). Conditions of offset distance and glare were also manipulated. Their dependent measure was reported both in terms of minutes of visual angle of character stroke width, as well as an equivalent Snellen fraction denominator. Their results demonstrated a "consistent need by older drivers for significantly larger character sizes to read individual words and--more important from an operational standpoint--complete (four-word) regulatory, warning and guide sign messages, relative to young/middle-aged drivers" (p.68). (See Fig. 2).

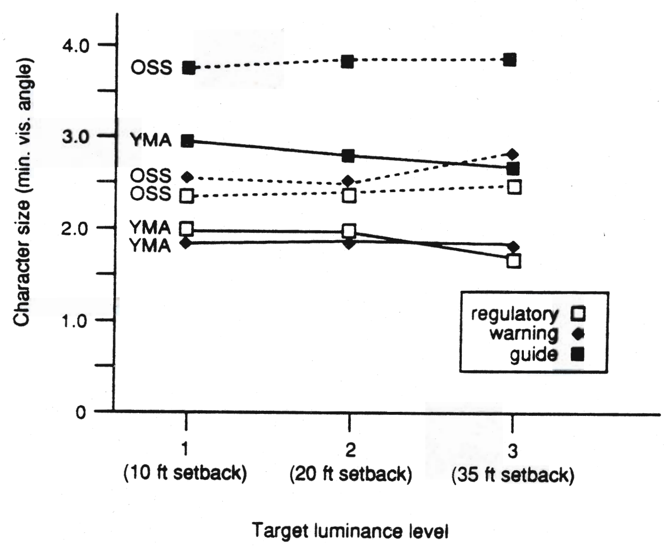

Figure 2. Mean character size in minutes of visual angle required for message legibility without glare for each sign type for each study group, under three luminance conditions simulating varying sign setback distances. (From Staplin, Lococo, & Sim, 1990).

Potential familiarity effects were eliminated by using novel combinations of words normally found on highway signs as test stimuli. Significant declines in performance by the older driver were also found with increasing distance between sign and driver, as well as for glare from oncoming headlights. In addition, variability in older driver performance and mean performance decrement relative to the young comparison group increased.

Recognition for alphabetic signs may also be directly related to luminance and color. It has been shown that legibility decreases with luminance, and color combinations such as black on orange and white on brown show definite decreases in visual acuity over black on white and white on blue (Forbes, 1976). Woltman, Stanton, & Stearns (1984) demonstrated in a laboratory experiment that as driver age increased in conjunction with a greater number of signs and higher background complexity, the error rates increased for correct identification of white-on-green and white-on-black signs. Consequently, color combinations are also important visual attributes particularly relevant to symbol sign color codes, and the acuity differentials are an important aspect of design (Allen, et al., 1980).

Dynamic Visual Acuity

Dynamic visual acuity (DVA) refers to the ability to resolve fine spatial detail for objects in motion relative to the observer. DVA is also perceptually more complex than static visual acuity processes, depending as it does on the sharpness of the retinal image plus oculo-motor coordination and higher-order visual nervous system mechanisms (Panek, Barrett, Sterns, & Alexander, 1977). Hulbert, Burg, Knoll, and Mathewson (1948) determined that dynamic visual acuity is negatively correlated with sign reading errors. Burg (1966) examined both static and dynamic visual acuity measures obtained from a sample of more than 17,000 drivers aged 16 through 92. He found that acuity for moving targets declined more dramatically with age than conventional measures of static acuity. Burg (1968) subsequently analyzed the relationship between a variety of vision test scores and driving record (i.e., convictions and accidents) over a large subject population. Using multiple regression, he found that dynamic visual acuity was most strongly related to driving record. Shinar (cited in Research and Development, 1989) looked at the relationship between age and visual performance in several areas considered important for safe driving; normal static acuity, low illumination static acuity, static acuity in glare, dynamic visual acuity, detection-acquisition-interpretation, detection of central angular movement, central in-depth movement of a small object, and central in-depth movement of a large object. Figure 3 shows a sample of the results for normal static acuity and dynamic visual acuity.

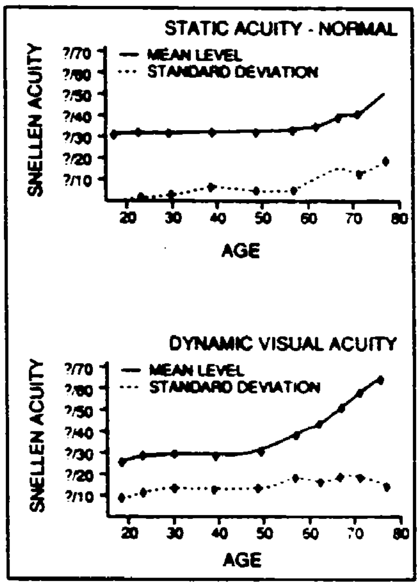

Figure 3. Relationship between age and visual performance as measured by the Snellen acuity test for normal static and dynamic visual acuity. (From Research and Development, 1989).

It can be seen that all functions decline with advancing age, but that the amount, rate, and onset age of deterioration varies widely among the functions. Variability with individual differences also begins to increase. Declines in static acuity are not significant before 60 years of age, but deterioration in more complex tasks begins earlier and accelerates faster with increasing age. Similar age-related declines in DVA have been reported by other investigators (e.g., Farrimond, 1967; Reading, 1972).

Predictive Power. Burg and Hulbert (1961) also reported evidence indicating than an individual's ability to discriminate a moving target could not be adequately predicted on the basis of static visual acuity measures. This dissociation between static and dynamic visual acuity appears to become more pronounced in older individuals, especially as target velocity is increased (Reading, 1972) However, Henderson and Burg (1974) have found that, unlike static visual acuity measures, dynamic visual acuity appears to have more predictive power in regard to driving performance and highway safety among older, but not middle-aged individuals. The differential decline of DVA in older individuals, along with its predictive power for performance on complex perceptual-motor tasks such as driving, suggests that it holds the potential of providing important new information about the aging of higher-order visual functions (Kline & Schieber, 1985). Consequently, if vision tests are included as a means of quantifying subject visual function, dynamic visual acuity is important to understand and include (Allen, Parseghian, & Van Valkenburgh, 1980).

Contrast Sensitivity

In addition, converging evidence from both psychophysical and electrophysical research indicates that different types of stimuli are detected by different neural channels in the visual system (cf. Levine & Shefner, 1981). Studies indicate that the visual system contains "transient" and "sustained" channels which can be distinguished on their temporal response properties as well as their selectivity for targets of different size or spatial frequency.

The Contrast Sensitivity Function (CSF) provides a comprehensive summary of the visual channels ability to discriminate spatially by relating the amount of contrast required to detect a grating. Spatial frequency contrast sensitivity is thus measured by the number of alternating pairs of black and white regions (sinusoidal gratings) that can be perceived per degree of visual angle. A high spatial-frequency grating is a finely patterned one with a large number of cycles per degree (c/deg), and the determination of its threshold is similar to a traditional visual acuity test. A low spatial-frequency grating, with fewer c/deg, is more coarsely patterned.

Spatial frequency contrast sensitivity may also be a predictor of other visual-perceptual deficits that relate to driving ability (Research & Development, 1989). However, the results on contrast sensitivity have not always been consistent. Two separate studies showed age deficits primarily at intermediate and high spatial frequencies of 4 c/deg and higher (Arundale, 1978; Derefeldt, Lennerstrand, & Lundh, 1978), while very large differences in sensitivity were observed at low spatial frequencies, and at the highest spatial frequency tested (16 c/deg), the sensitivity of the two groups was almost equal (Sekular & Hutman, 1980).

Kline and Schieber (1985) have reported on investigations which attempted to clarify such inconsistent results. Data obtained by using a threshold tracking method to determine CFSs for 16 young (aged 18 to 25) and 16 old (aged 55 to 70) subjects in oscilloscopically presented sinusoidal gratings ranging in spatial frequency from 0.5 to 12 c/deg demonstrated an age-related deficit in contrast sensitivity for target grating in the intermediate and high spatial-frequency range. Owsley, Sekular, and Siemsen (1983) have also examined the impact of age on the CSF. Contrast sensitivity for gratings ranging in spatial frequency from 0.5 to 16 c/deg were determined for subjects from seven different age groups (age range, 19 to 87 years). All age groups were found to be similar at low spatial frequencies, with a progressive age-related loss in sensitivity at the intermediate and high spatial frequencies. They conclude that their evidence indicates that when viewing conditions are kept constant and pupil size variation is taken into account, performance in the middle and high spatial frequencies (15-25 c/deg, for foveal viewing) is found to decline systematically with age; most significantly at ages over 40 to 45 years.

Kline and Schieber (1985) suggest that the previous failure to find age-related deficits in CSF at intermediate and high spatial frequencies may have resulted from a combination of factors including the small number of subjects employed, as well as matching subjects for good visual acuity (i.e., high spatial-frequency sensitivity). As a result, the "emerging consensus appears to indicate that the major effect of aging on spatial vision is a loss in contrast sensitivity for targets whose spatial frequency is around 2 c/deg and higher" (p.314). (See Fig. 4).

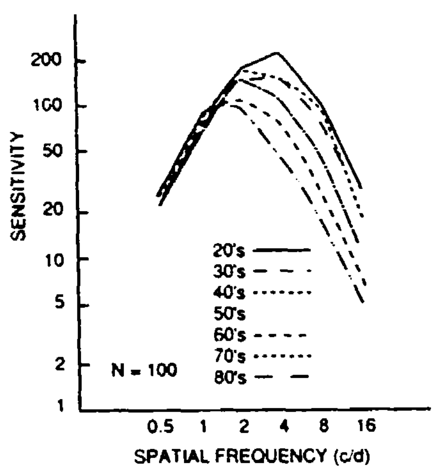

Figure 4. Age and contrast sensitivity as a function of grating spatial frequency. (From Owsley, Sekular, & Siemsen, 1983).

Staplin, Lococo, and Sim (1990) note that drivers can generally detect objects that exceed their threshold of sensitivity to contrast, where contrast is formally defined as the difference between target luminance and background luminance levels, divided by the background luminance alone. However, because contrast sensitivity is also dependent upon the ambient or adaptation level of background luminance, the contrast sensitivity of all drivers diminishes as the ambient light level decreases. For example, under daytime conditions a roadway hazard or traffic control device that has a low contrast with its environmental surroundings may be detected, but the same object may be invisible at night to the same driver. Staplin et al. (1989) also describe compounding problems for older drivers. Under constant viewing conditions, older individuals have significantly lower contrast sensitivity, while at the same time, their performance falls off to a significantly greater degree for a given reduction in ambient light levels. To express the net effect on this type of visual capability, Blackwell and Blackwell (1971) demonstrated that a 60-year-old driver requires approximately 2-1/2 times the contrast as a 23-year-old driver for the same level of target visibility. This obviously makes nighttime driving more difficult and hazardous for older drivers.

<u>Detection of traffic control devices (TDS's)</u>. Contrast sensitivity also underlies the detection and recognition of many traffic control devices. Both the brightness (luminance) of a detection/recognition target and that of its background, or surrounding roadway environment, play an important role in determining contrast level. Because sensitivity to contrast falls off for everyone to some degree as background luminance is decreased, high contrast is required by all drivers to see signs, roadway striping, etc. when lighting levels are low.

Apparently, older drivers are more impaired by reduced levels of sensitivity to intensity and contrast of dimming traffic signals at night than to signal color. Staplin, Lococo, and Sim (1990) suggest that older drivers need increased levels of signal luminance and contrast in certain situations to perceive traffic signals as effectively as a 20- to 25-year-old, but higher signal intensities may cause disability glare. They also note that, in general, experiments under conditions which simulate simple background settings at night indicate that reduced signal luminance does not cause detrimental effects on the performance of older drivers. However, the declines noted with advancing age suggest that disproportionate increases in traffic control device brightness may be required to accommodate older drivers under nighttime driving conditions.

In order to assess differences in contrast sensitivity within and across age groups, Staplin, Lococo, and Sim (1990) varied three levels of background luminance and three different age groups (older self-selected, OSS; young/middle-aged, YMA; and older, cross-validation, OCV) against the target contrast at each person's detection threshold, for each level of background luminance. They concluded that first, the spread between the visual capabilities of young/middle-aged drivers and a self-selected sample of older motorists is in general agreement with the age-related differences noted previously (e.g. Blackwell & Blackwell, 1971). (See Fig. 5).

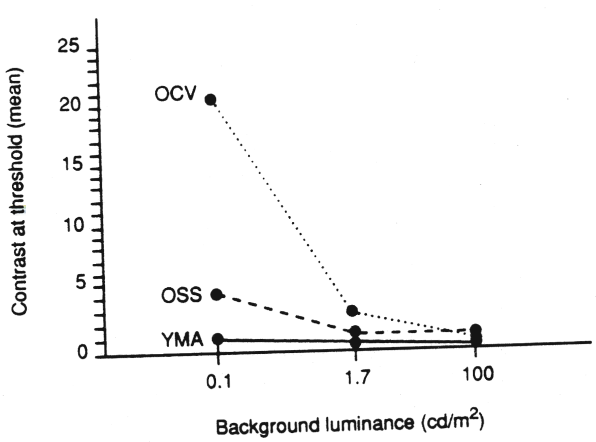

Figure 5. Mean threshold levels in contrast sensitivity screening. (From Staplin, Lococo, & Sim, 1990).

More seriously, however, they also conclude from their evidence that a substantial proportion of active, older drivers may in fact suffer far greater visual performance deficits than are typically detected in psychophysical studies of this nature.

Field of Vision

Another characteristic of the aging eye is loss of peripheral vision or field of vision. The extent of the visual field has important consequences for everyday activity, such as driving. Age-related changes in visual fields can be measured either as a reduction in field area for different target sizes and intensities, or as an elevation in threshold values at particular locations within visual field limits (Staplin, Lococo, & Sim, 1990). A recent study showed the incidence of visual field loss was 3.0 to 3.5 percent for persons 16 to 60 years old compared to 13 percent for those over 65 years. Drivers with visual field loss in both eyes may have twice the accident and conviction rates of those with normal field vision (Malfetti, 1985).

According to Birren and Schaie (1985), the most common clinical assessment of visual field incorporates the Goldmann projection perimetry technique. This measure involves projecting a spot of light of variable size and intensity upon the inner surface of a wide, dimly illuminated hemispherical shell. The spot of light is then moved from the periphery toward the central point of fixation along predetermined meridians ranging in orientation from horizontal to fully vertical. By taking measurements of maximum target eccentricity from all approach directions, the visual field of sensitivity for 360 degrees about the fixation point can be determined. This map for a stimulus of a given size is known as an isopter (Corso, 1981).

The field of vision of an eye is the total area over which effective sight is maintained relative to a constant, straight-ahead fixation point.

Changes in the visual field that accompany aging are typically studied by mapping the peripheral boundaries of threshold visual sensitivity by using a moving stimulus. This "kinetic" method of perimetry differs from the more rigorous "static" method of perimetry in which changes in sensitivity across the extent of the visual field are determined (Kline & Schieber, 1985). Investigations of kinetic perimetry have demonstrated that the visual field constricts with advancing age (cf. Harrington, 1964; Wolf, 1967; Burg, 1968), and also declines for both central and peripheral isopters (Drance, Berry, & Hughes, 1967). An extensive examination of peripheral vision for 17,000 subjects between the ages of 16 and 92 was conducted by Burg (1968). Targets subtending 46 minutes of arc, with a luminance of 7.5 foot-candles, were presented at various positions along the horizontal meridian for both eyes, and the peripheral extent of visibility was determined for each individual. Although the extent of both temporal and nasal visual fields declined with increasing age, this effect was particularly noticeable for the temporal field. The total horizontal visual field, represented by the sum of both temporal fields, was constant up to age 35, declined slightly between ages 40 and 50, and demonstrated an accelerated loss with age after that.

Wolf (1967) used the projection perimetry technique to assess the full range of the visual field for subjects between 16 to 91 years of age. For each subject, he determined the isopter for a 1-sq-mm, 3.3-millilambert (mL) spot projected against a 0.02-mL background. He found that the extent of the visual field remained fairly stable through age 55, but that the visual field then progressively diminished through the age of 91. This was particularly evident in those individuals over age 75. (See Fig. 6).

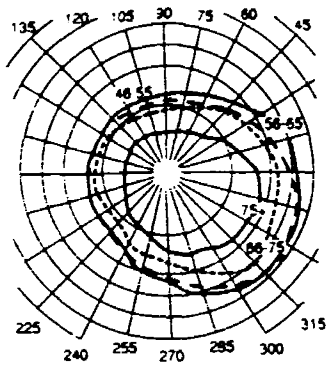

Figure 6. Average isopters of peripheral vision for right eyes as a function of age. (From E. Wolf, Studies on the shrinkage of visual field with age. Transportation Research Record 164, Transportation Research Board, National Academy of Sciences, 1967. In handbook of the psychology of aging. New York: Van Nostrand Reinhold, 1985.

Drance, Berry, and Hughes (1967) have reported similar results by showing that there is a significant increase in the size of the "blindspot" with advancing age.

Eye Movements

Another important component of spatial resolution involves eye movements which are controlled by the oculomotor system. Oculo-motor adjustment of the eyes allows the observer to keep moving objects fixated on the retina. Although objects can be detected over a large visual angle (about 200 degrees), they are best identified within a relatively small arc in the visual field (the central 5 degrees). This central region of high visual acuity is called the fovea, a discrete retinal structure about 1 mm in diameter. Optimal examination of objects in the visual environment requires that images be kept on the fovea for seconds or even minutes. If an object tends to "wander off" the fovea, the motor system can correct the slippage by moving the head, body, or eyes.

Smooth pursuit movements. Consequently, several aspects of driving may become impaired as the oculomotor system ages and deteriorates. For example, as a driver views moving targets in the environment, the eyes pursue the image so that it remains continuously on the fovea. For this type of smooth pursuit movement to occur, the brain must calculate the direction and velocity of the image on the retina. Smooth-pursuit eye movements refer to voluntary, sweeping motions of the eyes when tracking objects that cross the visual field. With advancing age, smooth-pursuit eye movements slow significantly, and latency in initiating such movements increases. Sharpe and Sylvester (1978) found that young subjects could follow targets moving as fast as 30 deg/sec, while older subjects had difficulty accurately tracking targets moving at 10 deg/sec.

Saccadic eye movements. Age-related changes have also been reported in saccadic eye movements. Unlike pursuit eye movements, saccades are characterized by short, rapid, ballistic movements that occur between successive fixations (Kline & Schieber, 1985). Chu, Reingold, Cogan, and Williams (1979) have reported that the maximum saccadic amplitude and peak saccadic velocity decline in old age. Consequently, since visual processes are greatly inhibited during saccadic movement and are optimal at fixation, it is possible that age-related reductions in the breadth and length of saccades could contribute to the observed age differences in perceptual span and/or processing time (Kline & Schieber, 1985). Chamberlain (1971) has also reported that old age is accompanied by a restriction in the ability to look upward, but that little or no limitation in the extent of lateral or downward gaze occurs.

As the saccadic eye movement system slows with age, there may be longer periods of blur as the system directs the fovea to a target of interest in visual space. Consequently, the older driver may experience critical lapses in encoding information about the external environment and attempt to guess as to the nature of these "blanks" based on experience. Because driving is a rapidly changing task, this type of compensation is highly undesirable. In addition, there is a delay of about 0.25 sec between spotting a target and initiating the saccade. After this latent period, it takes approximately 0.05 sec for the movement to be completed. Once the saccadic process has been initiated, the system is unable to make another saccade until 0.2 sec later, regardless of target behavior. That is, if a target is moved during that fraction of a second when the eye is making a saccade toward it, the fovea will always end up at the position where the target was at the beginning of the saccade. Obviously, slowing of this system has more serious implications for older individuals who must drive at higher speeds (e.g., freeways), and in fact many drivers do avoid high speeds with advancing age.

Depth Perception

The ability to localize objects in three-dimensional space, despite their two-dimensional representation on the retina, depends on the use of a large number of monocular and binocular depth cues. Although many cues are important to various extents at various times, experimental research in gerontology as it relates to depth perception has focused primarily on stereopsis (Pitts, 1982). Stereopsis is based on the integration of the separate images of each eye and may function up to distances of 450 to 650 meters. In addition to observation distance, stereopsis is also affected by several factors including luminance, lateral separation of objects, and retinal location (Kline & Schieber, 1985).

Hoffman, Price, Garrett, and Rothstein (1959) compared stereopsis for young subjects with that of subjects in their sixties and found that depth perception was significantly worse in the older group. By using subjects with visual acuity of 20/40 or better in the best eye and screening for visual anomalies, Jani (1966) found no significant differences in depth perception up to approximately age 45, but reported steady declines after this age. Reports from the Normative Aging Study also indicate a critical age between 40 and 50 years of age when depth perception begins to deteriorate (Bell, Wolf, & Bernholz, 1972).

Temporal Vision

Decline in speed of performance is one of the most commonly observed changes that take place with aging. This type of slowing appears in both the rate at which various processes are carried out and in the latency with which they are initiated. One aspect of this change is a loss in the temporal resolving power of the visual system. Visual stimuli appearing in rapid succession can usually be distinguished by younger individuals, but are often reported as appearing "fused" by older individuals in a wide variety of visual tasks (Kline & Schieber, 1982; Kline & Schieber, 1985). Measures of flicker fusion are often used as indices of this slowing process. Age-related declines in flicker fusion, where an image appears continuous with a lower rate of flicker, appear to be primarily attributable to pupillary factors (Brozek & Keys, 1945; Coppinger, 1955).

Critical flicker frequency (CFF). The critical flicker frequency (CFF) is the lowest frequency of a pulsating light source at which it appears to be on continuously. This represents the visual system's limited ability to track rapid illumination changes. The CFF threshold is a function of a variety of factors, including retinal adaptation, target luminance, target color, target size, retinal location, and the light/dark time ratio (Birren & Schaie, 1985).

Age differences in the critical flicker frequency represent some of the best documented age declines in visual temporal resolution (cf. Brozek & Keys, 1945; Coppinger, 1955; Misiak, 1947). CFF thresholds have been found to be significantly lower in older age groups, especially past 60 years of age (Wolf & Schraffa, 1964). However, only part of the decline in critical flicker frequency thresholds appears to be related to the reduction in retinal illuminance (Kline & Schieber, 1985). By studying the age differences in CFF at two illumination levels (21.9 and 0.041 foot-candles) as a function of the relative balance of light and dark time in the stimulus. McFarland, Warren, and Karis (1958) found that the age difference was greatest when the percentage of on time of the light was low and least when the light/dark ratio was high. However, the authors note that age differences were quite similar at both illumination levels which suggests that the age differences in CFF could not be attributed entirely to age differences in retinal luminance. Most driving tasks require head and eye movements to fixate on an object or an area of interest resulting in a minimization of the need for high temporal frequency processing. However, movement within a static surround may not allow for adequate fixation as the driver's eye follows the movement. This would result in taxing the temporal processing abilities of the driver to extract relevant information (Staplin, Lococo, & Sim, 1990).

Age differences in CFF represent a methodological tool for inferring temporal processing time. For example, as the CFF threshold declines, the older driver may experience a reduction in time, or diminished information, for relevant feature extraction resulting in a proportionate increase in error rate. A driving situation in which the older individual attempts to keep their head positioned straight ahead while keeping track of closely spaced signs off to the side may be particularly difficult especially with glare or poor illumination.

Image Persistence

Other researchers have proposed a stimulus persistence hypothesis to account for age-related failures in temporal resolution (Axelrod, 1963; Botwinick, 1978). The stimulus persistence hypothesis suggests that the nervous system of the older person has a longer latency to recovery period from the effects of stimulation, and, consequently, temporally contiguous stimuli are more likely to "smear" or overlap. This hypothesis is also in accord with the findings from CFF, recovery from glare, and visual masking studies.

Transient versus Sustained Channel Hypothesis. Kline & Schieber (1981, 1985) have proposed a "transient/sustained shift" hypothesis of visual aging that attempts to account for a variety of age-related visual changes, including those in image persistence, dynamic acuity, and integration of form in terms of the differential aging of the transient, as opposed to the sustained, channels of the visual system. The visual system, from retinal receptors to cortical cells, may be thought of as a set of modules operating on information in parallel. Channels within each module may perform specific functions and/or are designed to operate on specific information. This hypothesis suggests that the sustained channels are slow to respond when stimulated, have a relatively long integration time, and are most sensitive to high spatial-frequency targets.

Transient channels respond optimally to stimulus change (flicker or motion). Similarly, they also respond quickly and briefly to low-spatial-frequency targets. In addition, activated transient channels may inhibit the persisting activity of the sustained channels (Breitmeyer & Ganz, 1976). Kline and Schieber also suggest that the temporal response profile of the young visual system to stimuli that evoke a "sustained type" response (e.g., high spatial frequency, long duration, and low contrast) appear to mirror the failure that occurs in temporal resolution with aging. Specifically, they suggest an age shift in the relationship between the transient and sustained channels, resulting in an aging visual system that is "sustained-channel dominant" in comparison with its younger counterpart. Consequently, the older driver may again be disadvantaged in terms of being able to integrate, interpret, and respond to environmental stimuli.

However, all of the studies of age and CSF used stationary stimuli which optimize the likelihood of tapping the sustained channels, but may not expose an age difference in the transient channels (Harwerth & Levi, 1978). A recent study by Owsley, Sekuler, and Siemsen (1983) also supports this view. They found a decline in the effectiveness of the transient channels although sensitivity to motion enhanced was much greater for younger subjects, especially at the faster rate of movement. Kline & Schieber (1985) also note that an age-related shift from transient to sustained channel functioning may explain the increases in reaction time (RT) that cannot be attributed to losses in contrast sensitivity. (See Fig. 7).

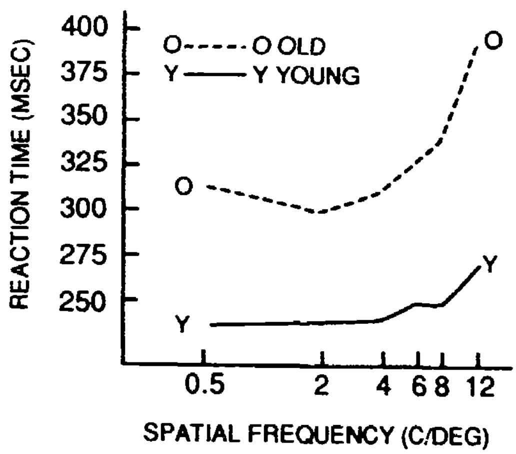

Figure 7. The reaction time of young and old subjects as a function of the spatial frequency of the target stimulus. (From Kline, Schieber, Abusamra, & Coyne, 1983).

Dark Adaptation

Dark adaptation refers to the visual system's ability to increase its sensitivity with a concomitant decrease in external illumination. In addition, there are two dimensions to dark adaptation: (a) how long it takes to develop maximum seeing ability, and (b) how sensitive a level is eventually reached. Tests of dark adaptation measure the course of increasing threshold sensitivity with time spent in the dark. Young adults with normal vision exhibit a rapid decline in threshold for the first few minutes and then level out. Over the next 10 to 15 minutes, a second rapid drop occurs and then plateaus within approximately 30 minutes.

Absolute threshold. Studies of age and dark adaptation have consistently found a marked elevation in the final, or absolute, threshold. The relationship between age and the final level of dark adaptation is so clear that rarely in psychological work are correlations so consistently high (Botwinick, 1984). This decline in final level of adaptation seems to be especially pronounced after 60 years of age (Pitts, 1982; McFarland, Domey, Warren, & Ward, 1960). However, a variety of factors appear to affect the eye's sensitivity to a test light after a time in the dark, including the color, size, retinal location, and duration of the test light, a variety of preadaptation parameters, and pupil size. In addition, many of these factors interact with age (Birren & Schaie, 1985). Studies also indicate the elevation in dark-adapted thresholds are least pronounced for longer wavelengths (e.g., red) and greatest for shorter wavelengths (e.g., blue). Increased lens density appears to account for most of the difference (McFarland, Domey, Warren, & Ward, 1960).

McFarland and Fisher (1955) conducted a study in which they obtained complete dark adaptation curves on subjects between 20 and 60 years of age. Pupil size, preadaptation level, and test-light duration were held constant. A correlation of 0.89 was found between age and final adaptation level. The intensity of the test light at threshold had to be approximately doubled for each 13 years of age. In fact, the relationship between age and final adaptation level was so reliable that it was possible to predict a subject's age to within three years based on this correlation (cf. McFarland, Domey, Warren & Ward, 1960; Domey & McFarland, 1961). (See Figure 8).

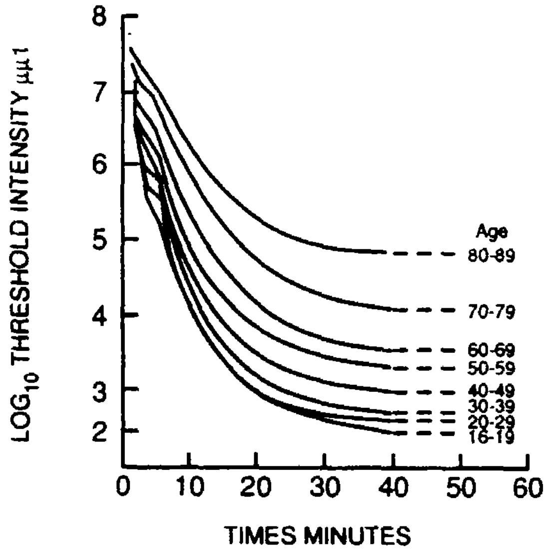

Figure 8. Dark adaptation as a function of age. (From McFarland, Domey, Warren, & Ward, 1960).

Rate of adaptation. The other dimension of dark adaptation, rate of adaptation, is less well understood. Birren and Shock (1950) concluded that only level was displaced with age. Older individuals appeared to see less well in the dark, but if given this as a baseline, they reached their level at the same rate as did younger subjects (cf. Weale, 1965). However, Domey, McFarland, and Chadwick (1960) concluded that the rate of dark adaptation, as well as the final threshold level, decrease with age. They suggest that the elderly not only see less well when finally dark-adapted, but that it takes them longer than younger individuals to get to their optimum level. Consequently, older drivers may experience significantly longer durations of diminished vision during nighttime driving due to increased rates of dark adaptation, as well as decreased threshold levels. And, in fact, many older drivers do reduce their nighttime driving.

Color Vision

Age-related changes in the ability to discriminate color are not clear, and several researchers have failed to find a relationship between age and color vision (e.g., Boice, Tinker, & Paterson, 1948; Chapanis, 1950; Staplin, Lococo, & Sim, 1990). However, Dalderup and Fredericks (1969) did observe a loss in color sensitivity that was apparent around 70 years of age and became more obvious in even later years. Considerable individual differences were also found between the right and left eyes, suggesting different rates of color vision loss in the two eyes. Although it appears that the discrimination of blues and greens (short wavelengths) is more difficult than reds and yellows (long wavelengths) for all subjects, the deficiency in matching blue and green may become more pronounced with advancing age (Kline & Schieber, 1985).

Changes in the optic media, particularly age-related yellowing of the crystalline lens, may shift the appearance of white light toward yellow. This results in a relative darkening of blue-colored objects and a bias of color perception toward the longer wavelengths. Many forms of color recognition impairment become particularly problematic when ambient illumination falls to lower photopic (cone) levels. Carter (1982) suggests that this may be because both acuity and hue discrimination decline as the retina approaches the transition between cone and rod functioning.

Several researchers (cf. Verriest, 1963; Verriest et al., 1982; Knoblauch et al., 1987) have reported results using the Farnsworth-Munsell 100-hue test in subjects with no observable pathology and found increases in error scores as a function of age. Increased errors for blue-yellow were most frequent. The mean error rate for older unpracticed individuals over 70 years of age was over 100 compared to a mean error score of 37 for subjects between 20 to 30 years of age (cited in Staplin, Lococo, & Sim, 1990). Janoff believes that this difference may be primarily attributed to increasing lens absorption of blue light with age. The impact on traffic control element use may be related to signal intensity and chromaticity standards, both of which also influence a driver's red-green discrimination capabilities (cited in Staplin, Lococo, & Sim, 1990).

Glare

Visual effectiveness is reduced when light that is excessively bright or improperly directed results in glare. Glare can be classified in several manners, including the account suggested by Bell, Troland, and Verhoeff (cited in Birren & Schaie, 1985). In veiling glare, stray light is distributed across a retinal image, reducing its contrast. For example, when room lights are turned on during the projection of a slide or motion picture, glare on the target stimulus may result. Dazzling glare involves the difficulty encountered in discriminating detail in an extremely bright visual stimulus. Reflective surfaces may result in this type of glare. Scotomatic glare is due to the protracted reduction in sensitivity that occurs when the retina is exposed to excessive light levels, even if they are very brief such as the exposure to a flash bulb. Unfortunately, the relationship between particular types of glare and age has not been studied extensively, particularly in the case of dazzling glare and, to a lesser degree, scotomatic glare (Kline & Schieber, 1985).

By studying the effect of veiling glare on the luminance required to identify a target, Wolf (1960) found that the illumination required to identify the target in the absence of glare rose significantly with age. Sensitivity to glare also increased with age, especially after age 45 (cf. Fisher & Christie, 1965; Sturgis & Osgood, 1982). Significant age-related declines have also been found in headlight-glare resistance when subjects were tested in a realistic driving simulator (Pulling, Wolf, Sturgis, & Osgood, 1982).

Staplin, Lococo, and Sims (1990) conducted a study to derive measurements of the required contrast for pavement delineation (striping) at which downstream heading on a curved roadway can be discriminated without error, both with and without the presence of veiling glare. They found that significantly brighter striping was required by older subjects to correctly discern the road's direction of (7 deg) curvature, and that the performance of older drivers was significantly impaired by the presence of veiling luminance simulating glare from oncoming headlights. An interaction effect between test group and presence of glare is presented in Figure 9.

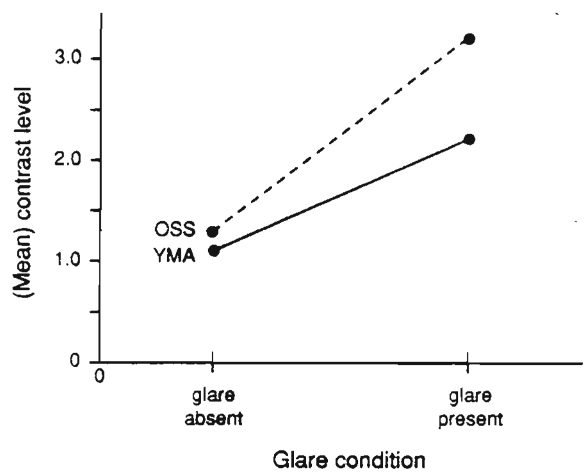

Figure 9. Contrast levels required for correct discrimination of curve direction 200 ft (61 m) downstream. (From Staplin, Lococo, & Sim, 1990).

They also found a consistent decline with computer-modeled detection performance for a 100-ft (31-m) long segment of pavement striping as a function of increasing driver age. This effect was also exacerbated by glare. In addition, variability in performance increased for older drivers, and was magnified under glare conditions. The authors conclude that a clear benefit exists for older drivers under conditions of increased delineation brightness. (See Figure 10).

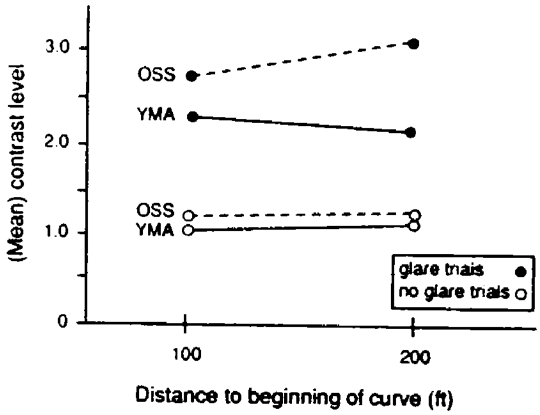

Figure 10. Test group-by-glare condition interaction in delineation recognition. (From Staplin, Lococo, & Sim, 1990).

Age-related changes also appear in studies of scotomatic glare. Older individuals exhibit a longer period of recovery to the effects of this type of glare. Progressive increases with age in relation to illumination threshold for target recognition as well as longer glare recovery times have also been noted (Burg, 1967). However, the functional significance of such studies is not clear, and given the functional importance of recovery from glare in such tasks as night driving, there is a need for further research in this area (Kline & Schieber, 1985). It is known, however, that glare from ocular media scatter may pose serious problems at night, in rain, or in bright sunlight, but may not present significant difficulties on mildly overcast days.

In sum, Staplin, Lococo, & Sim (1990) propose that a high proportion of drivers over the age of 60 will show a serious limitation in visual performance under at least some normal driving conditions. They also suggest that even if as small a group as the lowest scoring 25 percent on critical functioning tests are considered impaired, by adding this number to those experiencing clinical pathology one can estimate that one in every three drivers over age 60 may be seriously impaired.

Vision and Accident Frequency

Although the various components of visual acuity are certainly vital aspects of satisfactory driving performance, Owsley, Ball, Sloane, Roenker, & Bruni (1991) point out that despite intuitions that older adults' impaired vision should be related to an increased risk for accidents, research to date has failed to establish a strong link between vision and driving in the elderly. Although large sample studies have found significant correlations between accidents and various vision tests (e.g., static acuity, dynamic acuity, disability glare) the variance accounted for has been so low (less than 5 percent) that they are insignificant from the practical standpoint of identifying older adults who are at risk for accidents (cf. Hills & Burg, 1977; Henderson & Burg, 1974; Shinar, 1977).

Staplin, Lococo, and Sim (1990) provide a summary examination conducted by Maleck and Hummer (1986) of over 50,000 police-reported accidents in Michigan in 1983 which compared the relative frequency of accident involvement for different 5-year age groups. Relative accident involvement was an induced exposure measure which reflected the ratio of accident occurrences of drivers "at fault" to occurrences of drivers as "innocent victims" for all separate age groups. Overall, a marked U-shaped relationship was uniformly demonstrated across seven vehicle weight/size categories, with the highest relative involvement rates associated with the under-25 and over-65 age groups, respectively. Staplin et al. (1989) also indicate that within this overall pattern a family of separate curves was described which revealed that the U-shaped relationship was most pronounced for accidents occurring in urban settings. For rural settings, the curve describing relative accident involvement by driver age was nearly flat. In addition, isolated accident types which reflected common maneuvers in urban driving were examined (i.e., right-angle collisions, rear-end accidents, left-turn accidents, head-on crashes, and parking-backing accidents). Primarily, the same U-shaped function for relative involvement/driver age was found for all accident types, though some differences were apparent. Left-turn accidents showed the highest relative involvement by older drivers, along with parking/backing incidents. Right-angle, head-on, and rear-end crashes were less common, though still occurring at a rate equal to or exceeding that for drivers in their 20's.

The link between visual acuity and driving performance has been further complicated by a lack of consistency within the experimental design. For example, Hofstetter (1976) reported that the percentage of drivers with poor acuity who reported three or more accidents was approximately double the percentage of drivers with good acuity who reported three or more accidents. However, the criterion for determining acuity in various age groups was not consistent. Therefore, it is possible the "poor" acuity in the young group (who averaged 20/20 vision) may be better than "good" acuity in the older group (averaging 20/60 vision). Consequently, measures of visual acuity require further assessment and need to remain constant across age groups in experimental designs. Without this consistency, it becomes extremely difficult to determine whether the role of acuity is in fact stronger than obtained in other studies (Owsley et al., 1991).

Nevertheless, the elderly are involved in accidents well out of proportion to the time they spend on the road compared to the driving exposure of other drivers. While the elderly are overly represented in specific accident situations, very little scientific data exists that examines the primary causes for these driving failures as a function of the driving task. This is not to ignore the numerous studies that have been made on vision, hearing, and memory degradation that occur with aging. However, studies that directly relate such degradation to the driving task itself are limited and sorely needed (Yanik, 1985).

To date, the strongest link between a visual attribute and accident frequency has been with severe visual loss in both eyes. Johnson and Keltner (1986) reported in a large sample study that the small subset of drivers with this deficiency had accident and conviction rates twice those in the normal population. Owsley et al. (1991) suggest that since these drivers were primarily older adults, the Johnson and Keltner study may illustrate a relationship between impaired visual function and driving in the elderly. However, no study to date has established a link between driving and the more subtle types of visual field loss due to normal aging. Thus it still remains to be determined if there are any visual variables which have a strong and widespread relationship with driving performance in older adults.

Although visual sensory status by itself has not proven to be a powerful predictor of accident frequency, it is quite possible that it becomes an important component when interacting with other variables related to aging. It is also possible that the visual specificity of previous research is not a sufficient predictor of driving performance when considered in isolation or out of context (e.g., actual driving). Additionally, Owsley et al. (1991) indicate that the failure to document a firm link between vision and driving performance in older adults may be due to the use of vehicle accidents as the dependent measure for driving behavior. Because an accident is a fairly uncommon event when considered in relation to the number of miles driven per year, researchers face the statistical problem of trying to predict an improbable event. Secondly, accidents are not only caused by factors intrinsic to the driver such as vision and motor response time, but they can also be caused by external variables such as weather and road conditions. Driver performance under a variety of conditions on a simulator is preferable to accident data.

The choice of independent measures, that is, tests for evaluating vision, may be another possible reason why earlier studies have failed to document a strong link between vision and driving in the elderly. Oswley et al. (1991) suggest that sensory tests, such as visual acuity, contrast sensitivity, and visual field sensitivity may be appropriate for the clinical assessment of vision loss, but do not presently reflect the visual complexity of the driving task. In addition, when compared to standard visual tests, the visual demands of driving are much more complex and demanding. The driving task involves a visually cluttered array, both primary and secondary visual tasks, and simultaneous use of central and peripheral vision. In addition, the driver is usually uncertain as to where an important visual event may occur. As Owsley et al. point out, visual sensory tests do not typically incorporate these stimulus features, but instead seek to minimize perceptual/cognitive influences in order to obtain a purely sensory measure. This approach may be appropriate for the clinical assessment of eye disease, but it is most likely inadequate by itself when applied to understanding visual performance in a complex task such as driving. Staplin, Lococo, and Sim (1990) suggest that a combination of approaches which investigate these various areas is likely to be most productive in studying the consequences for safety and performance of diminished capabilities linked to to advancing driver age. By incorporating research which focuses on age differences in well-defined sensory (visual), cognitive, and/or psychomotor processes of the overall driving task, as well as broader ecological perspectives which seek to measure gains in net response effectiveness through manipulation of key TCD design parameters, a common goal of pinpointing the most significant deficiencies with signs, markings, and other traffic control elements and systems as currently experienced by older drivers may be achieved (Staplin, Lococo, & Sim, 1990).

Predicting Accident Frequency in Older Drivers

In an attempt to develop a theoretical model predictive of accident frequency in the older driver, Owsley et al. (1991) have begun to assess the quality of information at various levels in the visual/cognitive information-processing system in order to approach the problem from various perspectives.

Ophthalmological level. The first level considered in this model of the visual information processing system is the ophthalmological level, where structural and physiological changes in the eye and visual pathway due to disease can seriously impair visual function, and consequently lead to driving problems. For example, increased light absorption and scattering in the crystalline lens is the largest single factor contributing to declines in visual performance in the normal aging eye. Deterioration in the actual structures of the retina and neural pathway to the brain are also a contributing factor, but they account for significantly less variance. For instance, it has been suggested that persons with retinitis pigmentosa (inflammation of the pigment in the retina) are at risk for poor driving performance and increased accidents (cf. Fishman, Anderson, Stinson, & Haque, 1982; Szlyck, Fishman, Mater, & Alexander, 1990). The field and acuity of vision also declines with age due to such factors as a drooping of the upper eyelids ("senile ptosis"), a decrease of retro-orbital fat, a distortion of the retina by increasing intra-ocular pressure (Armaly, 1965), a slowing in the movements of the iris (Leinhos, 1959), a loss of accommodation (Fisher, 1969; Leighton, 1978; Weale, 1965), a yellowing of the lens (Charlton & Van Heyningen, 1968; Pirie, 1968; Vaughan, Schmitz, & Fatt, 1979), scattering of light (Wolf, 1960), and progressive astigmatism (Hopkinson & Collins, 1970; Leighton, 1978).

Functional impairment. However, Owsley et al. (1991) also indicate that it is doubtful that the presence versus the absence of ocular disease alone could provide sufficient information to determine accident risk. In fact, all other factors, apart from pathology, may be grouped as minor in overall impact (Staplin, Lococo, & Sim, 1990; Sekuler, Kline, & Dismukes, 1982). First, the functional impairment associated with a given diagnosis is quite variable. Two individuals can have very similar structural alterations in the visual system due to disease, yet have drastically different visual functional capabilities. In addition, different patients may adopt different coping strategies to accommodate their level of ocular disease whereby one person may have better, or more adaptive, functional capabilities than the other.

The functional effect of deterioration in the various sense organs is also modified by experience and the development of <u>specific</u> coping strategies, particularly where there is a high demand for sensory input (Szafran, 1968). However, the usual end result of these changes is a deterioration in the signal/noise ratio; the true signal becomes increasingly confused with electrical "noise" arising both at the periphery and within the central nervous system (Welford, 1984). A reduction in the number of functional nerve circuits within the brain gives less "smoothing" of occasional aberrant signals. The condition may be further worsened by random peripheral neural activity, a deterioration of short-term memory, and the long persistence of unwanted signals within the brain (Welford, 1984; Welford & Birren, 1965). It may then be argued that the diminished performance on various tasks by the elderly is largely an attempt to compensate for these problems. Freshly acquired information is melded with persistent signals until the strength of the new input is sufficient to be distinguished clearly from background noise (Shephard & Leith, 1990). Consequently, the direct assessment of functional vision (e.g., acuity, contrast sensitivity, and visual field sensitivity) is required in order to more fully understand the encoding of visual information as a crucial stage in the driving task.

Consequently, the most reasonable and effective approach to studying the older driver must address a number of different levels in the information processing system: status of the visual system in terms of health, the many aspects of visual sensory function, visual attentional skills, and cognitive abilities. "Given the integrated nature of such a system, it is not surprising that previous attempts to predict driving difficulty have largely failed, since earlier studies have typically examined only one level of analysis within the system. Previous studies on sensory variables have largely ignored higher-order perceptual or cognitive components, while studies focusing on mental status and cognitive variables have largely ignored sensory components" (Owsley et al., 1991, p.10). A comprehensive approach designed to determine the effects of several of these variables singularly and in combination as they interact within the same individual is required. Ultimately, final performance will remain the most valid criterion.

COGNITIVE CONSEQUENCES OF AGING

Changes in cognitive abilities with aging has been and remains one of the most intensely researched areas in gerontology. Studies of normative and pathological changes in intelligence, attention, learning, and memory are ubiquitous, and yet considerable controversy surrounds interpretations of these data (Sterns, Barrett, & Alexander, 1985). Many of these controversies stem from the series of inferential steps followed in cognitive assessment and interpretation. Staplin, Lococo, and Sim (1990) suggest that Wickens' information processing model (See Fig. 11) places an appropriate emphasis on the parallel nature of a driver's processing of roadway information, while identifying specific cognitive components that may help to define the locus of age-related differences in whole- or part-task measures of driving performance capabilities.

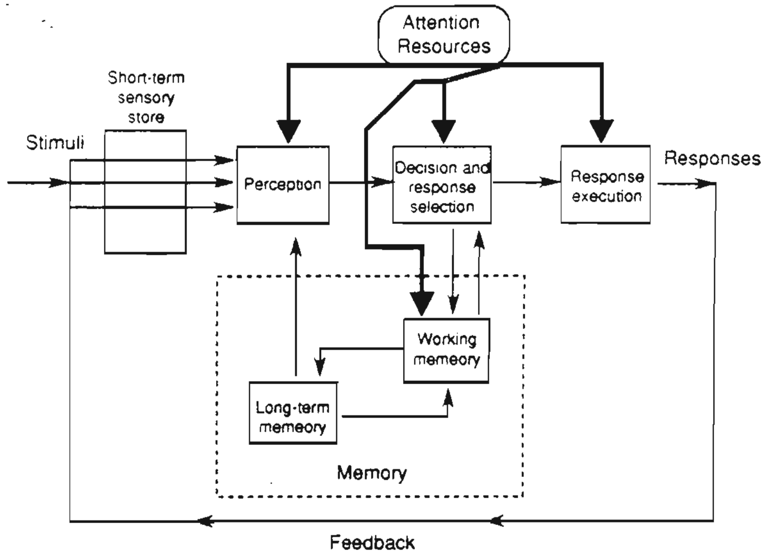

Figure 11. Wickens model of information processing. (From Wickens, 1984).

The etiology of age-related cognitive differences, as well as the interpretation of existing data, remains controversial. Part of the problem in interpretation is due to a limited knowledge base concerning the influence of biological systems on attentional and cognitive processing, as well as the influence of the interaction between the individual, the environment, and the specific task demands associated with performance (Poon, 1985).

Neuropsychological Changes

Contingent Negative Variation (CNV). The majority of findings point to decreased activity and/or atrophy associated with frontal lobe functioning. Lower blood flow rates in the frontal lobes of elderly subjects have been found, as well as greater atrophy (Shaw et al., 1984; Warren, Butler, Katholi, & Halsey, 1985). The Contingent Negative Variation (CNV), a component of the average evoked potential, is correlated with the prepatory set of the subject and has been found to be reduced in elderly subjects participating in simple reaction time tasks (Poon, 1985). This reduction in the CNV waveform appears to be particularly pronounced in the frontal lobes (Teece, 1978).

Loveless and Sanford (1974) have postulated that the reduced CNV reflects the older person's difficulty in initiating a prepatory set at an appropriate time. This type of perseverative attentional deficit interferes with the normally flexible refocusing of attention when environmental cues call for an immediate attentional shift (Teece et al., 1980; Teece et al., 1982). Staplin, Lococo, and Sim (1990) refer to this process of dynamic visual attention as being "exemplified by, for example, a need to scan many signs for those that are most relevant to the immediate driving task, as well as performance of maneuvers, such as merging, which depend upon quickly re-orienting one's attention" (p. 9). It should be noted that dynamic visual attention differs from attention switching because it involves the ability to quickly shift attention only within the visual scene for effective single task performance.

Frontal lobe and arousal. Albert and Kaplan (cited in Nauta, 1971) have suggested that changes in arousal/attention and visuospatial performance may signal focal neuropathological change in the frontal system. In support of this idea, Poon (1985) states that evidence from electrophysiological measurements of the autonomic nervous system, which indicates a correlation with arousal and attention, provides some support for the hypothesis that the elderly are underaroused and suffer from varying degrees of selective attention deficits. In addition, Botwinick and Kornetsky (1960) have demonstrated that the galvanic skin response (GSR) was reduced in older subjects in a classical conditioning paradigm. Underarousal was proposed as one possible mechanism for the lower level of performance demonstrated.

The magnitude of the late component (P3) of the average evoked potential, which is correlated with changes in activation and/or attention, has also been found to decrease with age and is also correlated with declines in cognitive performance (Marsh & Thompson, 1977). Given that an intact frontal system is needed for selective attention and set, the lower level of arousal and attention of the elderly seems to suggest an inadequacy in the frontal system with advancing years. Albert and Kaplan (cited in Poon, 1985) provided further evidence to support the frontal-system hypothesis from their qualitative analysis of the elderly's performance in a variety of visuospatial tasks. By looking at the similarity of the overall patterns of behavior between healthy older volunteers in the Framingham Heart study and patients with frontal area dysfunction, they were able to postulate that processes controlled by the frontal area may be impaired in older adults. In sum, current biological and neuropsychological research appears to indicate that aging is associated primarily with changes in the frontal lobes, and that the study of cognitive change with age is most appropriately focused upon those behaviors associated with the frontal system: arousal and attention, visuospatial skills, visual search behavior, memory functions and complex problem-solving.

Dementia. The neuropsychological aspects of age-related degenerative diseases of the central nervous system are also important considerations in the aging driving population. Dementia occurs in as many as 15 percent of persons over the age of 65. The greatest proportion (over 50%) is due to Alzheimer's disease, while another 15 to 20 percent is due to multiple infractions of the brain, sometimes in combination with Alzheimer's disease (Terry & Katzman, 1983). However, dementia patients are often adamant about their driving privileges, and attempts to limit their driving bring considerable family conflict and distress (Research & Development, 1989). Lucas-Blaustein et al. (1988) report that dementia patients who still drove performed better on a mental status examination, but that they were just as likely as those who no longer drove to have been involved in a crash since the onset of their dementia. However, the study also indicated that the majority of dementia patients who continued to drive made compensatory adjustments in their driving behavior, such as driving below the speed limit and only in their own neighborhoods.

Between 30 to 47 percent of older drivers with dementing illnesses are involved in crashes after the onset of their dementia, and although the more obvious symptoms are usually associated with advanced stages of the disease, a sub-group of dementia patients show dramatic visual-spatial deficits early in the disease (Martin, 1987). Neuropsychological measures of visual-perceptual and visual-constructional abilities have documented deficits in patients with only mildly severe dementia when such deficits may not be clinically obvious (Research & Development, 1989). Consequently, the issue of neuropsychological changes and the deficits associated with dementing illnesses merit further investigation into the relationship that bear to the driving task among older drivers.

Selective Attention

Because driving is a complex visual/cognitive task, it is possible that even if sensory functions are not impaired, different drivers may attend to different aspects of the environment, as well as interpret the visual information in different ways. However, the fundamental constraint that underlies all the operations of attention, imposing an essentially selective character, is the limited information-processing capacity of the brain (Posner, 1989). Consequently, individual information processing attributes must also be investigated.

Attention is most commonly measured using a visual search paradigm (cf. Ball, Roenker, & Bruni, 1990). Visual searches typically require an individual to search as rapidly as possible through a list of symbols (e.g., letters, words) for a specified target. In visual search, selective attention deficits are manifested as nontarget interference effects (manipulated by display size) on target detection performance. Not only do the older persons' reaction times and/or error rates increase as the display size increases, the peripheral aspects of processing, such as item encoding time and response execution, also require more time. Staplin, Lococo, and Sim (1990) indicate that the slower peripheral and/or central processing by older drivers will become apparent only when the whole stimulus array must be searched to find the relevant stimuli. They also suggest that if a slowing in processing is a result of a more complete but redundant processing of irrelevant stimuli, older persons may process distractors centrally to the point of identifying them, instead of engaging in the more efficient peripheral processing of such stimuli. Staplin, Lococo, and Sim (1990) attempted to measure the accuracy and flexibility of directed visual search, under time pressure, in two "trail making" tasks. This type of task, frequently used by clinical neuropsychologists to discriminate between a variety of cognitively impaired subject populations, requires an individual to locate sequentially-ordered test items on a sheet of paper and use a pencil to connect them in order as quickly as possible. Because the visual search behavior of drivers becomes less efficient as early as 50 years, involvement in certain types of accidents may be related to this type of diminished capacity. However, as the authors note, 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 tasks included in their test battery provided a quick and clinically proven technique for making comparisons in this area of operator performance. As expected, 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.

<u>Context</u>. In addition, the results from selective attention experiments indicate that the context in which a target symbol appears has a profound effect on the detection of that target. In other words, the influence of surrounding information and a persons own knowledge when performing a particular task turns out to be a critically important component of visual perception. Thus the interpretation of sensory signals, or the ability to discriminate relevant (or critical) from irrelevant (or less critical) stimuli depends on the whole environment in which they are embedded. Ambiguous perceptions may get interpreted in completely unambiguous (and often incorrect) ways depending on the context in which they are perceived and encoded (Ashcraft, 1989). Staplin, Lococo, and Sim (1990) conducted research designed to measure hypothesized age-related differences concerning the probability that drivers would selectively attend to a range of retroreflective traffic control elements in the presence of meaningful distractor stimuli. Selective attention in this context included both the "glance noticeability" for the sensory visual register (i.e., icon) of designated examples and categories of current traffic control devices, as well as their prioritization for further processing, or rehearsal, in working memory among older versus young/middle-aged test subjects. Their results produced preliminary evidence that certain highway signs and sign categories have less "attention-getting" value and/or are less likely to hold one's attention for further cognitive processing in older versus young/middle-aged drivers. Sign formats which appeared relatively less effective in attracting attention of older drivers included white/rectangle (regulatory

signs), yellow/diamond (warning signs), and yellow/pentagon (school zone signs). Once noticed, the regulatory sign format was most likely among this group to be accorded priority over distractors for further processing in a complex visual scene. The authors report that their findings were in agreement with self-report data from focus group discussions conducted, and suggest a potential benefit to older drivers, specifically, of treatments and/or policies to enhance daytime and nighttime sign conspicuity.

Several researchers have also noted that reaction times in visual scanning tasks slow considerably as subjects age (cf. Rabbitt, 1980; Schneider & Detweiler, 1987). In fact, Planek and Fowler (1971) have suggested that the accidents involving older persons may be due to overly attending to irrelevant stimuli in the driving environment. However, as Staplin, Lococo, and Sim (1990) point out, even though longer response times may be expected for older drivers as increasing numbers of stimuli must be scanned to perform a task, it is not clear whether older persons are less able to strengthen targets, weaken distractors, or both.

Serial vs. parallel processing. Visual attention, in the context of immediate perceptual-motor activities, can be assessed either at an attentive (serial) processing level, or at a preattentive (parallel) processing level. Pre-attentive processing is typically characterized as occurring without intention, not revealed to conscious awareness, consuming no conscious resources. In contrast, attentive processing is characterized as occurring only with intention, is open to awareness, and consumes some of the limited attentional resources in the cognitive system (Ashcraft, 1989). For example, although many of the procedures required for driving may be fairly automatic, or pre-attentive, for experienced drivers, the decisions and motor responses required while driving (e.g., safe lane change, interpreting road signs) do demand attentive processing.

Controversy also exists among researchers as to the appropriateness of considering these two types of information processing as mutually exclusive. One important set of assumptions underlying this controversy concerns the identification of exactly what is pre-attentive and what is attentive, including assumptions, implicit or explicit, about a presumed, monotonic ordering of stages. Posner (1989) indicates that this set of assumptions is quite difficult to reconcile with current neuropsychological evidence concerning the functional architecture of spatial and categorical coding in the brain because of the high levels of parallel modular specialization of perceptual and cognitive function.

Specifically, there is strong evidence indicating the existence of functionally specialized and neuroanatomically separable, parallel systems responsible for computing aspects of categorical identity ("What?") and with the computation of spatial relationships ("Where?").

Other researchers have also presented compelling evidence that the encoding of spatial location and spatial relations in terms of retinotopic and other head- and body-centered coordinates, as well as in terms of environmental relationships, is computationally highly complex (Feldman, 1985; Hinton & Parsons, 1988; Jeannerod, 1987; Zipsin, 1986). Posner also notes that "representation in terms of explicit visual-spatial location can be found from the earliest stages of visual coding through to very late levels of cognitive and even motor processing. Indeed processes sometimes attributed to early selection [pre-attentive] may actually take place only after the independent processing of figural identity and relative location, namely in the integration of these respective coding demands" (p.635-636).

Selective cueing and processing. Evaluating this conclusion in terms of a driving task appears particularly relevant. Posner (1989) believes that it is important to recognize the distinction between what he terms selective cueing, or the processes by which task-relevant information is recognized on the basis of some selection cue, (for control of a given response) and questions of selective processing. Primarily, selective processing refers to the selective, visual control of action. Most importantly for the driver, however, is the selectivity of perceptual-motor control or selection-for-action. This type of selectivity addresses the nature by which attention is established, coordinated, maintained, interrupted and redirected, both in spatial and nonspatial terms.

Consequently, the efficiency of selective cueing in the domain of visual attention is more adequately indexed by the presence or absence of response interference resulting from the presentation of task-irrelevant distractors (cf. Francolini & Egeth, 1980; Kahneman & Treisman, 1984). However, selective cueing in vision may operate more efficiently in the spatial domain. For example, when a selective cue in one representational domain (e.g., color or movement) is used to designate a subset of available information in another visual domain (e.g., form), this cross-domain cueing appears to depend on the shared coding of location (Nissen, 1985; Posner, 1989). Consequently, the distinction between selective cueing and selective processing is an important consideration in the development and design of effective highway markers particularly for older drivers who may depend more heavily on selective cueing for subsequent cognitive judgments and motor responses.

Information must be task-relevant; it also must be able to quickly and effectively communicate direction to a driver. Any aspects which may be confusing, ambiguous, or distracting must be kept to a minimum. However, once this initial stage is accomplished, intelligent highway design will also be able to effectively use TCD's to maintain, direct, and coordinate information sources for appropriate selection-for-action. For the elderly driver, this means less information to encode and integrate, and allows for a greater response time.

Selective responding. The complex visual array presented to a driver requires frequent and immediate selective responses. Posner (1989) states that these selective-response tasks may be summarized as follows: (1) When the designated target stimulus provides relatively the most compatible information source available for encoding into the representational domain (semantic category, color, name, relative location, and the like) needed for execution of the task, then minimal or zero interference from other, less compatible information sources is observed. (2) In contrast, when the to-be-ignored distractor information provides an equally, or even more compatible, specification (information source) for encoding into the required domain of representation than does the (task-designated) target information, interference - that is, delay in response, overt crosstalk error, or both - is liable to occur. (3) The extent of interference will then depend further on the availability of other (e.g. spatial) cues, enabling effective segregation of target and nontarget information (p.639).

Useful field of vision (UFOV). Oswley et al. (1991) suggest that a focus should be placed on attention at the preattentive level for the purposes of examining driving performance and ability because this earliest stage of attention is used to quickly capture and direct attention to highly salient visual events (such as the approach of vehicles in peripheral vision). A task which begins to assess the processes related to both aspects of visual attention (i.e., cueing and processing) is based on the concept of the useful field of view (UFOV). The UFOV refers to the visual field extent needed for a specific visual task (Sanders, 1970). Thus, the size of the UFOV is not the same as visual field size, and it is typically smaller than the area of visual sensitivity (Ball, Owsley, & Beard, 1990). The UFOV is typically measured binocularly and can require either detection, localization, and/or identification of suprathreshold targets in complex visual scenes (Verriest et al., 1983; 1985).

In addition, the size of the UFOV shows considerable variation across individuals and situations. For example, the size of the UFOV is reduced when the target is embedded in distractors (Drury & Clement, 1978; Scialfa, Kline, & Lyman, 1987; Ball et al., 1988), when stimulus duration is decreased (Ball, Roenker, & Bruni, 1990), when a secondary central task is added (Leibowitz & Appelle, 1969; Ball et al., 1988), and when the similarity between the target and distractor is increased (Engel, 1977; Triesman & Gelade, 1980; Bergen & Julesz, 1983). Furthermore, performance on these tasks progressively declines with age (Sekuler & Ball, 1986; Scialfa et al., 1987; Ball, et al., 1988; Ball, et al., 1990). Ball, Roenker, and Bruni (1990) propose that at least three mechanisms are required to account for older adults' UFOV restriction: reduced speed of visual information processing, inability to ignore distractors, and inability to divide attention. They also state that the prevalence of each of the problems increases with age such that a given individual may experience none, one, or more than one of these problems in later life.

Ball, Owsley, and Beard (1990) also indicate that older adults with UFOV shrinkage report more problems in their everyday activities, especially tasks using peripheral vision. Normal visual field sensitivity (as measured by clinical perimetry) was controlled, which implies that the subjects' UFOV restrictions and reported problems in peripheral vision were not due to impaired visual sensitivity throughout the field. They conclude that a test of the useful field of view may be quite helpful in understanding older adults' problems in routine visual activities.

As Owsley et al. (1991) notes, tests of visual attention, such as the UFOV, are dependent on the quality of visual information being processed by the visual sensory system. "That is, although the the UFOV task is not a 'sensory' test, it makes use of information coming through the visual sensory channel, and thus depends on the integrity of this information. For example, if a person has severe binocular field loss, this individual would most likely have an impaired UFOV, not necessarily because of an attentional deficit, but because the quality of the sensory information was poor. On the other hand, visual sensory field loss is not a necessary and sufficient condition for a constricted UFOV. A person can have a normal visual field, yet have a constricted UFOV" (p. 9-10). Finally, it is important to point out that since the driving task involves selective attention under varying visual search demands, often, but not always, the experienced driver knows where to look for required (e.g., traffic control) information.

Divided Attention

Because attentional resources may be more limited in elderly drivers, attentional capacity is an important consideration in highway and instructional sign design. For the purposes of emphasizing the processing of environmental information, performance on divided attention tasks is particularly relevant. In fact, research concerning age-related divided-attention abilities suggests that such abilities are not compromised by aging. However, although the research indicates no particular difficulty on the part of the elderly with shifting attention, there is a lack of consensus on the speed with which such shifts are executed (Plude & Doussard-Roosevelt, 1990). A divided-attention deficit is typically reflected in a performance tradeoff (or cost) between focused-attention versus divided-attention conditions. This type of task requires the shared processing of multiple sensory stimuli all of which are pertinent to an ongoing activity. For example, the concurrent monitoring of route/guide signing and other traffic control elements, plus changes in the traffic flow (particularly under high speed/high volume conditions) (Staplin, Lococo, & Sim, 1990).

Plude and Hoyer (1986) found that the magnitude of nontarget interference was greater among the elderly (a 50% increase in reaction time from one- to five-character displays) compared with young adults (a 35% increase in reaction time) under divided attention search tasks. However, nontarget interference was not statistically different between young (13%) and elderly (8%) subjects under focused attention nonsearch tasks. This pattern of effects held when targets were equated for foveal acuity and supports the conclusion of an age-related divided attention deficit. Salthouse, Rogan, and Prill (1984) investigated age-related divided attention effects by manipulating memory span tasks (concurrent versus isolated) in order to impose a greater demand on processing resources than studies which had failed to find age-related deficits (cf. Somberg & Salthouse, 1982). Consistent age-related differences were found and the authors concluded that task complexity was the key determinant of age deficits. McDowd and Craik (1988) also found that older adults exhibited larger divided attention deficits, but that the magnitude of the deficit was comparable to the level of manipulation of task complexity. Plude and Doussard-Roosevelt (1990) also note that if experimental designs assume that processing is confined to a single modality (e.g., vision) and to a single task (target identification) then the likelihood that a single mental resource (or pool of resources) is tapped is also maximized. By varying the demand on single resources, age-related divided attention effects can be more adequately assessed. In fact, evidence of age-related divided attention deficits in more ecologically valid studies of time sharing between two skilled behaviors has been demonstrated (Staplin, Lococo, & Sim, 1990).

Complexity effects. The role of complexity can also be seen when mean reaction time data for elderly subjects is plotted as a function of young adult performance (See Figure 12).

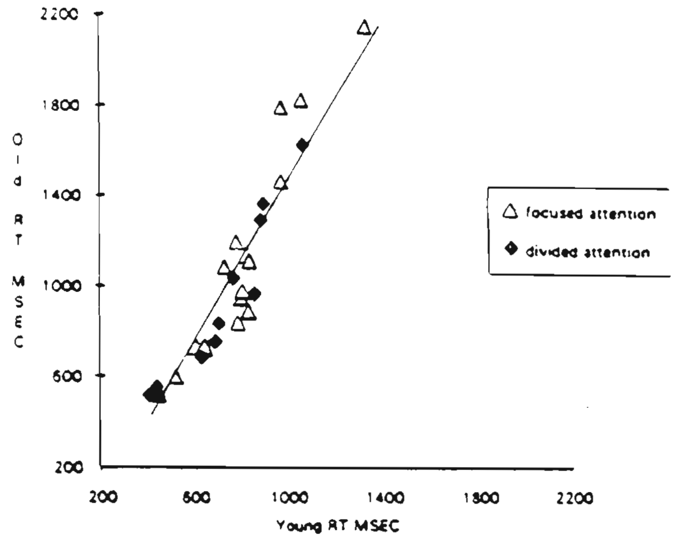

Figure 12. Complexity effects under focused (triangles) and divided (diamonds) attention. (From Lovelace, 1990).

In this case, increasing complexity is evidenced by increasing reaction time and age-related complexity effects are revealed in the slope of the function relating performance between the two age groups. If complexity exerted comparable effects between age groups, then the slope of the function should be 1.0, because both age groups would exhibit equivalent increments in reaction time under increasing complexity. If complexity exacted a heavier toll on the elderly, then the slope of the function should be greater than 1.0, because older adults would register greater reaction time increments compared with younger adults under increasing complexity. The solid line in Figure 12 gives the best-fitting linear function describing both sets of points. The slope of the function (1.72) accounts for 90% of the variance, and indicates that elderly adults are more adversely affected by complexity than younger adults. Plude and Doussard-Roosevelt (1990) analyzed this data separately for divided and focused attention conditions and found that the conditions were not statistically different from the overall analysis which supports the contention that task complexity, rather than the requirement to divide attention per se, is the primary determinant of age decrement. Thus the authors conclude that no evidence exists that divided attention ability is compromised by aging. Rather, it is the complexity of the task that determines the magnitude of age deficit in divided attention research (cf. Salthouse et al., 1984; McDowd & Craik (1988).

Staplin, Lococo, and Sim (1990) conducted a study designed to examine possible age-related differences in drivers' ability to rapidly interpret multielement, contingent (left turn) control displays as the presentation order of the elements was varied. This design provided for divided-attention test conditions which simulate the dynamic monitoring and control of lateral vehicle position in the roadway during an approach to an intersection. Their results indicated (See Figure 13) that older and younger

Test group	Right-of-way status							
	"Go"				"No go"			
	separate		together		separate		together	
	X	σ	X	σ	X	σ	X	σ
Group YMA (n=25)	1.9	1.0	3.1	1.5	2.4	1.2	3.5	1.6
Group OSS (n=30)	2.3	1.3	3.5	1.4	2.9	1.5	4.1	1.5

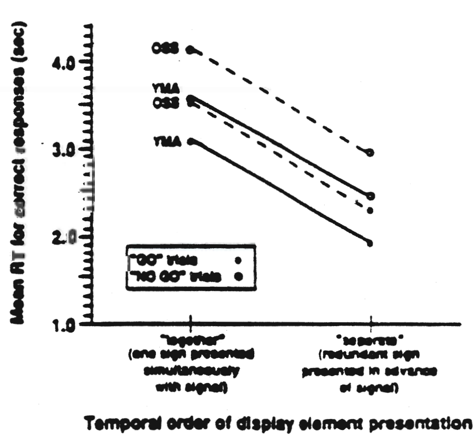

Figure 13. Temporal order of display element presentation. (From Staplin, Lococo, & Sim, 1990).

drivers alike reached correct decisions concerning the right-of-way status conveyed by sign-plus-signal left turn control displays significantly faster when the sign element was presented in advance of the signal element, versus when both elements were presented simultaneously. The authors also note that another finding from their study which indicated that displays conveying unprotected turn status were correctly understood significantly less often than displays conveying protected turn status raised a separate set of safety issue. Specifically, when coupled with age-related slowing of reaction, this failure-to-comprehend may explain in part the consistent overrepresentation of older drivers in accidents involving left turning maneuvers at signalized intersections.

Effortful vs. automatic processes. In addition, because age effects reflect differences in attentional resources available during encoding and storage, as well as due to increasing attentional demands of a task, then age effects should be more pronounced in effortful processes (e.g., those requiring processing resources), but minimal for automatic processes (e.g., those making little or no demand on such resources (Hasher & Zacks, 1979). Staplin, Lococo, and Sim (1990) suggest that for multitask performance, the most important issue may be the ability to consistently maximize performance on a high-priority task regardless of any change in the nature or difficulty of the overall situation. This idea concerns optimizing the allocation of attentional resources and is considered separate from time sharing efficiency. Consequently, it may depend most strongly on the development of automatic attention responses which require minimal processing effort. Tsang and Wickens (cited in Staplin, Lococo, & Sim, 1990) also suggest that this is an acquired skill that is to a large degree task and situation specific. Since high levels of practice may lead effortful processes to become automatic (Shiffrin & Schneider, 1977) then age effects could be expected to diminish with extensive practice

(Lovelace, 1990). However, this proposal has not received consistent support (cf. Plude & Hoyer, 1985; Charness, 1989; Salthouse, 1990). Consequently, Staplin, Lococo, and Sim (1990) suggest that this active area of research should begin to clarify age differences in performance, and that the goal of preserving and reinforcing the acquired responses of elderly drivers to traffic control elements should assume an important role in any traffic control device design effort.

Cognitive functioning in elderly individuals which depends on working memory, problem solving skills, decision making, reasoning and judgment are also important and appropriate factors to consider in driving behavior. And, as previously stated, research indicates that cognitive impairment in the elderly due to dementing disease is also associated with increased driving problems (Friedland et al., 1988; Lucas-Blaustein, Filipp, Dungan, & Tune, 1988; Kaszniak et al., 1990; Coyne et al., 1990).

Working Memory

Directly related to the concept of attention is working, or primary, memory. This stage of memory is typically conceptualized as a temporary, limited-capacity store in which an awareness of the information currently being used is present. Although working memory is temporary and limited, it plays an important role in the control and assimilation of information, and so it is an important process to examine in older individuals (Craik, 1977). Specifically, Staplin, Lococo, and Sim (1990) note that this function is critical to the driving task as sign, signal, and delineation information must be sampled and stored temporarily as the foundation for moment to moment vehicle control and the planning of future maneuvers. Consequently, the older driver will be at higher risk in situations that demand rapid mental operations for vehicle control, especially when they are required to perform such maneuvers and retain other (e.g., navigational) information for future use.

Capacity. The primary focus of research in the area of working memory has been placed on whether the capacity and the retention rate changes with age. This focus has been in large measure due to the fact that the findings of all working memory paradigms indicate that except for differences in response time, working memory is relatively unaffected by age. Explanations for these differences typically cite declines due to reduced processing efficiency (Morris, Gick, & Craik, 1988), impaired coordination of storage and processing of information (Rabbit, 1981), or declines in storage capacity (Inman & Parkinson, 1983).

Although working memory depends on cognitive processing, only the physical dimensions of stimuli are processed rather than the meaningful aspects. In fact, the differences with age that are found, for example in memory span tasks, may be more attributable to secondary, or long-term, memory (Botwinick, 1984). Parkinson, Lindholm and Inman (1982) conducted a study which utilized several different measures of working memory (for example, recall of the last four items in a list). Age differences (18-24 versus 58-89) were found in all working memory measures, with the older subjects doing less well. Wright (1982) conducted a study similar to Parkinson et al., but failed to find any significant differences between young subjects (mean age of 23) and older subjects (mean age of 71). Botwinick (1984) suggests that such conflicting studies indicate that some decline in working memory occurs with age, but that if working memory is defined in terms of three or four items of information, rather than more, age differences are less likely to be observed.

Staplin, Lococo, and Sim (1990) conducted a study in order to measure hypothesized age-related differences in drivers' ability to quickly make correct navigational decisions at freeway exit points. Both the amount of map information to be stored in working memory (low versus high memory load) and guide sign information content (single-entry versus multiple-entry) were varied. It was hypothesized that the multiple-entry format would facilitate rehearsal of a target exit name, as a driver read guide signs posted at earlier exits along a route, but could also potentially be associated with a longer visual search to extract the target name from the other entries on a sign. The single-entry format was hypothesized to restrict the amount of "upstream" rehearsal of a target name prior to the exit decision response time, but could provide for a simplified visual search to identify the recognition target. The dynamic monitoring and control of lateral vehicle position was simulated in order to test under ecologically valid conditions. The results of their study failed to demonstrate the hypothesized benefit for older drivers of multiple-entry (versus single-entry) guide signs that provide repeated upstream information concerning the sequence of downstream exits on limited-access highways. (See Figure 14).

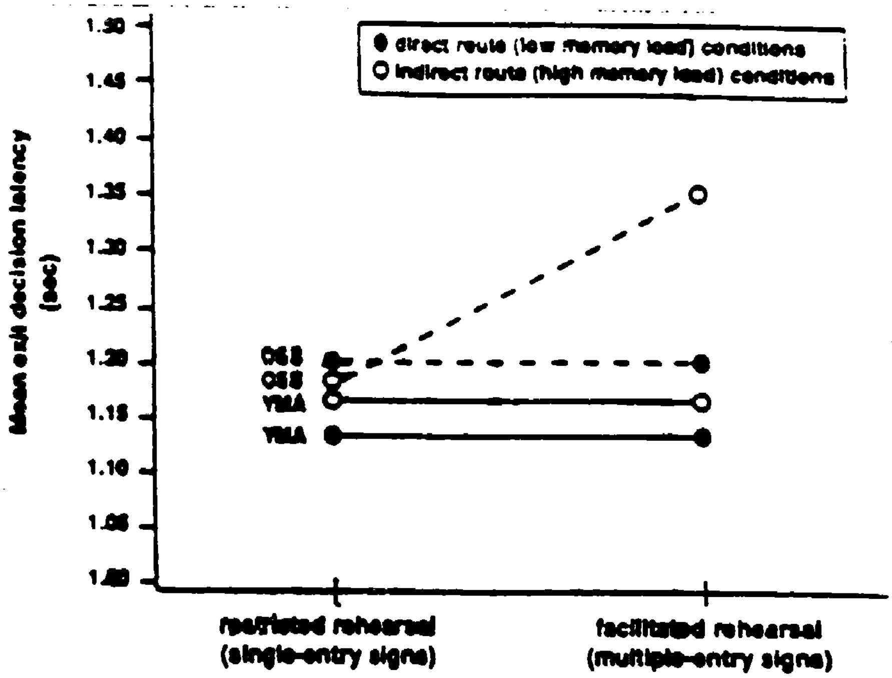

Figure 14. Performance differences for test group as a function of memory load and rehearsal conditions. (From Staplin, Lococo, & Sim, 1990).

The authors attribute this outcome to increased visual scanning requirements which characterize signs with more words versus fewer words. They also note that a conclusion consistent with these results is that older drivers may benefit from the increased rehearsal of downstream exit information provided by multiple-entry guide signs, but that the topmost sign entry (nearest the exit) should be accentuated by larger characters or some other treatment to facilitate drivers' scanning of sign information.

Symbol manipulation. Digit, or memory span tests are often employed as measures of working memory. This type of test refers to the number of items (usually in a row) that can be correctly recalled. Staplin, Lococo, and Sim (1990) employed forward and reverse digit span measures in order to obtain a more reliable means of describing differences in subjects' abilities to store and manipulate discrete items of information in working memory. They also note that the information-processing functions of working memory permit the integration of sensory input over time to hold current information for a brief time in order for more complex cognitive functions (e.g., decision-making, problem-solving) operations to be carried out. Their results showed that the differences between three age groups were relatively small. In fact, the forward span test indicated a general equivalence between the older self-selected and young/middle-aged groups in their abilities to recall information from working memory in the absence of any competing stimuli, while the performance of the older cross-validation test group showed only a slight decrement. Performance on the reverse span test indicated a somewhat greater spread as the youngest drivers were best able to reorganize and manipulate information in working memory. The authors conclude that the forward span measure suggested a functional equivalence between young and older drivers, insofar as information recall from immediate memory in single-task performance was concerned. However, young drivers were significantly better able to manipulate recently learned information prior to retrieval.

Staplin, Lococo, and Sim (1990) conducted another study designed to measure hypothesized age-related differences in the ability of drivers to rapidly encode the information contained in current symbol signing and to retain it in immediate, or working, memory for further processing. This ability was gauged against their performance for equivalent verbal (spelled out) messages, under both low and high secondary task loading conditions. The authors state that a general emphasis in their research was to present a meaningful subsidiary task, which could be calibrated for each driver to provide an approximately equal level of demand across subjects in both age groups. The primary dependent variable was the time required for a driver to make a correct yes-no response to indicate whether a later, "probe" stimulus was previously present. Demand was operationalized in terms of a required number of tracking task control movements, thus the interpretation of observed group differences on the primary dependent variable could be made with greater confidence. The primary independent variable of interest was equivalent sign messages (symbol versus verbal). They found a statistically significant slowing for older relative to young/middle-aged drivers for response to five out of six traffic control messages tested, and a superior response by all drivers to the verbal format version of equivalent verbal and symbol sign messages. However, the authors caution that because the actual age differences in response times were normally measured in tenths of a second, the operational significance of these data may be questionable. In addition, the indicated superiority of verbal over symbol message format could be attributable to the specific matching (stimulus recognition) task used as a measure of effectiveness. Most importantly, however, the differences between age groups for symbol versus verbal signs were minimized for the most common stimuli (e.g., the NO LEFT

TURN message). The authors conclude that their data suggests that any given sign message and/or message format can be utilized as effectively by older as by younger drivers, provided prior experience or training is sufficient to ensure equal familiarity with the traffic control device.

Rehearsal and retention. Because the capacity for short-term, or working, memory is limited, complex information which exceeds this momentary capacity can cause a breakdown in the ability to extract and process information from the environment. As a result, this ability is a vital component of the driving task. Staplin, Lococo, and Sim (1990) conducted a study designed to address the facilitated extraction of information from a highway scene under high-demand (divided-attention) conditions, as presented through the use of changeable message signing (CMS) in arterial/freeway settings. Specifically, their study measured message acquisition and retention in working memory, with maintenance of instant-to-instant vehicle control, for older (average age was 71.8) versus young/middle-aged drivers (average age was 36.3) for alternative discrete and sequential display strategies.

CMS display format was varied according to five alternative information presentation strategies: (1) baseline discrete, (2) redundant discrete, (3) cued redundant discrete, (4) baseline sequential, and (5) hybrid sequential/discrete stimulus. (See Table 2 for detailed descriptions). The primary dependent variable was CMS message recall accuracy immediately following termination of a test trial. In addition, the performance of emergency responses (brake pedal depressions) to detect and react to the simulated brake application of a lead vehicle, and/or the encroachment of a vehicle from an adjacent lane into the driver's path, was measured. Each message contained three lines, with one to three words per line. The first line of each message contained a problem statement; the second line contained an effect statement describing the location of the

Table 2.

Stimulus condition	Display format description
(1) Baseline Discrete	Static presentation of a three segment message on a sign placed at a simulated distance of 800 ft. (244 m) from the driver. The sign stimulus included three lines of not more than three words/symbols each. The driver was required to extract and process the message content into short-term working memory based on a single, static presentation of the message in its entirety. All characters were yellow on a black background.
(2) Redundant Discrete	Same as baseline condition except CMS was repeated three times during drivers' traversal of the roadway section. Signs were placed at simulated distances of 800 ft. (244 m), 1200 ft. (366 m), and 1600 ft. (488 m) from the driver; the sign separation distances corresponded to 5 sec. of driving time at a high arterial or low freeway speed of 55 mi/h (80 ft/s). All characters were yellow on a black background.
(3) Cued Redundant Discrete	Same as alternative (2) above, except that each of the three lines/message segments on the CMS was color-coded to cue thte driver where to pick up later parts of the message when reading successive signs. The intent of the color coding was to help drivers avoid starting at the tip when processing each repetition of the message. Moving from top to bottom, the lines on the displays were orange, white, and green, respectively, against a black background.
(4) Baseline Sequential	One CMS located at a sinulated distance of 800 ft. (244 m) from the driver, where only one segment/line of the message was displayed through the serial presentation of the three segments at a rate of 3.2 sec per line, or 14.4 sec. for the entire message cycle including the pre sentation of a string of asterisks for 3.2 sec to indentify the beginning/end of the cycle. All characters were yellow on a black background.
(5) Hybrid sequential and Discrete	Same as alternative (4) above, except sequential CMS was followed by a discrete CMS 5 sec. (400 ft/122 m) downstream. The discrete CMS was to reinforce the complete message if acquired from the first sign, and to fill in blanks in the dirver's memory if initial sign processing was incomplete. All characters were yellow on a black background.

problem; the third line contained an action statement, which provided instructions about how to avoid the problem. For example, Line one: 1 MILE AHEAD; Line two: EXIT 4 CLOSED; Line three: OAK ST CLOSED; and Line four: USE BYPASS.

The results indicated a clear benefit to older drivers of using repeated, full-message displays to convey changeable message sign information under simulated freeway operating conditions. Not only was correct message recall significantly improved under this condition, but the ability of older drivers to simultaneously attend and respond to "emergency highway events" (e.g., a lead vehicle suddenly applying the brakes) was raised to a level roughly equal to the response capability of the young/middle-aged comparison group. However, the specific number of message repetitions needed to achieve this facilitation of performance was not addressed, nor were correlations of drivers' responses with earlier screening measures calculated. Nonetheless, as the authors correctly note, improved traffic management which will rely increasingly on the use of changeable message signing, and optimal display formats for such systems to accommodate diminished capability drivers are not well established. Consequently, measures of working memory as it relates to the driving task may be more appropriately considered in terms of complex information processing which encompasses many aspects of the task, rather than attempting to isolate pure "working" memory aspects. While this endeavor may not explain previous conflicting results in this area, it is certainly more appropriate to developing safe and efficient driving aids to the older driver.

Long-term Memory

Long-term memory is not constrained by duration or capacity as is working memory. It has no limitations on the amount of information it can hold, and forgetting occurs relatively slowly, if at all. The literature indicates that no overall conclusions can be drawn about age-related differences in long-term memory due to the complexity of the situation, but it is clear that long-term memory functions are essential to safe driving.

However, elderly people do differ from younger people in terms of some kinds of long-term memory tasks. For example, Gordon and Clark (1974) compared memory performance on a recall task between older (average age of 71) and younger (average age of 25) while controlling for memory related covariates (i.e., number of years of education, verbal intelligence). Their results indicated that while the younger group was only marginally better at immediate recall, they were much more accurate at delayed recall (one week later). In the delayed recall task, younger people recalled an average of 10.7 items, while older people recalled an average of only 4.4 items.

Recognition vs. recall. Consequently, it is unclear as to whether there are substantial age differences when long-term memory is measured in terms of recognition rather than recall. For example, a now classic study by Schonfield and Robertson (1966) showed a significant drop in recall for older people, but no change in recognition (cf. Perlmutter, 1979) or cued recall (Hultsch, 1975). Craik, Byrd, and Swanson (1987) have recently concluded that the large age differences typically found in free recall are either reduced or eliminated in recognition. Certainly, the identification of roadway stimuli depends heavily on a recognition match with previously stored information. However, many driving decisions (e.g., navigational) would not be possible without the ability to recall information regarding alternative routes and layouts of neighborhoods and cities from the "cognitive map" that each driver creates over time with experience and stores in long-term memory.

In addition, it appears that both elderly and young test subjects perform similarly when the memory task involves automatic activation processes (e.g., identifying word fragments), but that they are likely to perform differently when the task involves conscious efforts to recall details (cf. Light, Singh, & Capps, 1986; Light & Singh, 1987).

Elderly people may even be more accurate than younger people on some kinds of information. Rodgers and Herzog (1987) conducted a study to establish the accuracy of older people in supplying information on survey questionnaires. Subjects were required to supply the type of information that could be verified via publicly accessible records (e.g., whether they had voted in the 1980 presidential election, the make and year of the cars they owned, etc.). The results showed that people over 70 years of age did not differ from those between the ages of 60 and 69, but both groups were more accurate than people under the age of 60.

In general, however, whenever the material to be remembered exceeds the span of working memory, comparatively larger age differences become more evident than seen in tests of sensory or working memory (Poon, 1985). Figure 15 illustrates the pattern of age differences in six subsets of the Guild Memory Test. Digit span tests, which are more indicative of working memory processes, are the least affected while substantial age differences are evident for measures of long-term memory.

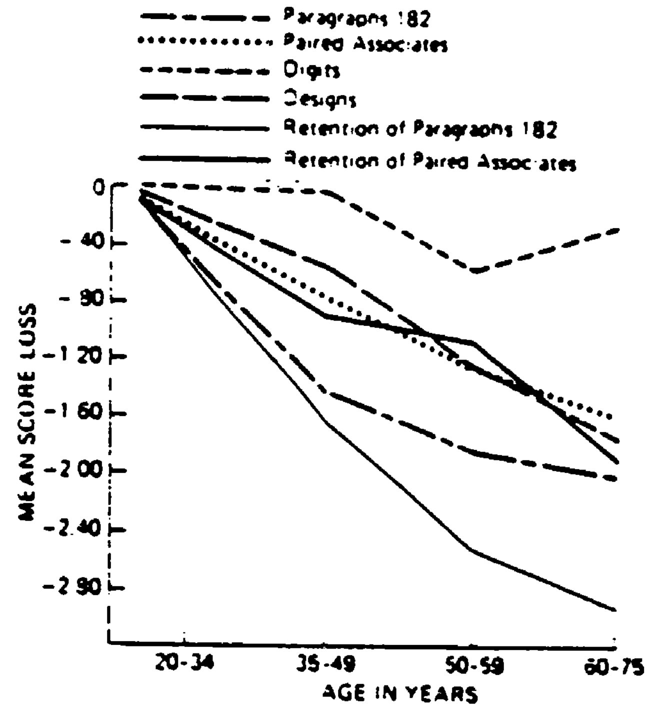

Figure 15. Differential decline on six subsets of the Guild Memory Test throughout maturity. (Gilbert & Levee, 1971).

Depth of processing. Poon (1985) cautions that an important question in assessing age differences in long-term retrieval is whether an obtained difference is due to a deficit in learning new information (i.e., the information is not successfully committed to long-term memory) or difficulty in retrieving the learned information (cf. Kausler, 1970). Consequently, older people may experience inefficient encoding of information into long-term storage, and would account for results indicating that younger persons are better able to perform deep or elaborative processing than older people (Eysenck, 1974).

A great deal of the research that follows this line of "depth" of processing and it's relation to the aging process has been concerned with the "level" (shallow versus deep) of processing. And, indeed, the literature does indicate that older people do not process information as deeply as younger people and that the elaborative character of their processing is not as extensive or rich. These conclusions have been primarily derived from studies based on the orienting experiment. In the orienting experiment, different instructions are given to different people, thereby directing them to different aspects of the information. In this way, some people will process primarily in a shallow way, others more deeply, and the rest in between. For example, in learning a list of words, shallow processing instructions might be to attend to a specific letter in the words (i.e., sensory physical dimensions) and deep processing instructions might be to form images of the words or to judge the words according to some subjective criteria (i.e., semantic, associative dimensions). Predictably, deep processing instructions should result in better learning and memory than shallow instructions. In fact, the overwhelming majority of studies indicate that deep processing, even without intention to learn, resulted in better performances than intentional efforts that, presumably, were not based on such deep quality processing (Botwinick, 1984).

Aging studies based on the orienting task generally indicate that although older people are better in their incidental learning performances with instructions for deep processing than for shallow, the difference between the two is not as great as among younger people. Specifically, Eysenck (1974) found that as processing proceeded from shallow to deep, learning and memory improved somewhat for older people (55-65), but more so for younger people (18-30). However, none of this processing resulted in increases in learning and memory performances that were as good as those with intentional learning (Botwinick, 1984). When level of processing and intentional versus incidental learning are manipulated, old and young subjects tend to differ significantly in deep processing, but not in shallow processing (Erber, Herman, & Botwinick, 1980). This appears to again indicate that the elderly do not or cannot process information as deeply as younger people. However, as Figure 16 indicates, deep processing without intention to learn lead to performances as good as those of intentional learning, if not better.

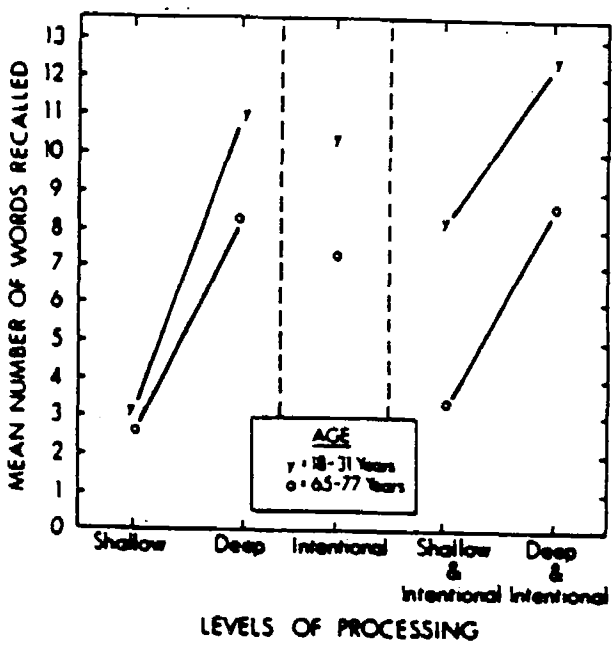

Figure 16. Mean number of words recalled as a function of depth of processing. (From Erber et al., in Botwinick, 1984).

In addition, many of these age differences disappear when subjects are required to recognize familiar stimuli rather than to recall information (Craik & Simon, 1980; Rankin & Hyland, 1983; Schonfield & Robertson, 1966).

It is well known that older adults tend to have slower acquisition rates in paired-associate learning (Poon, 1985). In addition, Thomas and Ruben (1973) have shown that older adults perform at a lower level in a standard no instruction condition, that organizational techniques can elevate performance, and that older persons tend to benefit more from organizational techniques, with the results that the observed age differences are minimized. Poon (1985) interprets these results as suggesting that older people tend to be inefficient spontaneous organizers. When efficient strategies such as appropriate elaborative or orienting instructions are provided, however, older subjects are able to utilize them and to improve their memory performance (cf. Smith, 1980).

Smaller age differences have also been reported when (a) the pacing of the experiment was modified to a level more suitable to the subject, (b) sufficient practice was given, and (c) the stimulus material was familiar to the subject (Poon, 1985). Thus the data suggest that the older subject who is given enough time or a mode of learning that is most suitable to his or her style can perform at a higher level and minimize age differences.

Item familiarity, important for traffic sign interpretation, is another factor that has been demonstrated to reduce age differences in retrieval from long-term memory. Although under test conditions, young and old subjects both benefit from additional semantic processing, older subjects tend to outperform the young on recall of words more familiar to them (cf. Barrett & Wright, 1981; Hultsch & Dixon, 1983). Although better recall for familiar items may not seem surprising, it does serve to highlight the flexibility of the long-term memory performance of older adults (Poon, 1985).

Individual ability variables also influence the magnitude of reported age differences in long-term memory retrieval of verbal material. For example, Bowles and Poon (1982) failed to find any significant age differences between young and old subjects with a high vocabulary level, but a significant age difference was obtained between those subjects with a low vocabulary level. In fact, Poon (1985) suggests that the vocabulary level of test groups might be a concomitant factor in the failure to find age differences in some studies (e.g., Gordon & Clark, 1974) and significant differences in others (e.g., Harkins, Chapman, & Eisdorfer, 1979).

Unfortunately, only a relatively limited amount of work on long-term memory has focused on allowing some comparison and generalization of findings to memory of the more contextual, and ecologically valid, information found in normal everyday activities. General findings point to the conclusion that significant age differences are found when rote recall or recall of verbatim surface information is required (Craik & Masani, 1967), but not when elaboration is required in the processing of text to draw meaning, gist, or implication even when the to-be-remembered information is quite long (Meyer, Rice, Knight, & Jensen, 1979). However, Labouvie-Vief, Campbell, Weaver, and Tannenhaus (1979) found elderly subjects to be more efficient on memory for gist, but younger subjects more efficient on memory for verbatim surface information. In sum, the evidence to date shows minimal age differences in memory for familiar discourse materials that may be found in the everyday environment (Poon, 1985).

In contrast, Horn (1982) suggests that aging may be associated with improvements in getting at information in long-term memory. For example, some of the variables that help describe crystallized intelligence, such as esoteric analogies, remote associations, and experiential evaluation, have been interpreted as indicating an ability to engage in a flexible structuring of information. Although these findings are not unequivocal, they may indicate that older adults differ from younger adults in having somewhat more flexible access to stored information. However, this interpretation should not be taken as indicating that older adults do not have more difficulty than younger adults in retrieving a particular item of information (cf. Schonfield, 1974), but only that older adults have more knowledge than younger adults (as mainly represented in crystallized knowledge) and can fluently express this knowledge when prompted to do so. It appears, then, that at least two distinct processes may be involved in aging changes in accessing information in long-term storage (cf. Fozard, 1980).

Competence vs. Performance Issues

A subtle, but recurrent, theme throughout the literature on perceptual and cognitive changes related to the aging process has been an emphasis on within-subject variation and individual differences. And, although complex problem solving and decision making are not typically considered as one of the "stages" involved in an information processing model of cognition, such skills are certainly dependent on perception and cognition and required for safe driving. Unfortunately, this area of aging is also characterized by the lack of an integrative theoretical framework with which to integrate and interpret the available research. Consequently, Reese and Rodeheaver (1985) suggest focusing on several conceptual issues about cognitive aging in general such as the competence-performance distinction, deficit versus difference, and cautiousness. However, a brief examination of these issues related to problem solving and decision making should provide a summative function in the sense of serving to emphasize the importance of considering individual and group variation in the elderly.

Because competence refers to performance under ideal, and often controlled, conditions, performance under actual conditions is subject to the effects of extraneous variables such as motivation, attention, memory, and task familiarity (Reese & Rodeheaver, 1985). For example, tests designed to measure problem solving skills may be significantly influenced by memory ability. It has long been speculated that the elderly have trouble remembering recent events due to a decline in sensory abilities and attention with the decline in attention due to a concomitant decline in interest. Reese and Rodeheaver also note that declines in sensory abilities represent possible neurological decay while declines in interest represent changes in other nonintellective factors. Consequently, there may be multiple causes of decline in problem solving ability among the elderly which are difficult to isolate and interpret. In addition, as the number of variables that covary with a selected dependent variable increase, the variance within the subject population will also increase and this is certainly the case when dealing with aging test groups.

Although selective attention is not a problem solving ability per se, Hoyer, Rebok, and Sved (1979) found that elderly adults had more errors and a reduced performance speed when the number of irrelevant stimuli were increased in a selective-attention problem-solving task. The authors interpreted their results as indicating an age effect on the ability to attend selectively to relevant information and to ignore irrelevant information. Thus irrelevant information may slow solution times for older adults, but not necessarily effect the number of errors made in specific tasks.

Task-familiarity is another performance-related factor. Sanders, Sanders, Mayes and Sielski (1976) conducted research designed to separate task familiarity from competence effects by including a control condition such as task practice with correct response feedback, but without specific strategy instruction. They found that strategy training improved performance significantly more than task familiarity. As a result, Reese and Rodeheaver (1985) have inferred that competence is not reflected fully by performance when the support system is deficient or inappropriate. In addition, although a particular cognitive strategy may be in a person's repertoire, it is often not used spontaneously but may be used if appropriately prompted (p.476).

Labouvie-Vief (1982) has been a leading researcher in emphasizing that cognitive _deficits_ identified in older adults may be more usefully characterized as cognitive _differences_. For example, increased cautiousness, as evidenced by errors of omission and slow reaction times, may account for a significant proportion of the variance in performance on perceptual, verbal and memory tasks (cf. Okun, 1976). Reese and Rodeheaver (1985) cite Okun's five sources of increased cautiousness among the elderly: physiological, rational, cultural, motivational, and generational.

The _physiological_ aging of the nervous system is associated with slow response time, leading to cautiousness in situations in which fast responses are required. Cautiousness is _rational_ when it reflects a realization that performing well will be difficult because the required abilities have declined. Consequently, the slowing may be purposeful in order to obtain accuracy either to be more careful or because of an increased tendency to make errors. The _cultural_ variables that lead to disengagement result in lower self-esteem. As a consequence of lowered self-esteem, the aged view themselves as less competent and, in turn, they may exhibit greater cautiousness as a means of keeping their egos intact. Increased cautiousness in old age could reflect _motivational_ changes, such as an increase in fear of failure and consequent decrease in achievement motivation. Differences in cautiousness during adulthood may also reflect _generational_ or cohort differences rather than, or in addition to, age differences.

Staplin, Lococo, and Sim (1990) also note that the single most compelling finding in their research with regard to implications for traffic control device use by diminished capability drivers has been the indicated exaggeration of individual differences within age cohort as age increases. They also stress that the interdependence of perceptual and cognitive processes, and their relative contributions in accounting for variance in driving tasks, is not well understood at this time. In sum, the present literature review indicates that the research and development of safer and more efficient traffic control devices, highway design, educational intervention and individual assessment must begin to address these issues within the framework of an experimental design which speaks to the individual needs of the aging person in terms of the driving task and environmental constraints.

SUMMARY AND RECOMMENDATIONS

The empirical evidence on perceptual and cognitive changes associated with aging consistently documents increasing deficits with advancing age. The mean values on virtually all perceptual and cognitive variables indicate that there is a higher probability of deficits for older as opposed to younger drivers. There are, however, several important considerations when applying this literature to the complex task of driving. The most important of these considerations are as follows:

1. Although all measures indicate performance deficits with age, the variability between individuals is typically quite large. For any given measure of sensory or cognitive performance, there are always individuals in older age categories whose performance exceeds the mean of individuals in younger age categories. Because of high within group variability, age is a poor predictor of either sensory or cognitive performance. Further, there is no single biological age for a given individual. Different sensory and cognitive systems age at different rates within the same person, so that the pattern of age related deficits is likely to be idiosyncratic.

2. The relationship between specific sensory or cognitive deficits and actual driving performance is largely unknown. The literature describes the physical problems facing elderly drivers and contains analyses of how cognitive and visual skill losses might create difficulties for elderly

drivers in understanding, interpreting, or responding appropriately to the demands of driving. However there are only a few studies that tie measurable losses in information processing capacity to actual driver behavior or accident rates. Further, the evidence from those few studies is inconclusive. The literature does not, for example, show clear relationships between any given sensory or cognitive deficit and accident rates. The evidence suggests that some drivers can compensate for a loss of sensory or cognitive capacity and still drive safely.

3. The perceptual and cognitive research has consistently focused on narrow areas of interest in order to avoid confounding variables. Information has been gathered in the controlled, but artificial setting of the laboratory. Although this is necessary in order to document problems in human information processing associated with age, it limits the applicability of the research to driving contexts. Driving requires the interaction of multiple processing capacities. The manner in which such capacities interact with each other, or are utilized in real world driving tasks, is conspicuously absent from existing literature. Only by engaging subjects in actual driving tasks and under actual driving circumstances can the individual changes in perception and cognition, and their impact on driving competence, be appropriately assessed.

4. The degree to which specific perceptual and cognitive deficits "stress" the driver is unclear. Most stress models (cf. Section I above) suggest that stress is the ratio of task demands to abilities. When abilities decline and task demands remain constant or increase, psychological and physiological stress is the likely result. This leads to the prediction that some sensory deficits may produce emotional reactions such as anxiety and may adversely affect the physiological status of the driver. However, the result of the interaction between information processing deficits, task demands and driver stress has not been empirically studied.

Recommendations:

1. Investigation of the relationship between sensory cognitive functioning and driver performance. It is necessary to develop specific age related measures of sensory/cognitive functioning that are demonstrably related to driving skill. The existing literature is a starting point for this exploration. The task is to find specific perceptual/cognitive variables that predict individual differences in performance among elderly drivers. Driver performance should be quantified either through realistic simulation procedures, or through real world driving tasks.

2. Exploration of the relationship between information processing deficits associated with age and driver stress. The degree to which information processing deficits associated with age stress the driver should be explored. Information processing capacity should be regarded as a variable that moderates or buffers the impact of difficult driving situations. Driving can be regarded as a task that continuously varies in terms of difficulty. Difficult situations are generally more likely to induce a stress response in the driver than are less difficult situations. For example, low illumination conditions are more difficult and hence more stressful for all drivers. The elderly driver who commonly suffers from increased sensitivity to glare and greatly reduced visual acuity under low light conditions will be more stressed than individuals who do not suffer from these deficits. Research is lacking that explores the relationship between the difficulty of various real world driving tasks and the information processing capacities of the driver. Such research seems a prerequisite for effective roadway and traffic control device design.

3. Exploration of the impact of IVHS technology on elderly drivers with various information processing deficits. IVHS technology may have the potential to ameliorate some of the common effects of aging, for example by

reducing the information processing demands facing the driver. Driving is a complex task that involves planning, navigating through space, manipulating the automobile, and remaining vigilant. To the extent that new technologies can simplify any of these simultaneous tasks, the potential stress on the driver is minimized. From this perspective IVHS technology may be regarded as a supplementary information processing system that minimizes deficits in the driver that are due to advancing age.

IVHS technology also has the potential, however, to increase the complexity of the driving task. IVHS informational systems such as electronic signboards or in-vehicle video maps constitute input that could be distracting to older drivers. For example, one of the most common deficits associated with aging is increased difficulty in switching back and forth between different sources of input. Older drivers cannot redeploy attention as quickly as younger drivers; consequently they may be unable to use visual displays within the vehicle or on the roadway while simultaneously monitoring traffic conditions. This example highlights the necessity for exploring the relationship between aging, information processing deficits, and the demands imposed by new roadway and vehicle technologies. Without such research IVHS has the potential to increase driving stress as well as to reduce it.

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III. Stress, Human Factors, and Illness: Individual Differences among Drivers That Moderate the Impact of Driving Stress

STRESS AND ILLNESS SUSCEPTIBILITY

Anecdotes that link stressful experiences with illness can be found throughout history. Worry, severe grief, or a sudden shock are commonly linked to subsequent physical or psychological disorders. There are several lines of evidence that suggest that psychological stress plays a causal role in the development of illness. First, there are animal studies that show physical pathologies induced by stress (e.g., Levy, 1985; Selye, 1976; Weiss, 1971). Second, there are human physiological responses such as fainting or nausea that occur under conditions of high emotion. These responses indicate that psychological events can cause transitory illnesses in humans. Third, there is evidence that human illness rates are higher following the death of a loved one (Engle, 1967). Finally, there is a significant body of data showing increased illness rates that occur following "life events" stress, commonly defined as a significant change in one's accustomed pattern of life (Dohrenwend & Dohrenwend, 1974; Holmes and Rahe, 1967).

The scientific study of such phenomena is commonly traced to the work of Selye (1976). Selye's discovery of a "stress" effect was serendipitous; it occurred while he was conducting research that required subjecting laboratory rats to drug injections. In his experiment, all rats received an injection; some received an experimental drug, some received saline. Selye unexpectedly found a high mortality rate in this study for both experimental and control rats. Autopsies of the deceased revealed peptic ulcers, atrophied immune-system tissues, and enlarged adrenal glands. Reasoning that the experimental procedures themselves may have produced these effects, Selye conducted subsequent studies in which rats were subjected to unfavorable living conditions such as extreme heat, cold, loud noises, pathogens, and toxins. Similar results occurred; many animals died with ulcers, atrophied immune system tissues, and enlarged adrenal glands.

Selye ultimately concluded that these illnesses and subsequent deaths had a common antecedent that he called "stress."

Physiological Mechanisms.

The task of identifying linkages between psychological stress and disease processes becomes increasingly difficult when questions concerning specific physiological mechanisms are addressed. Several reasons for this difficulty may be adduced. First, the etiology of most disease processes is not well understood, especially in relation to host variables. Second, different classes of stressors are not easily operationalized in physiological terms. Cold, bereavement, job difficulties, and traffic congestion all may qualify as stressful events, but it is difficult to reduce them to a common metric. Third, the various physiological systems of the body are interrelated. A stress induced change in one system is likely to initiate a cascade of events that results in changes in other physiological or biochemical systems. Specifying simple causal links between psychological events and resultant disease processes will likely require more knowledge about both bodily systems and disease processes than is currently available.

Hormonal and sympathetic nervous system response to stress. There are, however, a number of approaches to this problem that have proved fruitful. For example, in Selye's model there exists a final common physiological pathway for stressors of various types. Significant components of the stress response (which is diagrammed in Figure 1 below) are the hypothalamus and pituitary which control the secretion of cortisol by the adrenal glands. Two systems are commonly involved, the sympathetic adrenal-medullary (SAM) system, and the hypothalamic-pituitary-adrenocortical (HPAC) system.

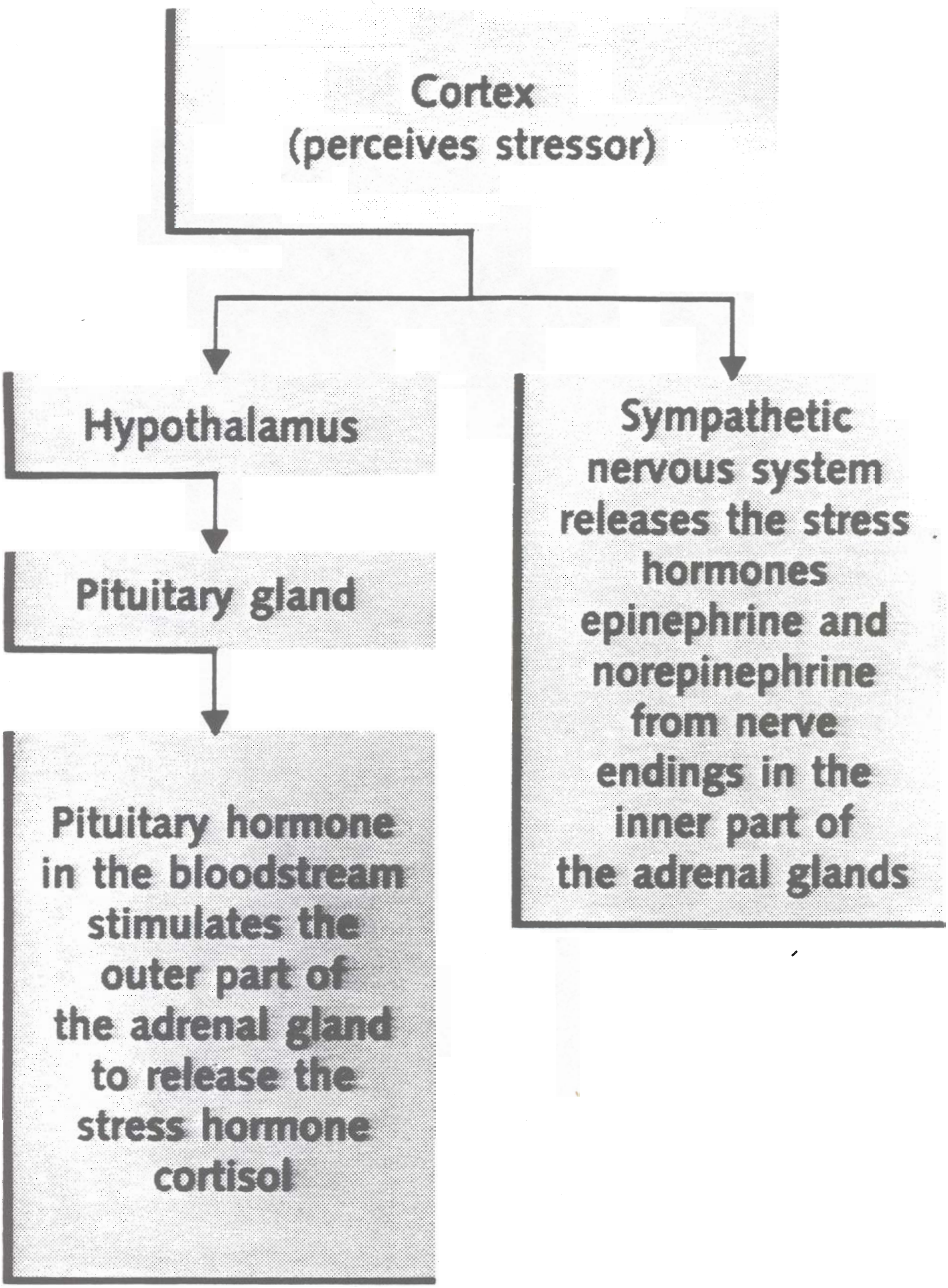

Figure 1. Hormonal and Sympathetic Response to Stress

The first step in the cascade of events occurring after the perception of a stressful event in the environment involves the activation of the sympathetic portion of the autonomic nervous system by the hypothalamus. The hypothalamus stimulates adrenergic neurons of the sympathetic nervous system. The term adrenergic refers to neurons whose chief neurotransmitter is epinephrine or norepinephrine. The action of epinephrine during a stressful situation causes the enlargement of blood vessels that feed large muscles, allowing more blood to the muscles that might be necessary during a "fight or flight" reaction. If extremely energetic activity is required, the muscles must be prepared, and epinephrine allows this by increasing the amount of blood to muscles from the normal 15% of the body's blood to up to 80%. Norepinephrine acts by constricting blood vessels that flow to the skin, kidneys and digestive system. These two neurotransmitters also help dilate pupils to let in more light, decrease salivation, open bronchi for increased oxygen intake, increase heart rate, and stimulate sweat glands. These activities performed by the sympathetic nervous system all prepare the organism for whatever action is necessary regarding the stressful stimulus that has been detected.

The hypothalamus concurrently activates the neuroendocrine system. The hypothalamus secretes corticotropin releasing factor (CRF) into the blood which stimulates the pituitary to release adrenocorticotropic hormone (ACTH). ACTH travels in the bloodstream to the adrenal glands where the hormone cortisol is produced. Cortisol enhances the sympathetic nervous system response by stimulating production of epinephrine and norepinephrine and inhibiting their breakdown. Cortisol also makes the receptors activated by these neurotransmitters more sensitive.

The hypothalamus also secretes luteinizing hormone-releasing hormone (LH-RH) into the blood which stimulates the release of luteinizing hormone (LH) by the pituitary. The pituitary also releases follicle stimulating hormone (FSH) which, along with LH, travels to the gonads to increase the production of testosterone. Testosterone increases the rate of glucose reaching the muscles, which aids the sympathetic response. This hormone also improves both vigilance and the ability to focus attention, which is helpful in detecting and locating stressful stimuli. When a threat is perceived, testosterone is suppressed and the sympathetic response and cortisol take over. Chronic or recurrent activation of the sympathetic nervous system imposes a strain on the adrenal glands and is assumed to be associated with their subsequent hypertrophy.

Immune system response to stress. Considerable attention is also currently being focused on the immune system in relation to stressful events. Although many questions regarding specific mechanisms remain unanswered, it seems clear that stress can result in decreased immune system function (Friedman & Booth-Kewley, 1987). Psychological stress which results in anger, hostility, depression, or anxiety has been associated with elevated levels of corticosteroids such as cortisol and catecholamines such as epinephrine. Increased levels of both corticosteroids and catecholamines have been associated with immunosupression.

Most hormones have been shown to be stress responsive and to have immunological effects. A variety of neuropeptides (proteins that modulate neural activity) have been shown to influence immune function. There are documented mechanisms that allow for bi-directional communication between the neuroendocrine and immune systems (O'Leary, 1990). It is becoming increasingly apparent that there are extensive pathways that allow for the influence of psychological processes on immune system function. The goal of neuroimmunological research is to identify associations between specific subjective psychological states, neuroendocrine processes, and immune system function. Since driving constitutes a recurrent daily activity that is associated with strong emotional reactions and subjective feelings of distress, its effect on immune system function cannot be discounted.

PERSONALITY FACTORS THAT MODERATE THE RELATIONSHIP BETWEEN STRESS AND ILLNESS: A REVIEW OF THE LITERATURE

In this section literature will be reviewed that documents linkages between stress, personality, and illness. 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).

Conceptualizing individual differences

The topic of individual differences and personality requires a division of effort when attempting to develop an appropriate classification scheme. One effort directs itself toward the static, descriptive, and noncausal analysis of those types of behavior typically referred to as personality, character, and temperament. The second is related to the more dynamic, causal problem of *why* a particular individual behaves in a certain way, shows certain traits of personality rather than others, or demonstrates one kind of ability over another. The first effort requires the development of a *taxonomy* of human behavior, while the second investigates the *dynamics* of human behavior (Eysenck & Eysenck, 1985). Taxonomy must necessarily precede dynamics, and the generalized trait approach provides one avenue for investigating the ways different individuals respond to specific situations such as those involved in everyday driving.

Traits are *dispositional* factors that regularly and persistently determine behavior in a variety of situations. Allport and Odbert (1936) originally defined traits as "broad patterns of determining tendency that confer upon personality such consistency as it displays. Consistent and stable moods are indicative of an individual's adjustment to his environment" (p.26). In addition, the contrast should be made between traits and states, which often refer to only single occurrences. Allport and Odbert (1936) define states as "present activity, temporary states of mind and mood" (p.26). Obviously states and traits are not unrelated, but the distinction is a useful one in that trait measures may often be helpful in predicting specific behaviors in specific situations. Consequently, the relationship between the individual differences associated with generalized traits should help us to understand, and hopefully predict, many of the behaviors associated with enduring characteristics of the individual and the stressful demands of driving.

Hardiness

Hardiness is a concept developed by Kobasa and her associates that refers to a personality trait that designates individuals that are relatively immune to stress. Hardiness is assumed to influence the manner in which individuals categorize, interpret, and appraise situations. Individuals scoring high on this trait are assumed to construe situations in a manner that minimizes the stress producing potential of life changes or environmental challenges. Kobasa (1979) originally described hardiness as a multifaceted trait that is composed of three characteristics: control, commitment, and challenge. Individuals high in Control believe in their ability to influence the course of events, individuals high in Commitment believe that assignments and tasks are meaningful, and individuals high in Challenge expect that difficult situations or difficult changes in life are normal and stimulate development.

Kobasa (1979) studied 161 middle and upper level executives who worked for a large public utility. The subjects (all of whom were male) were evaluated with respect to: (1) stress (using the Social Readjustment Rating

Scale), (2) Illness (using the Seriousness of Illness Rating Scale developed by Wyler, Masuda, and Holmes, 1968), and (3) Hardiness (measured by six standardized psychological tests). Kobasa found that executives who experienced high stress but low illness could be distinguished from executives who experienced high stress and high illness by their scores on the hardiness scales. High stress-low illness executives scored higher on commitment, control, and challenge than did high illness subjects.

Based on these results, Kobasa suggested that hardiness is an individual difference trait that acts to reduce the risk of illness in response to stress. Executives scoring high on hardiness would be more likely to approach changes in their life with a strong sense of capability. Life changes would tend to been construed as challenges. A sense of personal control would allow such executives to feel that their own actions would lead to desirable results.

Kobasa, Maddi, and Kahn (1982) employed a prospective research design to further explore the relationship between hardiness, stress, and illness. In this study, measures of stress, measures of illness, and measures of hardiness were gathered from a group of male managers at the outset of the study. Illness rates were assessed at one and two year intervals. The data indicated that the hardiness measures gathered at the outset of the study predicted illness data collected one and two years later. Subjects high on hardiness were less likely to become ill when they experienced high stress than were subjects who scored low on hardiness. In this and subsequent studies, hardiness seems to have the most pronounced effect on subjects who are experiencing high stress.

Type A behavior (cf. discussion of Type A-B Distinction, below) has also been studied in relation to hardiness. Kobasa, Maddi, and Zola (1983) measured hardiness, stress, illness, and Type A behavior in male executives. Stress and illness were reported retrospectively for each six months during the previous two years. The authors confirmed their hypothesis that stress was associated with an increase in illness, while hardiness was associated with a decrease in illness. Type A behavior was found to be essentially uncorrelated with hardiness. Variation in Type A behavior was found to be unrelated to variation in health. The authors did, however, observe a three way interaction such that Type A individuals reported the most illness when they were low in hardiness and under high levels of stress.

Failures to replicate. Five independent studies which assert that hardiness is a moderator of stress have been published. Of the four studies which used a composite measure of hardiness, one found a significant buffering effect, one found a buffering effect on one analysis of the data but not another, one found no buffering effect for total life events and a marginal effect for work related events, and one was uninterpretable. Four additional studies have failed to replicate a buffering effect of hardiness (cf. Cohen & Edwards, 1989).

Because of methodological problems in much of the research and because of the recurrent failures to replicate, the evidence that the hardiness construct operates as a stress buffer is weak. This is probably attributable to the poor internal consistency of the hardiness measure proposed by Kobasa. Although some components of hardiness may ameliorate the negative effects of stressful events, it is unclear what these components are or how they should be organized.

Locus of Control

Evidence from a variety of sources suggests that feeling in control of events is associated with positive emotional adjustment, mental health, and physical health (Lefcourt, 1980; 1982). Conversely, the perception that one is unable to exert control over events has been found to be debilitating (Seligman, 1975). The relationship between perceived control and health has been explored in research designed to test the theory of <u>learned helplessness</u> (Abramson, Seligman, & Teasdale, 1978; Seligman, 1975).

Standard procedures for demonstrating the development of learned helplessness in the laboratory involve confronting subjects with some kind of stressor such as blasts of irritating noise. Some subjects are assigned to a Positive Control condition in which they can engage in some behavior (e.g., puzzle solving) which will stop the noise. Other subjects are assigned to a No Control condition in which they can do nothing to stop the noise. After exposure to the stressor, subjects are given another task to complete and are given tests which measure anxiety or depression. Typically, in this type of paradigm, subjects in the No Control condition inappropriately generalize their perception of No Control to the second task. Subjects in the No Control condition perform less well on the second task and also report higher feelings of anxiety and depression.

Research has found that decreases in perceived control are related to increased feelings of crowding in congested areas (Schmidt & Keating, 1979), decreased academic performance (Dweck & Licht, 1980), and destructive behavior (Allen & Greenberger, 1980). Lack of perceived control is generally regarded as increasing the potency of a stressor and of increasing the amount of time that an individual requires to recover from the effects produced by the stressor.

The literature on perceived control and learned helplessness is related to the issue of driving stress in the following ways: (1) Personal factors such as age, experience, or perceptual-cognitive deficits can affect the degree to which the driver perceives that he/she can adequately control the vehicle. Drivers who perceive themselves to be high in the ability to control the vehicle should be more resistant to traffic stressors than are drivers who perceive themselves to be lower in ability. (2) External stressors such as traffic congestion which cannot be controlled or modified by an individual driver are likely to produce feelings of learned helplessness, and such feelings may generalize to other tasks in the individuals life. Traffic congestion may thus have hidden costs that extend beyond the time lost during travel. (3) New technologies for controlling the flow of vehicles (commonly referred to as IVHS) may affect the perception of personal control. To the extent that they increase the driver's perception of control (for example by enabling the driver to avoid congested areas) they should be stress reducing. However, it should be noted that IVHS technology has the potential to increase feelings of learned helplessness to the extent that it deprives drivers of opportunities to make choices and decisions.

Individual Differences in Perceived Control. Rotter's (1954) social learning theory posited that individuals would develop stable and general expectations concerning the likelihood that their behavior would result in positive outcomes. Individual differences in such expectations are commonly termed individual differences in locus of control. At one end of the locus of control continuum are internals, individuals who tend to believe that outcomes are related to their own efforts. Such individuals are likely to take credit for their successes and blame for their failures. At the other end of the continuum are externals, individuals who tend to believe that most of what happens to them is out of their control. Rotter's (1966) locus of control scale was designed to assess an individual's position on this trait dimension.

Initial research with the locus of control scale indicated a relationship between scale score and stress resistance: internals were generally found to be more resistant to the debilitating effects of psychological stress than were externals. The general logic of these investigations is based on the relationship between stress and coping. Individuals who generally believe that their own activities will effect outcomes (internals) should engage in more active, effortful coping behavior than should individuals who believe that outcomes are out of their control. In line with this reasoning, externals have been found to react with anxiety and depression to major problems in their life to a greater degree than do internals. Internals also have been found to use more active and effective coping strategies in dealing with stress than do externals (Anderson, 1977; Lefcourt, 1982; Lefcourt, Miller, Ware, & Sherk, 1981).

Factor analytic studies. In recent years the Rotter scale, which was designed to measure a unidimensional generalized expectancy of control over a variety of life situations, has been subjected to factor analytic study. Such studies have been designed to determine the extent to which the Locus of Control Scale measures one or more than one personality variable. Mirels (1970), for example, found that the scale was composed of two distinct dimensions, one related to personal goals and achievements, the other related to control over social-political systems. It is possible for a subject to be high on one of these dimensions while low on the other. Reid and Ware (1974) developed a three factor locus of control scale, which adds a third factor (the ability to control one's own behavior) to the two developed by Mirels. Lefcourt, von Baeyer, Ware, and Cox (1979) developed a locus of control scale (the Multidimensional-Multiattributional Causality Scale) which contains two subscales pertaining to the ability to control personal achievement and the ability to control social interactions.

The stress buffering effects of generalized expectancies regarding control have been examined in a number of studies (Johnson & Sarason, 1978; Lefcourt, Miller, Ware, and Sherk, 1981; Wheaton, 1982; Sandler & Lakey, 1982; Turner & Noh, 1983 Wheaton, 1983; Krause and Stryker, 1984; Krause, 1985). In these studies stress is typically measured by some version of either the Life Events Scale (LES) or the Social Readjustment Rating Scale (SRRS). Locus of control is conceptualized as a moderating variable, with individuals possessing high control expectancies (internals) predicted to be more stress resistant than individuals possessing low control expectancies. Dependent variables have included measures of anxiety, depression, schizophrenic symptoms, mood disturbance, psychological distress, and physical distress. The bulk of these studies report weak but significant stress buffering effects of control expectancies. Because of methodological inadequacies present in most studies (see Cohen & Edwards, 1989 for a critique of this literature), it is not possible to estimate the magnitude of the stress buffering effect provided by locus of control.

Specificity. Studies of the concept of locus of control seem to indicate that if one can specify a content domain in which one can succeed or fail, then it is possible to develop a locus of control scale that will measure expectancies in this area. Rotter's original notion of a generalized expectancy of control (in all content areas) has tended to be supplanted by more specific scales which measure expectancies in different content domains. Because the various dimensions of locus of control are only slightly related to one another, it is possible for a person to be an internal with respect to some areas of life, such as job achievement, while being an external with respect to other areas of life, such as interpersonal relationships (Burger, 1991). Thus far the concept of locus of control has not been extended to driving expectancies. The literature suggests, however, that this would be a fruitful extension. Expectancies concerning the ability to handle the car, as well as the ability to cope with a variety of driving situations, should constitute an individual difference variable that would allow more sensitive prediction of response to traffic stressors.

<u>Arousal, Sensation Seeking, Extroversion</u>

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 also becomes less regular than usual and the pupils usually dilate. When an immediate response to the environment is required, these changes are normally highly adaptive. However, chronic states of arousal may lead to many types of psychosomatic illness such as ulcers, coronary heart disease, arthritis, and asthma (Kalat, 1984).

However, not all individuals interpret arousal in the same way, and comfort levels of arousal vary from person to person. In fact, some individuals actually seek out higher levels of arousal or sensation. Preference for high levels of stimulation is also associated with willingness to take risks, 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. However, an examination of several studies which report on the stress buffering potential of sensation seeking appear primarily inconclusive (cf. Cohen, 1982).

The conceptualization of personality factors that moderate the impact of stressful events has shifted from unifactorial, global explanations to the reconceptualization of personality in terms of multilevel causal schemes. A crucial component of this endeavor is the coupling of genetics with social factors that produce individual differences in mental and behavioral development.

Eysenck (1967) attempts to incorporate these factors in a theory of personality which is dimensional rather than categorical. Individuals are placed along normally distributed continuums which reflect relatively stable personality types. Eysenck's theory of personality posits that an individual is a biological, as well as a social being. He considers personality to be a multi-dimensional interaction between biological predispositions and specific aspects of the environment (Eysenck, 1982). The three major constructs in this theory include extroversion, neuroticism, and psychoticism.

The dimension of psychoticism, or emotional independence (Royce & Powell, 1983), does not necessarily imply pathology; it refers to a tendency toward tough-mindedness, aggression, and hostility. Individuals scoring high on this dimension tend to be more aggressive, more unemotional in interpersonal relationships, and may exhibit more culturally defined behavior problems (Wakefield, 1979). Eysenck and Eysenck (1985) characterize the concept of psychoticism by the following: antisocial, aggressive, cold, unempathic, egocentric, impersonal, tough-minded, impulsive, and creative.

The neuroticism, or emotionality, dimension describes high scorers as highly emotional persons who worry excessively and have stronger reactions to stress and emotional situations; low scorers tend to be less emotional, and more stable (Wakefield, 1979). Eysenck and Eysenck (1985) describe the concept of neuroticism as being characterized by the following: anxious, depressed, guilt feeling, low self-esteem, tense, irrational, shy, moody, and emotional.

Extroversion is characterized by the following: sociable, lively, active, assertive, sensation-seeking, carefree, dominant, surgent, and venturesome (Eysenck & Eysenck, 1985). Although the entire range of extroversion-introversion is usually considered normal, individuals commonly differ most on degrees of sociability and impulsivity (Eysenck, 1967).

Persons innately predisposed to have habitually high arousal levels will tend to develop introverted behavior patterns, and those predisposed toward lower arousal patterns will exhibit more extroverted behavior patterns. Specifically, it is proposed that extroverts will raise their arousal level in response to minimally stimulating conditions, while introverts will lower theirs in response to maximally stimulating conditions (Eysenck & Eysenck, 1976).

Because chronic stress can lead to many emotional and physiological problems, it is important to understand the relationship between these personality traits and the ability to resist stress. What are the expected effects of stress on performance? Stress should impair performance because it involves a redirection of attention away from the task at hand.

According to Eysenck and Eysenck (1985), it is possible to relate some of these theoretical notions to personality theory. A person's level of neuroticism reflects the degree of arousal and reaction to emotional stimuli. Different arousal levels of people along the neuroticism dimension are distinguished from their different arousal levels along the extroversion dimension in that arousal along the extroversion dimension results from sensory input and problem solving activity rather than from emotional stimuli. Both personality dimensions are related to the person's arousal level - one emotional arousal and the other cognitive arousal. As a result, when considering the type of environmental stress encountered while driving, the two personality traits should be considered together, although scores on the extroversion scale may account for a greater proportion of the variance. High extroversion scorers should be able to resist environmental stressors better than low scorers due to their lower levels of arousal.

In fact, environmental stress may actually improve the performance of extroverts and impair the performance of introverts. The theoretical explanation for this difference involves three statements concerning the person's level of arousal. First, introverted persons are more aroused in general. Second, arousal enhances performance only up to a certain level - 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 extrovert, environmental stress raises the arousal level, resulting in improved performance. With the already aroused introvert, external stress pushes the arousal level past the optimal point and results in poorer performance (Wakefield, 1979).

Since introverts generally condition better than extroverts, it might be expected that neurotic introverts would be more susceptible than neurotic extroverts to conditioned anxiety in the form of worry. For example, as an older driver begins to become aware of diminishing capabilities while driving, generalized worry about mistakes or accidents begins to condition the driver to increase stress levels before actual driving even begins.

Although a person can have a very high level of psychoticism and still function adequately, stress or other environmental factors are more likely to result in explosive behavior for these people than for those who are lower on this dimension (Wakefield, 1979). Even high levels of psychoticism (or tough-mindedness) do not typically produce inappropriate behavior unless the individual is highly stressed (Eysenck & Eysenck, 1976). Consequently, individuals high on this dimension may be able to resist average levels of driving stress due to their insensitivity, but may also (when highly stressed) exhibit the type of dangerous or hostile driving presently seen in so many cities today.

Psychoticism is not directly related to somatic arousal; persons with high levels of psychoticism are no more or less aroused than others. However, people with high levels of psychoticism do seek environmental stimulation (e.g., the kind that can be provided by driving). They do dangerous or exciting things without considering the consequences. This type of activity is not characteristic of persons with lower levels of psychoticism. And, while psychoticism is not related to differences in arousal, it is related to differences in how gratifying high arousal states are (Eysenck & Eysenck, 1976).

The relationship between the three personality dimensions and arousal may be summarized in three statements. Extroversion reflects basic differences in arousal itself, with introverts being more highly aroused than extroverts. Neuroticism reflects differences in arousability, with highly neurotic persons being easier to arouse and consequently usually in a relatively high state of arousal. Psychoticism reflects differences in <u>seeking</u> high arousal, with highly psychotic persons seeking high arousal.

In terms of stress-buffering, we should see some positive effect for those individuals who score as stable (low neuroticism, low psychoticism), extroverted persons. Stress-susceptibility should be more pronounced for those individuals scoring highest on neuroticism and lowest on extroversion.

<u>Risk Taking</u>

Although some aspects of personality (e.g., extroversion, neuroticism, psychoticism, and locus of control) tend to be fairly stable over the life span, others are more directly related to developmental changes. A tendency toward risk taking is one such aspect of behavior that tends to decline in later years.

Risk taking shows a clear relationship with extroversion and an almost equally clear one with psychoticism. Specifically, risk taking correlates more with the venturesome aspects of extroversion than with the impulsive aspects of psychoticism and so should act as a stress-buffer for those individuals possessing this trait.

However, it is also known that as the sense organs begin to deteriorate with age, particularly where there is a high demand for sensory input (e.g., driving), stress will increase in response to these changes. One coping strategy often employed to accommodate such change is a slowing in performance resulting from diminished risk-taking on the part of the elderly; young subjects seem willing to respond on the basis of much more limited information (Botwinick, 1984). Because the elderly are more liable to misunderstand or misread the content of incoming signals, they resort to double-checking and risk-avoidance strategies that contribute to both slow vehicle speed and inappropriately cautious driving behavior.

Consequently, accuracy seems to be valued a great deal more than speed of response among the elderly. It has been hypothesized that a lack of self-confidence underlies this disinclination to venture response unless fairly certain of being correct. Elderly people seem to require a greater likelihood of success than younger people before taking a risk. However, cautious behavior takes many forms and is seen in varied contexts.

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 being a passenger in a car driven by an age cohort.

Matthews and Morgan (1986) documented that male drivers between the 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 and Finn (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 effects of risk-taking behavior due to relatively stable personality constructs and developmental changes.

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 situations, 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.

Risk perception and actual risk. The evaluation of risk perception can be used as a valuable tool in the prevention of AIDS, unwanted pregnancy, and alcohol and drug addiction. It has been well documented by Namerow, Lawton, and Phillber (1987) that teen-age girls' perceived risk did not correlate with the actual risk of getting pregnant. The same study also showed that the use of contraception among teen-age girls is guided by perceived risk instead of actual risk.

A person's evaluation of risk depends on many things. As shown by Pietromonaco & Rook (1987) the mood of a person affects their willingness to engage in risky activities. Peldin & Levin (1986) showed that people in a positive mood are more willing to take risks than are people in a more negative mood. Another variable that affects a person's risk perception is the media. Slovic, Fishhoff, and Lichtenstein (1980) determined that such things as a highly publicized train accident or the movie "Jaws" have a large impact on people's risk perception.

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.

The list of behavioral characteristics Friedman and Rosenman used as indicators of Type A personality is as follows: 1) obsessive attempts to achieve poorly defined goals, 2) love of competition, 3) a strong need for recognition and advancement, 4) a consistent preoccupation with time and a sense of "time urgency," 5) intense concentration and alertness, and 6) high levels of "free-floating hostility."

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. This study also confirmed the risk factors correlated with heart disease identified in the Framingham Study, namely that those with high blood pressure, high cholesterol levels, and cigarette smokers were more likely to develop coronary heart disease. 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.

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 reinfraction 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 score 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 discordance phenomenon it is impossible to determine if an individual is a hot or a cool cardiovascular reactor based on the person's surface behavior.

Buell has identified three types of hot reactors, based on the mechanism by which blood pressure is elevated. Type I ("output") reactors experience increased blood pressure primarily by increases in cardiac output, while system resistance remains unchanged. Type III ("vasoconstrictive") reactors experience increased blood pressure exclusively through vasoconstriction. Type II ("combined") reactors experience increased blood pressure through contributions of both output and resistance. Type III reactors appear to be at the highest risk for coronary artery disease.

This literature clearly defines an individual difference variable that is relevant to the topic of driving stress. Drivers who are hot reactors, 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.

Hostility. 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 those 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. These are the general characteristics associated with hostility and subsequent illness. 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 susceptibility has clear implications for the study of driving stress. Hostility is a common emotional reaction while driving. In one study (Turner, Layton, & Simons, 1975) 12% of the men and 18% of the women sampled reported that at times they could "gladly kill another driver." Lesser feelings of hostility are doubtless even more common. Individual differences in hostility reactions while driving are thus likely to predict some of the variance in health reactions to traffic conditions, with drivers who experience more hostility at relatively greater risk.

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 over their environment but will relinquish that control more rapidly 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 et al. 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-reports 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 and 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.

Dominance

Sapolski (1990) explored the relationship between position in a status hierarchy and the physiological response to stress among baboons. He found that two factors influence the levels of chemicals secreted during the stress response and also the overall health of the individual: (1) the manner in which an animal vents hostility, and (2) the amount of control that an animal has over its environment.

Social rank of the male baboons in a troop in Kenya was assessed. Sapolski found that subordinates had a higher resting cortisol level than dominants. It appears that this was due to differences between dominants and subordinates in the activity of the feedback mechanism in the hypothalamus which senses levels of cortisol in the blood, as shown in the figure below.

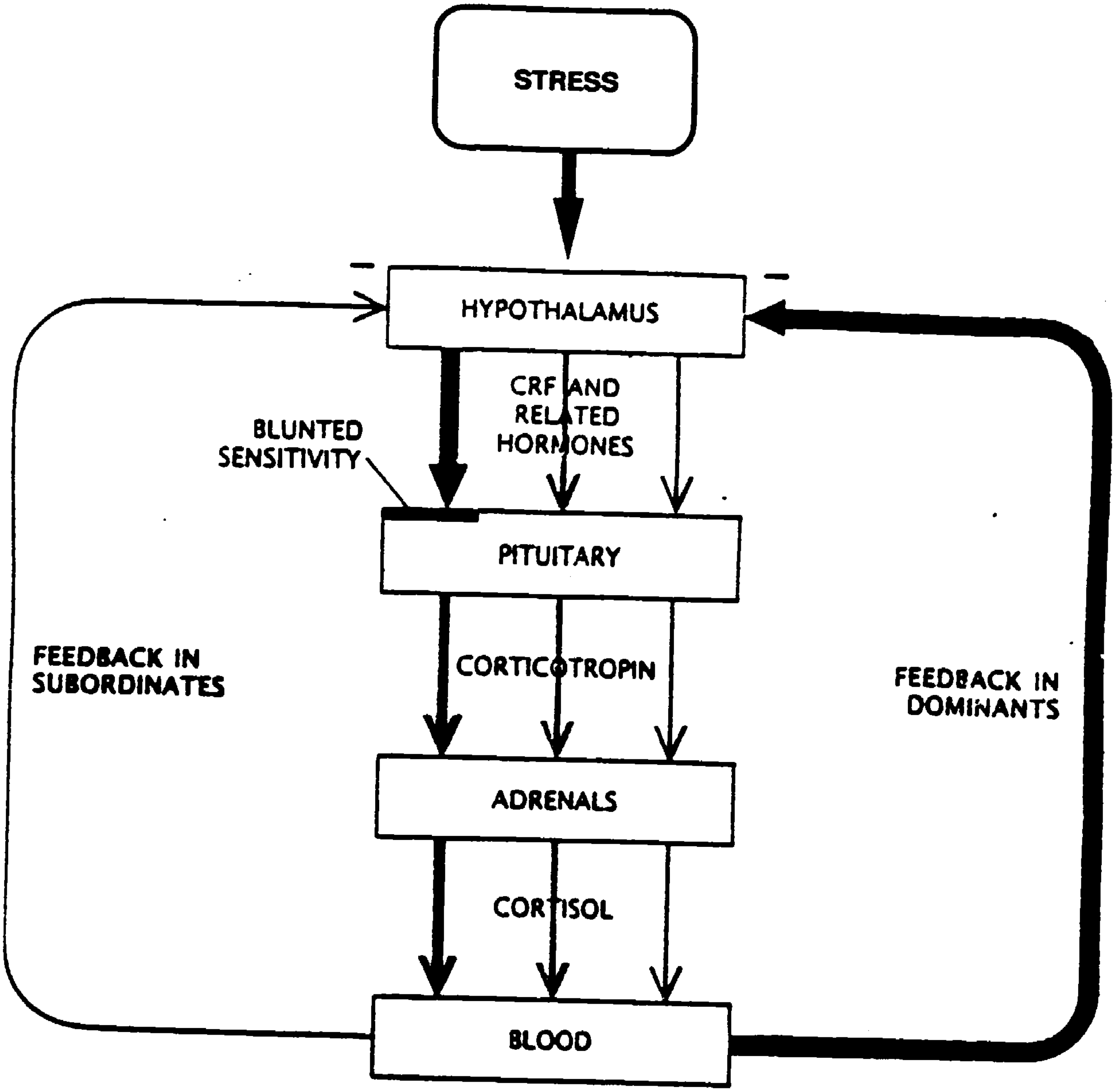

Figure 2. Response to Stress in Dominant and Subordinate Baboons

The hypothalamus in subordinates was found to be less sensitive to blood cortisol levels and thus overproduced corticotropin releasing factor (CRF). This, in turn, blunts the sensitivity of the pituitary to this CRF, causing the hypothalamus to secrete more CRF than usual in response to stress. The pituitary, even with this blunted sensitivity to CRF, hypersecretes corticotropin. The adrenals of both the dominants and subordinates were equally sensitive to corticotropin, but the higher levels of this hormone secreted by the pituitary in the subordinates caused higher levels of cortisol in the blood. Under prolonged stress, the hypothalamus of subordinate males becomes insensitive to the shutoff signal for cortisol and cortisol production continues unchecked. This higher level of cortisol depresses the immune system, causing fewer circulating lymphocytes and the possibility of more illness in the subordinates than dominants. The higher basal cortisol level found in subordinates also suppresses HDL cholesterol in the blood. High levels of HDL cholesterol prevent arteriosclerosis; its suppression leaves the subordinate males at greater risk of developing coronary heart disease.

Although the basal cortisol level found in the dominant baboon was lower, the transient rise in cortisol in response to stress was quicker. Dominants responded more quickly to stressful events in the environment, but were calmer overall when there was no immediate danger or threat. During a change in the dominance structure of this baboon troop due to the unexpected death of the leader, Sapolski had the chance to determine whether specific physiological traits caused the dominance hierarchy or dominance caused physiological differences between dominants and subordinates.

A subset of traits was found that distinguished dominants from subordinates. These traits were: 1) the ability to differentiate well between neutral and threatening actions of a rival, 2) if threatened, to control the situation by initiating a fight, 3) to behave differently after winning or losing a fight, and 4) to displace aggression onto a third party after losing a fight. The optimal physiology, one with a low basal cortisol level, was found only in males with at least one of these traits. Dominant males without these traits had cortisol levels similar to subordinants. Sapolski concludes that being able to predict and control the outcome of social interactions and to find outlets for tension blunts the negative long term effects of stress. Sapolski also found that the physiology of the dominant males looked like that found previously in subordinates; basal cortisol levels were elevated, and secretion of cortisol to stress was sluggish when the dominance hierarchy was in flux. The males with at least one of the psychological traits mentioned above became the dominants in the new hierarchy, and their physiology, after the hierarchy settled down, became similar to the profile of dominant males stated earlier.

Sapolski's research is unique in that it demonstrates specific linkages between general cognitive-behavioral variables and the physiology of the stress response. It appears that threat discrimination, venting of hostility, and expectations of control have tangible effects on the activity of the hypothalamic-pituitary-adrenal axis of the stress response system. The research suggests a model for the exploration of similar phenomena in humans.

SUMMARY AND RECOMMENDATIONS

An extensive body of literature documents substantial individual differences in the response to the same external sources of stress. 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 should arouse strong emotions. Applied to the context of driving, this literature suggests that some individuals should be relatively immune to the stresses and strains imposed by traffic situations, while other individuals might display an extensive stress response to the same situations.

Problems with the generalized trait approach

Despite the extensive literature on personality traits as stress buffers, it remains difficult to specify the constellation of traits that produces stress sensitivity or stress resistance in a given individual. The empirical literature in this area is replete with weak and equivocal findings. Traits that seem to confer immunity to stress in one context do not have equivalent effects when the nature of the stressor is changed. Some traits, such as locus of control, appear to be composed of component traits; a given individual may rank as high internal control on some components and low internal control on others.

A related problem concerns the lack of explicit linkages between trait taxonomies and process variables. As noted in the introduction to this section, the trait model assumes that trait taxonomies will predict the manner in which individuals will process information in trait related contexts. There is however, a notable lack of empirical investigation of such linkages. Concerning the topic of driving stress, there is no literature that explicitly links traits to either information processing or driving behavior.

Situation specific behavior. The lack of predictive power in the literature on "stress buffers" can be traced to the assumptions underlying trait theory. The personality trait model assumes that there are stable and general predispositions to behave that influence an individual's reactions in a wide variety of contexts. The empirical literature, on the other hand, indicates that trait related behavior is very situation specific. The locus of control trait, for example, assumes that individuals have generalized expectations regarding control that influence their reactions in a wide variety of contexts. A careful examination of the evidence, however, suggests a different conclusion. It appears that expectations regarding control are quite context specific. A given individual may expect to be in control in some contexts while not in control in others.

Similar findings characterize the other personality trait dimensions that have been identified a stress buffers. Hardiness, conceptualized as composed of challenge, commitment and control, appears to vary from stimulus context to stimulus context. A given individual may conceptualize one type of task as a challenge and another type of task as a threat. Type A behavior is associated with time urgency and hostility. The evidence indicates, however, that situations are strong determinants of whether a predominantly Type A personality will actually manifest Type A behavior.

On the positive side, the empirical literature does indicate that behaviors related to hardiness, locus of control, sensation seeking, Type A, risk taking, dominance are actually related to stress resistance or stress sensitivity. This literature suggests a direction for research concerning the problem of driving stress.

Recommendations

1. 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' response to stressful traffic situations. It should, however, be possible 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. Such an instrument would measure Driver Stress Susceptibility (DSS) and would be composed of questions regarding Hardiness, Locus of Control, Sensation seeking, Type A behavior, Risk Taking, and Dominance as they relate to driving. The literature, for example, shows that generalized expectancies of control weakly predict stress resistance in a variety of contexts. The DSS would contain questions regarding specific expectancies of control relevant to driving situations.

The DSS would therefore be based on the assumption that resistance to driving stress is an individual difference variable that is specific to the stresses imposed by driving. It would not predict response to stress in non-driving contexts; however, it should be much more powerful than existing instruments in predicting stress responses to driving situations.

The DSS would be constructed using conventional test construction procedures. An item pool would be generated based upon concepts suggested by existing instruments. That item pool would be administered to a representative subject sample. Factor analytic procedures would be employed to evaluate the dimensionality of the instrument and to insure high item-subscale correlations. Test construction would proceed until the instrument met conventional standards of reliability.

2. 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 susceptibility.

3. 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.

4. Evaluation of the relationship between traffic stress, personality, and immune system response. Research in the developing field of neuroimmunology clearly indicates that psychological stress can result in decreased immune system function. Life events that result in anger, hostility, depression, and anxiety have been associated with elevated

levels of corticosteroids such as cortisol and catecholamines such as epinephrine. Increased levels of both corticosteroids and catecholamines have been associated with immunosupression.

The goal of neuroimmunological research is to identify associations between specific subjective psychological states, neuroendocrine processes, and immune system function. Since driving constitutes a recurrent daily activity that is associated with strong emotional reactions and subjective feelings of distress, its effect on immune system function cannot be discounted.

During the past decade, radio immunoassay tests have been developed that allow evaluation of immune system reaction through the analysis of saliva. These tests are noninvasive and easily administered. This methodology should be employed to explore the degree to which traffic variables (such as congestion) and roadway design variables influence the immune systems of drivers. The literature suggests that an appropriate experimental design would involve exploring the interaction between stimulus variables, individual differences in stress susceptibility, and immune system response.

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