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ABSTRACT

It is generally recognized that age, by itself, is not an adequate criterion with which to judge a person's ability to drive. Individuals do not age at the same rate, and there are large intraindividual differences in the aging process. This study, the first phase of a proposed two-phase research project, investigated the relationship of physical fitness to older driver performance by examining descriptively the relative contributions of various measures of cardiorespiratory efficiency, range of motion, and reaction time/movement time to field-based assessments of older driver performance. A total of 106 subjects, ages 20-35 (N=43) and ages 60-75 (N=63) were administered a battery of health, psychomotor, and physical fitness tests and a field-based assessment of automobile driving skill. In general the results indicated that the physical fitness of older drivers was related to their ability to safety drive an automobile. Older people with higher levels of physical fitness tended to be more proficient at driving than were older people with lower levels of physical fitness. Joint flexibility and reaction time were found to be most predictive of driving ability with cardiorespiratory fitness somewhat less related to driving ability. If a sufficiently strong relationship is established by further research, the older driver may be given a test of physical fitness as part of a driver's licensing examination to determine the levels of his or her driving ability. Plans for phase 2 of the research are briefly outlined, and a list of 83 references is appended. (ABL)

PHYSICAL FITNESS AND THE AGING DRIVER

Phase I

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PREFACE

This report describes a research project carried out by the West Virginia University School of Physical Education. The research addressed the relationship between physical fitness and older driver performance. An interdisciplinary approach was taken, and contributions were made by faculty representing Safety and Health Studies, Exercise Physiology, and Gerontology. Funding for the two-phase project was provided by the AAA Foundation for Traffic Safety. The Phase I research program was exploratory in nature, focusing on the relationship among a number of health, exercise, and demographic variables relative to older driver performance.

The work described in this report was directed by four West Virginia University faculty members. They served in the capacities of principal investigator, co-principal investigator, and project phase investigators. The principal investigator was Dr. Kenard McPherson. Dr. McPherson was responsible for overall project direction, maintaining liaison with the AAA Foundation for Traffic Safety, and designing test measures which were utilized in the data-collection phases of the study. Dr. Andrew Ostrow served as co-principal investigator for the project. He was responsible for conducting the literature review, conceptualizing and specifying the data-analysis approach, supervising the data analysis, and managing preparation of the project report. Drs. Peter Shaffron and Rachel Yeater served as phase principal investigators. Dr. Shaffron was in charge of subject solicitation, subject management, supervision of data collection, and administration of the driver performance-related measures. Dr. Yeater was in charge of the health measurement phase of the project. She supervised administration of health-oriented measures and administered the cardiorespiratory measure.

Four project staff contributed to the writing of the report:

Dr. Kenard McPherson	Dr. Andrew Ostrow
Dr. Jeffrey Michael	Dr. Peter Shaffron

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Dr. Jeffrey Michael and Mr. Kevin Elko deserve credit for much of the success the project has achieved. These individuals are recognized for their enthusiastic commitment, long hours of dedication, and adeptness in managing day-to-day project affairs. They were responsible for subject processing, data collection, and data reduction. Carol Straight, Michael Spyra, Sharon Sisler, and Linda Lilly are due credit for copy preparation, editing, and administrative support.

Finally, our warm and sincere appreciation is extended to the local senior citizens who gave freely of their time as participants in this research effort.

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ABSTRACT

It is generally recognized that age, by itself, is not an adequate criterion to judge a person's ability to drive. Individuals do not age at the same rate, and there are large intraindividual differences in the aging process. Attempts to define old age chronologically have been hampered by the enormous diversity present among older people. Furthermore, declines in skillful performance commonly attributed to age may be caused by unrecognized disease processes and the deconditioning that results from an older person's increasingly sedentary lifestyle.

Among the solutions advanced to address the problems stemming from an increasingly older driver clientele, there is a notable absence of proposals seeking to modify the functional capacities of the older driver. This is rather surprising given the general, age-related declines in sensory input, speed of response, and coordinated movements that adversely affect skillful driving performance.

This project represents the first known empirical investigation of the relationship of physical fitness to older driver performance. A review of literature indicated that musculo-skeletal impairments and declines in the abilities to process complex information rapidly and efficiently negatively affected the automobile driving skills of older people. However, it is also known that older people are trainable, and that through exercise, the rate of decline in range of motion and in information processing abilities can be slowed. Therefore, this phase of the project was undertaken to examine descriptively the relative contributions of physical fitness to young and older driver performance.

The authors proposed a comprehensive, two-phase research project designed to examine the relationship of physical fitness to older driver performance. During Phase I of the project, the authors sought to answer the following questions:

1. What is the relationship of cardiorespiratory fitness to field-based performance assessments of driver performance, particularly on tasks involving a high order of judgment, decision making, and performance under definite time constraints?

2. What is the relationship of reaction time (particularly premotor time) and movement time to performance on driving tasks accentuating central nervous system processing?

3. What is the relationship of joint flexibility to driver performance?

4. What is the relationship of cardiorespiratory fitness to segmented reaction time?

5. What are the relative contributions of cardiorespiratory fitness, range of motion, and reaction time/movement time as they relate to older driver performance?

Thus, the major purpose of this research investigation was to examine descriptively the relative contributions of various measures of cardiorespiratory efficiency, range of motion, and reaction time/movement time to field-based assessments of older driver performance. Toward this end, a cross-sectional, correlational research design was employed to contrast both young adults and older adults on various measures of physical fitness and driver performance. This approach

enabled the investigators to examine, to some extent, the relative contributions of chronological age as it relates to the question of how physical fitness facilitates driver performance.

A total of 106 subjects, ages 20-35 years (n=43) and ages 60-75 years (n=63), were administered a battery of health, psychomotor, and physical fitness tests and a field-based assessment of automobile driving skill. Specifically, these subjects were administered: (a) a health history questionnaire, (b) a symptom limited maximal stress test, (c) range of motion tests at seven joint sites, (d) reaction time/movement time assessments (segmented by electromyography) on a driving simulator model, and (e) a modified version of the Automobile Driving On-Road Performance Test (ADOPT). Based on univariate and multivariate statistical analyses it was found that: (1) older drivers were less proficient than young drivers on maneuvers, safe practices, observing, vehicle handling and driver processing, (2) drivers categorized as low on cardiorespiratory fitness were less proficient at driving maneuvers and vehicle handling than drivers categorized as high on cardiorespiratory fitness, and (3) older drivers showed evidence of less shoulder flexibility, torso and neck rotation, and longer premotor reaction time latencies (i.e., greater information processing deficits) than young drivers, and, to some extent, these factors were predictive of driving skill.

In general, Phase I of this study found that the physical fitness of older drivers is related to their ability to safety drive an automobile. Older people with higher levels of physical fitness tended to be more proficient at driving than were older people with a lower level of physical fitness. Of the aspects of physical fitness which were measured, joint flexibility and reaction time were found to be most predictive of driving ability. Cardiorespiratory fitness proved to be somewhat less related to driving ability.

The findings of this study may be of direct benefit to the older driver. Since evidence was found that a relationship exists between the physical fitness and the driving ability of older people, older drivers who are concerned about their driving ability may attempt to enhance their driving skills by becoming more physically fit. This study suggests that the greatest gains in driving ability could be made through improvements in joint flexibility.

The relationship between physical fitness and driving ability may eventually have two types of impact on the older driver. First, the older driver may use an exercise program to improve his or her own driving ability. Second, if a sufficiently strong relationship is established by further research, the older driver may be given a test of physical fitness as part of a driver's licensing examination to determine the level of his/her driving ability.

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DEMOGRAPHIC TRENDS

One of the more dramatic demographic trends affecting modern, technologically advanced societies is the aging of its populations. During the early 1900's, only 3.1million Americans, or 4 percent of the population, were 65 years or older. Today, more than 28 million Americans, or over 12 percent of the population, are 65 years or older (Koss, 1986). More than 5,000 Americans celebrate their 65th birthday every day (Schmidt, 1985). In 50 years, it is projected that 55 million Americans, or 18 percent of the population, will be over 65 years (Kalish, 1982).

An examination of population data in the four regions of the world (North America, Europe, Asia, Oceania) represented by the Organization for Economic Co-operation and Development (OECD) indicates that the percentage of elderly is highest in the European communities (13 percent) and is lowest in the Oceania region represented by Australia and New Zealand (9 percent) and in Japan (9 percent). Western Europe has the greatest concentration of the elderly, over 22 million people (Traffic Safety of Elderly Road Users, 1985).

The "graying of America" is a popular euphemism that reminds us that the median age of Americans is gradually increasing. Today, the median age of Americans is 30 years; by 2030, it is estimated that the median age will increase to 38 years. The elderly represent the fastest-growing age segment in the United States , particularly among those 75+ (Ostrow, 1984). In 1985, the number of people 65-74 years (18 million) was nearly eight times larger than in 1900. However, the 75-84 age group was 11 times larger and the 85+ age group was 22 times larger (A Profile of Older Americans, 1986). Chronological age categories have frequently been used to demarcate the development status of older people. For example, Neugarten (1975) classified the "young-old" as individuals 55-75 years of age, and the "old-old" as individuals over 75 years. While these age categories are convenient, it should be recognized that older people are more diverse than similar and that, with increasing age there is greater biological and behavioral variability.

In the United States, the average life expectancy of Americans has increased from 48 to 73 years since the turn of this century, primarily as a result of the eradication of many fatal childhood diseases, improved sanitation, and advances in other public health measures. In 1985, males reaching 65 had an average life expectancy of an additional 14.6 years while females reaching 65, on the average, could expect to live an additional 18.6 years (A Profile of Older Americans, 1986). Similar life expectancy trends have been reported among OECD countries.

Demographically, the ratio of American women to men increases as a function of chronological age; this ratio increases dramatically after 60 years. More than 50 percent of women 65 and over are widowed and more than a third live alone (Murphy & Florio, 1978). Eighty percent of older adults who live alone are women (Tomorrow's Elderly, 1984).It is a common myth that many older Americans are incapacited and most are institutionalized. In fact, only 4 percent of those over 65 are institutionalized, with this figure approaching 17 percent among people 85+ (Botwinick, 1978). In 1982, more than 40 percent of the elderly had finished high school, and it is projected that the median number of years of schooling among older people will continue to increase (Tomorrow's Elderly, 1984).

Unfortunately, more than 3.4 million older adults live in poverty,with annual household incomes of less than $3500 (Murphy & Florio, 1978). Those elderly who live alone, the very old, and elderly women and blacks have the highest poverty rates (Tomorrow's Elderly, 1984). Two-thirds of the billions of dollars spent by the federal government on health care is for people over 65 (Butler, 1978). Approximately 85 percent of people over 65 have one or more chronic medical conditions such as high blood pressure, arthritis, ateriosclerosis, or heart disease (Butler, 1975). Osteoporosis, a debilitating bone disease, afflicts over 6 million Americans a year, and women make up approximately five-sixths of all victims (Smith, 1982). Medical expenditures by older persons exceed by 3.5 times those made by people under 65 (Botwinick, 1978).

THE EMERGENCE OF THE OLDER DRIVER

In spite of the medical problems associated with aging, older people still want to live fruitful lives. Good health, independence, and the opportunity to live more productive lives are essential ingredients affecting positive feelings of general well-being among the elderly. One important source of independence for older people is the opportunity to sustain transportation mobility (Malfetti, 1985). Driving an automobile affords older people the opportunities for greater social networking, particularly in a suburbanized society. And, of course, enhanced transportation mobility is essential for receiving rapid medical attention.

Between 1970 and 1982 the number of drivers in the United States increased by 33 percent; the 65 and over group increased by 80 percent ("Improving Safety," 1985). In 1983, there were 152,000,000 automobile drivers in the United States; 32,900,000 (or 21.6%) were 55+ (Klamm, 1985). It is projected that in the coming decades, concomitant to an aging society, a greater proportion of total travel by automobile will be accounted for by those over 65.

Improvements in quality-of-life indicators such as health status, economic security, and psychosocial well-being among the elderly will mean that more older adults will continue to drive and remain more active as drivers (Traffic Safety of Elderly Road Users, 1985). Furthermore, the increasing number of older licensed drivers reflects the growing suburbanization of older people ("Improving Safety," 1985; Winter, 1985). These changes will mandate that private and governmental agencies concerned with traffic safety must place greater emphasis on addressing the needs and problems of growing numbers of older drivers.

TRAFFIC SAFETY PROBLEMS EXPERIENCED BY OLDER DRIVERS

Accident Rate Statistics

Accidents are the sixth leading cause of death among the elderly after heart disease, cancer, stroke, pneumonia, and atherosclerosis. The second leading cause of accidental death among the elderly (after falls) is motor vehicle accidents (Verhalen, 1986). Use of the automobile accounts for the largest proportion of annual distance traveled by the elderly. However, the older person is as likely to be a passenger as a driver, (Traffic Safety of Elderly Road Users, 1985). In 1983, senior drivers were involved in only 8,100 automobile fatalities, or 13.9 percent of the total fatalities in the United States; they were involved in 4,100,000 automobile accidents representing 13.4 percent of the total number of drivers involved in accidents in 1983 (Klamm, 1985). However, if accident-rate and injurity-severity data obtained among the elderly are normalized for exposure, they approximate the data of those 15-25 years old (States, 1985; Traffic Safety of Elderly Road Users, 1985).

A 35-year-old, on the average, drives approximately 17,000 miles per year, whereas a 75-year-old male, on the average, drives only 6,000 miles per year. Also, the elderly drive less under risk conditions such as winter, rush hour, and nighttime (Traffic Safety of Elderly Road Users, 1985). Thirty-five-year-old males do about 30 percent more night driving on rural roads than the average driver; males aged 75 years do only one-sixth as much night driving as the average driver. The accident rate of 75-year-old male drivers on rural roads during the daytime is three and one-half times greater than that of 35-year-old male drivers. Female drivers evidence similar accident-rate statistics with increasing age (Solomon, 1985).

Furthermore, there is a lower recovery rate from injury among older people (Merrill, 1985). Older people are more physically vulnerable than young people and are more likely to be killed in the event of an automobile crash. In fatalities where one driver is 65+, the older driver is three and one-half times more likely to be killed than the younger driver ("Improving Safety," 1985).

The annual toll of automobile casualties results in prolonged or lasting conditions of disability and suffering among the elderly. Paradoxically, this precludes the opportunities for independence and autonomy sought through driving an automobile by the elderly (Traffic Safety of Elderly Road Users, 1985). In addition, medical costs for motor vehicle accidents borne by the elderly (now estimated to total over $168 million per year) are rapidly increasing ("Improving Safety," 1985). Hospital admissions and emergency room visits stemming from automobile accidents are much higher for this age group (States, 1985).

DISTINCTIVE TRAFFIC SAFETY PROBLEMS

Older drivers evidence distinctive crash and traffic violation patterns. The most common errors of older drivers are: (1) failure to yield right-of-day; (2) failure to obey signs, signals, and markings, and (3) improper turns (McKnight, Simone & Weidman, 1982; Yaksich, 1985). High density intersections are especially a problem for the elderly driver (Traffic Safety of Elderly Road Users, 1985; Yaksich, 1985). The elderly have a hard time negotiating a stop sign at an intersection; they also have difficulty at intersections between primary and secondary roads where there are demands for quick re-starting after having stopped (Traffic Safety of Elderly Road Users, 1985).

Older drivers opt for lower speeds. They tend to drive at irregular speeds or speeds below the normal traffic flow, increasing the possibility of collision (Solomon, 1985; Traffic Safety of Elderly Road Users, 1985). They use the accelerator less and brake more (Winter, 1985). Heavy traffic, lane changes, and high speed-traffic are particularly troublesome to older drivers (Marsh, 1985). Older drivers also have difficulty passing, turning, and backing (McKnight, et al., 1982, Winter, 1985). They show a preference toward lower speed. They are more favorable toward having speed limits, and they show less interest in fast cars.

In summary, older drivers tend to have problems in driving situations which are highly dependent on visual skills, rapid judgment, or decision making. Night driving, traffic surveillance, and observing to the rear while backing are examples of visually dependent driving tasks. Yielding, merging, or crossing a stream of traffic are tasks which require rapid judgments and decision making.

THE EFFECTS OF AGE ON HUMAN PERFORMANCE

Driving an automobile is essentially a decision-making process contingent upon accurate perceptions and judgments (Milone, 1985) and involves the integration of many complex motor skills. Many of these skills require the driver to react quickly to a multitude of visual, auditory and kinesthetic cues as are typically found, for example, when entering a complex traffic intersection. Unfortunately, many older drivers have difficulty reacting quickly in situations that are not self-paced, particularly as task complexity increases. They do better when they are not rushed and have sufficient time to weigh all factors needed to make a decision (Traffic Safety of Elderly Road Users, 1985). Older drivers frequently encounter problems in ignoring meaningless information and in correctly identifying appropriate cues. They need more time to perceive, organize, and respond to information (Milone, 1985). All of these factors contribute to the slowness in response commonly reported among older drivers.

THE REACTION TIME-MOVEMENT TIME PARADIGM

One of the most ubiquitous changes observed in human behavior is the increasing slowness of human performance with advancing age. This slowness is not limited to single motor responses commonly reported in the reaction time (RT) literature, but also affects complex forms of behavior such as driving skills.

In the laboratory, researchers generally fractionate human speed of response (or total response time) into two components: reaction time and movement time. For example, in a typical experiment an individual is asked (1) to release a telegraph key held by the hand when an unanticipated stimulus (or stimuli) is presented and (2) to move this hand as rapidly as possible to some target. In this paradigm, RT is typically defined as the measure of time from the presentation of the sudden, unanticipated stimulus to the initiation of the movement. Movement time (MT) is usually defined as the measure of time from the initiation of the response to the completion of the movement. Therefore, total response time is the summation of RT and MT.

The slowness of RT with age is one of the most replicated findings of behavioral change with age (Birren, Woods, and Williams, 1980, 294). In an overview of 26 studies on simple RT and age, Birren et al. (1980) reported that, on the average, there was a 20 percent difference in RT between 20-year-olds and 60-year-olds.

Using electromyography (EMG), researchers have proposed that RT can be segmented into central and peripheral components, i.e., into premotor and motor times. The time from the presentation of the stimulus to the activation of the muscle (i.e., when an evoked potential is recorded from the motor cortex) is typically termed premotor RT (Schmidt, 1982; Spirduso, 1980). Within a 200-ms total response time interval, for example, in which an individual (in response to a visual stimulus) quickly releases a microswitch (RT) and then depresses another microswitch (MT) in approximately 20 ms, we might expect premotor RT in the agonist or prime mover to approximate 160 ms (Spirduso, 1980). Thus, premotor RT (or the time when the EMG recording is silent) represents a substantial portion of the total response time interval.

In this paradigm, it takes approximately 40 ms for the visual stimulus to evoke a response in the occipital cortex. Most of the remaining 120 ms of premotor RT is thought to represent central information-processing time and is highly contingent on the integrity of the central nervous system (Spirduso, 1980). There seems to be a general consensus that this central component is predominantly responsible for observed age-related increases in RT. However, most research investigations of RT have not used EMG analyses to segment RT into central and peripheral components.

The time interval from the first recorded EMG activity to finger movement is termed motor RT (Schmidt, 1982) and includes both nerve conduction time and muscle contractile time (Spirduso, 1980). Thus, reaction time can be fractionated into premotor time (central nervous system processing time) and motor time (peripheral muscle contractile time).

The time it takes from the initiation of the response (e.g., to release a key or microswitch) to the completion of the response (e.g., to depress another key) is MT. Muscle contractile time plus MT are viewed as peripheral components in this RT paradigm. Although MT can be controlled to a few milliseconds in the laboratory, most driving skills require considerably longer MT intervals. Correlation coefficients between MT and RT have generally been found to be low, suggesting that the processes underlying one's ability to react quickly are different from those underlying the ability to move quickly once the reaction is made.

THE INFORMATION PROCESSING MODEL

One of the more popular and systematic approaches to studying the sensory motor system has been to conceptualize human skillful performance in terms of an information-processing model. This model depicts the driver, for example, as a processor of information. The execution of a motor response is thought to involve a series of stages that involve the acceptance, storage, and processing of information before effector mechanisms are activated. Information seems to follow through these stages, with each stage presumably characterized by higher levels of abstraction (Hoyer & Plude, 1980). These stages can occur serially (i.e., sequentially) or simultaneously (Schmidt, 1982).

Application of the Model

The simple RT paradigm can be discussed within an information-processing framework. It takes approximately 40 ms for a visual stimulus to be translated by peripheral receptors into electrochemical impulses and to evoke a response in the occipital cortex (perperceptual processes) during a 200-ms response time interval. This procedure has been termed detection, because environmental changes are coded into nerve impulses related to the characteristics of the visual stimulus. These impulses are stored briefly in what has been termed a short-term sensory store (STSS) (Stelmach and Diewert, 1977). This peripheral level of processing is thought to be a memory system in which large amounts of information are stored for very brief periods of time. It is not clear if separate STSS systems exist for each sense modality (Schmidt, 1982); there is some evidence (Walsh and Thompson, 1978) that the visual storage capacity of old subjects is not as great as that for young subjects.

Once the environmental stimuli are detected, they must be recognized or evaluated (Stelmach and Diewert, 1977); that is, only relevant information in the STSS must be selected for further processing (through selective attention). If one takes the position that perception involves the recognition or evaluation of information, then perceptual processes can be viewed as central rather than peripheral (Stelmach and Diewert, 1977). Perceptual processes invoke the central nervous system into action.

During the response-selection stage, the individual must decide on a course of action. A decision can be made not to respond or to select a response(s) from a large number of alternatives. The choice RT paradigm (i.e., more than one stimulus, more than one response required) has frequently been used to study information processing during this stage. It is well known (Hicks' law) that the relationship between choice RT and the logarithm to the base two of the number of stimulus-response alternatives is linear. In other words, there seems to be a linear relationship between the amount of information that must be processed (the logarithm of the number of stimulus-response alternatives) and the time required to make a decision (Schmidt, 1982). Thus, as Schmidt has observed, during the response-selection stage the individual attempts to reduce uncertainty about alternative responses to a given stimulus. The choice RT paradigm has been used to study the impact of aging on decision time during this response-selection stage.

Once a response has been selected, the individual must organize, plan, and initiate movement. During the response-programming stage, information must be translated into a set of muscular actions. Memory (stored information) is brought into play (as it is in the preceding stages of this model), and the duration of the response-programming stage appears to be related to the duration and complexity of the response required (Schmidt, 1982).

The information-processing model described here provides a systematic, behavioral approach to conceptualizing human movement in which inferences are made regarding central nervous system action through "input regulation-output observation" (Marteniuk, 1976). There seems to be some consensus, at least in terms of simple RT, that slowness due to aging lies in the central nervous system and occurs between the time at which sensory nerve conduction is completed and the time it takes to activate peripheral neuromuscular systems (Botwinich, 1978). Thus, an information-processing model provides a logical framework for identifying what stages during human performance (such as for some skills involved in driving an automobile) are most affected by aging processes. This viewpoint is not new and has found much support, particularly in papers by Welford (1965), Birren (1974), Stelmach and Diewert (1977), and Birren et al (1980).

<u>Preperceptual Processes</u>

Literature indicates that the decreased processing ability of older adults may be attributable, in part, to reduced detectability. The effects of aging on sensory input have most frequently been studied in relation to visual and auditory systems. As Botwinick (1978) has noted, the literature is very clear--older people do not see as well or hear as acutely as do younger people. Yet, about seven-eights of sensory input needed to drive comes via the eye ("Improving Safety," 1985).

The decline in visual acuity accelerates after approximately 50 years of age, with the loss most likely attributable to modifications in the crystalline lens and vitreous humor (Corso, 1971; Smith and Sethi, 1975). The proportion of adults with 20/20 vision diminishes by 75 percent between 60 and 80 years, and the reduced elasticity of the lens produces increasing levels of farsightedness among older people (Kalish, 1982). Reductions in visual acuity mean longer response times to traffic signals, signs, and events (Allen, 1985). Thus, there is a need to make traffic signs and signals large, graphic, simple, and clear (Malfetti, 1985).

Changes involving the crystalline lens also affect light transmission and refractoriness. Older people need greater levels of illumination, and they cannot see as well in the dark (Botwinick, 1978). There are losses of light intensity due, in part, to a reduction in the diameter of the pupil. "The combined losses of available light in the eyes of many older people can easily be equivalent to reducing street and automobile lighting up to 10% (or less) of their normal design levels-as if drivers were wearing a very dark pair of sun glasses for night-time driving" (Allen, 1985; 2).

It is no wonder, then, that older people avoid driving at night. These visual problems become even more acute if the older person drives with sunglasses or drives an automobile with tinted windows. Furthermore, one's sensitivity to glare increases between the ages of 40 and 70 years. Recovery time is slower from the glare of oncoming headlights or from reflecting sources such as windshields and windows (Winter, 1985). Thus, Allen (1985) recommended that the amount of light above the horizontal of headlights needs to be reduced to minimize glare. Headlight power should be increased. Tinted windshields should be avoided. Windshields should be repolished or replaced. Wider, brighter pavement stripping is warranted.

The ability of the eye to accommodate (i.e., discriminate) detail diminishes with age (Corso, 1971; Smith and Sethi, 1975; Winter, 1985), and there is less ability to adjust to changing amounts of light (Kalish, 1982). Dark adaptation is slower in the elderly. This creates problems for the older driver, for example, when entering and leaving poorly lit tunnels (Winter, 1985).

There is also a greater narrowing of the peripheral vision field with advancing age (Colavita, 1978; Kalish, 1982). Incidence of visual field loss is about 13 percent for those 65+. One-half of those with peripheral vision loss are unaware of this loss. People with visual field loss in both eyes have an accident and conviction rate that is double the rate of those with normal field vision (Winter, 1985).

Other visual problems affecting the elderly include cataracts and glaucoma. Cataract problems (i.e., detrimental changes in lens transmission with age) make oncoming headlights excessively glaring and night-time driving difficult or impossible. Glaucoma, the gradual loss of visual function usually attributed to increased intraocular pressure, also compromises driving skills evidenced by the elderly (Allen, 1985).

With respect to audition, while approximately 19 percent of people ages 45-54 have some hearing problems, 75 percent of those aged 70-79 years have hearing problems (Winter, 1985). The loss of auditory acuity with advanced age is termed presbycusis. This loss of acuity is more extensive for higher-range tones (Botwinick, 1978; Colavita, 1978; Kalish, 1982). This creates problems for the older driver in terms of hearing horns, sirens, and train whistles, particularly when the windows are up and the radio is on (Milone, 1985; Winter, 1985).

Older people evidence poorer discrimination among tones (Botwinick, 1978). Hearing impairment appears to be more common than visual impairment after 65 years, and older people have greater difficulty understanding speech (particularly in noisy environments) because of hearing problems (Corso, 1971; Kalish, 1982). However, Botwinick (1978) reminds us that hearing loss should not be confused with an increase in cautious behavior and a decrease in attentive behavior among older people.

Although there is a general decline in sensory processes with advancing age, the onset and rate of decline of these functions appear to vary both between and within sensory modalities (Corso, 1971). Peripheral changes in various sensory modalities may only account for a small proportion of the deterioration observed in premotor RT, at least in terms of simple RT (Weiss, 1965). Research reviewed by Botwinick (1965, 1978) clearly demonstrated that a slowing of peripheral nerve conduction velocity did not appreciable account for an increase in RT with age. There is also evidence that some reflexes (e.g., patellar tendon, Achilles tendon) deteriorate very little with age (Spirduso, 1984). All of these findings point to the notion that central mechanisms, rather than peripheral mechanisms, are responsible for psychomotor slowing with advancing age. However, given the absence of segmented RT research on automobile driving skills, the extent to which age-related declines in speed of processing during driving are due to sensory problems or deficits in the central nervous system is unclear.

Perception and Attention

As noted earlier, driving an automobile is essentially a complex decision-making activity heavily dependent on perceptions and accurate judgments (Milone, 1985). Perceptual mechanisms, within an information-processing framework, enable the driver to recognize or evaluate information through a process of selective attention--that is through an ability to separate relevant from irrelevant information. Perceptual processing is constrained by both space (the amount of information that can be processed) and time (temporal differences in the rate of processing) (Hoyer and Plude, 1980).

Most investigations of age-related changes in perceptual processing have focused on time constraints rather than spatial constraints. For example, in studies of masking (rapid sequential presentation of two visual stimuli leading to the occlusion of one of the stimuli), there is a general tendency for older people to require longer critical periods to escape masking effects (Birren et al., 1980; Hoyer and Plude, 1980). This phenonemon would have some bearing on the ability of the older driver to process a series of rapidly occuring stimuli as is commonly found, for example, when entering a high density traffic intersection. It may be that the first stimulus persists longer in the central nervous system of older people, particularly when interstimulus sequences are very short (Botwinick, 1978). As Winter (1985) observed: "In traffic situations requiring rapid reacting and decision making, stimulus overload coupled with perceptual motor problems make older drivers especially vulnerable" (p. 78).

There is a deterioration in the older adult's ability to judge distances and the speeds of vehicles (Milone, 1985; Solomon, 1985), which is detrimental to both the older driver and pedestrian. Misjudgement of the intentions and movements of other road users in complex traffic situations, such as a failure to yield right-of-way, make the elderly especially vulnerable to serious injury resulting from collision (Traffic Safety of Elderly Road Users, 1985).

Recognition-response distance estimates (i.e., the distance from a symbol sign at which it is correctly recognized) declines with age (Yaksich, 1985). Studies have demonstrated that the problems encountered by older people in perceiving signs and signals relate to more that just visual impairments--older people have difficulty in recognizing and deciphering information (Traffic Safety of Elderly Road Users, 1985). This leads to frequent errors among older drivers in terms of failing to obey traffic signs, signals, and markings. Thus, it is important that light signals be seen well ahead, and that signals are clearly visible in complex traffic environments.

An older person's errors in terms of judging speed or stopping distance increase at higher speeds. Under these conditions, the older driver is rushed and does not have sufficient time to evaluate all factors essential to making a decision. The elderly driver has little time to gather the necessary information or to assimulate it in its complexity. Conversely, fewer errors occur when the older driver is not rushed and has sufficient time to weight all factors needed to make a decision (Traffic Safety of Elderly Road Users, 1985).

The ability to recognize information may decline with age, in part, because of poorer attentional capabilities evident with advancing age (Stelmach and Diewert, 1977). Attentional ability might be defined as a limited, selective capacity (or resource) to address particular stimuli or information. Although attention demands appear to be made during all stages of processing, Schmidt (1982) has suggested that attentional demands become progressively greater as processing comes closer to a response, at least in terms of reaction time.

In a review of literature, Hoyer and Plude (1980) concluded that older people may have more difficulty ignoring irrelevant information and that there are age-related declines in the ability to attend. These contentions are reinforced by Milone (1985) who noted that the older driver has a problem in terms of "ignoring meaningless information and in correctly identifying meaningful cues" (p. 39). Older people need more time to perceive, organize, and react to information, particularly information that comes from multiple sources as is commonly found when driving.

Chronological age cannot be indicted as the sole attribute contributing to reduced attentional abilities among the elderly. For example, elevated levels of anxiety (based on perceived stress) may lead to greater distractibility, an excessive narrowing of attentional focus, and a redirection of attention toward task-irrevelant cues (Landers, 1980).

Welford (1965, 1969) originally proposed that, under high arousal, there was increased "noise" in the central nervous system due to the increased spontaneous but random firing of cortical cells. This elevation in neural activity produced interference, and fewer cells were left to carry appropriate information. Welford (1965) further noted that simple observations would suggest that many older people are tense and anxious and thus, perhaps, less attentive.

Schmidt (1982) speculated that high levels of arousal might hinder motor performance on tasks that required fine control, steadiness, and/or rapid decisions based on a number of alternatives. A cursory observation of motor tasks selected to study aging effects suggests that they often meet one or more of these criteria. Tasks that are self-paced and that have no time limits (and that, perhaps, are less affected by arousal conditions) show less marked age declines (Noble, 1978).

Many motor skills involved in automobile driving have decided time limits and are sometimes performed under stressful conditions. Older people drive better when they can control their own pace; they do not act as quickly in fast-paced situations (Winter, 1985). It may be that much of the decline in recognition among the elderly in a traffic setting can be attributed to their increased perceptions of stress and not merely their advancing age. Confidence, cautiousness, motivational state, vigilance, and other personal characteristics are all elements that either need to be controlled or evaluated systematically when examining the relationship of chronological age to perception and attention in a traffic setting.

Response Selection

Once information has been evaluated (based on perceptual processes), the individual must decide on a course of action. The decision may be not to respond, which may occur, for example, when an older driver fails to transverse a difficult intersection between primary and secondary roads. Or the decision may be to select a response(s) from a large number of alternatives. Response selection can be viewed as the translation between stimulus identification and the programming of the actual response (Clark, Lanphear, and Riddick, in press).

Decision processes have frequently been examined in the laboratory via the choice RT paradigm, in which the potential exists for establishing multiple stimuli-multiple response patterns under controlled conditions. One of the most important findings emanating from this line of research is Hick's law, which suggests a linear relationship between the amount of information that must be processed to make a decision (i.e., the logarithm of the number of stimulus-response alternatives) and the time required to make that decision (Schmidt, 1982). When the number of stimulus-response alternatives is doubled, choice RT appears to increase by a constant amount. However, this relationship is affected by the degree of stimulus-response compatibility and the amount of practice allowed on the task (Schmidt, 1982). It may also be affected by the ages of the subjects under investigation.

One of the most persistent findings in the research literature is that differences in reaction time between young and old become more magnified with increasingly more complex choice reaction time tasks. Illustrative of this phenomenon are data (see Figure 5) by Stern, Oster, and Newport (1980) who found that task demand accounted for 40 percent of the variance in decision (reaction) time among male and female adults (ranging in average age from 20 to 75 years). Similarly, in a review of literature by Cerella, Poon, and Williams (1980), it was found that data from 18 studies encompassing a wide variety of information-processing tasks supported the hypothesis that more complex tasks resulted in greater performance deficits for the elderly. In a traffic setting, it has been noted that the more there are possible choices of action, the longer it takes the elderly to reach a decision (Traffic Safety of Elderly Road Users, 1985).

Increasingly more complex choice reaction time tasks place greater cognitive demands on the subject. Given that response selection is memory-dependent (Clark et al., in press), attempts to describe an aging effect have considered the possibility of age-related declines in the memory access required for performing complex tasks (Cerella et al., 1980). Stelmach and Diewert (1977) speculated that increased choice reaction time with age might simply be a function of increased simple reaction time with age. However, there appears to be a general consensus (e.g., Cerella et al., 1980) that the proportional slowing of reaction time among older adults on increasingly more complex tasks represents a decline in central processes, although the mechanisms involved await further investigation.

Response Programming

During the response-programming stage, information must be translated into a set of muscular actions. The necessary motor commands are structured and organized prior to the initiation of movement. Experimentally, this stage has been evaluated by varying the nature of the response to be executed by manipulating the response parameters (e.g., movement, speed or direction) that are likely contained in a motor program (Larish and Stelmach, 1982).

There has been little systematic research toward determining a person's ability to organize or plan movements, especially with regards to age changes (Stelmach and Diewert, 1977). In a study examining the execution of a ballistic motor act, it was found that while older female subjects reacted and moved more slowly than young females, the differences could not be attributed to the response programming conditions (Larish and Stelmach, 1982). The authors indicated, however, that there was a tendency for the older women to become more deliberate in identifying the response to be made prior to executing the movement or before beginning the programming and reprogramming operations. Furthermore, there may have been a greater tendency for these individuals to visually fixate on the target before completing the necessary response programming operation(s). Perhaps these findings can be generalized to the older driver who tends to be more cautious on skills involving decision-making, thereby sacrificing speed for accuracy and fewer errors.

Summary

An information-processing model of human performance is useful in identifying what motor control mechanisms are responsible for increased psychomotor slowing with advancing age. There is still controversy as to whether the reduced speed seen in the elderly is attributable to a general decline in central nervous system processing or to greater declines in one or more components of the system (Spirduso, 1983). Nevertheless, it is now accepted that central rather than peripheral processes are primarily responsible for reduced speeds of response and coordinated movement with advancing age.

From an applied standpoint, an information processing model is useful in providing a graphic framework for the systematic investigation of age-related declines in psychomotor proficiency among skilled drivers. What is needed, however, is more research focusing on the stages of information processing within a traffic setting using tasks appropriate to driving an automobile. Too much of the information on older driver processing problems is based on anecdotal evidence and inference rather than systematic research.

Age-Related Changes in Joint Flexibility

Flexibility, or adequate range of joint motion, is an essential component of the physical fitness of older people. The upper extremities play a vital role in driving, particularly in terms of mobility and coordination (States, 1985). Unfortunately, with advancing age there is decreased head and neck mobility adversely affecting the older adult's ability to complete driving tasks such as scaning the rear, backing, and turning the head to observe blind spots (Malfetti, 1985).

It is estimated that flexibility declines, on the average, 20-30% in the older adult (Smith and Raynor, in press). Decreased flexibility with age is probably the result of combined histological and morphological changes in the components of the joint, including cartilage, ligaments, and tendons (Adrian, 1981; Serfass, 1980). The greater calcification of cartilage and surrounding tissue, the shortening of muscles, increased tension and anxiety, and the prevalence of arthritic and other orthopedic conditions all contribute to reduced flexibility (Piscopo, 1981).

Flexibility assessments have been designed specifically for the elderly (Tichy and Tichy, 1982) that maximize stretching with only a small amount of effort and little danger of injury. Data-based assessments of flexibility in the elderly (e.g., Walker, Miles-Elkousy, Ford, and Trevelyan, 1984) generally support the conclusion of a decline in flexibility in the middle and later years but the results are not totally consistent (Smith and Walker, 1983).

As noted above, reduced range of motion is an impediment to automobile driving. States (1985) wrote:

> Reaction time is necessarily increased by arthritic joints and tight musculature. Joint flexibility is a related factor caused by those changes in the joints that are precursors of arthritis but not identified by the clinician as pathological. Aging brings about changes in the components and structure of the articular cartilage, underlying bone, ligaments and muscles which impair the capability of the musculo-skeletal system to perform the driving act (p. 63).

While driving, complex arm, leg, and head movements tend to be quite limited among the elderly (Milone, 1985). This was confirmed in a recent survey of the traffic safety needs and problems of the elderly (N = 446; 55+). More than 35 percent reported problems with arthritis, and 21 percent reported it was somewhat difficult to turn the head and look to the rear when driving or backing. Yet, surprisingly, 83 percent of the respondents indicated that painful or stiff joints never interfered with driving (Yee, 1985).

There is no evidence that age alone is the sole determinent for the declines seen in flexibility. Certainly, disease and disuse are also contributing factors. As Adrian (1981) reported: "There is no evidence that biological aging processes cause this decrease in flexibility, since most research links degenerative diseases with loss of flexibility "(p. 55).

THE EFFECT OF REDUCED FUNCTIONAL CAPACITIES ON OLDER DRIVER TRAFFIC SAFETY PROBLEMS

An information processing model has been used to describe the functional capacities of older drivers in terms of preperceptual, perceptual, response selection, response programming, and output movement processes. Research has indicated that age-related functional declines are most evident in the cerebral processes of perception, response selection, and response programming. The peripheral processes of preperception and output movement contribute somewhat less to age-related declines in information processing.

Driving Task Analysis

Since automobile driving is essentially a series of sequential and simultaneous information-processing tasks, the distinctive driving problems of older drivers can be analyzed in the context of an information-processing paradigm. The act of driving a automobile can be reduced to a set of tasks and organized by categories according to common characteristics. Each category can then be analyzed for dependence on either central or peripheral components of the information-processing model. Several information-processing and task analysis models are available for use as a starting place in the categorization. The analyses are available from human factors design efforts and driver education curriculum development projects. For the purposes of this work a task analyses prepared for the U.S. Department of Transportation, served as a basis of categorizing the act of driving into six groups:

Basic Control Tasks. Simple control movements such as accelerating, braking, and steering.

General Driving Tasks. Behaviors which must be performed continuously or periodically while driving without regard to traffic situation, e.g., navigation, surveillance, speed control.

Tasks Related to Traffic Conditions. Behaviors which are required in response to specific traffic situations, e.g., following, passing, lane changing, yielding, and merging.

Tasks Related to Roadway Conditions. Behaviors which are required in response to specific road way situations, e.g., negotiating intersections, hills, curves, and proper lane usage.

Tasks Related to the Environment. Behaviors or behavior modifications required in response to environmental conditions such as weather or night driving.

Tasks Related to the Automobile. Behaviors required in response to specific vehicle requirements such as fuel and oil maintenance or responding to emergency situations such as a flat tire or stalled engine.

DRIVING TASKS AS RELATED TO INFORMATION PROCESSING

The first group of tasks, the basic control tasks, involves a relatively low order of mental processing. The actual movement of the vehicle's controls can be viewed primarily as an output movement activity. The modulation of the control pedal or steering wheel does involve some feedback or preperceptual activity to achieve the desired rate of vehicle movement, but the task can be characterized as output-movement dependent.

The second group of tasks, the general driving tasks, is a more abstract set of behaviors than those in the first group. Although general driving tasks such as surveillance and navigation involve a higher order of mental processing than do the basic control tasks, the tasks in this group are primarily preperceptual. The senses of sight, hearing, smell, touch, and balance are all utilized either continuously or periodically in collecting information concerning the vehicle's speed, direction, and general condition.

The third and fourth groups of driving tasks, those relating to traffic or roadway conditions, are the most abstract sets of driving behaviors. The behaviors in these groups involve a high order of judgment and decision making and are often performed under definite time constraints. Tasks in these groups may be performed periodically or continuously and can occur in rapid succession or as several simultaneous tasks. Of the two groups, reacting to traffic conditions is slightly more complex than response to roadway conditions due to the constantly changing nature of traffic. Selecting a safe gap to cross a stream of fast-moving traffic or staying in the appropriate lane on a congested freeway are tasks which require rapid and accurate decision making. Both task groups are highly dependent on the central mental processes of perception, response selection, and response programming.

The fifth group of driving tasks, those related to the environment such as night driving or driving in inclement weather, can be viewed as modifications to the basic control and general driving tasks. These tasks are primarily dependent on the peripheral processes of preperception and output movement. The preperceptual component of vision is heavily taxed during night driving or in inclement weather. The basic control tasks become very important in situations where vehicle traction has been reduced by water or ice.

The remaining group of driving tasks, those related to the automobile itself, comprise a variety of operations, some of which are ancillary to the actual driving of the vehicle. Maintenance of the vehicle's mechanical condition, monitoring the fuel and oil supply, and responding appropriately to vehicle malfunctions are tasks which require a multitude of physical and mental processes. The disparity of the tasks within this group prevents a meaningful analysis with respect to information processing.

Performance of Driving Tasks by Older Drivers

Since research has indicated that age-related functional declines have a greater effect on the central mental processes than on the peripheral functions, one can expect to find most of the distinctive older driver traffic safety problems in the task categories heavily dependent upon central processing. According to this driving task analysis, the majority of older driver traffic safety problems are likely to involve response to traffic or roadway conditions. The tasks in these groups are not only heavily dependent on central processing but also particularly difficult for the older driver in that they may be required in rapid succession or simultaneously. The tasks more dependent on peripheral mental processes and those related to basic control, general driving, or to the environment would be expected to pose less of a problem for the older driver.

Compensatory Practices

Less easily identifiable than the declining functional capacities of older drivers are the compensatory or adaptive practices which seniors often utilize to reduce accident risk. The older driver tends to compensate for his or her biological, psychological, and psychosocial limitations by exercising greater caution and adjusting personal behaviors (Nelson, 1985). Increased safety-mindedness, greater caution, added experience, mature judgment, and a tendency to replace impulsiveness with reason result in a definite reduction in accident involvement and a slowing in the effects of physical deterioration (Marsh, 1960).

Specific identification and measurement of these adaptive strategies is difficult. However, the majority of such practices appear to take three main forms (Traffic Safety of Elderly Road Users, 1985):

A change in the amount and type of automobile usage. Trip lengths are typically shorter and are taken at times other than peak traffic hours.

A deliberate avoidance of situations presenting some discomfort such as night driving, busy intersections, or bad weather. The older driver tends to limit his or her driving to well-known routes and stable conditions.

A recourse to more careful driving. Wherever possible, replacing speed with precision improves the older driver's performance.

While the effects of these compensatory and adaptive practices are definite, they are also limited. The direct results of declining functional capacities are not altered, but their effect on the accident risk of older drivers is reduced to some extent. The driver practicing the adaptive strategies does not become a better driver per se, but attempts to lower the level of difficulty he or she must confront in driving situations. The overall result of these practices is not to correct deficiencies in functional capacities but to reduce their effect on accident risk.

COMMON SOLUTIONS TO PROBLEMS EXPERIENCED BY OLDER DRIVERS

A number of solutions have been proposed to reduce the number of injuries and fatalities stemming from the rapidly expanding number and proportion of licensed older drivers. The most common solutions have centered on changing the environment in which the older person drives, changing the design of the vehicle, or using education and training to update the skills of the older driver.

For example, suggested improvements in highway design to aid the older driver have included increasing the size and clarity of street signs and traffic signals, making more readily visible road delineations and markings, giving more advanced warning through informational signing, and reducing the complexity of driving requirements at complicated intersections (Allen, 1985;

Solomon, 1985; Traffic Safety of Elderly Road Users, 1985; Yaksich, 1985). Recommended improvements in the design of the vehicle that aid the older driver have included automatic transmission, power steering, the use of nontinted windows, larger interior and exterior mirrors, pivoting seats, repolished windshields, windshield wipers with wider sweeps, better designs and colors for reading dashboard gauges and dials, and increased headlight power (Allen, 1985; Malfetti, 1985; Traffic Safety of Elderly Road Users, 1985; Yaksich, 1985).

Comprehensive educational programs addressing the cognitive and behavioral deficiencies of the older driver are recognized as essential. McKnight et al (1982) noted that older drivers, as a group, are widely deficient in safe driving knowledge (although perhaps no more so than other drivers). They have particular difficulty in understanding new traffic rules and performance-based statements of driver safety and in identifying the proper responses to infrequently encountered regulatory devices. McKnight et al. recommended that instructional materials for the older driver be developed based on an understanding of the older adult's unique needs and learning abilities. For example, materials should be viewed by the older person as directly useful, practical, and providing immediate benefits. Materials must present realistic situations that challenge the older person to work out practical solutions. Information must be presented in a noncondescending manner that avoids treating all older persons alike and that helps the older person deal with driving problems likely to be encountered with advancing age (McKnight et al., 1982).

Among the solutions advanced to address the problems stemming from an increasingly older driver clientele, there is a notable absence of proposals seeking to modify the functional capacities of the older driver. This is rather surprising given the general, age-related declines in sensory input, speed of response, and coordinated movements that adversely affect skillful driving performance.

As noted earlier, numerous reports indicate that older drivers suffer from declines in visual acuity, they cannot see as well in the dark, and they have difficulty adjusting to changing amounts of light. Furthermore, the older driver evidences declines in perception, decision making, and judgments involving the use of short-term memory. These changes may be more frequently the cause of accidents and fatalities among older drivers than among the younger drivers. As Yaksich (1985) noted, the increase in accident rate per mile driven appears to correlate with certain age-related declines in psychomotor capabilities among the elderly.

It is generally recognized that age, by itself, is not an adequate criterion to judge a person's ability to drive (Malfetti, 1985; McKnight et al., 1982). Individuals do not age at the same rate, and there are large intraindividual differences in the aging process (Ostrow, 1984). Attempts to define old age chronologically have been hampered by the enormous diversity present among older people. Furthermore, declines in skillful performance commonly attributed to age may be caused by unrecognized disease processes and the deconditioning that results from an older person's increasingly sedentary lifestyle.

Nevertheless, when one examines the more frequent types of traffic safety problems affecting older drivers, such as failure to yield, to back up safely, or to change directions safely, it is apparent that many of these problems may stem from a general decline in the physical fitness levels of adults as they age. Declines in information processing essential to reacting quickly and in muscular strength/joint flexibility appear to be particularly significant in adversely affecting the driving skills of older adults.

Role of Exercise in Ameliorating Information-Processing and Range-of-Motion Deficits

A number of conferences have been held recently to highlight the needs and problems of older drivers. It is now recognized that many of the problems facing the older driver stem, in part, from declines in muscular strength and flexibility and in the ability to process information rapidly and accurately. While these declines are age-related, they are not necessarily age-regulated.

Mann (1972) observed that comprehensive educational programs going beyond driver training were needed to assist the older driver. Mann recommended that such programs include information on diet and exercise as well as stress management. Apparently Mann's suggestions were not heeded; few, if any, educational programs have been reported in the literature that center on modifying the functional responses of the older person to driving. None of the recommendations arising from a recent national older driver colloquium (Malfetti, 1985) focused on enhancing the physical fitness status of the older driver. Furthermore, in a comprehensive report prepared by the Organization for Economic Cooperation and Development (Traffic Safety of Elderly Road Users, 1985) on the emerging older driver, only eight sentences could be found focusing on the potential benefits of physical training to older driver performance.

Perhaps these observations should not be seen as surprising, however, given that only recently has attention been drawn to the potential ameliorative effects that exercise, particularly aerobic exercise, has in inhibiting the commonly reported declines in information processing seen with advancing age. As Winter (1985) astutely observed, keeping older adults in peak physical and mental condition is critical to their performance and safety as drivers.

Neurophysiological Bases

As indicated previously, with advancing age there is a deterioration in speed of movement and neuromuscular integration. Declines in speed of response, particularly reaction time, have been attributed to a deterioration in central nervous system functioning; peripheral factors (such as declines in visual acuity or hearing loss) appear to be less significant in effecting speed-of-response losses with increasing age.

When evaluating the role of exercise in deterring information-processing losses in the elderly, it is important to distinguish between anaerobic exercise and aerobic exercise. Anaerobic exercise involves relatively high physical work levels resulting in the accumulation of lactic acid in the bloodstream, which inhibits the duration of physical exertion because of localized muscular fatigue (Tomporowski and Ellis, 1986). Activities that are more anaerobic in nature include maximal weight-lifting exercises of short duration, squeezing a hand dynamometer, etc. Aerobic exercise, on the other hand, "involves the presence of oxygen in the muscle cells to assist in the metabolism of free fatty acids into sources of energy for muscle contractions" (Tomporowski and Ellis, 339). Aerobic energy production enables the individual to sustain a constant level of exercise for an extended period of time. Physical activities commonly viewed as more aerobic in nature include walking, running, swimming, and bicycling. Of course, most exercises involve a combination of anaerobic and aerobic energy production.

The literature on exercise, information processing, and aging indicates that exercise that is primarily aerobic in nature may prevent premature aging of the central nervous system, perhaps by modifications of the cardiovascular and neuroendocrine systems (Spirduso, 1983). Increased cerebral blood circulation, and a concomitant enhanced supply of oxygen to the central nervous system may lead to improvements in information-processing capabilities among the elderly. The basic premise is aptly summarized by Stelmach and Diewert (1977);

> In the information processing view, afferent nerves conduct information codes from sensory receptors to the higher brain centers and these centers translate and decode the information contained before issuing an effector command. Accordingly, if the cells of the brain and lower centers are deprived of oxygen these will not function properly and performance will be impaired (p. 128).

The belief that oxygen deprivation may contribute to reduced information processing stems from McFarland's (1963) observations that both the young and old suffered similar perceptual and cognitive impairment under hypoxic conditions generated at high altitude. McFarland extrapolated these results to the aging individual; i.e., impaired central nervous system metabolism may be due to the inaccessibility of oxygen in the aging brain. More recent reviews (e.g., Toole and Abourezk, in press) have indicated that decrements in energy metabolism in the brain may be due to changes in cerebral blood flow, oxygen consumption, and/or glucose utilization. Exercise has been shown to increase cerebral blood flow to areas of the brain that are involved in the programming, control and execution of movements such as the prefrontal, somatosensory, and primary motor regions and the cerebellum (Fletcher, 1985). Thus it appears that exercise, particularly aerobic exercise that is intensive and long-term, could conceivably have a nurturant effect on the central nervous system through increased cerebral blood flow and oxygen utilization.

Other lines of circumstantial evidence have suggested that exercise, by its trophic effect on the central nervous system, may retard age-related declines in psychomotor speed. Reviews by Birren and co-workers (1980), Dzewaltowski (1985), Fletcher (1985), Spirduso (1980, 83), and Toole and Abourezk (in press) all note that studies on cardiovascularly impaired men show that these individuals evidence slower reaction time scores than healthy men of similar ages. Spirduso (1983) pointed out that reaction time is the slowest in the cerebrovascular diseased, i.e., in patients who have transient ischemic attacks and strokes. According to Spirduso (1983), reaction time is next slowest in brain damaged and untreated hypertensive patients. Reaction time is also slower than normal in those with coronary heart disease.

The impact of age-related declines in cerebral blood flow and/or energy metabolism on central nervous system functioning as reflected in reaction time is still controversial. Toole and Abourezk (in press) noted that the inclusion of senile demented and arteriosclerotic subjects may account for some of the slowness in response. Furthermore, in a recent thesis, Fletcher (1985) found that hyperoxia conditions did not result in faster reaction and movement times among a group of elderly men and women.

Besides the possibility that exercise delays reductions in the oxidative capacities of the brain, exercise may also alter age-related declines in neurotransmitter substances. For example, with advancing age there are declines in acetlycholine, dopamine, and serotonin which regulate chemical activity at the cell synapse (Toole and Abourezk, in press). Furthermore, exercise may delay morphological changes in the aging brain by postponing structural changes in the nerve cell and the loss of dendrites (Spirduso, 1980).

Retrospective Analyses

The idea that physical fitness may be related to central nervous system integrity stemmed from early reports of retrospective analyses of "fit" and "unfit" young and old individuals on speed of response tasks. For example, Botwinick and Thompson (1968), in a posteriori analyses of reaction time data, found that college male nonathletes were no faster than elderly men (although the college athletes were significantly faster on reaction time than the elderly men). The athletes were team sport-participants who self-reported that they exercised regularly; the nonathletes indicated that they exercised irregularly or not at all. Spirduso (1980) overviewed data that indicated (in at least 11 studies) that older athletes had faster reaction time scores than older nonathletes.

In retrospective analyses one must assure that other confounding variables are controlled. For example, it is not clear whether these differences in reaction among older athletes/nonathletes are due to differences in aerobic capacity, or the confounding effects of differences in athletic experience, genetic factors, or a greater familiarity with competitive environments among the athletes.

Other studies have examined retrospectively the fitness/information processing relationship by contrasting young and older groups on reaction time among individuals who self-reported differences in exercise participation. For example, Ohlsson (1977) found that physically fit elderly men were faster than a group of physically unfit elderly men on a paper-and-pencil test of reaction time. Clarkson and Kroll (1978) found that old physically active men were more similar to young inactive men than to old inactive men in both simple and choice movement time responses. Their study was one of the few in which reaction time was segmented into peripheral and central components by electromyography. They concluded that physical activity, rather than chronological age, was a more important determinant of the effects of practice on both simple and choice movement time responses, particularly in terms of premotor time.

Sherwood and Selder (1979) compared physically fit and sedentary males, ranging in age from 20 to 59 years, on simple and choice RT tasks. Individuals categorized as physically fit ran an average of 42 miles per week. They found that reaction time deteriorated with age among the sedentary males; however, the physically fit males showed no evidence of a slowing in simple and choice reaction time when age changes were examined cross-sectionally.

More recently, Rikli and Busch (1986) contrasted simple and choice reaction times (as well as balance, flexibility, and grip strength) among sixty females categorized by both age and self-reported exercise levels. Women assigned to the active group were involved in physical activity on a regular basis at least 3 times a week for 30 minutes or more over the past 3 years (10 years for the older participants). Faster reaction times were found for the more active women, particularly when the active older women (M age = 68.7 years) were compared to the inactive older women (M age = 68.9 years).

A major concern of the studies just cited relates to the adequacy by which cardiorespiratory efficiency was defined. The use of self-report data to assess cardiorespiratory fitness is highly questionable. An individual's recollection of previous exercise activity may be inaccurate. Furthermore, this appoach may have restricted validity in terms of identifying exercise type, intensity, frequency, and duration of activity.

Cross-sectional Analyses Based on Direct Assessments of Cardiorespiratory Efficiency

More recent approaches to examining cross-sectionally, the relationship of physical fitness to information processing as a function of chronological age have utilized more direct assessments based on oxygen consumption and other physiological correlates of cardiorespiratory efficiency. For example, Dzewaltowski (1985) contrasted young and old adults on segmented simple and choice reaction times on a task involving a dorsal flexion of the right leg in response to a light stimulus or two light stimuli. Subjects were classified as high or low fit based on estimated VO2 max. Dzewaltowski found that while there were no differences in segmented simple or choice reaction time among young and old subjects, the high fit individuals performed faster (in terms of simple and choice premotor times) than the low fit subjects. Thus, it would seem that aerobic fitness rather than age was the determinant of processing abilities as reflected in premotor time.

Era, Jokela, and Keikkinen (1986), utilizing a direct method for assessing VO2 max, found moderate correlations between VO2 max and choice reaction times (for both visual and auditory stimuli) among 71-75 year old males. Unfortunately, the extremely limited number of trials given on the tasks may have resulted in practice effects confounding the relationships reported. In the study reported previously on hyperoxia by Fletcher (1985), she found that reaction time correlated poorly with maximal oxygen uptake in either normoxic or hyperoxic conditions. Fletcher noted, however, that larger differences in mean maximal oxygen uptake might have resulted in more observable reaction time differences among those individuals classified as high or low fit on the basis of VO2 max.

Experimental Approaches

A more direct examination of the effects of aerobic exercise on information processing in older adults would be through experimental manipulation. Ideally, long-term, carefully regulated experimental studies of aerobic exercise (in comparison to other forms of exercise such as range-of-motion exercises) are needed to decipher the impact of exercise on the processing capabilities of older drivers. No studies relating to older driver performance have been reported. However, a few short-term, experimental studies have reported on the effects of exercise on the information-processing abilities of older adults .

Dzewaltowski (1985), after concluding that fitness rather than age accounted for the discrimination between young and old adults on processing times (i.e., premotor times), sought to evaluate the effects of participation in an eight-week aerobic training program on changes in processing time. Both young and older subjects underwent an individually prescribed walking or jogging program that was held three times per week for an eight-week duration. While Dzewaltowski found improvements among the older adults on both simple and choice premotor times and on simple reaction time after the eight-week program, the results could not be attributed to the changes in VO2 max or resting heart rate that were experienced by the subjects.

Dustman and his colleagues (Dustman, Ruhiing, Russell, Shearer, Bonekat, Shigeoka, Wood, and Bradford, 1984) examined the effects of four months of exercise on neuropsychological tests of performance, depression indices, sensory thresholds,and visual acuity among 43 male or female sedentary volunteers, ages 55-70 years. Subjects were assigned to one of three groups: (a) participation in an experimental aerobic exercise program consisting of fast walking and occasional slow jogging, (b) participation in an exercise control group consisting of strength and flexibility exercises, or (c) participation in a nonexercise control group. Subjects in each group met for three one-hour sessions a week over the four-month period. The investigators found that the aerobically trained group demonstrated significantly greater improvement on the neuropsychological test battery than did either control group. Interestingly, while significant improvements were reported for simple reaction time after the aerobic exercise program, there were no improvements in choice reaction time. This is rather surprising in that one would hypothesize that performance on the choice reaction time task would be more affected by cardiorespiratory conditioning than simple reaction time performance because of the greater processing demands of the choice condition.

Several other experimental studies have been reported in the literature but were less controlled. Boarman (1978) did not find any changes in simple reaction time or movement time among elderly subjects participating in a five-week, twice-a-week folk dance program. However, significant changes in simple reaction time were reported by Van Fraechem and Van Fraeche (1977) among sedentary females, ages 70 to 80 years, after two months of exercise. Neither study measured oxygen consumption directly.

In summary, evidence is emerging to suggest that exercise (particularly aerobic exercise), by its trophic effect on the central nervous system, may retard the deterioration in reaction time and speed of response commonly associated with advancing age. Most of the evidence is circumstantial in nature. A few, well-conducted experimental studies have provided stronger support for the favorable impact of aerobic exercise on the information processing capabilities of the older adult.

From a practical standpoint, the evidence points to the importance of keeping our older citizenry physically fit, particularly as they rely more and more on the automobile as a source of transportation mobility and independence. Driving an automobile involves numerous and complex psychomotor skills. Many of these skills require rapid decision making without the benefits to the older driver of self-paced execution. From the previous pages, the reader may gather that the value of sustained aerobic exercise to the older driver goes beyond cardiovascular gain or improved mental health. It now appears that aerobic exercise can deter impairments in cognitive functioning that commonly occur with advancing age. These benefits extend to short-term memory deficits (Abourezk, 1986), attentional processes (Tomporowski and Ellis, 1986), and speed of movement.

The Trainability of Older Adults with Respect to Improving Range-of-Motion Deficits

Physical training may compensate for physical changes and impairments associated with aging, including loss of joint range of motion. As noted earlier, declines in flexibility, or adequate range of motion with age restrict complex leg, arm, and head movements essential to driving an automobile. For example, impediments in backing an automobile, in observing blind spots, and in parallel parking may stem, in part, from limited shoulder and head rotation.

Malfetti (1985) noted that "we should try to determine such matters as the best method to accomodate the physical limitations of aging; namely, reduced strength and decreased flexibility and comfort in relation to steering, braking, seeing to the side and rear, sitting, climbing in and out, adjusting the seat belt, and so on." One obvious solution to the problem of reduced flexibility in the aging driver is the promotion of a regular diet of exercise emphasizing range-of-motion activities. Muscles, tendons, and the joint capsules that are responsible for movement resistance are modifiable through training across age (Munns, 1981).

A number of research studies have examined the benefits of exercise to range-of-motion among the elderly. For example, Parks (1979) reported improvements in flexibility among 15 women, ages 65-82 years, who participated in 10 weeks of exercise. Similarly, Frekany and Leslie (1975) reported significant gains in flexibility among a limited sample (_N_ = 15) of women, ages 71-90 years, who participated in a seven-month exercise program. In both studies, control was less than optimal, with subjects in the latter study even being permitted to exercise on their own. Furthermore, exercise sessions were limited in frequency and duration in both studies.

Kriete (1976) investigated the effects of participation in Frankel's Preventicare exercise program (Frankel and Richard, 1977) for seven weeks on specific joint mobilities in healthy women over 60 years of age. Fifteen of these individuals were assigned to a control group. The investigator reported no changes on six of eight flexibility measurements taken. The lack of improvement in flexibility may result from the exercise program's not being specifically targeted to enhance range of motion in the joint sites tested.

Munns (1981) examined the effects of a twelve-week exercise dance program on improving flexibility among 40 elderly individuals (ages 65-88 years), one-half of whom were assigned to a control group. Subjects were tested at six body sites. Multivariate statistical analyses revealed overall flexibility gains in the exercise group. Follow-up analyses indicated that the exercise program contributed to gains in flexibility at all six joint sites tested among these elderly individuals.

Retrospective analyses (Smith and Walker, 1983) failed to confirm a relationship between the frequency of physical activity participation (based on self-report) and joint flexibility in the elderly. However, as noted previously, self-report statements of activity participation are less accurate than experimental manipulations of exercise involvement. For the most part, the data confirm Harris's (1983) conclusion that physical exercise can develop, maintain, and improve flexibility in the elderly.

While States (1985) correctly noted that no satisfactory medical therapy can restore the loss of head and neck motion from degenerative changes in the cervical spine, it is clear that for the older driver who is unencumbered by severe degenerative disease, a daily routine of simple stretching exercises may go a long way to sustaining adequate range of motion. It can be hypothesized that exercises specifically targeted to the joint sites commonly associated with problem driving would be an innovative solution to enhancing an older person's ability to drive an automobile effectively.

The Research Problem

The review of literature highlighted a number of significant issues pertinent to older driver performance:

1. During the coming decades, a greater proportion of total travel by automobile will be accounted for by those people over 65 years.

2. When accident rate and injury-severity data obtained among the elderly are normalized for exposure, they approximate the data of those 15-25 years old.

3. The most common errors/problems of older drivers include a failure to yield right-of-way, a failure to obey signs, signals, and markings, improper turns, and difficulty transversing high density intersections.

4. A driving task analysis indicates that the majority of older driver traffic safety problems cluster around responses to traffic or roadway conditions that are heavily dependent on the ability of the older driver to process complex information simultaneously or sequentially, and rapidly.

5. The above finding is congruent with research on an information-processing model of human performance which indicates that the slowing in psychomotor response and coordinated movement with increasing age is due primarily to a deterioration of central nervous system activity rather than a loss of peripheral abilities.

6. The most common solutions proposed to reduce the number of injuries and fatalities stemming from an increasingly older driver clientele have centered on changing the environment in which the older person drives, changing the design of the vehicle, or using education and training to update the skills of the older driver. There has been a noticeable absence of projects designed to modify the functional capacities of the older driver.

7. Research indicates that aerobic exercise, by its tropic effects on the central nervous system, may deter the decline in speed of processing and coordination of movement commonly observed in the elderly. Furthermore, range-of-motion exercise training has been shown to improve flexibility, which may help many older adults compensate for restricted leg, arm, and head movements essential to driving an automobile.

8. No research studies have examined the relationship of physical fitness to older driver performance.

The Problem Statement

The authors proposed a comprehensive, two-phase research project designed to examine the relationship of physical fitness to older driver performance. During Phase I of the project, the authors sought to answer the following questions:

1. What is the relationship of cardiorespiratory fitness to field-based performance assessments of driver performance, particularly on tasks involving a high order of judgment, decision making, and performance under definite time constraints?

2. What is the relationship of reaction time (particularly premotor time) and movement time to performance on driving tasks accentuating central nervous system processing?

3. What is the relationship of joint flexibility to driver performance?

4. What is the relationship of cardiorespiratory fitness to segmented reaction time?

5. What are the relative contributions of cardiorespiratory fitness, range of motion, and reaction time/movement time as they relate to older driver performance?

Thus, the major purpose of this research investigation was to examine descriptively the relative contributions of various measures of cardiorespiratory efficiency, range of motion, and reaction time/movement time to field-based assessments of older driver performance. Toward this end, a cross-sectional, correlational research design was employed to contrast both young adults and older adults on various measures of physical fitness and driver performance. This approach enabled the investigators to examine, to some extent, the relative contributions of chronological age as it relates to the question of how physical fitness facilitates driver performance.

Hypotheses

Generally, it was hypothesized that the physical fitness stature of each subject was correlated positively with his/her performance as automobile drivers. More specifically, based on the review of literature and the intuitive judgments of the investigators, it was hypothsized that:

1. There is a positive relationship between cardiorespiratory fitness and field-based performance assessments of driver performance, particularly on tasks involving a higher order of judgment, decision making, and when performed under definite time constraints. It is predicted that this relationship will be higher for older subjects.

2. Reaction time (particularly premotor time) is positively correlated to subject performance on driving tasks accentuating central nervous system processing, especially among older subjects.

3. Joint range of motion is positively correlated to driver performance, particularly ankle flexibility (dorsiflexion) and rotation of the nec . and shoulder.

4. Cardiorespiratory fitness (e.g., VO2 max) is positively correlated to subject reaction time (particularly premotor time) and movement time.

Research Plan

A total of 106 adults participated in a research project designed to investigate the relationship of physical fitness to driver performance. A cross-sectional developmental research design was employed. After obtaining informed consent each subject was administered a battery of tests including (a) a health history questionnaire, (b) a symptom limited maximal stress test, (c) range-of-motion tests at seven joint sites, (d) reaction time/movement time assessments on a driving simulator model and (e) a field-based assessment of driver performance using a modified version of the Automobile Driving On-Road Performance Test (ADOPT). These tests were selected on the basis of their relevance to the objectives of the study, measurability, repeatability, and objectivity. While every effort was made to randomize the order of test administration, some tests were administered at the convenience of the subject. Most subjects were tested over a 2-3 week period; however, some subjects were administered one or two tests (eg. range of motion assessments) at a later time.

Selection and Characteristics of Sample

A total of 106 adults completed one or more of the assessments in the test battery. An incidental sample was obtained among volunteer males and females who ranged in age from either 20-35 years or 60-75 years. Subjects ranging in age from 20-35 years were labeled the "young adult" group; those individuals 60-75 years were classified as the "older adult" group. A total of 26 males and 17 females comprised the young adult group; 35 males and 28 females comprised the older adult group.

Subjects were recruited primarily from the Morgantown, West Virginia area. Recruitment was accomplished through public service announcements on radio, television, and in the newspapers. Older adults were also contacted through the Rotary and Kiwanis clubs and the American Association of Retired Persons. They also were recruited among participants of a "Fitness Over 60" program conducted at West Virginia University. Table 1 presents the means and standard deviations of several demographic variables characterizing the young adult and older adult samples that were obtained from their responses to the health questionnaire.

Table 1
Demographic Characteristics of the Young and Older Adult Samples*

	Young Males	Young Males	Older Females	Older Females
age	29.58 years (2.59;n=24)	29.44 years (3.63;n=16)	66.91 years (4.90;n=35)	67.38 years (3.49;n=26)
weight	180.09 lbs. (30.76;n=23)	140.14 lbs. (22.86;n=15)	174.41 lbs. (23.87;n=18)	152.36 lbs. (29.08;n=14)
stress (general)	3.14 (0.64;n=22)	2.80 (0.41;n=15)	2.78 (0.65;n=18)	3.43 (0.65;n=14)
stress (job)	2.86 (0.71;n=22)	2.60 (0.51;n=15)	3.07 (0.59;n=15)	3.27 (0.65;n=11)
physical fitness status (perceived)	3.55 (0.80;n=22)	2.73 (0.59;n=15)	3.72 (0.89;n=18)	3.77 (0.83;n=13)

A series of 2 (age) x 2 (sex) factorial ANOVA for an unbalanced design were computed to determine to what extent the subjects, classified by age and sex, differed statistically on these demographic variables. As can be seen in Table 2, the ANOVA analysis confirmed that males and females were similar in age within each age group.

Table 2
Obtained F-ratios Characterizing Differences on Demographic Variables as a Function of the Age and Sex of the Subject

	Age	Sex	Age x Sex
age	2251.46**	0.08	0.15
weight	0.00	22.94**	1.83
stress (general)	0.19	0.74	11.26**
stress (job)	6.10*	0.18	2.07
physical fitness status (perceived)	7.40**	4.58*	4.79*

*p < .05

**p < .01

As expected, males weighed significantly more than females within each age group [F(1,66) = 22.94; p < .01]. Interestingly, while there were no significant differences in perceptions of general stress among these samples, older females generally felt more stressed than did young females or older males [F(1,65) = 11.26; p < .01]. Figure 1 illustrates the interaction between age and sex in terms of perceptions of general stress. Surprisingly, the ANOVA analysis indicated that the older subjects rated their level of physical fitness higher than did young subjects, [F(1,64) = 7.40; p < .01]; males rated their fitness higher than did females, [F(1,64) = 4.58, p < .05].

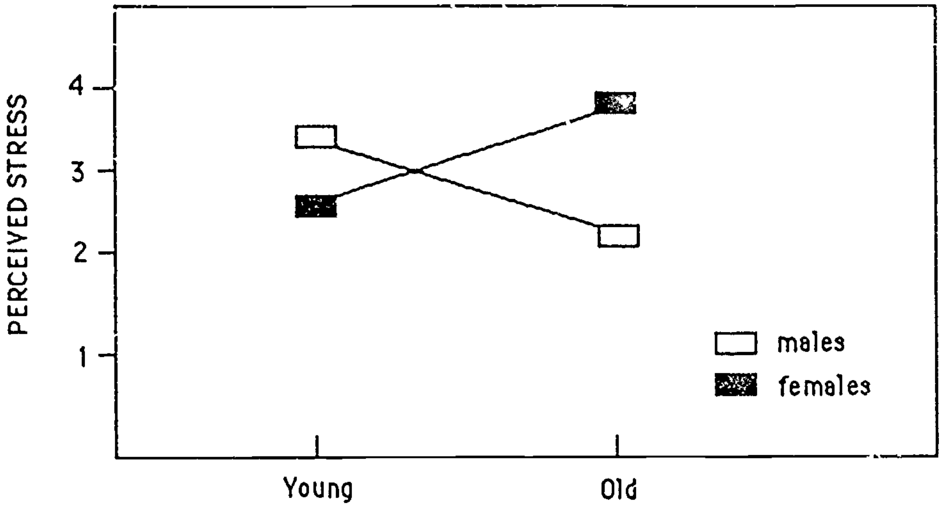

Figure 1. A comparison of young and old age groups on perceived levels of general stress.

An examination of the statistically significant interaction [$F(1,64) = 4.79$; $p < .05$] as depicted in Figure 2 show the tendency for older females to evaluate their fitness similar to older males while young females viewed their level of physical fitness as lower than did young males.

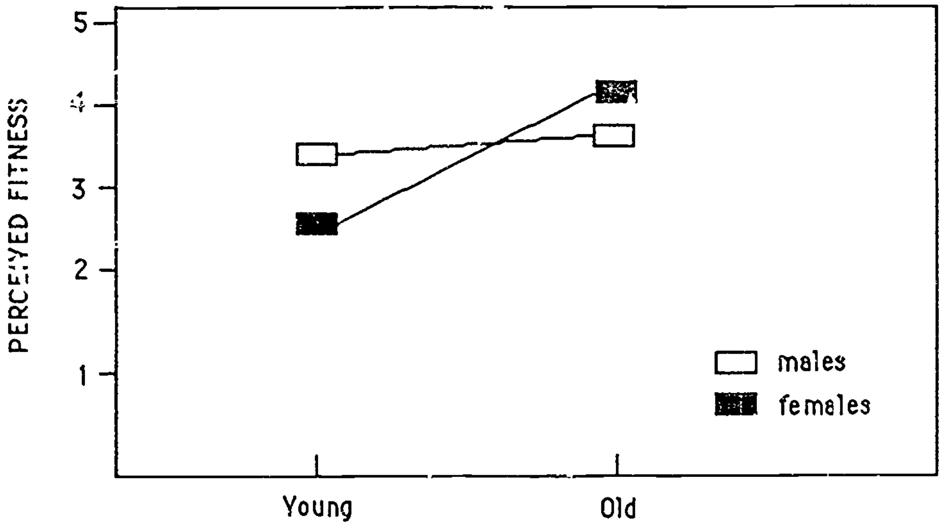

Figure 2. A comparison of young and old age groups on perceived levels of physical fitness.

Test Measures

This section presents a detailed description of the questionnaires and tests used as part of the data collection procedures.

Health History

A detailed health history was obtained from each subject. The report provided information relevant to an assessment of general physical condition and also served as a screening tool for subjects with high-risk health conditions who were then not considered for further testing. The specific variables of interest to this study follow: Chronological Age, Gender, Weight, Educational Level, Self-report General Stress Level, Self-report Job Stress Level, Self-report Physical Fitness. These variables were used to describe the demographic characteristics of the sample; they were also correlated with the various performance measures in the study.

The health history was obtained by self-report in a personal interview conducted by a trained staff member. Subjects were assured that their responses would remain confidential. While the questionnaire had face validity, the reliability of the health history was maximized by: (1) using only trained interviewers; (2) using a standardized format and (3) employing a questionnaire routinely used for the collection of health history data.

Cardiorespiratory Fitness

A measure of cardiorespiratory efficiency was taken on each subject as a further indicator of general physical condition. A modified symptom-limited maximal treadmill test was utilized. This test was necessary due to the difficulty of estimating maximum performance values from submaximal tests with older subjects. The value representing maximal oxygen consumption was termed VO2 max and was used as the measure of cardiorespiratory efficiency. The VO2 max score was then normalized according to the subject's weight and age to allow comparisons between subjects. In addition to VO2 max, measures of heart rate, blood pressure, and perceived exertion were also taken. Each of these measures contributes to an assessment of general physical condition.

The validity of VO2 max as a factor of general physical condition has been verified by prior research. The reliability of this information is limited somewhat by the subject's perceived level of exertion and potential difficulties in reaching a maximal level of exertion. However, with a trained staff and standardized procedures, the reliability is assumed to be acceptably high.

Joint range of motion

Range-of-motion measures of twelve critical skeletal joints were taken from each subject. Based on relevance to the act of automobile driving, the following joints were selected for measurement: Neck Rotation, Torso Rotation, Right Shoulder Flexion, Left Shoulder Flexion, Right Elbow Flexion, Left Elbow Flexion, Right Hip Flexion, Left Hip Flexion, Right Knee Flexion, Left Knee Flexion, Right Ankle Dorsiflexion and Plantar Flexion, Left Ankle Dorsiflexion and Plantar Flexion.

A double-armed goniometer was used to measure range of motion at all joint sites except neck and torso. A head mounted goniometer was designed and utilized for the neck and torso rotation measurements.

A trained examiner made each measurement by positioning the instrument on the joint site and instructing the subject to move the joint appropriately. Each measurement represented degrees of motion from anatomical standard. A pilot study of ten subjects was utilized to ensure measurement accuracy and inter-examiner reliability.

The reliability was maximized by the use of trained examiners and standardized procedures. Measurements from subjects tested early in the study were performed under the direction of a laboratory supervisor to determine that the appropriate protocol and technique were being applied. Measures were also taken by the supervisors to assure the accuracy and reliability of measurements made by the project staff.

__Reaction-time testing__

A series of 15 trials of simple reaction time and movement time were obtained from each subject. An automobile simulator equipped with an adjustable seat was built to reproduce typical body position and movement while driving. A light box containing a single red light stimulus was mounted in front of the simulator at (approximately) subject eye level. When the light stimulus was presented (using 1-2 second random foreperiod times), the subject was asked to release his/her right leg from the fully depressed accelerator pedal as rapidly as possible and then fully depress the brake pedal.

Three electrical timers were utilized (available from Lafayette Instrument Co., Lafayette, IN 47903). The first timer measured total response time; i.e., the total time from the initiation of the stimulus to the time when the brake pedal was fully depressed by the subject. A second timer measured a component of total response time/reaction time. Reaction time was defined as the time from the initiation of the stimulus to the release of the accelerator pedal by the subject. A second component of total response time that was measured was termed movement time. This was computed by subtracting each subject's reaction time score from their total response time score. Thus, movement time was an indication of how quickly the subject moved his/her right leg to depress the brake pedal once the accelerator had been released.

The third timer utilized a portable electromyography machine to segment reaction time into two components--premotor time and motor time. Premotor time was defined as the time from the initiation of the stimulus to the initial activation of the quadricep muscles of the subject's right leg (prior to releasing the depressed accelerator pedal). Motor time was the time interval from the first recorded EMG activity to leg movement. Motor time was calculated by subtracting premotor time from reaction time. An EMG amplifer recorded the interval between initiation of the stimulus and the beginning of muscle contraction by marking a moving tape. The tape was later transcribed to calculate premotor time. As noted previously, the majority of time involved in premotor time is central nervous system processing time. Thus, by using electromyography, the investigators were able to determine if the slowness in reacting with age was attributable primarily to reduced processing time or to muscle movement.

Subjects were given three practice trials to become familiar with the apparatus. They were then administered fifteen trials in three sets of 5 trials with a rest pause (1 to 1 1/2 minutes) between each set to minimize fatigue and boredom. Error trials were recorded, but "catch-up" trials were not given since it was felt that the number of errors recorded might be correlated with age.

An examiner was trained to conduct the reaction-time testing. A standardized dialogue was developed to instruct and prepare the subject. A data sheet was developed to record subjects' premotor, motor, reaction, movement, and total response times on each of the 15 trials. The testing was limited to fifteen trials to provide adequate reliability without undue subject fatigue. Reliability was also maximized by the careful training of the examiners and the standardization of dialogue and procedures. A preliminary evaluation of a subsample of young (n=15) and older (n=15) subjects confirmed that high reliability was achieved. As can be seen in Table 3, split half odd-even internal consistency coefficients (adjusted by the Spearman-Brown formula) were high for both young and old subsamples across the 15 trials. Furthermore, moderate to high test-retest reliability coefficients were computed among the older subjects across a 6-day time interval.

Table 3

Reliability of Reaction and Movement Time Scores Among Young (n=15) and Older (n=15) Adults on the Driving Simulator

	Internal Consistency	Test-Retest Reliability*
	Older Adults (n=15)	
Premotor time	.94	.69
Motor time	.97	.42
Reaction time	.91	.91
Movement time	.99	.93
Total response time	.96	.71
	Young Adults (n=15)	
Premotor time	.93	
Motor time	.91	
Reaction time	.92	
Movement time	.99	
Total response time	.98	

*Average test-retest time interval was 5.6 days

Driving Ability
The group of driving ability variables were selected to measure the subject's capability to apply safe practices and skillfully operate an automobile. A review of current literature on older driver performance was used to identify particular driving problems of the elderly. The individual driving measures used in this study were then concentrated on the areas, problems, or driving situations presenting the greatest problem and risk for older operators.

Candidate Measures
Researchers in the field of older driver highway safety have commonly identified a number of high-risk driving situations specific to the older driver. The most frequently cited situations follow:

Maintaining Proper Speed -- Driving at a consistent rate appropriate to highway and traffic conditions.

Operating in Heavy Traffic -- Negotiating urban rush hour or stop-and-go traffic.

Operating in High-Speed Traffic -- Driving at or near maximum legal speed while in close prioximity to other vehicles as encountered in urban freeway driving.

Lane Changing -- Selecting the appropriate lane and completing the tasks necessary for a safe lane change including speed adjustment, observing the blind spot at rear quarter not visible in rearview mirrors, signalling, and steering.

Overtaking and Passing -- Judging the relative speeds of two or more vehicles and selecting appropriate passing zones.

Judging right-of-way -- Giving or taking right-of-way in accordance with traffic situations or regulations.

Following Distance -- Selecting a safe following distance based on speed, traffic and roadway conditions.

Looking Far Ahead -- Anticipating oncoming traffic or roadway conditions by visual checks of distant roadway.

Determining Stopping Distances -- Predicting minimum vehicle stopping distance according to speed and roadway conditions.

Backing -- Driving the vehicle safely in reverse involving turning of the head and body for proper visual checks and steering skill.

Observing Behind -- Monitoring the rearview mirrors with sufficient care and frequency to remain aware of traffic conditions behind the vehicle.

Observing Blind Spot -- Turning the head to observe the rear quarter area not visible through the rearview mirrors.

Parking -- Positioning the vehicle in a limited space along the curb in line with traffic. The task involves distance judgment, backing, and steering skills.

Night Driving -- Driving the vehicle safely at night in all traffic conditions involves low-light-level sensitivity, glare resistance, and adjustments in speed to allow for reduced visual field.

Merging with Traffic -- Joining a merging stream of traffic as encountered on a freeway on-ramp. Selection of an appropriate gap in traffic and speed adjustment are required.

Turning -- Completing a change of direction at a roadway intersection. The task involves signalling of intention, yielding right-of-way, speed adjustment, and vehicle positioning on the roadway.

Making Left Turns -- Negotiating a turn across one or more lanes of oncoming traffic involves judgment of relative speeds and distances, signalling, selection of an appropriate gap in traffic, and speed and steering adjustment.

Negotiating High-Density Intersections -- Following specified traffic flow patterns, signalling intentions, and yielding right-of-way as necessary for safely negotiating a complex urban intersection.

Entering Traffic Flow -- Entering a heavy-traffic primary road from a light-traffic secondary road. The task involves stopping the vehicle in proper position, selection of an appropriate gap in traffic, and accelerating at an appropriate rate.

Responding Appropriately to Traffic Signs and Signals -- Obeying traffic direction and flow procedures as specified by lane markings, traffic signs and signals.

The above situations are primarily based on reports/data cited in Marsh, 1960, 1985; McKnight et al., 1982; Solomon, 1985; and Yaksich, 1985. The listing reflects a consensus of opinion about situations posing difficulties for senior operators.

In addition to the above list of older-driver-specific problems, it is recognized that the elderly face at least the same risk as other age groups in other general driving problems. A list of these general driving problems was added to the list of older-driver-specific problems for consideration in the selection of measures to be used in this study. These general driving problems follow:

Communicating Intentions -- Proper use of advance warning signals such as directional signals and hazard flashers.

Managing Traffic Space -- Maintaining vehicle position relative to lane boundaries and other vehicles, especially in heavy traffic.

Recognizing Hazards -- Perceiving and identifying potential hazards in the vehicle's path.

Selecting Emergency Responses -- Selecting the most appropriate evasive or corrective action when confronted with a hazardous situation.

Selecting Measures

The combined list of twenty-five high-risk traffic situations was reviewed and considered for measurement. The criteria used in consideration follow.

Testability -- The degree to which the driver's performance can be accurately measured. Included in this criterion are judgments of the reliability of the measure, the observability of the measure, and the objectivity of the measure.

Risk -- The degree to which the performance may be measured without risk of injury or property damage.

Administrative Limitations -- The degree to which the performance measure may be completed within legal, financial, and time limitations.

Using these criteria the following list of traffic safety problems is included in the older driver performance measure:

- Maintaining Proper Speed
- Turning
- Yielding to Traffic
- Backing
- Merging with Traffic
- Observing Behind
- Determining Stopping Distances
- Entering Traffic Flow
- Lane Changing
- Parking
- Observing Blind Spots
- Making Left Turns
- Communicating Intentions
- Reacting Appropriately to Traffic Signs and Signals
- Looking Far Ahead

Traffic safety problems reported but not included in the measure are listed below, along with the reasons for their omission.

Heavy Traffic -- Rejected due to a lack of repeatability and reliability in measure.

High-Speed Traffic -- Rejected due to low reliability and potential risk.

Following Other Vehicles -- Rejected due to low reliability.

Reacting Appropriately to Traffic Conditions -- Rejected due to lack of repeatability and low reliability.

Night Driving -- Rejected due to observability and potential risk.

Overtaking and Passing -- Rejected due to potential risk.

High-Density Intersections -- Rejected due to low reliability and potential risk.

Managing Traffic Space -- Rejected due to low reliability.

<u>Recognizing Hazards</u> - Rejected due to observability and potential risk.

<u>Selecting Emergency Responses</u> -- Rejected due to potential risk.

<u>Driving performance test</u>
The in-car driving measure was adapted from the Automobile Driver On-Road Performance Test (ADOPT) developed by Dr. Kenard McPherson (1981). This test, developed under contract from the National Highway Traffic Safety Administration, has proven to be a highly reliable, valid test instrument. The ADOPT also assesses many of the areas in which older drivers experience a problem. Finally the assessment approach used in the ADOPT is highly task-specific and routine-specific, resulting in identifiable operator behaviors that can be measured with a high degree of objectivity.

<u>Test situations</u>
Drawing upon the ADOPT, several specific driving situations were selected.

The <u>Handling Test</u> was selected to measure driving performance in backing, parallel parking, and turning situations. This test uses a parallel parking maneuver to assess overall vehicle handling skills. Included in the test are ratings for speed, accuracy, and distance judgments.

The <u>Restricted Travel Test</u> was selected to measure driving performance in determining stopping distance and obeying traffic signs, markings, and signals. The restricted travel test is designed to measure the driver's ability to position and stop the vehicle within legally designated boundaries.

The <u>Gap Selection Test</u> was selected to assess driver performance in yielding, merging, and left turn situations. The test is also applicable to testing performance at an intersection between primary and secondary roads. The Gap Selection Test measures the driver's ability to judge a safe gap for crossing or entering a stream of traffic.

The <u>Maintaining Speed Test</u> was selected to measure the driver's ability to maintain a safe and appropriate speed. Assessments are made of maintaining speed while traveling straight and in a turn.

The <u>Observation Test</u> was selected to assess the driver's use of proper visual search procedures. Observing behind, scanning, and observing blind spots are each measured.

The <u>Communicating Lane Change Test</u> was selected to measure the driver's performance in communicating and performing lane-change maneuvers.

The <u>Lanekeeping Test</u> was selected to measure the driver's ability to maintain the vehicle position within lane boundaries while negotiating turns and intersections.

The ADOPT Test specifies in detail the procedures to be used in the development of the test route, the design of the data-collection forms, and the training of the examiners. These ADOPT procedures were closely followed throughout the development of the driving ability instrument. The final instrument consists of a 6.8 mile road test which requires 45 minutes to administer.

ADOPT Measurement Accuracy

The validity and reliability of the ADOPT Driving Test were closely examined by its authors and described in their final report. The measurement reliability was assessed through the use of different examiners and test routes. The total measurement reliability was found to exceed .7. The validity of the ADOPT Test was assessed by correlation with an independent driving-skill measure. The correlation between the ADOPT and the independent skill test was found to be .56, a moderately strong association.

In this study, two examiners were trained to administer the driving ability test. The training consisted of approximately forty hours of familiarization with the test route and scoring criteria. A pilot study consisting of twenty driving tests was completed. During the pilot study, both examiners rode with each subject, simultaneously and independently scoring the subject's performance. The test scores were plotted and correlated. Correlation began at .86 and improved to over .91 after 20 trial runs indicating high observer reliability.

The driving test measure was designed and selected to be highly objective. Like the ADOPT, specific test and examiner procedures were outlined and adhered to.

Data Collection Procedures

The study, administered by project staff from the Safety and Health Studies and Sport and Exercise Studies departments of West Virginia University, involved a five-month period of testing. Supporting services for the study were provided by the AAA Foundation for Traffic Safety and West Virginia University. The study was conducted in Morgantown, West Virginia.

A brief letter was drafted explaining the nature of the study and the requirements for the volunteer subjects. This letter was used as a basis for all solicitations. Volunteers were requested to telephone the project secretary, who would record names and telephone numbers for a return call from the project staff. On the return call, the potential subject was given the details of his or her participation and, if over 60 years of age, was asked to secure a physician's consent. The volunteer was then scheduled for two visits of one and a half hours each.

On the first scheduled visit, the subject reported to the project laboratory in the West Virginia University Coliseum. A staff member greeted the subject and introduced the subject to the laboratory. A project consent form was read aloud and signed, and the physician's consent form was collected, if necessary. All subjects were then asked to complete a visual acuity test. At least 20/70 vision in one eye was required for further participation.

Every effort was made to administer the tests to each subject in a predetermined sequence. The order was:

1. Reaction-time testing
2. Range-of-motion testing
3. Health history
4. Cardiorespiratory-fitness testing
5. Driving-ability testing (ADOPT)

As noted earlier, not all subjects completed each test. Also, "catch-up" testing was done later for some subjects who had missed the reaction time testing or range of motion testing.

Reaction time testing procedures

The subject was acquainted with the reaction time test apparatus and seated at a reaction simulator. The examiner explained the testing procedure while attaching the EMG electrodes to the subject's right leg. As noted earlier, the subject was told that he or she would receive a warning signal, then after a random interval, a visual stimulus (light) would follow. On seeing the stimulus, the subject was to move the right foot as quickly as possible from the accelerator pedal to the brake pedal. After ensuring that the subject was comfortable and that the EMG amplifier was correctly calibrated, a series of five practice trials was given. The practice trials established that the subject was following instructions and that the timing apparatus was functioning properly. The examiner then proceeded with the testing, which consisted of fifteen additional trials. No feedback concerning performance was offered to the subject during the testing.

Joint range-of-motion testing

Before moving from the reaction simulator, the subject was introduced to the joint range of motion measuring instruments. A goniometer was placed on the subject's head and adjusted for fit and comfort. While still seated, the subject was asked to turn his or her head as far as was comfortable to the right and then to the left. Head movement was measured in degrees of rotation from front center. The subject was then asked to turn the head and upper body to the right and look directly behind as far as possible, as if backing an automobile; the right foot was to remain on the brake pedal and at least one hand on the simulator's steering wheel. This task permitted a measurement of torso rotation, which was assessed in degrees from front center.

The examiner then escorted the subject to the exercise physiology laboratory where a double-arm goniometer was used to measure range of motion of the shoulders, elbows, hips, knees, and ankles. In each case the subject was asked to move as far as was comfortable and the measurement was taken in degrees from an anatomical standard.

Health history

The health history interview took place in the exercise physiology laboratory. The subject was introduced to the exercise physiologist who privately conducted the interview. In addition to the variables of interest to this study, the exercise physiologist obtained sufficient information to judge the appropriateness of a VO2 max test for this individual. If VO2 max testing was judged inappropriate, all testing procedures were concluded at this point and a new subject was selected.

Cardiorespiratory fitness testing

Following the health history interview, the subject was introduced to the exercise physiology lab staff. The technicians demonstrated the equipment to be used in the VO2 max test and explained the procedures for testing. The test required walking on a motor-driven treadmill at a constant speed of 2 to 3.5 miles per hours, depending on leg length and physical condition. Elevation was increased 1 percent after each minute. The subject was asked to continue walking until too tired to continue. An ECG was monitored throughout the test and blood pressure was taken each minute. An expired air sample was collected when the subject's heart rate reached 80 percent of the age-predicted maximum and during the last minute of exercise to determine maximal oxygen consumption. The testing was stopped if at any time the subject's symptoms became abnormal or if requested by the subject.

After collection and analysis of an expired air sample, a VO2 max value and an age-related fitness category were calculated. Resting heart rate and blood pressure and a last-stage heart rate were also recorded. The subject was then briefed concerning his or her fitness level.

Driving ability testing

The driving test was administered when the subject returned to the project laboratory for a second scheduled visit. Project staff member ascertained that the subject was carrying a valid driver's license and escorted the subject to the test vehicle. A late-model compact vehicle with power steering, power brakes, and automatic transmission was used as the test vehicle. The vehicle was equipped with a dual-control braking system which allowed the examiner to apply the brakes in case of an emergency.

The examiner occupied the front passenger position and explained the operation of the vehicle controls. A list of traffic safety reminders was reviewed to encourage the subject to follow safe driving practices. The subject was then instructed to start the vehicle and drive to the test range. Five minutes were then allocated for the subject to become familiar with the vehicle's operation. He or she was told to practice braking, accelerating, and turning to learn the response of the test vehicle.

The ADOPT was then administered on the test range and on street. No feedback concerning driving performance was given during the road test. After the ADOPT was completed, the subject was briefed in general terms on his or her performance.

During the study phase, interexaminer reliability was monitored by simultaneous scoring of each fifteenth subject by two examiners. Reliability remained at the high level achieved during examiner training.

Data Analysis Procedures

This section contains a description of the data-reduction procedures that were followed in the project. Also, the statistical procedures employed to evaluate the hypotheses of the project are outlined.

Health History Questionnaire Variables

The following variables, based on subjects' responses to the Health History Questionnaire, were included in the data analyses:

Chronological Age (Years)	General Stress Level
Gender (Male/Female)	Job Stress Level
Weight (lbs.)	Physical Activity Level
Education Level	Physical Fitness Level

Subjects' educational level was evaluated on a 4-point ordinal scale as either below high school, high school, college, or graduate level. Their self-report general and job stress levels were measured using a 4-point Likert format ordinal scale. A high score of 4 indicated little, if any, stress; the lowest score of 1 indicated severe stress.

Subjects' self-report levels of physical activity participation were treated as a dichotomous variable. A score of 1 was assigned if an indvidual reported that he/she participated in aerobic activity at least 3x/week for 30 minutes each day; a score of 0 was assigned if a subject participated in aerobic activity less than 3x/week for 30 minutes each day or if a subject did not participate in aerobic activity. Finally, subjects' perceptions of their level of physical fitness were evaluated using a 5-point Likert format ordinal scale. For example, a low score of 1 indicated that subjects felt they were unfit; a high score of 5 indicated that subjects felt they were very fit.

Cardiorespiratory fitness testing scores

The following variables, representative of cardiorespiratory function, were included in the data analyses:

Resting Heart Rate	Last-stage Heart Rate
Resting Systolic Blood Pressure	VO2 max (ml/kg/min.)
Resting Diastolic Blood Pressure	Perceived Exertion

A subject's last-stage heart rate, VO2 max, and perceived exertion scores were included in the data analyses only if the subject reached 80 percent of the age-predicted maximum during the last minute of exercise on the motor-driven treadmill (stress test). Perceived exertion was evaluated using a 20-point Borg scale; a high score indicated that the subject, while on the treadmill, subjectively appraised his/her work effort as high.

Joint range-of-motion test scores

The following joint range-of-motion test scores were entered into the data analyses:

Neck Rotation	Right Hip Flexion
Torso Rotation	Left Hip Flexion
Right Shoulder Flexion	Right Knee Flexion
Left Shoulder Flexion	Left Knee Flexion
Right Elbow Flexion	Right Ankle Dorsiflexion
Left Elbow Flexion	Left Ankle Dorsiflexion

Each joint site was measured in terms of degree of rotation.

Reaction time testing scores
Six measurement scores, based on subjects' performances on the automobile simulator. were included in the data analyses:

Premotor Time	Movement Time
Motor Time	Total Response Time
Reaction Time	Errors

It should be noted that each performance score (e.g., premotor time) represented a subject's average score for 15 trials on the task. The errors variable represented the number of trials, if any, in which a subject did not successfully complete the performance requirements of the task.

Driving performance test measures
Subjects were evaluated on a total of 21 driver performance test scores on the ADOPT test. For the purposes of data reduction and interpretation, these 21 ADOPT scores were clustered under 9 driver functions. These 9 driver functions were derived based on the review of literature and the intuitive judgments of the investigators.

Each of the 21 ADOPT scores was standardized by conversion to a percentage score. A high percentage score indicated that the subject successfully performed that particular ADOPT component. To obtain each of the 9 driver function scores, the ADOPT scores included under each driver function were averaged. A list of the 9 driver functions and the ADOPT variables included under each function follows.

Maneuvers

Handling: Time
Handling: Directions
Handling: Striking barrier
Handling: Position
Straight back: Lane keeping
Straight backing: Time

Driver Processing

Gap selection
Gap selection: Merge
Lane change merge
Maintain speed: Straight
Maintain speed: Turn

Maintaining Speed

Maintain speed: Straight
Maintain speed: Turn

Signaling

Lane change signaling

Observing

Handling observing
Straight back: Observing
Observe: Rear quarter
Observe: Behind
Observe: Side
Visual scan

Safe Practices

Handling: Observing
Straight Back: Observing
Restricted travel
Restricted travel: Stop
Lane change signal
Observe: Rear quarter
Observe: Behind
Observe: Side
Lane Keeping: Turn
Visual scan

Vehicle Handling

Handling: Time
Handling: Observing
Handling: Striking barrier
Handling: Position
Straight backing: Time

Traffic Restriction

Restricted travel
Restricted travel: Stop
Lane keeping: Turn

Right-of-Way

Gap selection
Gap selection: Merge
Lane change: Merge

In addition, a total driving score was computed for each subject by deriving an average of the subject's 21 ADOPT component scores.

<u>Statistical procedures</u>
Descriptive and inferential statistics were employed to evaluate the hypotheses. Measures of central tendency (means) and variability (standard deviations) were computed for each variable evaluated. Pearson product-moment correlation coefficients were computed to describe the relationships among variables; biserial or point biserial correlation coefficients were computed when evaluating the intercorrelations of variables that were dichotomous. In addition, multiple correlations were computed to examine the extent to which combinations of predictor variables (e.g., VO_2 max, premotor time, ankle dorsiflexion, chronological age) were related to driver performance.

Two way factoral analysis of variance (ANOVA) was used to examine to what extent males and females within each of the two age groups differed on the variables examined in the project. Stepwise multiple regression analysis enabled the investigators to determine which combination of fitness and motor performance variables were most predictive of driver performance. The critical level used by the investigators in evaluating the significance of the results was set at the .05 level.

RESULTS

This section summarizes the results of the data analyses centering on the relationship of physical fitness to older driver performance. The results of the descriptive and inferential data analyses comparing young and older drivers on reaction and movement time responses (driving simulator) are first presented. Subsequent sections present similar analyses comparing young and older drivers on range of motion, cardiorespiratory efficiency, and driver performance (ADOPT). Following these analyses, data regarding the relative contributions of reaction time/movement time, range of motion, and cardiorespiratory efficiency to predicting driver performance are presented.

Age/Gender Comparisons on Reaction Time/Movement Time

Table 4 presents descriptive data (means/standard deviations) comparing young and older drivers, by gender, on the five components of reaction time/movement time that were assessed using the reaction simulator. The average number of trials (for 15 trials) in which an error was recorded is also presented for each group.

Table 4

Means and Standard Deviations Comparing Young and Older Drivers by Gender on Reaction Time/Movement Time

	Young Males (n=23	Young Females (n=17)	Older Males (n=31)	Older Females (n=23)
Premotor Time	191.13 (38.87)	187.65 (31.94)	222.09 (44.54)	215.17 (35.03)
Motor Time	106.17 (25.26)	106.41 (27.02)	113.94 (33.11)	169.65 (168.63)
Reaction Time	290.96 (22.66)	294.00 (37.85)	335.77 (50.61)	350.35 (66.95)
Movement Time	179.26 (46.23)	215.06 (66.15)	201.77 (49.58)	324.30 (137.59)
Total Response Time	470.09 (60.12)	508.82 (87.57)	537.48 (83.00)	674.78 (196.08)
Errors	0.09 (0.29)	0.06 (0.24)	0.07 (0.27)	0.05 (0.22)

Two-way factorial analysis of variance (ANOVA) for an unbalanced design was computed. A series of 2 (age) x 2 (gender) ANOVA's were computed for each dimension of reaction time/movement time assessed on the reaction simulator. As can be seen in Table 5, across the fifteen trials of the reaction simulator task, the older subjects were slower in terms of reaction time than the young subjects, $F(1,90) = 24.39$, $p < .01$. These ages differences in simple reaction time were due to differences in premotor time $F(1,90) = 13.23$, $p < .01$, rather than in motor time. In other words, cognitive rather than movement differences between the two age groups accounted for the slower reaction time scores of the older drivers. There were no gender differences on reaction time or on the components of reaction time among these subjects.

Table 5

F-ratios Comparing Young and Older Drivers
by Gender
on Reaction Time/Movement Time Responses

	Age	Gender	Age*Gender
Premotor time	13.23** (12.75)	0.45	0.04
Motor time	2.98	3.12	2.27
Reaction time	24.39** (21.09)	0.92	0.32
Movement time	12.05** (9.04)	24.98** (18.74)	6.26* (4.70)
Total response time	19.73** (15.34)	14.99** (11.65)	3.91* (3.04)

*p <.05
**p <.01
Numbers in parentheses represent the percent of variance accountable in the ANOVA model.

In addition, older drivers were slower on movement time than young drivers, $F(1, 90) = 12.05$, $p < .05$; females were slower than males on movement time, $F(1, 90) = 24.98$, $p < .01$. The percentage of accountable variance found (Table 5) would suggest that gender differences were more prominent than age differences on movement time. There was also a statistically significant interaction between age and gender on movement time, $F(1, 90) = 6.26$, $p < .05$. As can be seen in Figure 3, female subjects evidence greater slowing in movement time than male subjects with increasing age. Interestingly, older males were faster on movement time than young females.

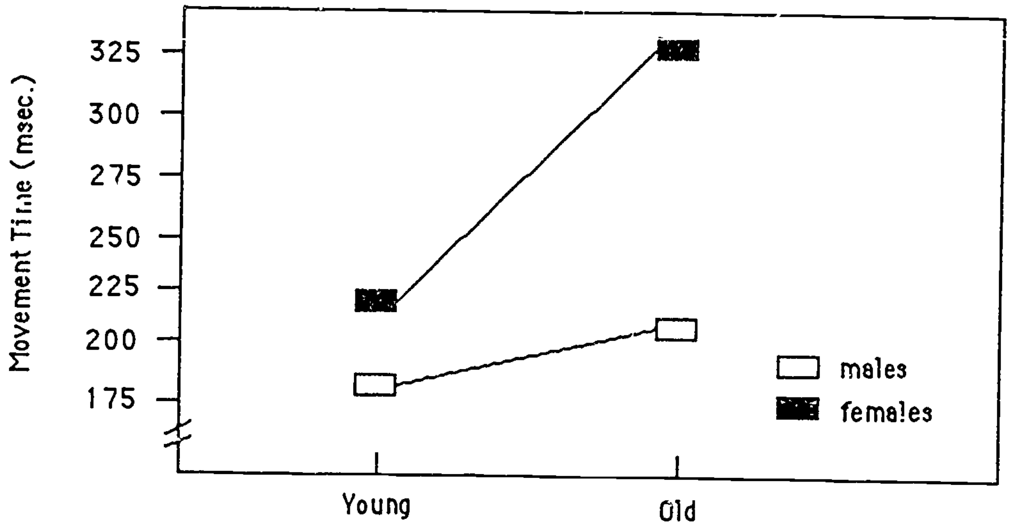

Figure 3. A comparison of young and old age groups on movement time.

In terms of total responsse time, the older drivers were slower than the young drivers, F (1, 90) = 19.73, p <.01, and females were slower than males, F (l, 90) = 14.99, p <.0l. Furthermore, the interaction between age and gender on total response time was statistically significant, F (1,90) = 3.91, p <.05. As can be seen in Figure 4, this interaction paralleled that of movement time; female subjects evidence greater slowing in total response time with increasing age than did male subjects.

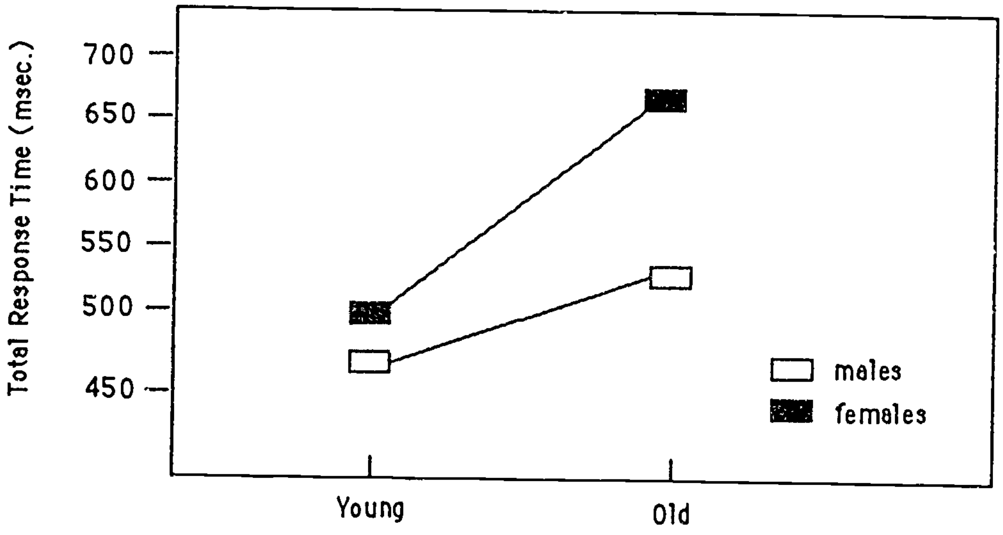

Figure 4. A comparison of young and old age groups on total response time.

Pearson product-moment correlation coefficients were computed to determine the extent to which reaction time and movement time components were independent within each group. As can be seen in Table 6, premotor time correlated significantly (p <.01) with reaction time scores within both age groups, while the correlation coefficients between motor time and reaction time, while statistically significant ($p < .05$), were somewhat lower in each age group. In other words, differences in subjects' premotor time scores (rather than motor time scores) had greater bearing on their reaction time scores.

Table 6

Intercorrelations of Reaction Time/Movement Time Components on Driving Simulator for Young ($n = 40$) and Older ($n = 54$) Drivers

	Premotor Time	Motor Time	Reaction Time	Movement Time	Total Response Time
Premotor time		-.25	.59**	.13	.34*
Motor time	-.04		.36*	.11	.22
Reaction time	.51**	.28*		.40*	.70**
Movement time	.16	.26	.62**		.93**
Total response time	.30*	.29*	.82**	.96**	

*p <.05
**p <.01
Correlation coefficients below the diagonal represent the older age group.

Interestingly, reaction time was correlated with movement time, particularly among older subjects ($p < .01$). Thus, the ability to react quickly to the light stimulus to some extent paralleled these subjects' ability to move quickly from the accelerator pedal and depress the brake. Both reaction time and movement time correlated highly with the total time it took subjects (in each age group) to complete the task.

Age/Gender Comparisons on Cardiorespiratory Efficiency

Table 7 presents descriptive data (means/standard deviations) comparing young and older drivers, by gender, on various resting measures of cardiorespiratory efficiency.

Table 7

Means and Standard Deviations Comparing Young and Older Drivers By Gender On Resting Measures of Cardiorespiratory Efficiency

	Young Males (n = 23)	Young Females (n = 15)	Older Males (n = 18)	Older Females (n = 14)
Self-report fitness	3.55 (0.80)	2.73 (0.59)	3.72 (0.89)	3.77 (0.83)
Resting heart rate	71.17 (9.51)	80.42 (16.53)	75.72 (10.36)	75.93 (12.42)
Systolic blood pressure (resting)	114.87 (16.49)	110.27 (8.71)	136.67 (16.85)	132.29 (13.83)
Diastolic blood pressure (resting)	76.00 (8.46)	71.47 (6.21)	81.67 (7.40)	79.14 (6.92)

A series of 2 (age) x 2 (gender) ANOVAs was computed comparing young and older drivers, by gender, on these measures of cardiorespiratory efficiency. As can be seen in Table 8, there were statistically significant age-group differences when subjects were asked to self-report how physically fit they were at the present time, F (1, 64) = 7.40, p <.01. Surprisingly, older drivers rated their physical fitness higher than did younger drivers. There were also gender differences on self-rated fitness, F (1, 64) = 4.58, p <.05, and the age-gender interaction was statistically significant, F (1,64) = 4.79, p <.05. Inspection of the means (Table 7) revealed that males perceived their physical fitness to be higher than did females.

Table 8

F-ratios Comparing Young and Older Drivers
By Gender on Resting Measures
of Cardiorespiratory Efficiency

	Age	Gender	Age*Gender
Self-report fitness	7.40** (9.20)	4.58* (5.66)	4.79* (5.94)
Resting heart rate	0.15	2.82	2.35
Systolic blood pressure	37.60** (35.75)	1.58	0.00
Diastolic blood pressure	12.61** (15.22)	3.95	0.31

*p <.05
**p <.01
Numbers in parentheses represent the percent of variance accountable in the ANOVA model

There were no age or gender differences on resting heart rate. However, there were statistically significant age differences on (resting) systolic and diastolic blood pressure, $F\ (1,66) = 37.60$, $p < .05$ and $F\ (1, 66) = 12.61$, $p < .01$, respectively. Older drivers evidenced higher systolic and diastolic blood pressure than young drivers. There were no gender differences or significant interactions, although the difference between males and females on diastolic blood pressure approached statistical significance.

Table 9 presents the intercorrelations, by age group, of these various measures of cardiorespiratory efficiency. For the most part, the data indicate that these various measures were independent, although there was a statistically significant positive relationship between young drivers' ratings of their physical fitness and their resting heart rate.

Table 9

Intercorrelations of Resting Cardiorespiratory Measures among Young (n = 37) and Older (n = 31) Drivers

	Self-report Fitness	Heart Rate	Systolic Blood Pressure	Diastolic Blood Pressure
Self-report		-.51**	.11	.26
Heart rate	.18		.10	.00
Systolic blood pressure	-.08	.34		.69**
Diastolic blood pressure	-.26	.12	.38*	

*p <.05
**p <.01
Correlation coefficients below the diagonal are for the older driver.

Cardiorespiratory Efficiency in Relation to Reaction Time-Movement Time

The relationship of cardiorespiratory efficiency to subjects' reaction time/movement time latencies on the reaction simulator was examined among those subjects for whom an estimate of maximal oxygen consumption was obtained. As can be seen in Tables 10 and 11, there was no indication that maximal cardiorespiratory efficiency was related to these subjects' segmented reaction time/movement time scores on the reaction simulator.

Table 10

Intercorrelations of Maximal Cardiorespiratory Efficiency to Reaction Time/Movement Time Measures among Young (n = 28) Drivers

	Maximum Heart Rate	VO2 Max (ml/min)	VO2 Max (ml/kg/min)
Premotor time	-.24	.08	.16
Motor time	.22	.05	-.09
Reaction time	-.36	-.07	-.01
Movement time	-.34	-.22	-.06
Total response time	-.39*	-.19	-.05

*p <.05

Table 11

Intercorrelations of Maximal Cardiorespiratory Efficiency to Reaction Time/Movement Time Measures among Older (n = 9) Drivers

	Maximum Heart Rate	VO2 Max (ml/min)	VO2 Max (ml/kg/min)
Premotor time	-.39	.31	.08
Motor time	.54	-.47	-.37
Reaction time	.43	-.01	-.05
Movement time	.49	-.63	-.64
Total response time	.53	-.46	-.48

Clearly, the low sample size (particularly for older drivers) among subjects for whom an estimate of maximal oxygen consumption was obtained was a major factor precluding the possibility of obtaining significant intercorrelations among these measures. It should be noted, however, that the relationship of maximum heart rate to total response time was statistically significant but low for the young drivers. The relationship between VO2 max and movement time approached statistical significance among the older drivers (p <.07).

Subjects were assigned to an age-related fitness category based on the assessment of their cardiorespiratory efficiency. Subjects were assigned to one of five categories: low, fair, average, good, or high on cardiorespiratory efficiency. For the purposes of the evaluation of cardiorespiratory efficiency in relation to reaction time/movement time, these five categories were collapsed into two fitness categories: low fit or high fit groups. Young drivers who were originally evaluated as low, fair, or average on cardiorespiratory efficiency were categorized as "low fit"; young drivers originally evaluated as good or high were categorized as "high fit." Older drivers who were initially evaluated as low or fair were categorized as "low fit"; older drivers originally evaluated as average or good on cardiorespiratory efficiency were categorized as "high fit." (It should be noted that few, if any, older drivers were initially evaluated as high on cardiorespiratory efficiency.)

A series of 2 (age group) x 2 (fitness category) ANOVA were computed to examine the extent to which age or fitness levels were more important determinants of subject differences on reaction time/movement time. Table 12 represents the descriptive data and Table 13 contains the results of the ANOVA analyses. As can be seen in Table 13, there was again evidence of age differences on reaction time, movement time, and total response time with the older drivers performing more poorly than the young drivers. Differences in reaction time were due to the slower information processing capabilities of the older drivers as evidenced by longer premotor reaction time latencies.

Table 12

Means and Standard Deviations Comparing Young and Older Adult Drivers by Fitness Category on Reaction Time/Movement Time

	Low Fit Young (n = 16)	High Fit Young (n = 24)	Low Fit Old (n = 35)	High Fit Old (n = 19)
Premotor time	177.88 (16.88)	197.50 (42.59)	223.09 (43.04)	211.89 (35.44)
Motor time	108.31 (23.49)	104.92 (27.46)	128.26 (57.30)	155.00 (179.36)
Reaction time	286.19 (29.41)	296.29 (29.75)	351.20 (65.54)	325.00 (36.33)
Movement time	194.44 (61.29)	194.50 (56.42)	265.89 (133.73)	232.00 (60.66)
Total response time	480.44 (7[illegible].05)	490.63 (78.65)	617.09 (184.01)	557.06 (76.64)

Table 13

F-ratios Comparing Young and Older Drivers by Fitness Category on Reaction Time/Movement Time

	Age	Fitness	Age*Fitness Category
Premotor time	13.35** (12.45)	0.41	3.50
Motor time	3.28	0.07	0.62
Reaction time	21.28** (17.38)	4.92* (4.13)	3.15
Movement time	7.25** (7.20)	2.74	0.70
Total response time	13.76** (12.56)	4.19* (3.83)	1.63

*p <.05
**p <.01
Numbers in parentheses represent the percent of variance accountable in the ANOVA model

Interestingly, subjects classified as high on cardiorespiratory fitness had faster reaction times and total response times than those subjects categorized as low on cardiorespiratory fitness. However, the differences in reaction time could not be explained in terms of information processing deficits since there were no statistically significant differences on pre-motor time between high and low fit groups. In addition, there were no statistically significant age group by fitness category interactions.

Age/Gender Comparisons on Joint Range of Motion

Table 14 presents descriptive data (means/standard deviations) comparing young and older drivers, by gender, on range of motion at various joint sites.

Table 14

Means and Standard Deviations Comparing Young and Older Drivers by Gender on Joint Range of Motion

	Young Males (n = 20)	Young Females (n = 13)	Older Males (n = 29)	Older Females (n = 18)
Shoulder				
Right	173.80	178.62	152.47	157.22
	(16.51)	(17.15)	(27.86)	(12.74)
Left	174.35	177.46	150.27	159.56
	(15.89)	(16.31)	(25.85)	(11.22)
Elbow				
Right	135.15	139.77	131.00	140.44
	(7.69)	(7.55)	(23.48)	(5.29)
Left	133.80	132.08	130.87	141.33
	(5.30)	(28.92)	(23.80)	(8.14)
Hip				
Right	112.30	109.62	106.83	113.44
	(17.44)	(17.25)	(21.17)	(27.72)
Left	116.55	111.23	107.83	112.72
	(22.53)	(16.95)	(22.92)	(28.37)
Knee				
Right	133.55	135.00	125.76	121.61
	(24.00)	(8.22)	(21.97)	(29.31)
Left	132.95	132.08	127.03	121.06
	(24.58)	(14.18)	(22.71)	(29.05)
Ankle				
Right	12.40	16.92	14.03	12.50
	(5.00)	(6.37)	(4.78)	(5.46)
Left	13.20	15.77	13.48	13.83
	(6.18)	(7.53)	(4.58)	(6.[illegible])
Torso				
Right	136.44	130.42	110.79	114.78
	(12.53)	(11.76)	(28.49)	(29.83)
Neck				
Right	74.20	72.85	66.17	63.11
	(8.13)	(9.46)	(6.96)	(16.84)
Left	76.45	77.92	65.77	68.28
	(7.94)	(11.93)	(12.35)	(18.55)

A series of 2 (Age) x 2 (Gender) ANOVAs for an unbalanced design was computed comparing young and older drivers, by gender, on these measures of joint flexibility. As can be seen in Table 15, older drivers were less flexible than young drivers at shoulder, torso, and neck joint sites. Based on the percent of accountable variance, the most prominent difference among these two age groups was on shoulder flexibility. Surprisingly, there was no evidence of gender differences on joint flexibility with the exception of (right) elbow flexibility; female drivers were more flexible than male drivers at this joint site. With the exception of the flexibility of subjects' right ankle, there were no statistically significant interactions.

Table 15
F-ratios Comparing Young and Older Drivers
by Gender on Joint Range of Motion

	Age	Gender	Age*Gender
Shoulder			
Right	26.88** (25.55)	0.55	0.19
Left	34.30** (30.24)	1.97	0.17
Elbow			
Right	0.04	9.39* (10.84)	0.17
Left	1.93	1.88	2.62
Hip			
Right	0.66	1.78	3.20
Left	0.01	0.31	2.62
Knee			
Right	2.60	0 00	0.16
Left	0.78	0.28	0.06
Ankle			
Right	0.22	1.18	5.47* (6.60)
Left	0.14	1.18	0.52
Torso			
Right	12.14** (14.04)	1.04	0.27
Neck			
Right	14.51** (15.82)	0.16	0.05
Left	14.08** (15.00)	2.21	0.56

*p <.05
**p <.01
Numbers in parentheses represent the percent of variance accountable in the ANOVA model

Age/Gender Comparisons on ADOPT

Table 16 presents descriptive data (means/standard deviations) comprising young and older drivers, by gender, on the nine derived ADOPT driving functions.

Table 16

Means and Standard Deviations Comparing Young and Older Drivers by Gender on Nine ADOPT Driving Functions

	Young Males (n = 20)	Young Females (n = 15)	Older Males (n = 35)	Older Females (n = 26)
Maneuvers	84.38	78.33	73.12	65.38
	(5.87)	(8.80)	(15.98)	(16.86)
Safe practices	79.78	79.09	65.34	65.05
	(9.00)	(11.27)	(12.80)	(10.64)
Driver processing	99.51	99.73	98.57	96.87
	(1.29)	(1.03)	(3.57)	(5.34)
Vehicle handling	87.08	78.06	68.00	60.80
	(8.54)	(10.26)	(20.32)	(20.36)
Maintaining speed	99.80	99.33	98.69	97.31
	(0.89)	(2.58)	(2.54)	(6.14)
Traffic restriction	84.69	85.93	86.15	85.55
	(15.85)	(14.89)	(10.90)	(10.08)
Signaling	100.00	89.73	90.89	93.73
	(0.00)	(27.19)	(13.54)	(14.19)
Right-of-way	99.24	100.00	98.59	96.51
	(2.35)	(0.00)	(5.76)	(7.16)
Observing	73.91	73.91	50.55	50.09
	(11.37)	(16.06)	(19.81)	(16.58)

A series of 2 (age) x 2 (gender) ANOVAs for an unbalanced design was computed comparing young and older drivers, by gender, on these nine driving functions. As can be seen in Table 17, older drivers performed significantly poorer in terms of maneuvers, F (1, 92) = 16.71, p <.01, safe practices, F (1, 92) = 35.58, p <.01, driver processing, F (1, 92) = 5.32, p <.05, vehicle handling, F (1, 92) = 25.09, p <.01, and observing, F (1, 92) = 43.18, p <.01. Based on the percent of variance accountable by the ANOVA model, the strongest evidence for age differences on these ADOPT functions was in terms of safe practices, observing, vehicle handling, and, to a lesser extent, maneuvers. An overall score was derived for each subject on ADOPT. A 2 (age) x 2 (gender) ANOVA revealed that, overall, older drivers performed more poorly on ADOPT than did young drivers, F (1, 92) = 36.40, p <.01. There was no evidence of sex differences on this overall ADOPT score.

Table 17

F-ratios Comparing Young and Older Drivers by Gender on Nine ADOPT Driving Functions

	Age	Gender	Age*Gender
Maneuvers	16.71** (14.52)	6.24* (5.43)	0.08
Safe practices	35.58** (27.88)	0.85	0.01
Driver processing	5.32* (5.28)	1.81	1.56
Vehicle handling	25.09** (20.55)	4.91* (4.02)	0.06
Maintaining speed	3.63	1.86	0.33
Traffic restriction	0.06	0.00	0.12
Signaling	1.16	0.38	3.98*
Right-of-way	2.83	0.94	1.61
Observing	43.18** (31.94)	0.01	0.00

*p <.05
**P <.01
Numbers in parentheses represent the percent of variance accountable in the ANOVA model

There was also some evidence that female drivers performed more poorly than male drivers on maneuvers and vehicle handling. Furthermore, as can be seen in Figure 5, the interaction between age and gender in terms of driver signaling was statistically significant. Males declined on this driving function; surprisingly, females improved on driver signaling with increasing age.

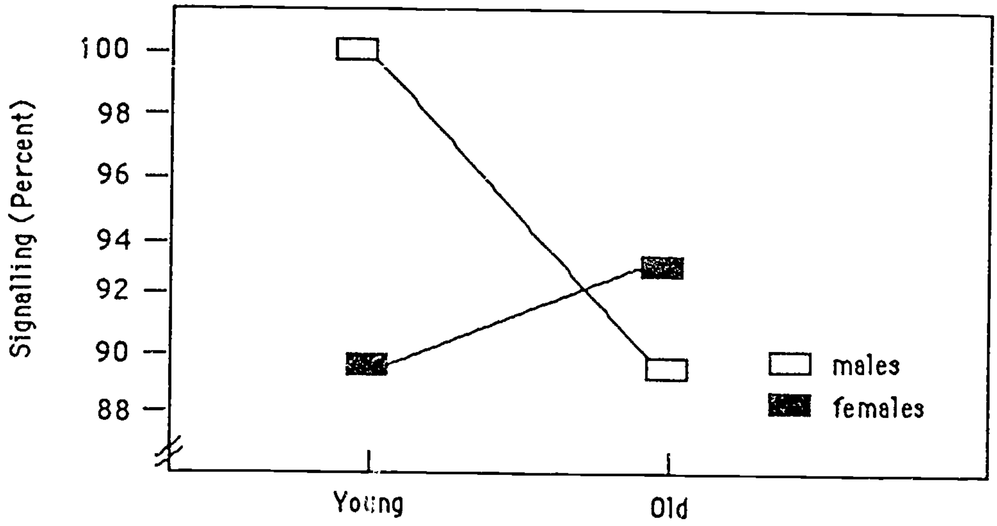

Figure 5. A comparison of young and old drivers on signalling (ADOPT).

Table 18 presents the intercorrelations, by age group, of these nine measures of driving function. These data indicate the extent to which each driving function is independent, i.e., measures a different component of driving. As can be seen in Table 18, the majority of correlations were low or not statistically significant. However, there is evidence that observing and safe practices are measuring highly similar components of driving among both young and older drivers. To a lesser extent, this was also true of the functions of driver processing versus yielding right-of-way.

Table 18

Intercorrelations of Nine ADOPT Driving Functions among Young ($\underline{n}$ = 35) and Older ($\underline{n}$ = 61) Drivers

	M	SP	DP	VH	MS	TR	S	ROW	O
M		-.02	.44**	.65**	.43**	.22	.07	.20	-.16
SP	.51**		.07	.28**	.12	.61**	.04	.00	.87**
DP	.18	.07		.32	.57**	-.01	-.08	.79**	.11
VH	.93**	.57**	.12		.26	.08	-.07	.16	.32
MS	.20	.18	.53**	.16		.28	-.06	-.06	.00
TR	.25	.40**	.17	.20	.05		-.04	-.22	.19
S	.05	.10	-.16	.00	-.08	.23		-.06	-.16
ROW	.12	.00	.91**	.07	.13	.18	-.16		.14
O	.47**	.95**	.05	.56**	.19	.11	-.08	-.03	

*p <.05
**p <.01
Correlation coefficients below the diagonal represent the older driver

Key:

M =	Maneuvers	TR =	Traffic restrictions
SP =	Safe practices	S =	Signaling
DP =	Driver processing	ROW =	Right-of-way
VH =	Vehicle handling	O =	Observing
MS =	Maintaining speed		

Physical Fitness in Relation to ADOPT Performance

A series of 2 (age group) x 2 (fitness category) ANOVAs for an unbalanced design was computed to determine the extend to which age versus cardiorespiratory fitness impacted subjects' performances on the nine ADOPT driving functions. Table 19 presents the descriptive data, and Table 20 presents the inferential statistical data contrasting young and older drivers, by high or low fitness categories, on these nine driving functions.

Table 19

Means and Standard Deviations Comparing Young and Older Adult Drivers by Fitness Category on Driving Performance (ADOPT)

	Low Fit Young (n = 13)	High Fit Young (n = 22)	Low Fit Old (n = 42)	High Fit Old (n = 19)
Maneuvers	82.05 (6.22)	81.63 (8.69)	67.88 (18.61)	74.12 (10.45)
Safe practices	79.15 (10.83)	79.68 (9.54)	64.11 (12.05)	67.65 (11.25)
Driver processing	100.00 (0.00)	99.37 (1.45)	97.31 (5.22)	99.03 (1.32)
Vehicle handling	80.13 (9.03)	85.04 (10.65)	64.25 (22.91)	66.45 (14.13)
Maintaining speed	100.00 (0.00)	99.36 (2.26)	97.81 (5.21)	98.74 (1.91)
Traffic restriction	88.58 (9.74)	83.24 (17.61)	84.69 (9.89)	88.56 (11.49)
Right-of-way	100.00 (0.00)	99.31 (2.25)	97.00 (7.52)	99.25 (2.28)
Signaling	100.00 (0.00)	93.00 (22.73)	89.93 (15.66)	96.89 (6.21)
Observing	70.90 (17.07)	75.69 (10.65)	49.47 (18.61)	52.32 (18.11)

Table 20

F-ratios Comparing Young and Older Drivers
by Fitness Category on Driving Performance (ADOPT)

	Age	Fitness Category	Age*Fitness Category
Maneuvers	11.84** (10.70)	5.68* (5.14)	1.13
Safe practices	36.08** (27.88)	0.96	0.36
Driver processing	3.49	2.91	2.14
Vehicle handling	19.36** (16.56)	5.38* (4.61)	0.12
Maintaining speed	2.82	0.94	0.88
Traffic restriction	0.08	0.00	2.79
Right-of-way	1.67	2.13	1.59
Signaling	0.77	0.62	4.18* (4.28)
Observing	43.67** (31.94)	0.98	0.07

*p <.05
**p <.01
Numbers in parentheses represent the percent of variance accountable in the ANOVA model

As can be seen in Table 20, young drivers exceeded the performance of older drivers on maneuvers, safe practices, vehicle handling, and observing. Most interestingly, subjects classified as high on cardiorespiratory fitness exceeded the performance of subjects classified as low on cardiorespiratory fitness in terms of driving maneuvers and vehicle handling. There were no statistically significant differences between high and low fit subjects on the overall ADOPT score. No interactions were statistically significant except for signaling. As can be seen in Figure 6, cardiorespiratory fitness facilitated signaling among older drivers; surprisingly, however, cardiorespiratory fitness had a negative impact on the signaling abilities of young drivers.

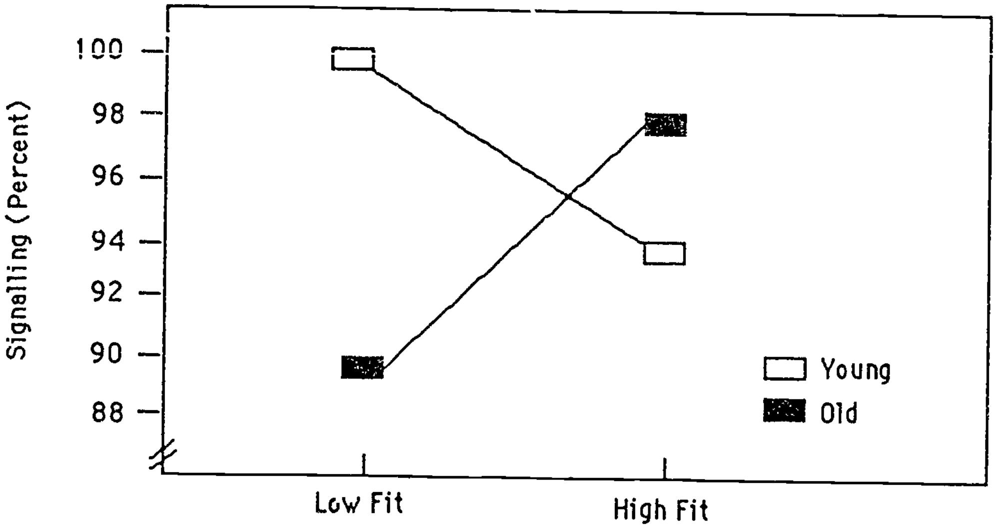

Figure 6. A comparison of young and old drivers, by fitness category, on signalling.

Stepwise multiple regression analyses were utilized to determine the extent to which reaction time/movement time and range of motion were predictive of subjects' performances on ADOPT. Based on the review of literature and the intuitive judgments of the investigators, the following variables were hypothesized to be predictive of each ADOPT driving function.

Maneuvers

Neck rotation
Torso rotation
Shoulder flexibility
Elbow flexibility
Hip flexibility
Knee flexibility
Ankle flexibility

Safe Practices/Driving Processing

Neck rotation
Torso rotation
Premotor time
Reaction time
Movement time
Total response time
Shoulder flexibility
Elbow flexibility
Hip flexibility
Knee flexibility
Ankle flexibility

Maintaining Speed

Premotor time
Reaction time
Movement time
Total response time

Traffic Restrictions

Neck rotation
Shoulder flexibility
Elbow flexibility

Signaling

Premotor time
Reaction time
Movement time
Total response time
Elbow flexibility

Observing

Neck rotation
Torso rotation
Premotor time
Reaction time
Movement time
Total response time
Shoulder flexibility

Table 21 summarizes the results of the regression analyses for the older driver. Ankle flexibility and neck rotation were somewhat predictive of driving maneuvers (R^2 = .19). Movement and reaction time (simulator) and hip and ankle flexibility were predictive of safe practices among older drivers (R^2 = .36); there were no significant predictors of safe practices among young drivers. Knee and elbow flexibility were predictive of driver processing among older drivers (R^2 = .20); there were no statistically significant predictors of driver processing among young drivers. Interestingly, information processing, as operationally defined by premotor time on the reaction simulator, was not predictive of ADOPT driver processing.

Movement time on the reaction simulator was predictive of maintaining speed among older drivers (R^2 = .12) and was also predictive of traffic restrictions among older drivers. Reaction time was predictive of signaling among young drivers (R^2 = .18); there were no predictors of signaling among older drivers. Finally, while there were no significant predictors of observing among young drivers, premotor time/movement time and hip flexibility were predictive (R^2 = .28) of observing among older drivers.

Table 21

Multiple Regression Summary Table for Prediction of Older Driver Performance

Variable	F	p	R2	BETA
Driving Maneuvers				
Ankle flexibility (right)	7.23	.01	.14	1.18
Neck rotation (right)	4.89	.01	.19	0.35
Safe Practices				
Movement time	7.08	.01	.14	-.04
Hip flex (right)	7.49	.01	.25	.31
Reaction time	6.33	.01	.31	.06
Ankle flex (left)	5.67	.01	.36	.54
Driver Processing				
Knee flexibility (left)	7.95	.01	.15	.001
Elbow flexibility (right)	5.29	.01	.20	.002
Maintaining Speed				
Movement time	13.44	.001	.21	-.000
Traffic Restrictions				
Shoulder flexibility (right)	3.56	.07	.07	.002
Shoulder flexibility (left)	3.07	.06	.12	-.004
Observing				
Movement time	6.66	.01	.13	-.06
Hip flex (right)	5.96	.01	.22	.40
Premotor time	5.31	.01	.28	.12

SUMMARY OF FINDINGS

The following are the major findings of the first phase of the research:

1. Older drivers were less proficient overall than young drivers on the ADOPT test, a field-based assessment of driving ability. In large part, these differences were due to the poorer performances of older drivers on maneuvers, vehicle handling, safe practices, observing, and, to a lesser extent, driver processing. There was no evidence of age differences on maintaining speed, traffic restrictions, signaling, and adhering to right-of-ways.

2. Drivers categorized as scoring higher on cardiorespiratory efficiency were more proficient than drivers categorized as low on cardiorespiratory efficiency in terms of driving maneuvers and vehicle handling. However, given the univariate model adopted and the probability of committing Type I errors, these results should be viewed cautiously. Cardiorespiratory efficiency was not a factor in accounting for differences in driver processing abilities.

3. Older drivers showed evidence of less shoulder flexibility and torso/neck rotation than young drivers. To some extent, neck rotation, ankle flexibility, hip flexibility, knee flexibility, and elbow flexibility were predictive of older driver performances.

4. Older drivers evidenced slower reaction times and movement times on the reaction simulator when compared to young drivers. Age differences in reaction time were due to differences in premotor time, i.e., in central nervous system differences in information-processing abilities. To some extent, reaction time and movement time were predictive of safe practices, maintaining speed, and observing among older drivers.

5. While drivers categorized as high on cardiorespiratory fitness reacted more quickly than drivers categorized as low on cardiorespiratory fitness, regardless of age, there was no evidence that cardiorespiratory efficiency was a factor in accounting for age differences in the ability to process information quickly.

DISCUSSION

The first phase of older driver research conducted at West Virginia University was designed to study the relationship between physical fitness and driving ability among older drivers. The findings of this study have implications which pertain directly to the older driver and also provide unique evidence to lend direction to further research.

In general, this study found that the physical fitness of older drivers is related to their ability to safely drive an automobile. Older people with higher levels of physical fitness tended to be more proficient at driving than were older people with a lower level of physical fitness. Of the aspects of physical fitness which were measured, joint flexibility and reaction time were found to be most predictive of driving ability. Cardiorespiratory fitness proved to be somewhat less related to driving ability.

FLEXIBILITY

This study found that, in general, older people had less flexibility of skeletal joints than did younger people. It was also found that, among older people, those with less flexibility tended to have lower driving ability than those with more flexibility. The probable cause for the relation of flexibility to driving ability is that the safe operation of an automobile requires freedom of body motion. Restricted joint movement makes driving difficult for the older driver. Basic vehicle control and guidance operations such as steering around a corner or observing behind before changing lanes require quick body movement and an ample range of joint motion.

REACTION TIME

It was found that older drivers tended to have slower reaction time than did younger drivers. The age-related differences in reaction time proved to be due to differences in premotor (information-processing) time rather than in movement time. This finding is in accordance with expectations based on the information processing model. The older person requires a longer period of time to recognize a stimulus and select a response than does a younger person. The difference in premotor time between young and old was expected to be greater than the differences in movement time.

This study also found that simple reaction time was related to the safe practices, maintaining speed, and observing aspects of driving ability. No relation was found between simple reaction time and the more complex driving tasks which involve a higher level of driver processing. The lack of relationship between simple reaction time and driver processing may be due to the brief information processing time involved in a simple reaction. A relationship between reaction time and driver processing may be revealed if the reaction time measurement requires a longer information processing period, such as in a complex reaction time measurement. The complex reaction time measurement may be more predictive of driver processing than was the simple reaction time measurement.

CARDIORESPIRATORY FITNESS

This study found that a relationship existed between an older driver's cardiorespiratory fitness and his/her driving ability. Those older drivers with higher levels of cardiorespiratory fitness tended to be more proficient at the maneuvering and vehicle handling aspects of driving ability than were those older drivers with lower cardiorespiratory fitness. The drivers with high cardiorespiratory fitness also tended to have lower reaction times than did the drivers with low cardiorespiratory fitness. No relationship was found between cardiorespiratory fitness and driver processing or between cardiorespiratory fitness and the information processing portion of reaction time.

Although a relationship did exist between cardiorespiratory fitness and driving ability, the linking did not prove to be through information processing, as had been predicted by the information processing model. The aspects of driving ability which were related to cardiorespiratory fitness were those which involve low levels of information processing. This would suggest that there is not a cause-and-effect relationship between cardiorespiratory fitness and driving ability. The probable explanation is that an unidentified variable or variables is responsible for the changes in both cardiorespiratory fitness and driving ability.

IMPLICATIONS FOR THE OLDER DRIVER

The findings of this study may be of direct benefit to the older driver. Since evidence was found that a relationship exists between the physical fitness and the driving ability of older people, older drivers who are concerned about their driving ability may attempt to enhance their driving skills by becoming more physically fit. This study suggests that the greatest gains in driving ability could be made through improvements in joint flexibility.

The relationship between physical fitness and driving ability may eventually have two types of impact on the older driver. First, the older driver may use an exercise program to improve his or her own driving ability. Second, if a sufficiently strong relationship is established by further research, the older driver may be given a test of physical fitness as part of a driver's licensing examination to determine the level of his/her driving ability.

IMPLICATIONS FOR FURTHER RESEARCH

The findings of this study have indicated several areas for productive future research.

To verify the connection between flexibility and driving ability of older people, an experimental study is needed. A controlled intervention of flexibility training conducted in a longitudinal study would reveal the effect of increased flexibility on the driving ability of older adults.

To clarify the relationship between reaction time and driving ability among older people, a complex reaction time measurement is required. Comparing complex reaction time to driving ability may reveal a connection between premotor time and driver processing tasks.

Since cardiorespiratory fitness did not prove to be related to information processing, alternative means to improve driver processing need to be investigated. An intervention based on mental imagery would be a different type of attempt to influence information processing. A longitudinal study may reveal the effects of an intervention such as mental imagery on the driving ability of older people.

This study also served to refine test measures which may be used again in future studies. The driving ability test was refined by collapsing the subgroups which showed small amounts of variance into fewer, more variable groups. The nine subgroups utilized in this study--maneuvering, vehicle handling, traffic restrictions, safe practices, observing, maintaining speed, signaling, right of way, and driver processing--could be reduced to two more meaningful subgroups. The two subgroups in the revised test are vehicle handling and safe practices.

PLANS FOR PHASE II RESEARCH

Plans for the second phase of older driver research at West Virginia University include the verification of research findings from Phase I and the use of knowledge and expertise gained from the first year of research to examine some promising new areas of investigation.

A longitudinal research plan has been designed to study and contrast the effects of flexibility training and mental imagery training on the complex reaction time and driving ability of older drivers. The flexibility training is expected to have a positive influence on the vehicle handling aspects of driving ability. The imagery training is expected to impact the safe practices aspects of driving ability which include information procesing tasks.

Two types of imagery training will be utilized. The task-oriented imagery training will be administered as a nontraditional form of driver training. The first type of imagery training will include coping skills which allow the older driver to relax and concentrate in uncomfortable traffic situations. The other type of imagery training will involve mental practicing of specific driving task skills. This mental practice may increase older driver skill in performing specific tasks which the driver finds difficult.

Phase II research will be conducted over an eleven-week period involving three testing periods and two intervention periods. The results of the Phase II study will be published in the second volume of the final report.

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