U.S. Department
of Transportation
National Highway
Traffic Safety
Administration

Conference on Research and Development Needed to Improve Safety and Mobility of Older Drivers

August 23-24, 1989
Lister Hill Conference Center
National Library of Medicine
Bethesda, Maryland

Preface

This document synthesizes the proceedings of the conference on "Research and Development Needed to Improve Safety and Mobility of Older Drivers," held August 23 and 24, 1989. Joint sponsors of the conference were the National Institute on Aging, the Centers for Disease Control, the Federal Highway Administration, and the National Highway Traffic Safety Administration.

A key objective of the conference was to identify the research required to minimize older driver risk while maximizing older driver mobility. Specifically, conference participants presented and reviewed the latest research findings in functional areas related to driving abilities. They also identified researchable issues that apply specifically to the needs of the older driver.

The researchable issues identified herein are based solely on participant discussion. These issues, and the order in which they are presented herein, do not necessarily reflect the policies, opinions, or priorities of the sponsoring agencies.

The idea of the conference emanated from discussions between John Eberhard of the National Highway Traffic Safety Administration (NHTSA) and Dan Foley of the National Institute on Aging (NIA). Eberhard and Robin Barr (NIA) were then assigned by their respective agencies to develop the agenda and serve as co-chairmen of the conference. Other individuals who made significant contributions to the development of the conference were: Constance Atwell, National Eye Institute; Harold Bishop, NHTSA; Terrence Chorba, Centers for Disease Control; Richard Sattin, Centers for Disease Control; James Fozard, NIA; Evan Hadley, NIA; Truman Mast, Federal Highway Administration; Sam Yaksich, AAA Foundation for Traffic Safety; Anthony Yanik, General Motors Corporation; and Stephen Stiles, American Association for Retired Persons.

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1. Introduction

On August 23 and 24, 1989, a multidisciplinary conference addressing the needs of the older driver was held at the Lister Hill Conference Center, National Library of Medicine in Bethesda, Maryland. The conference, "Research and Development Needed to Improve Safety and Mobility of Older Drivers," was hosted by four agencies: the National Institute on Aging (NIA), the Centers for Disease Control (CDC), the Federal Highway Administration (FHWA), and the National Highway Traffic Safety Administration (NHTSA).

Goals

These sponsoring agencies are interested in minimizing the risks to older drivers and—simultaneously—maximizing older driver mobility. The link between relevant physiologic conditions and driving functions is unclear. Also, the influence of diminished functional abilities on driver performance has not been adequately determined.

The conference sought to identify the research required to answer this question. Specifically, the conference objectives were:

- To present and review the latest research findings in functional areas related to driving abilities.
- To identify researchable issues that apply specifically to the needs of the older driver.

Additionally, the conference sought practical applications of the research and their implications as they apply to function and intervention.

Structure

Because the conference focus was on function rather than illness, participants were leading functional specialists. The conference brought together 170 specialists in such diverse areas as ophthalmology, epidemiology, gerontology, pharmacology, human factors, and highway and vehicle safety and design. Participants included researchers, clinicians, administrators, policy analysts, and advocates. Federal and state agencies, universities, medical schools, private practices, independent consulting groups, vehicle manufacturing industries, and foundations and associations such as the American Automobile Association and the American Association for Retired Persons were all represented.

The conference was a two-day event consisting primarily of plenary sessions and planning sessions. It opened with welcoming remarks that stated the conference objectives and noted the diversity of issues. These brief remarks were followed by the keynote address, which emphasized the research needs related to the older driver.

Four of the conference's six plenary sessions were held on the first day. Each plenary session summarized current research on a given topic area as it related to older drivers. The plenary topics were:

- General medical conditions.
- Dementia.
- Cognition.
- Vision.
- Motor control.
- Medication and alcohol.

Each session was conducted by a panel consisting of a chairperson, a major presenter, and at least two discussants. Most sessions were followed by a question-and-answer period; however, few questions could be answered given time limitations.

At a dinner following the first day's plenary sessions, a staff member of the House of Representatives related recent Congressional events affecting older drivers. A second dinner speaker discussed Transportation 2020, a national planning effort in which the country's highway transportation needs are being assessed through the early part of the 21st century.

The plenary sessions continued through the morning of the second day, at which time the group broke for lunch and listened to an address on recent research findings of the National Institute on Aging. After midday, the seven concurrent planning sessions began. At these sessions, participants identified future research directions in each of the following topical areas as they relate to older drivers:

- General assessment.
- Vision assessment.
- Functional assessment.
- Driver intervention.
- Vehicle design.
- Highway design.
- Basic research.

The objective of the planning sessions was to determine discrete researchable issues. Although the format of the sessions varied, most planning session leaders made brief prepared statements, citing specific ideas and parameters. They then distributed blank cards on which participants were asked to note preliminary research issues. Following this, session leaders presented the issues to the groups for discussion and refinement.

The planning sessions were followed by a consolidated summary session in which the researchable issues identified during the planning sessions were itemized. Conference closing remarks followed the summary session.

About This Report

This document, which is a synthesis of the conference proceedings, places particular emphasis on the plenary and planning sessions. It has been organized to parallel the general structure of the conference itself. Special presentations—the conference welcoming and closing remarks, keynote address, and dinner and luncheon speeches—are summarized in Chapter 2. They provide in-depth background on the issues. Chapter 3 contains a synthesis of the plenary sessions for each of the functional areas. Chapter 4 documents the issues emerging from the planning sessions; it also includes a summary of the considerations behind the issues.

Completing the document are three appendices. Included in the appendices are the conference agenda, a list of the participants, and the rosters of each planning session.

2. The Older Driver: Traffic Safety and Mobility

Research issues related to the safety and mobility of older drivers were identified, and background and overview information provided, in several special presentations complementing the conference plenary sessions. Experts and senior officials from the fields of transportation policy and planning, transportation research, behavioral and social research, and injury epidemiology and control drew on their respective backgrounds to summarize current findings, ongoing efforts, future plans, and pending issues with regard to the older driver. Specifically, speakers addressed:

- Broad changes proposed for the U.S. roadway system to meet the needs of older drivers.
- The latest findings from research on aging.
- Trends in public sector funding of older driver programs and research.
- Prioritization of older driver research issues identified during the conference.

Synopses of these special presentations—made during the conference opening session, in dinner and lunch addresses, and in closing remarks—are included in this chapter.

Profile of the Older Driving Population

In welcoming participants to the conference, Adele Derby, Associate Administrator for Plans and Policy of the National Highway Traffic Safety Administration (NHTSA), established the needs and concerns of the older driver, and placed them within a societal context:

- The American population is aging.
- Older Americans are healthier, wealthier, and more mobile than were previous cohorts.
- Most older Americans are licensed drivers and take most of their trips by automobile.
- Mobility, especially by automobile, is essential to the lives of older Americans.
- America's roadway system—its roads, signs, vehicles, licensing, and training—was designed for healthy 25-year-olds, not for older drivers.

The challenge is to adapt this system to promote the mobility and safety of older persons in the face of limited funding at all levels. Specific issues for consideration include:

- *Roadway design.* Most researchers agree that roadway changes could assist older drivers. Such changes include larger and better-illuminated signs, improved roadway markings, and improved left-turn geometrics (such as separate left-turn lanes). All of these changes, however, are expensive to implement. Given their cost, how important are roadway improvements to the safety and mobility of older drivers? And, more fundamentally, should roadway design criteria be changed to reflect an older driving population?
- *Vehicle design.* Can controls and displays be adapted to serve older drivers better? Do current restraint system designs and crashworthiness standards properly balance the protection requirements of older versus younger occupants?
- *Driver licensing.* Current licensing examinations are inexact, crude tools for certifying driver ability. How can these examinations be improved, and at what cost? How should medical history and treatment affect licensure?

- *Driver training.* Recent results in the State of California suggest that current retraining programs for older drivers may reduce traffic violations and crash injuries. Will these results hold true for a broader population? Can the current retraining course be improved?

Ms. Derby concluded her remarks by advising participants to think broadly, but realistically, in meeting the conference objective of identifying and prioritizing the short- and long-term older driver research agenda.

Issues in Older Driver Research

A number of complex issues surround the central question of ensuring the mobility and safety of older drivers. These include examining the trade-offs between mobility and safety and those between the risks and benefits to older drivers and society as a whole. Other issues revolve around developing and implementing transportation policies in answer to the specific needs of the older driver. In the conference keynote address, Dr. Patricia F. Waller, Director of the Transportation Research Institute at the University of Michigan, explored many of these issues at length.

Mobility Versus Safety

There are always tradeoffs between mobility and safety regardless of the population segment under consideration. These tradeoffs, however, become most critical when dealing with the older segment, which is increasing both in number and in proportion to the total driving population.

Mobility is essential to the well being of all persons but is of special significance to older individuals. Although it is obvious that health can affect mobility, it may be overlooked that mobility can also affect health. Safety and health are a key concern when discussing older drivers. It is well established that, as a group, older drivers are more likely to be seriously injured or killed in a crash of given severity. This increased vulnerability is associated with both immediate and delayed consequences of crashes. Older drivers who survive crashes are still more likely than younger drivers to succumb later to secondary complications, such as sepsis.

Are older drivers at greater risk of crash involvement? The answer depends on how risk is calculated. For example, based on the number of crashes sustained by older drivers in relation to the number of licensed older drivers, crash risk is no higher than that for drivers in general. With regard to absolute number of crashes, which is a statistic of interest to both departments of motor vehicles and insurance companies, the older driver poses no special problem. However, when crash risk is correlated with exposure to risk, differences between younger and older drivers do arise.

For example, if Driver A drives 5,000 miles a year and has one crash, and Driver B drives 100,000 miles a year and has two crashes, Driver B is—in terms of absolute number of crashes—twice as hazardous a driver as A. Correlating crash risk and exposure to risk (that is, number of miles driven), Driver B's performance is 10 times better than A's. Thus, when considering crash risk per mile, the older driver may constitute the most hazardous group of drivers in the population.

This risk of crash per mile driven is lowest for drivers in their late twenties up to their middle fifties. Crash risk begins to climb in the late 50s with the rate of risk increase accelerating with increasing age. As a group, older drivers try to limit their driving to times and places where risk is lower; they avoid driving at night, in heavy traffic, or in other more demanding circumstances. Even though older drivers restrict themselves to safer exposure, their crash rate increases. Such a relationship has special implications for the employment of older drivers in situations that require them to meet driving schedules on a routine basis.

The Older Driver Cohort

The changing demographics of our population—the so-called "graying of America"—are mirrored in our driving population. Between 1976 and 1986, the number of licensed drivers in North Carolina increased by 26 percent. In the same decade those drivers age 65 and older increased 83 percent, while those age 75 and older increased 131 percent. Drivers younger than age 25 actually decreased as a proportion of the total licensed population. Consequently, whatever enhanced risk older drivers may pose may lead to heightened problems as their numbers and driving increase.

Cohort differences may, to some extent, diminish this effect. Today's drivers of age 65 and older differ from the drivers of age 65 and older 20 years ago; in turn, they also are different from those who will be 65 and older 20 years hence. These differences (e.g., years of driving experience, etc.) are especially marked for older female drivers, who have shown especially great increases in number licensed and amount of driving.

Cohort differences may result in unprecedented problems among older drivers. For example, the nation's older population currently uses medications at a higher rate than the population in general; they may also use alcohol. However, 25 years from now, the older driver cohort may consist of many individuals who routinely use drugs whose effects on driving are still largely unclear. The possible interactions with aging are also unclear.

The bottom-line message is that it cannot be assumed that the characteristics of today's older drivers will necessarily be the same as those of older drivers at any future time.

Defining the Older Driver

If aging drivers show an increasingly accelerated risk of crash, and if society as a whole is put at greater risk given the rising numbers of older drivers, why can't drivers above an age associated with an unacceptable risk level be removed from the licensed population? The problem is not that simple, for these reasons:

- There is a difference between chronological age and functional age.
- There is no agreement as to the definition of "older" driver.
- There must be no appearance of discrimination against older people in efforts made to protect the public from potentially hazardous drivers.
- There is a shocking lack of basic information for use in developing rational policies to determine licensure qualifications.
- The highway transportation system was never designed with the older driver in mind.

Each of these factors is described below.

Chronological Age Versus Functional Age. While available evidence shows a gradual deterioration in performance associated with a gradual increase in crash risk, the data are based on group performances. The individual performances that make up these group curves look very different. Driver A may begin to show decline in the early 50s and be totally unable to function by age 60; Driver B may continue with little apparent difficulty until a much later age. Older drivers in fact show the greatest variability of any age group. This variability in performance on various measures of cognition, vision, complex reaction time, and other driver-related skills has been well documented. While the probability of deteriorating performance increases with increasing age, this fact of individual variation means that no specific chronological age may be singled out as an appropriate age at which a license should be denied automatically. Indeed, no State has such a policy.

It is also claimed that this group of drivers may show the greatest within-subject variability; that is, the same driver may perform quite differently from one time to the next. The implications for licensure are obvious; ordinarily only one passing performance is required, and the applicant may take the test again and again until he or she does pass. Because the probability of deteriorating performance rises at an accelerating rate with increasing age, a few States have instituted more intensive evaluation beginning at a specific chronological age such as 69 or 75. These practices and their effectiveness have not been fully examined, nor is there sound evidence that the more intensive evaluations are effective in improving older driver performance.

Definition of "Older." "Older" probably is most often defined as "65 and older," although some studies classify drivers in their late 40s or early 50s into this category. However, "65 and older" can be misleading. Because the curve showing increased crash risk is accelerating, it can be argued that drivers in their 60s are, as a group, qualitatively different from those in their 70s, and certainly different from those in their 80s. Consequently, some investigators have attempted to classify drivers into various "older" groups, such as "young-old" (55-64), "middle-old" (65-74), "old-old" (75-84), and "very old" (85 and older). Such classifications can be useful reminders of the differences among different older groups, but it is also important to remember that individual members of these categories may not adhere to the overall norms.

Age Discrimination Versus Administrative Liability. Efforts to remove older drivers from the licensed population in the absence of clear evidence that they pose a significant hazard will almost certainly result in legal consequences. On the other hand, States' immunity to suit has been removed or greatly limited, and driver licensing administrators have been brought into court for licensing drivers who then proceeded to cripple or kill other highway users. For example, suppose a given State, which requires licensure renewal in person every 4 years, renews a license for someone age 93. Three years later, that driver runs a traffic signal and injures someone. It is then discovered that for the last 2 years, the driver in question has scarcely been able to see or has shown evidence of extreme confusion. Can the licensing agency truly defend its position that the driver was apparently problem-free 3 years earlier? Should overwhelming evidence that the probability of deteriorating performance is rising rapidly as age increases be ignored? This example is not entirely hypothetical. Licensing authorities are having to defend themselves from such actions.

Lack of Adequate Guidelines. No basic information is available for effective evaluation of the age at which performance is adversely affected. Even in the case of pilots, for whom much more expensive and thorough evaluations have been conducted, the information does not exist. A 1981 report of the National Institute on Aging (NIA), which examined age 60 as a mandatory age for retirement of airline pilots, concluded "that there is no convincing medical evidence to support age 60, or any other specific age, for mandatory pilot retirement." However, it also found that:

> "age-related changes in health and performance influence adversely the ability of increasing numbers of individuals to perform as pilots with the highest level of safety and, consequently, endanger the safety of the aviation system as a whole. Moreover, the panel could not identify the existence of a medical or performance appraisal system that can single out those pilots who pose the greatest hazard because of early, or impending, deterioration in health or performance."

The report recommended that the age-60 limit for air carrier pilots-in-command and first officers be retained. It also recommended that the Federal Aviation Administration or other appropriate Federal agency conduct the research necessary to consider changing the age-60 rule. Whether, and to what extent, such information exists 8 years later is not readily available, but it is at least as important for licensing drivers as for licensing pilots.

The Highway Transportation System. Although aging and its accompanying impairments are real, it is also important to recognize that the highway transportation system has really never considered the older highway user. To the extent that driver licensing programs have been designed at all, it is to qualify the young beginning driver. Vehicle design is only beginning to consider the capabilities and limitations of older drivers. And, finally, highways are built according to standards based on performance measures of young males.

System Modifications Aimed at the Older Driver

Modifications to accommodate the older driver can be made in four major areas as follows.

- *Driver evaluation.* Our licensing programs are desperately in need of better information on what drivers can and cannot do and what skills and capabilities are truly related to safe driving. Furthermore, if procedures are to be adopted, it is necessary that they be politically acceptable and reasonably priced.

- *Driver training*. Training or retraining older drivers is finally being recognized as a possible approach to modifying performance of this age group, many of whom have never experienced any formal driver education. Because their problems are often different, the usual driver education designed for young beginning drivers is not appropriate.

- *Vehicle modification*. The automotive industry is finally considering the older driver in vehicle design, but again, much of the necessary research has not been conducted.

- *Highway modification*. The roadway itself can be modified so as to facilitate the driving task for older users. Drivers do not need to adapt to the highway transportation system; the system can be made flexible to adapt to driver needs. No one functions at optimal level at all times, and our highway transportation system must take into account the characteristics of the real world driving population and not be designed for a hypothetical ideal.

Implementation of these modifications will help older drivers meet their own transportation needs for as long as possible. This self-reliance in turn benefits the larger society in two ways:

1. *By facilitating the driving task for all roadways users*. To the extent that the driving task is facilitated for the older driver through improved signing and highway markings, simplification of dash displays and vehicle controls, and more effective driver evaluation procedures, all drivers are helped. The same signing improvements that help the older driver also help the fatigued driver, the preoccupied driver, the impaired driver, the driver who, for whatever reason, may temporarily be functioning at less than optimal level.

2. *By reducing the transportation burden on the larger society*. To the extent that the community can enable older persons to continue to meet their own transportation needs, the community is less burdened by these needs.

It should be noted, too, that transportation needs will not cease with loss of licensure. Effective ways to coordinate licensing programs with alternative transportation for older citizens need to be developed so that, as older drivers experience restriction or denial of licensure, they can be directed toward other community resources and services to meet their transportation needs.

The American population is aging; with this increasing age comes change, some of which may affect driving performance. Restriction of driver exposure is not an acceptable first solution. In this regard, Dr. Waller urged conference participants to consider the available research information and evaluate it critically. She also noted that an information base is needed around which to develop a system that enables an older person to function effectively and safely for as long as possible before being moved into alternative transportation programs.

Highway Systems of the Future

Major current and projected efforts address the broad issue of the nation's surface transportation program; aspects of these specifically target the needs of the older driver. Two speakers at the conference's dinner summarized key public and private sector undertakings in this area.

Congressional Plans and Progress

The Interstate Highway System will be completed in 1993. Consequently, the nation's surface transportation programs are expected to undergo a major redefinition. This redefinition will undoubtedly address the needs of the older driver. Caryll Rinehart, a professional staff member of the Public Works and Transportation Committee of the U.S. House of Representatives, discussed key congressional efforts in this regard.

Glenn Anderson, Chair of the Public Works Committee, has long supported highway safety; he is especially committed to highway construction improvements that will benefit the older driver. Recently, Rep. Anderson authored a study conducted by the National Academy of Sciences (NAS) that identified problems which may inhibit the safety and mobility of older drivers. This study, authorized by the Surface Transportation Assistance Act of 1987, dovetailed with an ongoing related project initiated by the Transportation Research Board (TRB) in 1986.

The recommendations of the NAS study panel will be reviewed by the Subcommittee on Surface Transportation as part of its overall highway safety focus in connection with the highway reauthorization process. Subcommittee Chair Norman Mineta has made it clear that his mission is to preserve and enhance safety through a continued—and even expanded—Federal commitment to safety research, safety applications, and safety projects. This expanded commitment will include a reexamination of funding levels and requirements for highway safety construction and hazard elimination projects to ensure that the needs of older drivers are addressed through improved safety design, devices, maintenance, or a combination of these strategies.

Transportation 2020

Carlton C. Robinson, Executive Vice President of the Highway Users Federation, described a major 2-year undertaking of the public and private sectors to design and develop a surface transportation program that will enhance the safety and mobility of all highway users in the year 2000 and beyond. This effort, called Transportation 2020, was initiated to fulfill two objectives:

1. *Prevent worsening traffic conditions and gridlock from becoming a permanent feature of life.* Traffic is increasing in every part of the country; in many areas, it is expected to double by the year 2000. At the same time, 52 percent of the nation's pavement needs work, 42 percent of its bridges are deficient, and 61 percent of peak hour travel on urban interstates is congested, up 50 percent since 1975. Unless corrective action is taken, the cost of traffic congestion—measured in time lost from work and other delays—may increase by as much as 400 percent in the coming years.

2. *Establish a national transportation plan that addresses the increase in traffic related to the mobility needs of a growing economy.* The use of cars and trucks underpins the nation's economy. Every product moves by road at some point between production and consumption, and 93 percent of American workers commute to their jobs by motor vehicle. In addition, reliance on the private vehicle is growing: for example, 80 percent of the trips by persons older than 65 are currently made in automobiles.

The Highway Users Federation is recommending the Transportation 2020 plan to Congress for enactment as the surface transportation program beyond the Interstate.

Transportation 2020 Plan Components. The Transportation 2020 plan evolved from a series of 65 public forums held across the country in 1987 and 1988 and a follow-up conference, the Highway Users' Congress on Transportation Futures, held in Washington, DC. The plan calls for specific programs to ensure a high quality of road and bridge maintenance, improve highway safety, relieve urban congestion, expand Interstate-type highway service into areas not presently served by Interstates, and protect service on existing Interstates.

The plan also would set goals and measure progress toward relieving traffic congestion and solving other problems. In urban areas, it would improve both roads and transit services. In rural areas—particularly those that are economically depressed—it would upgrade roads and bridges and help develop scenic routes to serve growing numbers of tourists and recreational drivers.

Traffic safety would receive increased emphasis under Transportation 2020. Funding of specific techniques for reducing fatalities and increasing roadway safety—such as improved and properly maintained signs, signals, and markings—would be increased. Traffic safety would also be enhanced by increasing the funding for research and development.

Implementation of Roadway Improvements to Enhance Safety and Mobility. The Highway Users Federation has recommended a 10-year research program on intelligent vehicle highway systems and has stressed the implementation of current traffic management actions to enhance both safety and mobility. For instance:

- Every U.S. city could improve the movement of surface traffic through its signalized intersections using on-the-shelf technology and equipment. This upgrade could be done either on an areawide basis and involve several hundred intersections or it could be confined to a single arterial or corridor.

- Similarly, funds could be invested today to use the best, brightest, and newest street and guidance signs, signals, and pavement markings to help the aging traveling public.

In addition, in cooperation with the Federal Highway Administration (FHWA), the Federation is sponsoring a workshop on implementation of the roadway improvements recommended in TRB Special Report 218, "Transportation in an Aging Society." These recommendations include:

- Inclusion of a performance standard for signs in the *Manual on Uniform Traffic Control Devices* (MUTCD). The standard should be based on the minimum distance needed by older drivers for visibility. The standard may require bigger and brighter signs and wider use of advance signs.

- Development of systematic procedures by State and local governments to inspect and maintain signs to ensure their optimal condition, mounting, contrast, and retroreflective performance.

- Provision of roadway markings (i.e., painted edge lines, raised pavement markers, and post mounted markers) that meet the highest accepted standard by State, county, and local agencies.

- Greater emphasis by State and local governments on routine inspection and maintenance of roadway markings, including their retroreflective performance.

- Evaluation by local and state traffic engineers of intersections with signal timing that assumes a walking speed of 4 feet per second or faster. At intersections regularly used by older persons, traffic engineers should either (1) phase traffic lights to provide adequate time for older pedestrians to cross or (2) provide pedestrian-activated signals, refuge islands at the median, or other design improvements.

- Local government enhancement of the pedestrian environment by incorporating pro-pedestrian features into subdivisions and redevelopment plan approvals and into zoning regulations.

- Conformity to the standards recently adopted by the MUTCD to ensure uniformity in pedestrian signals among communities. In addition, the meaning of those standards must be communicated to the public more extensively by local traffic safety officials.

- Development of a procedure for determining the need for dedicated left-turn lanes by the American Association of State Highway Transportation Officials. It should provide guidance on use of this procedure in the *Highway Design Guide*.

Results of Recent Research on Aging

During the 15 years in which the NIA has funded basic research on the topic of aging, the field has grown enormously. Ms. Matilda Riley, NIA Associate Director for Behavioral and Social Research, discussed highlights of Institute research at the conference luncheon presentation.

NIA research has resulted in an enhanced understanding of older adults, an understanding far removed from earlier stereotypes. For example, it is now known that not all of the declines concomitant with aging are universal, inevitable, or irreversible. Further, methods of intervention have been developed that can help individuals adapt to aging declines—or sometimes even prevent them.

These results are exciting, but they barely touch on the array of problems facing older adults. One of the most pressing of these problems is driving. While NIA-supported work hints at how basic research can contribute to resolution of the driving problem, answers are still too few.

General Findings

Four general findings derived from NIA's basic research relate to the older driver:

1. Research must address population diversity.
2. Core research is needed to make accurate predictions.
3. Interventions must be carefully planned.
4. Future research must address the driving environment.

The findings are summarized below.

Research Must Address Population Diversity. Much recent research does not acknowledge the diversity of America's older population. Because it is based instead on averages, this research is likely to misrepresent the population. Classifying older Americans into various subgroups enables researchers to better account for the population's diversity. Classification schemes include grouping by chronological age, degree of disease or disability, and functional status. Of these, the last method is probably the most useful, since it best allows for group—and individual—diversity. Functional status can differ from moment to moment (depending, for example, on the stress of a given driving situation).

In the future, researchers must evolve classification systems that are meaningful with regard to older drivers. A minimal goal might be to produce accident statistics for older adults subdivided by relevant aspects of their diversity.

Core Research Is Needed to Make Accurate Predictions. It would be tempting to predict that the accident rates and driving patterns of future cohorts will show an improvement over today's cohort of older drivers—even without planned interventions. Such a prediction cannot be made with any certainty or accuracy; however, because each succeeding birth-cohort differs from its predecessors in the way it ages.

To address this difference, a core of research on cohorts of people who are not yet old is needed. Data from this research can be used to predict how future accident rates and driving patterns will likely differ from current rates and patterns. Without this research core, our ability to anticipate future driving needs and patterns will be severely constrained.

Interventions Must Be Carefully Planned. Training and other methods of intervention work extremely well in a variety of areas. Research shows, for example, that a single training session for subjects healthy in one kind of reasoning can have a beneficial effect on their performance as much as 7 years after training completion.

Interventions work best when they are planned with a detailed knowledge of both the task to be performed and the targeted population. Careful analysis of the problems of older drivers is therefore doing much to identify the likely structure of successful interventions. This approach, cautioned Ms. Riley, must be maintained, since premature interventions that fail because of insufficient planning can damage the credibility of the intervention method.

Future Research Must Address the Driving Environment. In studying the problem of older drivers, researchers must be concerned not only with the drivers themselves but also with the environment with which these drivers interact. This environment includes the present and possible future design of vehicles and other modes of transportation, the design of highways and road signs, and the social situations in which driving occurs. (An interesting concept related to this last is the possibility of a "co-pilot.") Although the environmental element has been noted in the past, much further consideration and a great deal more research are needed. Subsequently, successful interventions can—and must—be made in the driving environment, not only in the driver.

Ordering of Researchable Issues

At the conclusion of the concurrent planning sessions, conference participants gathered for another plenary session. Here, session leaders presented lists of the researchable issues identified in each session.

Following the presentations by individual session leaders, Richard Pew, from Bolt Beranek and Newman Laboratories, Inc., summarized the issues identified.

Concluding Remarks

In the concluding session, Dr. Richard Waxweiler from the Centers for Disease Control (CDC) and representatives from the other sponsoring agencies described in general terms the status of research within their respective agencies related to older drivers and pedestrians and the applicable procedures for funding research activities. It was emphasized that firm research agendas are not yet in place; staff from these agencies are currently working together to develop a cohesive plan for Federally sponsored research. Interagency agreement on such a plan is expected in the months ahead.

The conference was characterized as a means to elicit the opinions and judgments of a wide array of professionals engaged in research that has implications for improving older driver safety and mobility. The results and recommendations of the conference, along with information from many other sources, will provide the basis for decision making in charting the directions and substance of a cooperative Federal research program for the future.

3. Plenary Sessions

The "Research and Development Needed to Improve Safety and Mobility of Older Drivers" conference featured six plenary sessions focusing on functional topics related to the older driver. The sessions were conducted over a 2-day period, with four on the first day and two on the morning of the second. Some 170 functional specialists attended the sessions.

Each of the sessions was chaired by a specialist in the subject under consideration. A primary presenter introduced the topic at some length, presenting a detailed overview of the issues surrounding the subject and the current and projected research efforts being made in the area. Supplementing the primary presenter were between one and three discussants; these authorities brought out specific aspects of the subject matter for further consideration. At the conclusion of the formal presentations, questions from the audience were solicited and discussed by the plenary session panel members.

The information presented in the sessions was used as a framework for the planning effort conducted on the afternoon of the second day. This planning was directed at identifying researchable issues for improving older driver safety and mobility.

The topics of the six plenary sessions, in the order in which they were presented, were as follows:

1. General medical conditions.
2. Dementia.
3. Cognition.
4. Vision.
5. Motor control.
6. Medication and alcohol.

This chapter presents a synthesis of the information covered in these six plenary sessions.

General Medical Conditions

The plenary session on General Medical Conditions was chaired by Dr. Adrian Ostfeld, a physician epidemiologist at Yale Medical School. The primary presenter was Dr. Julian Waller, a professor of medicine in the geriatrics unit at the University of Vermont. Dr. Waller provided an overview of the epidemiologic and medical conditions that are common among older people.

Dr. Robert Wallace, who added to the presentation from the perspective of gerontologic epidemiology, highlighted definitional and methodological concerns. Dr. Wallace heads the Department of Preventive Medicine and Environmental Health at the University of Iowa. Finally, Dr. Sheldon Retchin, chair of the Division of Geriatric Medicine at the Medical College of Virginia, spoke on issues of subtle impairments and combinations of illnesses. He addressed the limitations and implications of using different models for assessing the functional capabilities of older drivers and proposed a severity of illness model as an alternative approach for the study of the medically impaired driver.

Common Medical Conditions

It is well known that older people have higher rates of chronic disease. Heart disease, chronic obstructive pulmonary disease, arthritis, and diabetes are all chronic diseases with high prevalence rates among older adults. In his presentation, Dr. Retchin noted that almost 40 percent of persons 75 years old and over have developed some glucose intolerance (Adams and Collins, 1987). Further, at least two of these conditions—heart disease and diabetes—have been related to an increased risk of accidents and driving incapacity (Waller, 1967; Frier et al., 1980).

Dr. Waller related that most studies of the effect of cardiovascular disease on an older driver's performance have been conducted using drivers whose condition was already known to motor vehicle agencies. Most of these studies, such as those completed in Washington and California during the 1960's, have concluded that drivers known to have heart disease have nearly a twofold increase in crash risk. However, a Vermont study (Naughton et al., 1982) involving a representative sample of drivers hospitalized with ischemic heart disease did not show an increase in crash experience, nor was there an increase for those with more severe disease. A study performed in Sweden (Ysander, 1966), which differed substantially in study design, also found no such increase. The Swedish study identified disease at the time of licensure but had no information about the driver's current medical status; in contrast, the American studies were based on current health status. Also, Waller (1987) indicated that persons with heart disease were more likely to stop driving entirely or to reduce their mileage and avoid driving in high-risk situations. Unfortunately, none of the studies examined whether drivers with heart disease who are known to licensing agencies are typical of most drivers with this condition.

One study of drivers with heart disease and other medical conditions (Waller and Goo, 1969) found that only about one-fourth of the excess crash experiences involved obvious clinical episodes, while many of the remainder were attributed to inattention. Another study (Bellet et al., 1968) found that many drivers with heart disease showed electrocardiographic changes as they drove in heavy traffic. These data suggest that the clinical contribution to crashes often may be quite subtle. Therefore, evaluation of drivers with cardiovascular disease should involve consideration of functional status such as frequency and severity of angina, syncopal episodes, or shortness of breath. However, rehabilitation professionals generally assume that drivers are functionally capable if they can drive well enough to pass a simple driving test. These measures do not consider the level of safety with which the driver performs, the ability to perform under less than optimal environmental circumstances, or the ability to perform over time.

Another problem Dr. Waller cited is the lack of studies that evaluate the combined effects of multiple diseases or normative aging on functional severity. Most studies of medical conditions and crash risk have focused on one medical condition at a time, ignoring the fact that the individual with heart disease, for example, may also have diabetes and hypertension, that a seizure pattern may be caused or exacerbated by alcoholism, or that the older driver with diabetes, heart disease, or Alzheimer's disease probably also has normative changes that include reduced night vision, glare recovery, and contrast sensitivity. Table 1 shows the frequency of these comorbid conditions for persons with ischemic heart disease. As Dr. Wallace observed, it may not be the presence of one or more diseases that constitute the salient risk factors, but rather the net impact on functional status. The session highlighted the need to examine crash risk in relation to the individual as a person rather than as the carrier of a single disease.

Table 1. Comorbid conditions for persons hospitalized with ischemic heart disease

Condition	% of patients
High blood pressure	41
Lung disease	23
Arthritis	14
Depression	13
Diabetes	12
Alcoholism	11
Cerebral vascular disease (TIA and stroke)	11
Severe vision problems	9
Peripheral vascular disease	8
Deafness	6
Kidney disease	5

Dr. Waller noted that the same study limitations apply to persons with diabetes mellitus as to persons with heart disease: the study populations usually are known to departments of motor vehicles, the presence or absence of other diseases is unknown, and the data are not age-specific. Also, the studies in general have not kept up with changing treatment technology. Recent treatment techniques seek much tighter control of blood glucose levels to avoid renal, cardiac, or visual complications in the later stages of the disease. Data from the Diabetes Control and Complications Trial, however, show that under this stricter regimen, hypoglycemic episodes are more common

(DCCT Research Group, 1987). Furthermore, other recent studies (Pramming et al., 1986; Holmes et al., 1983) indicate important cognitive changes with only modest levels of hypoglycemia at times when the driver may be totally unaware of the condition.

Because crashes involving alcohol consumption and alcoholism usually affect younger drivers, the role these factors play in crashes of older drivers has largely been ignored over the years. However, new information has revealed that alcohol consumption may affect the older driver more severely than the younger driver. Research, therefore, is needed to evaluate safe levels of blood alcohol content for older drivers. Psychotropic drugs and medications may also warrant attention.

Little, if any, research has been done regarding frailty as a factor in driving capability, noted Dr. Waller, although it is potentially important because of the fast-growing group of older female drivers. Furthermore, there is little information available about the crash risk of older persons who drive for employment, such as school bus and taxi drivers.

Both Dr. Wallace and Dr. Retchin observed that some common yet less glamorous conditions, such as arthritis, should be considered in relation to accident risk. Though as yet unstudied for its influence on driving capability and injury, arthritis has a relatively high prevalence rate and may lead to impaired mobility that can interfere with driving performance. Almost half of the community-dwelling population 75 years old or older are afflicted with some form of arthritis (Adams and Collins, 1987).

Research Models

Medical impairment implies disability due to poor health resulting from specific diseases which are thought of as end-organ dysfunction (e.g., cardiac) or metabolic deficiency (e.g., diabetes). Dr. Retchin noted that although this approach is helpful, the link between the physiologic and functional capacity of the individual is the important factor in driving. Disease is a "condition" of injury, whereas impairment is an "anatomical, physiological, intellectual, or emotional abnormality or loss" (Nagi, 1976). For example, cerebrovascular disease may lead to a stroke, but the residual effects are more accurately described as impairments, not disease.

In searching for a practical approach toward the impaired older driver, most researchers have focused on medical disease rather than functional impairment. For example, the majority of medical care for the elderly today is predicated on the disease model, and, at first glance, it appears to have conceptual appeal as a strategy for identifying medically impaired older drivers. However, although specific diseases have been targeted for study in relation to driving skills, heterogeneity in disease expression and comorbid illnesses has seriously confounded attempts to use a disease-specific model.

Expression of disease in aged persons is unpredictable as a model of function. One example of this problem is the Prospective Payment System, introduced through the Medicare program. Despite substantial declines in inpatient costs (Vladeck, 1984), the diagnostic categories, or diagnostic related groups, used in this system have been poorly correlated with health care needs, such as rehabilitative care for recovering hip fracture patients (Fitzgerald et al., 1987; Minaker and Rowe, 1985). A disease model has also been shown to be faulty in its predictive capacity for functional outcomes involving older adults. Williams and Hadler examined the ability of three groups of older women from a range of social settings that reflected increasing dependency and found that manual dexterity was the highest predictor of the ability to live independently (Williams et al., 1982). Yelin et al. (1980) reported that disease states in rheumatoid arthritis were less predictive of the capacity to work than functional indicators. The need for institutionalization of elderly persons has also been shown to pivot more on functional status and less on diagnosis (Williams et al., 1973; Rubenstein et al., 1984).

One practical approach to studying the problem of multivariate disease with differing levels of severity is through a severity of illness model. Over recent years, an enormous amount of work on patient classification systems has been devoted to assignment of patients to different severity of illness levels based on diagnostic and clinical data. Most of this work has been to improve the predictive capacity of resource utilization. For instance, renewed interest in a more functional approach to geriatric care through comprehensive assessments has arisen recently. This approach has been widely adapted for specialized multidisciplinary care units. It has improved functional outcomes effectively, reduced the need for institutionalization, and even lowered mortality (Rubenstein et al., 1984). Use of a severity of illness index, as compared to diagnosis alone, has also explained more than 60 percent of the variance in health care resource use by elderly persons (Horn et al., 1983).

Any of several methods could be implemented for measuring severity of illness appropriate to the study of medical impairment and driving using clinical data relatively accessible through the Medicare program. The first, called staging, refers to measurement of disease in discrete levels of progression with increasing severity. Staging algorithms are largely disease-specific, with discrete categories based on the biology and physiology of the condition. Although a number of staging algorithms are available, each follows the same concept (Gonnella et al., 1984), for example: stage 1, disease with minimal severity; stage 2, disease limited to one organ system, but with greater likelihood of complications than stage 1; stage 3, multiple organ involvement with poor prognosis and greater likelihood of complications than stage 2; stage 4, death likely. As pointed out by Gonnella et al. (1984), staging is conceptually modeled on the disease process itself and may or may not be related to specific outcomes. To aid in controlling for severity of illness, computerized algorithms have been developed (Jencks et al., 1984).

Several investigators have developed generic severity indices as measures of illness intensity. For example, Horn and her colleagues have developed the Severity of Illness Index that determines the level of illness severity based on seven dimensions (Horn and Horn, 1986a). This index has been computerized for wider application into the Computerized Severity Index (Horn and Horn, 1986b). One of the best known and most widely used severity of illness measures is the medical illness severity grouping system (MedisGroups). MedisGroups, which was developed using as a quality assurance instrument, uses admission data on clinical and laboratory variables to determine severity of illness (Brewster et al., 1985). It uses "key clinical findings" indicative of illness severity and is based on clinical judgment. MedisGroups has been applied to medical, obstetrical, pediatric, and surgical illnesses (Iezzoni and Moskowitz, 1988) and has been shown to be predictive of in-hospital deaths. Pennsylvania has mandated the use of MedisGroups for hospitals Statewide. However, use of a severity of illness model for determining driving capabilities requires either the availability of claims data or new approaches to data collection and monitoring.

A member of the audience noted that, while working on a study in Vermont, he had focused on the work of Horn and others in determining measures of functional impairment. He found, however, that published studies, including the Social Security approach, deal with factors that can be observed now, whereas licensing deals with a prospective issue. He pointed out that researchers lack the ability to translate what is observed now about an individual to how it relates to daily living and the relative driving risk over the next driving period.

Dr. Retchin discussed the functional model developed by the Social Security Administration for its disability insurance and Supplemental Security Income programs. The severity of illness model that has been implemented in these programs serves as an alternative approach to the disease model, although more data are necessary to duplicate such an effort for older drivers. To qualify for assistance under either of these programs, an individual must have a "medically determinable impairment." For instance, for arthritic patients to qualify for assistance, roentgenographic evidence of joint destruction and restriction of normal range of motion must be documented. Assistance for visual impairment requires documentation of loss of more than 80 percent of normal "visual efficiency." Although the impact of the adoption of a severity of illness model on Social Security disability programs is unclear, the approach seems conceptually appealing for this application.

Use of the "social model" for research was proposed by Dr. Wallace. This model involves the study of the social reasons that force impaired persons to drive under adverse circumstances, such as having no alternative transportation for critical needs (e.g., doctor visits). Changes in the residential and social environments to address this problem should be explored.

Physician's Role

Dr. Retchin next addressed issues and difficulties regarding the physician's role in the evaluation of medical impairment. Although recent judicial decisions have placed at least part of the responsibility for evaluating drivers' medical impairments on physicians, they are understandably reluctant to assume this role. The physician's role may be critical to primary data collection to assess severity of illness; however, the medical evaluation of older drivers should be limited to special circumstances, and this role needs further clarification. The role of the physician should be to provide technical information, not to determine licensing. Although the clinical information supplied by physicians is an important component of the overall evaluation, the decision to provide assistance is an administrative one based on specific clinical criteria.

Table 2 shows the training required of physicians for assessing the severity of illness in older drivers. While visual function could be assessed by optometrists or ophthalmologists, most of the measurements now in routine use can be applied by technicians with modest training. Moreover, assessment of some functional parameters (e.g., reaction time and handgrip strength) are not routinely available in most physicians' offices.

The physician's role in evaluating cognitive impairment is a particularly thorny one and deserves special comment. First, previous work indicates that, although older drivers appeared to limit their driving based on psychomotor and visual dysfunction, significant cognitive impairment failed to influence driving status because the drivers were unaware of their impairment (Retchin et al., 1988). Second, medical decisions for patients with significant cognitive impairment are among the most difficult for health professionals to make (Glosser et al., 1985), and professional responsibility is often neglected in this area (Cassel and Jometon, 1981). Third, because cognitive impairment is often subtle, significant declines are frequently undetected even by physicians. Therefore, if physicians are to evaluate older drivers for medical impairments, structured mental status testing should be included. One strategy for conducting this type of testing is to introduce a mental status instrument (Pfeiffer, 1975) as a screening device at the time of licensure.

Finally, Dr. Retchin observed that the inclusion of physicians in the evaluation of older drivers is not likely to bring clarity to the assessment process. Like other professionals, some physicians are likely to be overly sympathetic and worry more about the patient's autonomy than public safety. Others may be too concerned about the potential for professional liability and may be overly rigorous in defining the functional skills necessary for driving safely. Medical care includes too variable a degree of personal advocacy for uniformity in physician assessments to be realized.

Methodological Issues

Issues of methodology in epidemiologic study emerged repeatedly throughout the session and became one of the thematic concerns of the conference.

One of the first requirements for epidemiologic study is the ability to define which individuals with an alleged condition or characteristic are to be included or excluded. Although theoretically many conditions may adversely affect driving ability, the exact relationship for at least some of these may never be determined because researchers cannot agree upon sufficiently precise criteria to define the condition.

The relative rarity of the crash phenomenon makes sampling problematic and complicates

Table 2. Areas of assessment of illness severity for older drivers and the technical training necessary for evaluation

Function	Specific measurement(s)	Test	Training required
Vision	Static visual acuity	Snellen	Modest
	Dynamic visual acuity	N/A	N/A
	Peripheral vision	Goldman bowl	Moderate
Hearing	Tones, speech, lateralization	Audiometry	Moderate
Cognition	Judgment, memory, attention	Mental status	Moderate to Significant[1]
Strength	Handgrip, leg strength	Dynamometer Cybex	Modest[2]
Stamina	Exercise tolerance	Exercise, treadmill test	Significant[1]
Mobility	Range of motion, reaction time	Physical exam, goniometer, electronic timer	Significant to moderate[2]
Risk of unexpected medical event	Risk appraisal	Medical history, physical exam, labs	Significant[1]

N/A = Not applicable.

1 Most frequently requires physician evaluation.

2 Strength and mobility assessments require significant training, but health professionals other than physicians receive substantially more instruction in these areas.

the study of older drivers who tend to drive fewer miles and under different environmental circumstances than do younger drivers. In addition, the number of older persons with certain medical conditions is extremely small for study purposes. Patients from specialty clinics and hospitals often are markedly atypical, representing greater severity overall or at the moment of referral or unique diagnostic or management problems.

A member of the audience brought up a dilemma, i.e., a large sample size should be used to reflect the community; yet, accuracy decreases as sample size increases. Dr. Waller responded that for certain less common medical conditions, researchers will never be able to do definitive studies but will have to extrapolate from knowledge of other medical conditions that have somewhat comparable symptoms. Health maintenance organizations (HMOs) may be useful in these efforts because they may provide a large sample that is more representative of the community with better standardization of diagnostic criteria.

Dr. Retchin presented three study designs to consider for the evaluation of the effects of medical impairment on driving capability: a concurrent, or prospective, cohort study; a historical, or retrospective, cohort study; and a case-control study (Fletcher et al., 1988). Cohort studies have less potential for bias than case-control studies, but they require large sample sizes to detect significant differences among groups because accidents are relatively rare events. Furthermore, cohort studies rely on either previous records of exposure, as in the historical cohort, or laborious data collections for the concurrent cohort. Due to infrequent outcomes of interests (accidents), case-control studies may be the most efficient method for determining the risk of medical impairment. Dr. Wallace pointed out that because case-control studies can be done more quickly and inexpensively, they should be encouraged. However, they can address only certain questions because some consequences of accidents among cases may preclude health evaluation.

Regardless of the type of study performed, the selection of appropriate control groups is crucial. The selection of cases and controls and the measurement of exposure must be conducted as rigorously as in randomized controlled trials to avoid spectrum, selection, or other biases. Spectrum bias occurs when subjects are selected from immoderately different groups; it leads researchers to conclude mistakenly that an evaluation is clinically useful (Ransahoff and Feinstein, 1978). For example, researchers studying the risk of accidents in demented drivers might find it appealing simply to select drivers from a dementia referral clinic and compare their driving records with a randomly selected group from the community. This approach would inflate the risk associated with dementia and underestimate the risk associated with other medical conditions commonplace in referred patients. Selection bias results when the process of selecting case and control groups is not equitable. Cases are selected on the basis of a particular outcome (e.g., accidents) so that sampling a control group from the same source is not possible. To avoid these biases, the cases selected should be incident cases.

The criteria for determining crash risk is also an issue. One consideration is whether crash risk should measure per unit drivers or per unit miles. A second determination is whether to compare drivers having specific characteristics with the average for all drivers, with drivers representing the safest group permitted to drive, or with the highest risk group routinely permitted to drive.

Dr. Wallace stressed the need for a common taxonomy and used the term "elderly" in illustration. The assignment of a specific age threshold for any screening program would misclassify persons from a functional perspective. The impact of chronic disease on accident risk is really an issue of the impaired driver and not an issue of age. Distinguishing between normal aging and disease is unproductive from a preventive viewpoint. The term implies that the declines associated with aging are irreversible and that they are not related to detectable and preventable environmental causes nor to the pathogenesis of conventionally defined diseases. These implications are incorrect: Some cognitive and physical skills important to safe driving are subject to training and improvement.

Researchable Issues

The following research recommendations emerged from the session.

- Establish a committee of researchers and motor vehicle licensing personnel to develop guidelines regarding the appropriate types of person and/or exposure denominators to be used for comparison with drivers with medical conditions.
- Determine the interaction of features of normative aging and specific medical conditions on overall crash risk and crash type.
- Determine the extent and nature of the interaction of two or more

medical conditions in one person on overall crash risk and crash type.

- Study crashes among older drivers involving the abuse of alcohol and other substances for content levels and other driver characteristics.

- Examine the risk of different levels of severity of medical impairment on driving capabilities using secondary data analysis and case-control research. Study designs to consider are, in diminishing order of strength, a concurrent (or prospective) cohort study, a historical (or retrospective) cohort study, and a case-control study.

- Document the pattern and range of normative and pathological decrement over a specific licensing period and develop driver screening methods that can stress the driver sufficiently to determine how he or she is likely to cope with circumstances that have high crash risk.

- Conduct studies of diabetes to take into consideration the recent changes in medical regimen and their possible effects.

- Determine the effect on driving ability and crash risk of the learning phase, normative aging, and pathological features including frailty.

- Develop better criteria for the medical aspects of driver licensing and possible training programs to permit more people to continue driving for a longer period.

- Investigate the association between mental illness and cognitive and motor performance, decreased attention span, and distractibility.

- Conduct an empirical human factors analysis of the driving task.

- Study the social circumstances of older persons related to driving needs and crash risks.

- Study crash risk, and potential screening or training to reduce crash risk, of older persons who drive for employment such as school bus or taxi drivers.

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Dementia

The plenary session on Dementia as it relates to the older driver was chaired by Dr. Germaine Odenheimer, a geriatric behavioral neurologist at Harvard Medical School's Division on Aging. Dr. Alfred Kaszniak was the session presenter. An expert on the neuropsychological aspects of age-related degenerative diseases of the central nervous system, Dr. Kaszniak provided an overview of available research on dementia and driving, reviewed recent research concerning cognitive deficits in dementia that are relevant to driving ability, and suggested future research directions aimed at determining specific relationships between these deficits, driving ability, driving history, and roadway design.

The first discussant, neuropsychologist Dr. Marilyn Albert, presented possible methods of testing cognitive tasks and driving skills. Dr. Penelope Keyl, a professor in the Johns Hopkins University Department of Epidemiology, then considered the issues involved in testing demented drivers.

Driving Studies

Dr. Kaszniak reported that little empirical research has been conducted to investigate driving or crash histories and dementia despite the condition's prevalence among older persons and the expressed concern of clinicians and caregivers. Dementia occurs in as many as 15 percent of persons older than 65 (Mortimer, 1983). This prevalence increases in older age groups; it is four to seven times more prevalent in individuals older than 80 than in persons aged 70 to 79 (Mortimer et al., 1981). Although dementia can have more than 50 different possible causes, 50 to 70 percent of cases are attributable to Alzheimer's disease (AD). Another 15 to 20 percent are due to multiple infarctions of the brain, i.e., multi-infarct dementia (MID), sometimes in combination with AD (Terry and Katzman, 1983). Although the different types of dementia have neuropsychologic differences, no research has been performed to address the implications these differences have with regard to the driving task.

The potential association between dementia, particularly AD, and driving errors that clinicians have long recognized has led them to question a diagnosed patient's driving ability. Dementia involves a chronic, progressive deterioration of memory, intellect, and communicative functioning (American Psychiatric Association, 1987; Bayles and Kaszniak, 1987; and Kaszniak, 1986). In the context of driving, dementia thus affects the safety of the patient and others. However, dementia patients are often adamant about continuing to drive, and attempts to limit their driving bring considerable family conflict and distress.

Only two studies have systematically investigated driving and dementia. The first (Lucas-Blaustein et al., 1988) studied 53 of 72 consecutive referrals to the outpatient dementia research clinic of Johns Hopkins Medical Center. The patients' mean age was 71.8 years, and the average duration of illness was 3.2 years. Of the 53 patients, 30 percent had been involved in a crash, and 11 percent were reported to have caused crashes after the onset of dementia. At the time of the study, 16 of the patients were still driving, 14 continued to drive alone, and 10 drove at night. The patients who still drove performed better on a mental status examination and on confrontation and generative naming tests, but they were just as likely as those who no longer drove to have been involved in a crash since the onset of their dementia. Current drivers and nondrivers did not differ in diagnoses.

Friedland et al. (1988) conducted a similar study comparing 30 AD patients to 20 healthy age-matched control subjects in a longitudinal study. Data were gathered retrospectively on the 5-year crash experiences of both patients and control subjects. During the 5 years, 47 percent of the AD patients and 10 percent of the control subjects were involved in crashes. Nine of the fourteen patient crashes involved injury or more than $500 in vehicle damage. One AD patient had two crashes, and two patients had more than two crashes. Most crashes involved driving errors at intersections or in changing lanes. Among the AD patients, neither overall dementia severity nor neuropsychological measures were related to crash experience; crashes occurred in both early and middle disease stages. During the period studied, 19 of the 30 AD patients quit driving. Only eight who had no crashes did so, all at their families' urging. Others strongly resisted giving up their driving privileges.

These two studies indicate that 30 to 47 percent of older drivers with dementing illnesses were involved in crashes after the onset of their dementia. Between 31 and 35 percent of the patients in the studies were still driving. Although the study by Friedland et al. (1988) confirmed the patients' reluctance to relinquish their driving privileges, the Lucas-Blaustein et al. (1988) study indicates that the majority of dementia patients who continued to drive made compensatory adjustments in their driving behavior, such as driving below the speed limit and only in their own neighborhoods. Neither study revealed a correlation between neuropsychological measures and crash history. This lack of correlation may be due to several factors: (1) the compensatory adjustments, which would reduce driving risk and limit any observed relationship between crash history and dementia severity or test performance; (2) the small size of the dementia patient sample, which may have been skewed toward more severe dementia because the patients were recruited from referrals and a longitudinal study; (3) other crash variables such as traffic, roadway, and weather conditions; and (4) less than optimal neuropsychological assessment measures chosen because the researchers were examining crash history, not driving performance.

Considerably more research is needed to determine the relationship between the presence and severity of dementia and driving. Such research should indicate if safe driving can be predicted on the basis of measures that could be administered in a clinician's office. Future studies should examine driving performance, preferably in a closed course or open road test, but at least using a sophisticated driving simulator. Furthermore, the measures chosen to predict driving performance should receive detailed consideration. Assessment of cognitive functions such as visual-perceptual functioning, attention and concentration, response organization, inhibition, sequencing, and speed seem most relevant due to the information-processing demands posed by the driving situation.

Cognitive Deficits in Dementia

Dr. Kaszniak stated that dementia patients have obvious visual-perceptual problems in the moderate to severe stages of the illness. The problems are manifested in the failure to recognize familiar persons or the misperception of common objects. Although these obvious problems occur in more advanced dementia, a subgroup of dementia patients show dramatic visual-spatial deficits early in the disease (Albert and Moss, 1984; Martin, 1987). Neuropsychological measures of visual-perceptual and visual-constructional abilities have documented deficits in patients with only mildly severe dementia when such deficits may not be clinically obvious (Eslinger and Benton, 1983; Storandt et al., 1984; Wilson et al., 1982). In a recent study (Henderson et al., 1989), caregivers for 28 outpatients with diagnoses of probable AD reported that 39 percent of their patients experienced at least three or four specified instances of spatial disorientation three or more times per week. Stepwise multiple regression analysis showed that neuropsychological measures of memory and visual—constructive functions—but not overall dementia severity, attention, or language impairment-were significant predictors of caregiver-reported spatial disorientation. However, no research has been conducted to determine if these episodes relate to becoming lost while driving.

Although these visual-perceptual impairments are common to various dementing illnesses (Eslinger and Benton, 1983), the nature of impairment may vary between different etiologies. For example, one study compared mildly demented AD and Huntington's disease patients with healthy control subjects on a variety of visual-spatial and visual-constructive tasks (Brouwers et al., 1984). The results showed significant impairment, relative to the healthy controls, in both sets of patients. However, the two groups showed different patterns of impairment. The researchers interpreted the disparity in performance as consistent with differences in the anatomic distribution of pathologic brain changes. Nevertheless, the aforementioned studies do not help to clarify the locus of impairment in a demented patient's visual information processing.

Sensory System. Despite these problems in visual information processing, the neuropathology of AD does not involve the optic media, nerves, or tracts, or the retina. AD patients show the optic media and retinal changes of normal aging (Kline and Schieber, 1985), and they are not altogether immune to age-related ocular disorders such as cataract and glaucoma. However, static visual acuity in mild to moderate AD patients is comparable to that of healthy age-matched controls (Schlotterer et al., 1983).

One possible source of impairment of the sensory system in visual sensory processing involves spatial frequency contrast sensitivity, a basic capacity of the visual system presumably required for all spatial perception. It is measured by the number of alternating pairs of black and white regions, termed sinusoidal gratings, that can be perceived per degree of visual angle. Studies of this aspect of visual sensory processing have produced contradictory results. One study found that AD patients of mild to moderate dementia severity did not differ from healthy age-matched subjects, although both groups showed impairment relative to younger subjects (Schlotterer et al., 1983). The other study (Nissen et al., 1985) showed an association between AD and reduced sensitivity to spatial contrast, even in patients whose clinical symptoms did not appear to involve visual-perceptual impairment. Although the reason for this discrepancy is unclear, Dr. Kaszniak maintained that it indicates a need for further research to determine whether spatial frequency contrast sensitivity may be a predictor of other visual-perceptual deficits that relate to driving ability.

Another hypothesis typically implied by information processing models is the existence of modality-specific postsensory mechanisms that permit brief storage of information for further processing. These mechanisms are referred to collectively as sensory memory; iconic memory is specific to vision, and echoic memory is auditory. Iconic memory is ordinarily measured by a technique called backward masking, which involves the interaction between two visual traces when stimuli are flashed in rapid succession. When the first stimulus obscures the second, the technique is referred to as forward masking, but when the second stimulus obscures the first, it is backward masking. In either case, researchers hypothesize that the interference is due to the time required by the visual system to recover from the stimulation (Hoyer and Plude, 1980). A longer recovery time allows greater opportunity for masking to occur.

One study (Schlotterer et al., 1982) compared AD patients, healthy age-matched control subjects, and healthy younger subjects using a visual pattern backward masking task. The older subjects—both AD patients and healthy—required more exposure time than the younger ones to escape the effects of the mask. However, the AD patients needed significantly more processing time when the stimulus was a visual pattern. Another study (Coyne et al., 1984) also found that AD patients are more susceptible to masking by a visual pattern. Furthermore, this susceptibility correlated negatively with performance on a standard verbal intelligence task and with the rated level of cognitive functioning. These results may indicate that AD patients experience only normal aging changes in the more peripheral processes contributing to iconic memory, but that they are more impaired than age-matched controls in higher order contributors to early information processing. Also, iconic memory assessment paradigms may be useful measures for investigating the relationship between visual perception in dementia and driving ability.

Attention and Pattern Recognition. Attention and pattern recognition are other aspects of visual information processing in which demented patients may suffer impairment. Information processing theories generally distinguish two aspects of attention: (1) a selective property through which a particular feature of perception or thought is made the focus of awareness; and (2) a concentration or capacity property through which mental effort amplifies or enhances a mental representation. Various approaches have been used to study selective attention, including digit or letter cancellation tasks, line drawing location tasks, automated visual search tasks, and various methods of eye movement monitoring. The research clearly demonstrates that AD patients suffer deficits in selective visual attention. Approaches employing eye movement recording appear particularly promising for research on driving ability, noted Dr. Kaszniak. Future research should examine the possibility suggested by Steffes and Thralow (1987) that AD patients have a unique impairment in visual attention to and eye movement toward stimuli appearing in the superior quadrants. The implications of this research would have an impact on roadway design features such as the placement of traffic signals.

Attentional capacity is an important aspect of visual information processing. Hasher and Zacks (1979) pointed out that specific information processing operations vary in their attentional capacity requirements. Some operations, termed automatic, use little of the individual's hypothetically limited attentional capacity; others, termed effortful, employ much attentional capacity. Similar distinctions have been drawn between automatic and controlled processes (Schneider and Schiffrin, 1977) and between conscious and unconscious processes (Posner and Snyder, 1975). Effortful, controlled, or conscious processes are presumed to make greater demands upon limited processing resources than automatic or unconscious processes.

Until recently, no one had attempted to test the hypothesis of attentional capacity impairment in AD patients. Techniques to test the theory that normal aging results in decreased attentional capacity often involve the assessment of an individual's ability to perform two tasks simultaneously. Amount of practice and other task dimensions are varied to manipulate the degree to which one or both tasks can be processed automatically or effortfully.

The recent studies show that AD patients exhibit a disproportionate deficit in the performance of various dual tasks involving both visual (Baddeley et al., 1986; Morris, 1986) and auditory (Grady et al., 1989) information processing. These results have been interpreted within the context of a working memory model (Morris and Baddeley, 1988) as consistent with an impairment of central executive control processes in mildly demented AD patients.

This impairment has several implications for driving ability. First, although mildly demented AD patients may retain the ability to perform various familiar and well-practiced driving tasks simultaneously, they may experience difficulty when dual driving tasks are novel and require effortful processing such as quickly turning the wheel to avoid a sudden obstacle while simultaneously monitoring a changing traffic signal. This impairment has obvious implications for the design of dashboards and control panels. Second, an attentional capacity deficit, which results in impaired working memory, may affect driving performance due to the influence of distracting stimuli. For example, the AD patient may experience exceedingly rapid forgetting of recent information such as traffic signals in conditions of competing stimulus-processing demands such as busy intersections. Finally, this impairment may contribute to increased difficulty with information integration, particularly when the information arrives through different sensory modalities. Response to emergency situations in driving may often require rapid integration of cross-modal (e.g., visual-auditory or visual-tactile) information. Future research efforts to relate attentional capacity deficits to driving ability in AD patients would profit from paradigms using both intra- and cross-modal dual tasks.

Reaction Time. Speed of response, a critical cognitive function in the driving task, is also affected by AD. Systematic studies have confirmed clinical impressions of increased reaction time in AD patients. One study showed evidence of greater slowing in central decision processes as opposed to sensory or motor processes (Pirozzolo et al., 1981). Another study (Vrtunski et al., 1983) that attempted to further define the locus of response slowing in AD used continuous recording of movement components to reflect various aspects of psychomotor organization. The AD patients were slower than the control group in all movement components, and the patients' psychomotor organization appeared to be disintegrated. The researchers interpreted this finding as consistent with an impairment in the AD patients' ability to prepare, organize, and execute a response. Because a variety of driving tasks are appropriate for the measurement of response speed in demented patients, any investigation of the correlates of driving ability in dementia should include such tasks.

Other Cognitive Functions. Dr. Kaszniak briefly discussed two other cognitive processes that are relevant to driving. The first involves the formation, maintenance, and shifting of abstract cognitive sets as measured in the Wisconsin Card Sorting Test (Heaton, 1981). In this test, the subject must sort a deck of cards by a particular categorical principle such as color, shape, or number of shapes printed on the cards. The category is not explicitly provided to the subject but must be inferred on the basis of feedback from the examiner. The category may be shifted without warning after 10 consecutive correct card sorts. Measures include the total correct categories, total errors, and total number of perseverative errors (continuation of sorting according to a previously reinforced category). AD patients generally complete fewer categories and make significantly more perseverative errors than healthy controls. Such patients find sustaining attention and response set very difficult under conditions of slow monotonous stimulus presentation such as those of open highway driving (Wilkins et al., 1987).

The second cognitive process upon which Dr. Kaszniak commented was the area of implicit learning and memory. Most studies investigating memory in AD and other dementing illnesses use explicit memory tasks in which subjects are asked to recall a study episode and retrieve or recognize target information. On the other hand, implicit memory is inferred when task performance is facilitated by prior study of or experience with target materials, even though no explicit recall or recognition is requested. Recent studies have shown intact implicit motor-skill learning in AD patients (Bondi and Kaszniak, 1989; Eslinger and Damasio, 1986; Heindel et al., 1989). This intact ability may be important in allowing mildly demented AD patients to adjust driving to varying road or traffic conditions, even though the brain systems responsible for explicit learning and memory may be severely compromised. Future research is needed to clarify the characteristics of AD patients and the tasks that result in preserved implicit memory performance and to relate these to specific aspects of driving.

Testing Alternatives

Dr. Albert, the first discussant, began her presentation with an anecdotal report of one demented patient who had difficulty looking to his left because of effective brain damage on the right side. When he took his driving test, the examiner noticed that his performance was adequate as long as the examiner kept reminding him to look to the left. The examiner gave him a passing mark on the test with the admonition to remember to look to the left.

This story clearly illustrates the need for a standard driving test with enough complexity to reveal the wide array of possible driving problems. Even if such a test existed, however, the conditions under which it is administered must be uniform to maintain fairness. Also, ensuring that the conditions are uniform would preclude placing drivers in situations associated with accidents; therefore, a patient's performance in stressful conditions still would not be tested.

Simulators may be one answer to the problem of fair testing conditions. Current simulators, which cost about $30,000, are obsolete and have technological problems. For example, the 16-millimeter cameras used to portray the road image are noisy, and the seats are often not like those in a car. Furthermore, current simulators are not interactive— the subject's actions are recorded, but what is seen on the screen is not altered. Although more sophisticated simulators have been developed, they are too expensive and also have certain problems. For instance, pilots who spend numerous hours in the simulator sometimes suffer from simulator sickness and cannot fly for a specified period after completing simulator training.

A better solution for the future, is computerized testing. Computers would be readily available for doctors' offices or government facilities for screening potential drivers in a medical evaluation. However, no software programs are available to measure abilities beyond reaction time and eye-hand coordination, and the limited programs that are available have not been validated against driving skills either on the road or in a simulator.

Research is needed to establish tools to measure driving skills and to observe their relationships with one another and with tasks of cognitive ability. Research is also needed to determine which cognitive tasks can be used to assess driving skill, but this determination cannot be made without the proper tools.

Testing Issues

The final discussant, Dr. Keyl, agreed with Dr. Albert's position that much research is necessary before a candidate test for assessing the demented driver will exist. Research efforts should be extended to ascertain if any measurements currently used can predict which driving tasks are sensitive to dementia. Researchers should consider unified driving assessment rather than studying isolated disease entities. Also—because AD patients are vulnerable to competing stimulus-processing demands and emergency situations requiring rapid integration of cross-modal information—researchers should focus on selected visual attention deficits and the attentional capacity impairment experienced by AD patients. Moreover, as researchers collect empirical data, it is not premature to consider the general issues that must be faced when a comprehensive and uniform test is identified. Dr. Keyl identified several such issues for consideration, including the nature of dementia and how it differs from the problems of other drivers; compensatory strategies; subgroups of dementia; and analyses of driving study designs.

First, AD differs from other diseases in its steadily progressive nature, which has obvious implications for successful driver assessment strategies. Berg et al. (1987) studied 43 subjects, aged 64 to 82, with mild senile dementia. They were evaluated at the start of the study, after 12 months from the start, and after 30 months. Although they showed different patterns of progression, the subjects showed a general decline of 3 to 4 points per year on a 30-point mini-mental state examination. The subjects showed a decline in all items with the duration of illness that indicates a progression in all deficits: registration and recall, visual construction, language, and orientation.

Given the progression of dementia, the most appropriate question is not if patients should drive, but when they should stop driving. Family members, physicians, or caregivers should initiate this discussion early in the disease process so that planning for the change can take place in a timely manner. The frequency of assessment for demented patients should be different from that for patients with diseases from which they will eventually recover (such as stroke) or which can be controlled (such as diabetes). Also, because the progression of dementia is more rapid if the patient suffers from visual-spatial or memory problems, research should be conducted to determine impact of these problems on driving.

Second, the compensatory strategies generally performed by older drivers do not carry over to AD patients. Compensatory behavior requires insight and self-criticism, and AD patients may suffer from personality changes—such as increased impulsiveness, aggressiveness, and irritability—that affect judgment. These changes affect drivers' awareness of their impairments and their willingness to restrict their driving as warranted. Also, demented patients overrate their performance considerably. This aspect of AD in relation to driving should be examined in a systematic manner. Research should determine if AD patients can be helped to compensate for changes in personality, perception, and response time. Different forms of compensation should be examined, and the rate of decline and the level of dementia that is amenable to help should be established. One study of subjects with head trauma found a correlation between test scores and basic driving skills although there was no correlation between test scores and in-traffic driving performance. These results suggest that the subjects have the ability to compensate for impairments in behavior. Proper decisions made on the strategic and technical levels would allow the driver to avoid time pressures that would cause trouble.

Third, dementia has different causes, and the subgroups of dementia have different symptoms with different implications for driving. Some demented individuals have visual-spatial deficits rather than memory or attention deficits. Patients who suffer an earlier onset of dementia (before age 64) show poor performance on visual construction abilities and lack control of the speed-accuracy trade-off in response time. This issue is not a serious one, if the test measures the differing symptoms. Also, if the symptoms are related to the rate of disease progression, they can be used as the basis for deciding how frequently to test the patient.

Finally, the research designs of studies to correlate AD and driving performance are important. Associations found in driving histories may be weak even if the time covered is 2 years or more because the patient may not be demented during this period. Also, there may be a time lag between the onset of dementia and changes in driving behavior. The ability to generalize some studies may be compromised because the subjects usually are those already under professional care. These studies do not consider the factors of disease or patient ability that determine whether or when a patient should be under a physician's scrutiny. Dr. Keyl suggested that the validity of screening tests should be viewed in an epidemiologic framework based on the following factors:

- Sensitivity—the degree to which a test identifies subjects with inadequate performance.
- Specificity—the degree to which a test identifies subjects with adequate performance.
- Positive predictive value—the measure of the proportion of individuals failing the test who, in fact, should not drive.

The ideal standard screening test should have high levels in all three areas.

Researchable Issues

The speakers identified the following researchable issues in the course of their presentations:

- Determine the relationship between the presence and severity of dementia and crash histories. Examine the possibility of predicting driving performance on the basis of measures that could be administered in a clinician's office.
- Examine driving performance using closed course or open road driving tests or sophisticated simulators. Consider the choice of driving measures including visual-perceptual factors, attention and concentration, response organization, inhibition, sequencing, and speed.
- Investigate the relationship between visual perception in dementia and driving ability using iconic memory assessment paradigms.
- Study the impairment in AD patients of visual attention to and eye movement toward stimuli appearing in the superior visual quadrants. Consider changes in roadway design features such as placement of traffic signals to compensate for this impairment.
- Consider possible changes in roadway intersection design to accommodate the problems that AD patients experience in responding selectively to particular visual stimuli under

conditions of simultaneous or rapidly successive competing visual stimuli.

- Conduct intra- and cross-modal dual task studies in an attempt to relate central executive-attentional capacity deficits to driving ability in AD.
- Design automobile dashboards and control panels that alleviate the effort involved in dual task processing for demented drivers.
- Measure cognitive processing and response speed in demented patients and determine their correlation to driving ability.
- Clarify the characteristics of AD patients and driving tasks that result in preserved implicit memory performance and relate these characteristics to specific aspects of driving performance.
- Examine the different presenting symptoms of the subgroups of dementia and their relationship to driving ability.
- Establish tools to measure driving skills and observe their relationships to one another and to tasks of cognitive ability. Study alternative testing methods including simulators and software programs. Validate these methods against actual driving tests.
- Determine the basic cognitive tasks relevant to driving on which performance should be based.
- Ascertain if driving tasks or measurements of driving ability are sensitive to the impairments of demented drivers.
- Establish criteria to determine how often a demented driver's performance should be reevaluated.
- Determine if demented drivers can be helped to compensate for their impairments, what form this help should take, and the rate of decline and level of dementia that is amenable to help.

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Cognition

The plenary session on Cognition was chaired by Dr. Maria Vegega, a research psychologist with the National Highway Traffic Safety Administration. Presenter Dr. Arthur Fisk, who is an assistant professor of engineering and experimental psychology at Georgia Institute of Technology, provided background material on past research relevant to cognition and aging as it applies to the safety and mobility of the older driver. Dr. Fisk stressed that to understand age differences obtained in laboratory studies and to relate those findings to driving tasks, one must be concerned with the consistency of the task and the amount of practice.

The first discussant was Dr. Loren Staplin, an applied experimental psychologist researching human factors issues in driving performance. Dr. Staplin's presentation focused on the link between functional relationships and age and their contribution as design parameters in future research efforts to promote highway safety across the entire driving population. Dr. Karlene Ball, whose primary research emphasis is the determination of underlying bases for common visual problems of older adults, next discussed age-related differences at the automatic level, their effect on the ability to orient to the environment, and the effect of deficits in the ability on driving performance. Dr. Leonard Ross, the final discussant, identified the information still needed to determine the relationship of visual and cognitive deficiencies to age-related driving differences and accident causation. Dr. Ross is an experimental psychologist interested primarily in human factors and engineering psychology.

Information Processing

Dr. Fisk began his presentation by explaining that although a number of factors such as vision, coordination, personality variables, and social behavior interact with driving behavior, an evaluation of accident causes in relation to age shows the increasing importance of understanding the cognitive factors related to safety and driving. For example, Fell (1976) reported that 60 percent of accidents involving older drivers are due to informational causes such as information intake and processing. These same causes are present in only 35 percent of accidents for drivers under 21 and only 25 percent of accidents for drivers 21 to 25.

Consistent practice leads to some qualitative performance characteristic denoted as skill. The nature and extent of practice largely determine the final level of performance regardless of the individual's initial abilities (Ackerman, 1988). The distinction between performance on a novel task and performance on a task after lengthy practice is clear. The changes that take place both quantitatively—in terms of task accuracy and speed—and qualitatively characterize the essence of learning a skill. In some circumstances, the novice's effortful, slow, and generally poor task performance may fail to change with practice.

Schneider and Shiffrin (1977) found that two classes of processes underlie differences in a wide range of tasks. These processes are either automatic or controlled types of information processing. Controlled processing is used when the task allows neither consistent rules nor consistent sequences of information-processing components; it is also necessary when the task is novel and its consistencies have not been learned. Controlled processing is slow, requires attentional effort, and is amenable to quick alterations. It uses and places limits on available attention and therefore requires serial information processing. Automatic processes, on the other hand, are fast, effortless, and not easily altered by the driver's conscious control. They allow parallel operations with other information-processing task components. Automatic processing develops through extensive practice under consistent conditions and is implied in skilled behavior. Research examining automatic process development is particularly appropriate to the study of driving because driving involves development of new skills, integration of new skills with old, and interactions between strategic, controlled processing and automatic processes.

Dr. Fisk discussed the cognitive components involved in driving in the framework of Wickens' model of information processing (1984) shown in Figure 1. These cognitive components are: response time, which generally slows with age; memory and visual search; dynamic visual attention; working memory; and attention switching and multitask coordination (divided attention).

Response Time. Studies show that young adults are anywhere from 20 to 60 percent faster at performing a specified activity than older adults. This slowing with age is influenced by various factors such as declining visual acuity and the resulting altered perception and a reduced ability to make rapid decisions and respond quickly. Although this general slowing with age is an important issue relevant to driving, the important theoretical question addressed by current research concerns the nature or cause of age-related slowing, which may be due to sensory motor or mental factors or a combination of the two. Data from studies by Cerella (1985) and Salthouse (1985) led them to conclude that age-related slowing is due to slowing of central processes and that it affects all mental processes equally by about the same proportional amount. However, in a recent examination of the issue, Bashore et al. (1989) argue that the response time data—gathered from subjects inexperienced with the task—may have been altered by variables unrelated to information transmission rates. This point indicates the need to study reaction times of both young and old subjects after extensive practice, when strategies, error rates, and learning have stabilized. Research is also needed to study performance across tasks of increasing difficulty where the input and output parameters remain equated as difficulty increases.

One such study (Fisk and Rogers, 1989) measured performance after several thousand practice trials on both consistent and inconsistent versions of memory and visual search tasks. Consist memory (CM) and varied memory (VM) tasks were separated so that the researchers could examine situations where task-specific learning can (CM tasks) and cannot (VM tasks) occur. The data showed that for inconsistent driving tasks, effects of sensory motor factors will predict age-related slowing in performance quite well; however, for consistent tasks, sensory motor factors will influence performance differences, but older adults will exhibit proportionally larger deficits compared to young adults as task complexity increases. These results clearly show the need to separate CM from VM tasks when examining age effects.

Memory And Visual Search. An important component of driving is the ability to scan the environment, detect relevant stimuli, and act upon those stimuli quickly and appropriately. Search mechanisms are important in many

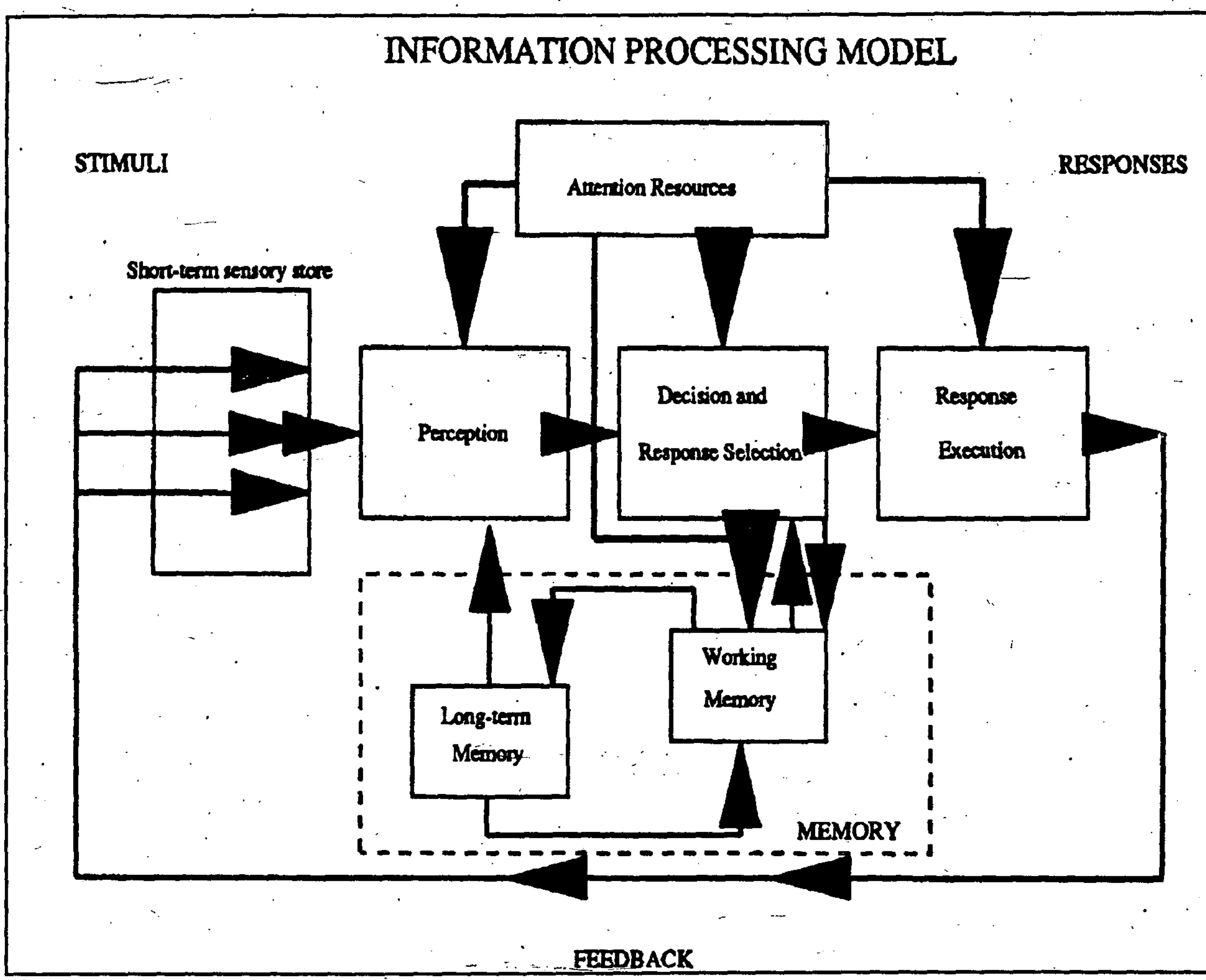

Figure 1

components of the driving task such as detecting and categorizing signal lights, signs, road markings, and other vehicles. Searching is a combination of the perception of the object and long-term memory, which stores the information needed to identify the object; both are needed for successful searching to take place.

Researchers have been particularly interested in identifying situations that do or do not result in qualitatively different performance for older drivers. However, those situations have not been well specified, and the data are inconsistent. Dr. Fisk explained the discrepancies in the data as the difference in the results of early and extended practice (Fisk et al., 1988; Fisk and Rogers, 1989; Fisk et al., 1989; Rogers and Fisk, 1988a and 1988b). The studies show that, early in practice, both young and old subjects exhibit improving CM search performance and that the age-practice interaction is insignificant. However, after extended practice, older adults were slower and showed qualitative differences in performance.

Unfortunately, the data do not show why young and old adults exhibit equivalent learning early in practice and subsequent divergence late in practice. Schneider and Detweiler (1987, 1988) have shown in their model that automatic processing is acquired in a gradual, continuous transition through five phases; phases 1 to 3 incorporate changes in memory-related processes, and phases 4 and 5 bring about reductions in attentional processing due to increases in the attention-calling strength of CM-trained stimuli. Three experiments were conducted that allowed simultaneous but separate examination of memory, visual, and hybrid memory-visual search (Fisk and Rogers, 1989). The results showed that for consistent tasks, older adults are not differentially slowed as memory load increases. However, age interacts with added scanning requirements in visual search. These findings support the view that the separation of memory and visual search components is critical for predicting age-related performance differences and help explain the discrepancies in previous data. They also support the hypothesis that older adults are quite capable of associative learning with CM practice, but that they differ from younger subjects in their ability to differentially strengthen targets relative to distractors.

Dr. Fisk described one experiment (Rogers, 1989) designed to allow a systematic investigation of the relative influence of target learning in comparison with distractor learning and to determine the cause of age-related performance differences. The results show definite age differences in target and distractor learning, especially when the combined effects of target and distractor learning are assessed. Older adults are less able to strengthen target stimuli sufficiently or to weaken distractor stimuli so that they fade into the background.

These studies allow researchers to predict when age-related differences in search tasks will occur. The extent of these differences can be expected as a result of the task's degree of consistency, the task structure, the complexity of stimuli, and the level of practice at which performance is evaluated.

Dr. Karlene Ball continued this discussion by presenting her studies of preattentive and attentive vision. The preattentive system is used to orient the individual and to attract attention to relevant information in the environment. The preattentive mode covers a large visual area, is conducted in parallel (target detection is independent of the number of background elements), and is based on the presence of conspicuous local features or textons. The preattentive system is similar to an automatic process except that stimuli already have salience to the individual without prior training.

Dr. Ball's work has dealt with the size of the visual area in which target stimuli attract attention with respect to several other variables: age, target-distractor salience, stimulus duration, and the complexity of a central visual task performed concurrently with the peripheral localization component of the task. She has also investigated the degree to which performance on this already automatic task improves with practice and the extent to which practice generalizes to other situations and is maintained without further training. This line of research was based on the background of visual changes with age and on the comments of older participants related to their everyday visual experiences. In the experiment, observers aged 20 to 90 had to locate an odd target in a large visual area while performing a concurrent central visual task. The dependent variable was the size of the visual area within which information could be extracted preattentively, or the useful field of view (UFOV).

Dr. Ball's studies revealed that the UFOV shrinks with age. The degree of shrinkage varies greatly depending on the levels of the variables of interest. However, age is really a surrogate for other effects such as slowing of processing and difficulties with divided attention. In general, the variability of field sizes is small in the youngest age group (20 to 40) and increases dramatically with age. The most extreme cases of shrinkage do not occur until after age 60. Specifically, the study revealed that:

1. There is a trade-off between the presentation's duration and the UFOV size, with the oldest age group requiring double the time to process the same visual area.

2. There is a trade-off between the target stimuli's salience and the UFOV size.

3. For the oldest age group only, increasing the complexity of the center task increased center task errors and caused the UFOV to shrink.

4. Practice improved performance for all age groups.

These results indicate that older drivers with a shrinking UFOV may spend more time reorienting attention randomly, rather than being triggered to the appropriate location immediately, depending upon the salience of the vehicle, traffic control device, or any other specified target scanned during the traversal of a route. Older drivers also would require a longer time frame with each fixation to acquire the same information.

Dr. Ball and her colleagues also collected data to determine how strongly performance on the task correlates with different everyday activities. They noted that observers who had difficulty on the UFOV tasks were more likely to report problems reading signs among a large number of signs, bumping into objects outside their field of view, and taking more time to perform visually guided activities. Therefore, a reduced UFOV may result in accidents due to failure to notice signs, other vehicles, pedestrians, or other obstacles—particularly those in the periphery—failure to yield right of way, or difficulty merging into busy traffic. Size of the UFOV thus is a much better predictor of specific reported problems in driving than age alone.

The ability to predict the older driver's problems in memory and visual search situations is important to the issue of aging and driving. Only weak relationships have been found between accident rate and screening measures of visual acuity or field of view using standard clinical visual tests because they minimize environmental and cognitive factors typical under everyday conditions. Further research is needed on tests of functional vision to determine their utility in screening older drivers. Research is also needed to determine when intervention training will be effective.

Dr. Fisk stated that, although the foregoing studies investigated the development of new automatic processes, a separate issue involves the maintenance of processes that are automatized before the driver becomes senescent. This issue has been addressed by several well-documented studies including the Troop interference task, lexical decision tasks, and implicit memory studies. The studies have yielded relatively consistent findings: generally, older adults do not lose the ability to activate well-learned processes automatically. These results show, however, that individuals cannot always choose to avoid processing conflicting aspects of stimuli, and that older adults are more at risk to the deleterious effects of conflicting information from visual stimuli than are young adults. Furthermore, older individuals are less able to inhibit the interference effects even with repeated exposure to the conflicting situations. Because these situations occur often in driving, further research on intervention strategies is clearly needed to guard against this type of interference.

Dynamic Visual Attention. The ability to focus one's attention and then quickly reorient that focus is called "dynamic visual attention. This ability—evident when the driver must merge onto a busy freeway, turn across a busy street, or scan several signs for those that are pertinent—is limited by the amount of attentional resources available to the driver. Dynamic visual attention differs from attention switching because it involves the ability to quickly shift attention only within the visual scene for effective single task performance.

Dynamic visual attention was tested by having subjects rapidly count stimuli presented in arrays of varying visual confusability (Rogers and Fisk, 1989). The researchers manipulated the digit configuration and the relationship between the digits in the display. They also varied the instructions to the subjects so that counting strategies were utilized. The study revealed that dynamic visual attention tasks are easier when the items are easily separable into individual units so that focusing and shifting attentions are facilitated. However, similarity and confusability of stimuli influence the ability to focus and shift attention rapidly. Young adults counted heterogeneous conditions faster because they spontaneously used a grouping strategy. When older adults were trained to use the same strategy, their ability to perform the dynamic visual attention task improved.

Working Memory. Another cognitive factor of driving involves working memory components. Working memory is temporary and its capacity limited; it therefore must be updated continually to provide necessary current information about the driving environment. Working memory interacts with the decision and response selection and the long-term memory components of Wickens' model. Dr. Fisk reported that the concept of working memory is central to many models of skill acquisition (e.g., Anderson, 1983; Carlson et al., 1989; Schneider and Detweiler, 1987). However, researchers have almost invariably examined working memory with unpracticed tasks and have used the tasks to measure the amount of information a person can remember during information processing or to obtain information about memory functioning during concurrent cognitive processing. Most measures of this static working memory show age effect in favor of the young, but the reason for this difference is still in question. Research is needed to determine the locus of this difference and to study the interaction between working memory, age, and practice effects. Information is also needed concerning how working memory changes as experience is gained on a task.

Dr. Staplin described a laboratory study involving working memory which required young/middle-aged (19 to 49) and older (65 to 80) drivers to make verification decisions for freeway navigational sign entries in relation to a stored-memory set. Subjects concurrently performed a subsidiary, divided attention tracking task in which they were required to keep a high-contrast target dot on a cathode-ray tube (CRT) aligned laterally as close as possible to a center reference mark. Researchers hypothesized that multiple entry sign format would potentially be of the greatest benefit to drivers with a working memory deficit because it facilitated rehearsal conditions. However, this benefit was not realized, a result attributed to the older drivers' difficulty in ignoring irrelevant (nontarget) entries on a sign. In practical terms, the study showed that older drivers searching for a guide sign entry to match against a stored route or exit name would benefit most by placement of immediate exit information on separate signs or by other means of emphasizing the information such as through color contrast or larger letter sizes.

Dr. Staplin cited another study in the same ongoing project in which young/middle-aged drivers and older drivers made go-no go decisions based on perceived right-of-way status in maneuvering left turns against oncoming traffic. The researchers hypothesized that older drivers would be penalized in performance dependent on inhibition of previously learned automatic responses, particularly where a signal element previously associated with one behavior is incorporated into a control display requiring another, conflicting behavior. The results revealed the most pronounced age-related decrements for two displays conveying no go status. Both displays showed only a steady green light which, according to instructions on an accompanying sign panel, served as a discriminative stimulus for when *not* to proceed (with right of way).

Attention Switching and Multitask Coordination. Successful cognitive functioning in driving requires the ability to divide attention to control the pedals, steer, detect road signs, and perform other tasks. Divided attention requires the distribution of a limited amount of attentional resources. Although novice drivers experience overload rather quickly when attempting to perform multiple cognitive activities, experienced drivers require a lesser amount of attentional resources due to the automatization of many driving task components, which frees resources from those activities. Experienced drivers can time-share other attention-demanding activities quite easily while concurrently performing routine driving tasks. The ability to switch attention from one information stream to another is a good predictor of accident proneness (Avolio et al., 1985; Hahneman et al., 1973; and Gopher and Kahneman, 1971). In a complex decision-making task such as driving, the individual may fail to react to appropriate cues relevant to one of the many component tasks of driving.

Research shows that older individuals perform poorly in situations that require division of attention, especially in dual task situations of varying complexity or difficulty (McDowd and Craik, 1988). Although a general slowing of central processes may be the reason for the age-complexity interaction, another possibility may be the subject's ability to deal with the overall task in a coordinated, holistic manner. Research is needed to address what characteristics of complexity lead to age effects in the dual task situation.

Although much research has been performed on aging and dual task situations, little of it seems directly applicable to aging and driving due to the lack of information regarding age-related dual task performance after some reasonable amount of practice. The issue of divided attention deficits with relatively novel tasks and situations is applicable. However, because driving is an extended practice situation, an even more appropriate direction for future research is to determine how or if older drivers differ from younger ones in terms of attention allocation strategies and multitask prioritization and coordination.

Dr. Staplin pointed out that, as experts, drivers have well-established task prioritization hierarchies, and that an understanding of how best to accommodate older drivers' needs can be strengthened by recognizing these priorities and using them to identify stimulus attributes and response requirements in studies investigating cognitive processes in driving.

Compensatory Strategies

According to Dr. Fisk, although the idea of discovering compensatory activities which could then be taught to older drivers is appealing, this position poses various problems. First is the problem of why the compensatory behavior occurs and whether the behavior is the result of a conscious decision. There is also the problem of skill and basic abilities. Compensatory mechanisms described and measured by some researchers may be simply the skill itself. It may be a mistake to assume that some compensatory mechanism is accounting for the older individual's performance other than more skillful performance.

Although these problems may make the quest for compensatory mechanisms less than fruitful, researchers must not take a pessimistic view of the potential for intervention strategies. A more productive enterprise may be in understanding the mechanisms of complex skill development in general and age-related complex skill development in particular. This understanding will reveal when older adults are at an advantage, at a disadvantage, or on equal footing with their younger counterparts in terms of skill development. It will also show the task's skill components in which young and old adults will either differ or show equivalence. From this understanding, researchers could design an age-specific skill development program and training technologists could adapt theory-driven task-analytic methodologies to uncover age-dependent training approaches.

Compensatory strategies can also be conceived of as natural or behavior-modified strategies. Older drivers may actively modify when and how they perform a task in the interest of safety. For instance, some older drivers limit their driving to daylight hours because of reduced visual abilities. These changes should be investigated. Researchers need to understand, from a taxonomic perspective, the classes of possible natural compensatory behaviors, which behaviors are most effective for safety, which behaviors are accidental, and the appropriate motivators leading to natural compensatory behavior. This direction of investigation, coupled with the foregoing training strategy, could lead to the development of effective intervention training strategies.

Future Research Directions

Dr. Ross pointed out that, while investigators have added greatly to the knowledge of cognitive processes and the differences of age in these processes, several questions are as yet unanswered in assessing the relevance of this research to the safety and mobility of the older driver. To sort out the relative importance of visual, cognitive, and motor processes on the driving task, however, researchers need more detailed information on the task and on accidents with respect to the older driver. Specifically:

- Have the major variables that affect the older individual's information-processing performance in laboratory situations been identified? Can other age-related factors change or modify some of the conclusions reached about age deficits? For example, what is the relationship of motivational and emotional variables to cognitive performance? Are these factors being studied sufficiently with respect to their possible impact on cognitive performance in driving situations?

- What is the extent of individual differences in older persons' performance on information-processing component tasks? Do the differences vary sufficiently to permit regression analysis or the selection of persons for prospective and retrospective studies of accident rates or analysis of performance in closed course or simulator situations?

- Are the age differences in performance great enough in absolute terms to justify the conclusion that they are a major source of older drivers' accidents? Significance in a statistical sense is not necessarily important in a practical sense.

- To what extent do these processes covary in individuals? Are researchers looking at older individuals who have a number of deficits or do they show individual cognitive component deficiencies?

- Could other cognitive components be identified as important to the driving process? For example, a number of studies have investigated spatial cognition in older adults, including the relationship of spatial cognitive ability and neighborhood knowledge and use (Walsh et al., 1981) and intersection recognition after scene rotation (Bruce and Herman, 1983), but none have been concerned with the older adult in a driving situation.

- What cognitive processes are particularly susceptible to alcohol or medicines that affect the older driver more adversely than younger drivers?

- Under what specific circumstances do older adults have the majority of their driving problems? Although studies have indicated some of these circumstances, researchers need a much more detailed analysis of older driver accidents that reveals which components of the driving task are most relevant to the occurrence of accidents.

- What aspects of driving cause the most concern for older drivers? Although this sensitive information may be difficult to obtain, in-depth interviews may provide useful data for gaining insight into older drivers' difficulties.

- Can researchers gain more detailed information about the compensation strategies used by older drivers? Dr. Ross referred to Dr. Fisk's discussion about compensatory strategies and emphasized the need for more knowledge on how the older driver drives in various traffic situations.

Research is needed that evaluates the relationship between visual and cognitive deficits and driving performance either through correlational studies of driver characteristics and accidents or through studies in which older drivers' performance is examined with respect to their visual and cognitive capabilities. A few such studies have taken place, but much more work of this type should be done on a variety of topics. A major task remains in tying cognitive and visual limitations to the driving problems of the older driver in a manner that will be of value to those involved in all areas represented at the conference.

Researchable Issues

The speakers discussed several researchable issues in their presentations. They identified the following issues for further research:

- Examine automatic processes in terms of the development of new skills, integration of new skills with old, and interaction between strategic, controlled processing and automatic processes.

- Design an age-specific skill development program.

- Study the performance across tasks of increasing difficulty where the input and output parameters remain equated as difficulty increases.

- Conduct studies that separate CM from VM tasks when examining age effects.

- Conduct studies that will enable researchers to predict when older drivers are likely to have problems in visual search tasks in specified driving environments.

- Determine when intervention training will be effective in visual search and dynamic visual attention tasks.

- Determine how working memory changes as experience is gained on a task.

- Determine what characteristics of complexity lead to age effects in dual task situations.

- Determine how older drivers differ from younger ones in terms of attention allocation strategies and multitask prioritization and coordination, taking situational factors into account. Determine the prioritization hierarchies that older drivers use and identify stimulus attributes and response requirements from those priorities.

- Adapt theory-driven, task-analytic methodologies to uncover age-dependent training approaches.

- Study the classes of possible natural compensatory behaviors which behaviors are most effective for safety, which behaviors are accidental, and the appropriate motivators leading to natural compensatory behavior. Use the results of this study to develop effective intervention training strategies.

- Determine the utility of functional vision tests in screening older drivers.

- Develop a comprehensive, validated survey on visual function which would aid in determining which laboratory paradigms are worth pursuing with respect to a large sample study of drivers.

- Determine if improvement on cognitive skill tasks transfers to the driving situation.

- Conduct studies to further identify the major variables that affect the older driver's information-processing ability.

- Determine the extent of individual differences in older persons' performance of information-processing tasks.

- Determine if age differences in the performance of cognitive tasks are a major source of older drivers' accidents.

- Determine the extent to which cognitive deficits co-vary in individuals.

- Identify other cognitive components or processes such as spatial cognition that may affect the driving process.

- Determine which cognitive processes are particularly susceptible to the adverse effects of alcohol or medicines.

- Identify the specific circumstances under which older drivers have the majority of their driving problems as they relate to cognitive functioning.

- Determine which aspects of driving cause the most concern to older drivers.

- Establish criteria for ecological validity in generalizing measures of cognitive function to the driving task.

- Further investigate the relative contribution of cognitive factors to other (e.g., sensory) deficits in the *diminished* net response effectiveness of older drivers on gross behavioral measures, such as (choice) reaction/response time or maneuver effectiveness.

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Vision

The plenary session on Vision as it relates to the older driver was chaired by Dr. Ray Briggs, a faculty member in the Department of Safety and Human Factors at the University of Southern California. In his introductory remarks, Dr. Briggs, paid tribute to Al Burg, who pioneered the development of automated visual testing for drivers and correlated visual scores to accident involvement and conviction rates. Dr. Briggs showed a video prepared by the California Division of Motor Vehicles that illustrated an updated version of Al Burg's approach to visual testing.

Following the short tape, Dr. Briggs introduced the presenter, Dr. David Shinar, chair of the Department of Industrial Engineering and Management at the Ben Gurion University of the Negev. Dr. Shinan described the role of vision in driving—particularly for the older driver—and recommended the vision testing needed for older drivers. Epidemiologic researcher Dr. Ronald Klein, the first discussant, spoke on common ocular disorders that affect older persons. Dr. Cynthia Owsley, whose current research addresses the nature and mechanisms underlying impaired vision in older adults, and Dr. Frank Schieber, whose research focuses on computer models of spatial vision, raised issues relevant to future research needs.

Role of Vision in Driving

Dr. Shinar began his presentation by defining the role that vision plays in driving. Vision is the primary sensory channel for driving, responsible for up to 95 percent of sensory inputs. This role is supported by studies of driving task analysis (McKnight and Adams, 1970), and the fact that most vehicle control is guided by visual inputs.

Although good vision is important for safe driving, studies have not proven that poor vision necessarily leads to unsafe driving. The lack of such a relationship has been attributed to various factors such as poor criteria of unsafe driving or the choice of irrelevant measures of visual performance. Some large-scale studies have yielded weak but consistent data for the relevance of visual performance levels to safe driving (Shinar, 1977; Burg, 1968; Henderson and Burg, 1974; Johnson and Keltner, 1984; and Davison, 1985). These studies compared accident measures (absolute numbers, exposure-based rates, and accident types) with visual performance measures on different types of tests. However, because they were all correlational studies, the only support of causality between vision and accident involvement is based upon theoretical considerations, rather than empirical evidence.

This lack of a causal relationship between visual performance and accident involvement should be expected for various reasons. First, accidents usually result from multiple causes rather than from one driver's single impairment. Also, an Indiana study of accident causes showed that the most common human errors normally cited are attention or higher order perceptual failings (Treat et al., 1977). Furthermore, the requirement of a visual acuity of 20/40 for drivers in most jurisdictions reduces the chances of a relationship that might exist in the general population. Many studies are based on unreliable vision data obtained from gross driver screening devices rather than on diagnostic devices (Council and Allen, 1974; Burg, 1964; and Davison, 1985), yet some relevant visual factors such as contrast sensitivity and functional field of view have not been evaluated in any large-scale studies. Highway and vehicle design increasingly reduce accident risks with divided highways and retroreflective materials for signs and delineation marking. Finally, there is evidence that many drivers who are aware of reduced capacities compensate by restricting or altering their own driving behavior.

Research should be devoted to studying relationships between visual impairments and related driving tasks rather than the relationship of vision to accidents. For example, studies have shown that sign reading distance correlated significantly with depth perception (McKnight et al., 1985), and sign reading accuracy similarly correlated with contrast sensitivity (Evans and Ginsburg, 1984).

Vision and the Older Driver

The 65-and-older population is growing faster than other age groups; by the year 2030, it will represent 26 percent of the population. Ample evidence indicates that although older drivers drive fewer miles, they currently are involved in a disproportionate number of accidents. Projection of these facts indicates that in 2030, many more older drivers will be involved in fatal crashes (Williams and Carsten, 1989). These facts necessitate research directed at those driving-related visual skills that are most susceptible to the degeneration or disease prevalent among older people because vision is so critical to driving and older people are so susceptible to deterioration in visual performance.

One study shows the relationship between age and visual performance in a variety of areas considered relevant to safe driving (Shinar, 1977). The data were obtained from a sample of 890 drivers using an integrated prototype of a vision tester. The functions studied included normal static acuity, low illumination static acuity, static acuity in glare, dynamic visual acuity, detection-acquisition-interpretation, detection of central angular movement, central in-depth movement of a small object, and central in-depth movement of a large object. Figure 2 shows a sample of the results for normal static acuity and dynamic visual acuity.

The data from this study led to several general observations. First, all functions deteriorate

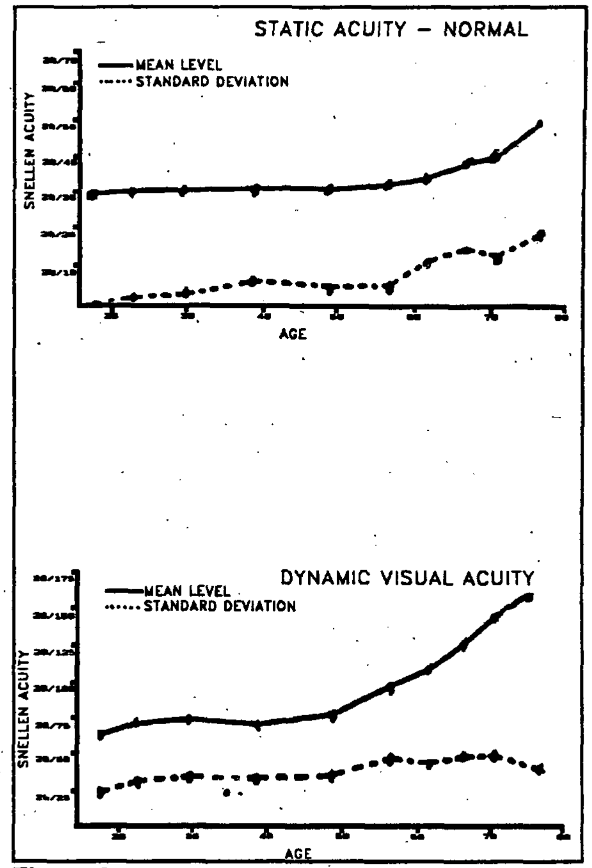

Figure 2

with increasing age. However, the amount, rate, and onset age of deterioration varies widely among the functions. The age-related average deterioration for each function is accompanied by a marked increase in individual differences as shown by the standard deviations. Also, the deterioration in static acuity is not significant before age 60, but deterioration in more complex tasks begins earlier and accelerates faster with increasing age. More recent research supports these findings for these functions and others such as contrast sensitivity and field of view. A few studies indicate that deterioration in several different areas may result from a single cause.

The low frequency of accidents involving older drivers, as compared to the high accident rate relative to exposure, suggests that older drivers limit the amount and type of driving they do. This assumption is a commonly accepted one and has some empirical support (e.g., Retchin et al., 1988). However, one recent study found no correlation between the amount of driving reported by older drivers and their performance on a driving simulator. Likewise, the study shows no correlation between their performance on vision tests and their self-assessed quality of vision. This study and others show that many older drivers are unaware of vision problems and, therefore, do not restrict their driving.

The challenge then, according to Dr. Shinar, is to monitor or control the older driver through the licensing system. Meeting this challenge depends on two factors: (1) increasing the validity of vision tests as they relate to driving task requirements, providing empirical support for different types of restricted licenses; and (2) developing measures to detect early signs of age-related visual deterioration.

Improving the validity of vision scores can be achieved best—if at all—by using the older driver population because of the differences in individual performance, the reduction of other factors such as youth-related risk taking or alcohol use, and individual differences in driving skills and exposure as opposed to visual/perceptual motor skills. Dr. Shinar warned, however, that implementing different types of restricted licenses requires good data that would link particular restrictions with specific deficiencies. New approaches are promising because they link traditional and new measures of vision with performance on visually dependent, relevant everyday skills (Owsley and Sloan, 1987). The search for good visual screening measures has been intensified as the limitations of measuring only photopic visual acuity have become apparent. One alternative to restricting licenses for older drivers is improving the driver's visual environment by designing vehicles and roads with the older driver in mind. Such designs should include nonglare panels in vehicle displays, better roadway illumination, increased contrast in signs and delineation markings, and appropriate letter sizes in signs to allow for increased processing time and reduced visual abilities. The designs should also consider visual search and the problems of clutter in the visual field and information overload when new information is added to dashboard displays. Another alternative is improving vision through optical aids or training. Glasses and contact lenses are the most popular means of correcting for optical refraction problems.

On the other hand, training can be a very effective way of improving the performance of more complex visual tasks. Figure 3 (Shinar, 1977) indicates the learning that occurs on complex tasks such as dynamic visual acuity in comparison with the much more stable performance on static acuity. More recent studies have also demonstrated similar visual-perceptual learning phenomena (Ball and Sekuler, 1986).

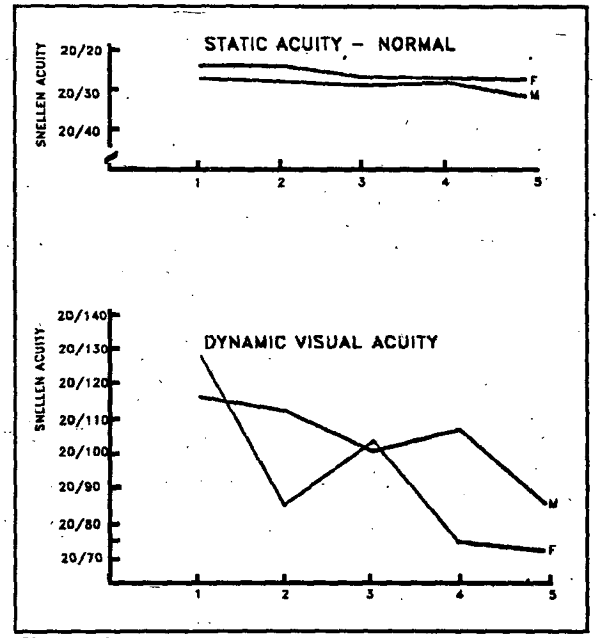

Figure 3

Vision Testing For Older Drivers

Dr. Shinar noted that visual screening for older drivers cannot be done simply by adding a few quick tests to those already in use at state driver licensing agencies. More intensive screening is warranted due to the older person's decrease in performance level for most visual functions and the increase in individual differences in performance. However, the same factors preclude the use of age-dependent criteria for driving restrictions.

A more promising approach than retesting at the department of motor vehicles would be to require older drivers to present a certificate of good vision from a licensed ophthalmologist or optometrist. This approach would ensure a more focused method of screening older drivers and provide them with professional help in improving their vision. In Israel, every driver 65 or older must undergo a medical and vision test every 2 years to retain a license. An evaluation of this process based on 11,000 older drivers (Zaidel and Hocherman, 1986) revealed that no licenses were revoked, but vision problems were discovered and corrected with glasses. The process was useful because 39 percent of those who required glasses first discovered their problem as a result of the license renewal vision test.

Dr. Shinar concluded that the benefits of any type of vision testing for older drivers would serve the interests of public health more than of traffic safety. Research and development should be based on the assumption that future vision testing for older drivers will not necessarily be limited to department of motor vehicles sites and will serve drivers' well being beyond accident involvement.

Age-Related Ocular Disorders

Dr. Ronald Klein explained that four age-related ocular conditions are primarily responsible for the visual deterioration that occurs in vision functions such as acuity, visual field, and night vision and that is associated with accidents. Unfortunately, these diseases cannot be prevented at present, and little epidemiologic data are available for research. More information about visual decline and how it affects driving is needed, and pragmatic approaches for detecting and assessing the older driver with functional visual deficits should be developed.

Other visual functions used in driving that change as people age include: static and dynamic photopic (daylight) visual acuity, perception of angular movement or of movement in depth, visual field, glare sensitivity, contrast sensitivity, scotopic (nighttime) vision, and color vision (Bailey et al., 1988). Abnormalities in some of these functions have been correlated with increased accident rates. For example, Burg reported (1967, 1968, and 1971) a significant relationship (although correlations were low) with dynamic and static visual acuity and accident rates of a large group of California drivers aged 54 and older who were followed for 3 years. Another study showed an increased risk of multiple accidents for drivers with poor visual acuity. One study of 1,000 British drivers (Davison, 1985) revealed a higher correlation between accident rates and poor visual acuity in drivers over the age of 45.

Here again, limited population-based epidemiologic data are available that relate functional changes to anatomical changes (e.g., pupil miosis, brunescense of the lens, or cataract). Moreover, most population-based studies have demonstrated a decline in visual acuity with age, even without the presence of ocular disease. This decline has been attributed to senile miosis, increased light scattering, decreased retinal illumination, and dropout of neural cells in the retina and brain (Weale, 1975). A constriction in the peripheral visual field associated with increased age has been attributed—in the absence of disease—to the position of the upper lids and globe, senile miosis, yellowing of the lenses, dropout of neural cells in the retina and brain, and a delay in reaction time (Drance, 1967). Still, the most important causes of significant decline in visual acuity and visual field are the following age-related ocular disorders:

- Cataracts.
- Age-related maculopathy and degeneration.
- Open-angle glaucoma.
- Diabetic retinopathy (National Society to Prevent Blindness, 1980).

The prevalence of these diseases is widespread and increases with increasing age (Sperduto and Siegel, 1980; Kahn and Milton, 1980).

Cataracts are characterized by clouding and opacification of the lens, which is normally clear. Cataracts have been linked to high blood pressure, use of steroids or diuretics, cigarette smoking, diabetes, exposure to ionizing radiation or sunlight, nutrient deficiencies, and excessive alcohol use (Leske and Sperduto, 1983). Although most early cataracts do not affect visual acuity, they do affect light scattering, glare sensitivity, color perception, and night vision. An older driver who has cataracts but good visual acuity may have difficulty in recovering distance vision after exposure to oncoming headlights and may complain of glare. Fortunately, cataract extraction, a common procedure, is 95-percent successful in restoring useful vision with intraocular or contact lenses. The procedure is expensive, however, and may involve complications.

Age-related maculopathy and degeneration is the development of retinal drusen (deposits in the back layer of the eye) behind the retinal pigment epithelium. It may be followed by degeneration of the retinal pigment epithelium, bleeding, scarring, or atrophy in the retina's macular area. This degeneration leads to a significant decrease in vision (it is the leading cause of blindness) and a scotoma (a gray or blank area in the central field of vision). The presence of age-related macular degeneration has been associated with high blood pressure, cigarette smoking, farsightedness, lighter iris color, ultraviolet light exposure, and nutritional and genetic factors (Ferris, 1983). Drivers with age-related macular degeneration may be unable to read road signs or see cars due to loss of central vision, and only a small percentage can benefit from laser photocoagulation.

Open-angle glaucoma is caused by high intraocular pressure associated with damage to the optic nerve and visual field abnormalities. Because the condition is painless, the driver may be unaware of a deficit in the visual field and may not see pedestrians or vehicles approaching from the side due to a constriction in the peripheral visual field. Once the condition is detected, a number of treatment options are available, including eye drops, pills, and different types of surgery. These treatments carry few risks, but they are not always successful.

Diabetes afflicts 10 to 20 percent of the older population (Harris et al., 1987). It increases the risk of cataracts and open-angle glaucoma, affects color vision, and results in blurred vision if the blood sugar level changes rapidly. Diabetic retinopathy is a constellation of abnormalities affecting the small retinal blood vessels that may result in permanent loss of vision. Timely argon laser photocoagulation may reduce loss of vision. Longer duration of diabetes and higher blood glucose levels have been associated with a higher incidence and progression of diabetic retinopathy and loss of vision (Klein et al., 1988).

Dr. Klein emphasized that most older drivers have good visual acuity. However, a number of functional changes that may affect driving performance occur with age even in the absence of disease. The frequency of these functional changes and resultant accidents is uncertain, and the deterioration may not be revealed by current testing methods. A number of practical approaches may be used to identify the small percentage of older drivers with functional visual deficits (Bailey and Sheedy, 1988). These approaches include an assessment of driving needs, ability, experience, and record in conjunction with relevant information on the visual disorder or other sensory-motor disability. For persons suffering from age-related ocular disease, but who have visual acuity of better than 20/200, Dr. Klein recommended periodic individual driving tests and restrictions on the license, but stressed again that more research is needed.

Future Research Directions

The second discussant, Dr. Cynthia Owsley, raised four issues related to Dr. Shinar's and Dr. Klein's comments that she believes should guide future research in regard to vision and driving.

First, Dr. Owsley questioned what visual skills are important for driving. Although the correlations shown in previous studies between visual function and driving records may be significant from a statistical standpoint, they are not significant from a practical standpoint. Before more research is devoted to developing new devices for screening, the skills to be tested should be defined.

The visual skills crucial to driving are more likely to be perceptual cognitive skills rather than sensory skills. This fact does not minimize the importance to safe driving of the sensory input level needed for information processing. However, the strongest correlates to driving performance are skills that reflect the complexity of driving behavior. Assessing the wrong visual skills may be the reason for the poor correlations in previous studies. Research should evaluate the following skills beyond the sensory domain: primary and secondary tasks, visual clutter (distractors), central and peripheral field components, dynamic display, contrast and luminance, and target localization and identification.

Dependent measures used to link vision to driving should not consist of the end result of bad behavior but should reflect the behavior, itself. Accident and violation rates are not ideals for representing driving performance. Research should focus on driving behavior by using alternative dependent measures such as performance on simulated and actual driving tasks and reported driving problems. Developing these dependent measures may be difficult and expensive, but they will benefit research because they will relate more readily to visual functions.

The criteria for licensure should be based not on age or disease, but on visual performance measures. Disease itself is not a predictor of driving performance; the functional impairment process is. Screening instruments should detect potential problems regardless of the driver's age.

Dr. Frank Schieber, the final discussant, continued to raise issues relating to future research. According to Dr. Schieber, the mission of future efforts in vision research should be clarified: is the goal to improve safety, mobility, or both? If research is to concentrate on mobility, the influence of vision on physical and psychological comfort and the resulting effect on performance should be evaluated.

Research should also examine the interaction between vision and cognition. Well-controlled studies are needed that relate specific visual functions to specific behaviors. These studies will require detailed driving task analyses, which will make performance problems observable. At the same time, the validity of self-screening should be evaluated.

Vision screeners need a basis for establishing schedules for retesting. Longitudinal data indicate the rapid decline of visual acuity with advancing age. Screeners also need new visual assessment techniques that augment current screening, provide measures of functions not predicted by acuity measures, and are more sensitive to age-related pathologies. In developing these techniques, researchers should free themselves from the notion that no assessment should last longer than one minute. Certification should be done by medical professionals rather than under the constraints of the licensing process.

Research directed at modifying the driver's visual environment would be of great benefit to the older driver. The most promising area for this type of research is improving nighttime driving because the problems are well documented and significant potential exists for intervention through improved lighting, signs, and road delineation. Research should first establish the available data such as the pertinent visual problems and demands of night driving. Establishing this data may require a simulator or a well-controlled field study on a well-instrumented driving track. This type of study would answer questions on design issues such as the need for tinted windshields and visibility versus glare trade-offs in headlight design.

In conclusion, Dr. Schieber reiterated that any future research must carefully consider the relationship of visual functioning to cognitive capacity and the interplay among the various cognitive factors.

Researchable Issues

In the course of their presentations, the speakers touched on numerous issues regarding vision's role in driving that require further research. They agreed that the following issues should be addressed before new vision testing procedures can be implemented.

- Improve understanding of the pathological processes responsible for specific visual functioning. For example, recent research has provided new understanding of some age-related macular degeneration, but research on the loss of contrast sensitivity is still inconclusive concerning the role of optical versus neural factors. Determine the relationship of specific impairments to unsafe driving performance.

- Examine the interaction between vision and cognition and relate specific visual function to specific behaviors. Evaluate areas such as primary and secondary tasks, visual clutter, central and peripheral field components, dynamic display, contrast and luminance, and target localization and identification.

- Suggest methods for improving vision through optical aids and particularly through training.

- Determine the visual skills necessary for safe driving and focus efforts on vision tests that are potentially the most relevant to driving needs. Past research suggests that these tests should include contrast sensitivity, dynamic visual acuity, photopic and mesopic acuity, effective visual field, and glare resistance. Develop better measures of determining glare, setting a threshold, and determining the effect of loss of visual field on driving performance. Study the effects of aging on stereopsis.

- Study day and night visual acuity and how they affect driving ability. Determine specific visual problems of night driving and methods for improving night vision using a simulator or well-controlled field study.

- Develop test standards that pertain to driving task requirements and test instruments that yield high test-retest reliability. Identify key parameters that affect test scores such as the luminance levels used in acuity tests.

- Develop criteria for licensure based on visual performance measures rather than on age or disease.

- Study the changes in the driver population that might result from the imposition of new visual standards and the effects of these changes.

- Study the effect of different in-vehicle and out-of-vehicle displays on the visual functioning of older drivers.

- Conduct studies relating vision to accident involvement and driving behaviors. Two types of studies are needed: (1) a large-scale study of the relationship between visual performance on measures currently considered relevant and accident involvement by accident types, and (2) small focused studies that would relate new performance measures to everyday visual tasks considered critical to safe driving.

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Motor Control

The plenary session on Motor Control was chaired by Dr. Neil Lerner, who, as Human Factors manager with COMSIS, manages several projects, dealing with highway safety, warnings, and special user groups. Extensive data have been published in recent years describing motor deficits that accompany aging. Dr. George Stelmach, the primary presenter, provided a review of the findings related to cognitive motor control and their implications for the aging driver. Dr. Stelmach is director of the Motor Behavior Laboratory and chair of the Department of Physical Education at the University of Wisconsin-Madison.

The discussants of the presentation, Dr. Allan Jette and Dr. James O'Hanlon, added to aspects of the issues of motor control and of the future research needed. Dr. Jette, Senior Research Scientist at the New England Research Institute, additionally emphasized the distinction between motor control functions lost to illness and those lost to normative aging factors. Dr. O'Hanlon—who currently is the Director of the Institute for Drugs, Safety and Behavior at the State University of Limsburg in Maastricht, the Netherlands—elaborated on compensatory behavior and his own findings in this area.

The Motor Control System

Motor control functions are an aspect of the body's central nervous system but are not separate from the operations of perception, decision making, response, and execution. Driving skills are continuous skills exercised in response to the spatial and temporal information of the environment brought in primarily through vision. It is generally through the discrete motor skills of braking, steering, turning, and skid recovery that we relate to driving behavior, and Dr. Stelmach oriented his presentation to a review of basic research findings in these areas.

One of the more universal findings in aging research is that motor responses become slower and less accurate with advanced age. Motor processes slow down, become more variable, and move from a predictive state to a reactive state that influences how information is processed. There are more parameters for the older driver, who is increasingly unable to prepare for the parameters and requires increasing time to evaluate each one.

Motor Control Reaction Time

Reaction time (RT) is defined as the time interval from the presentation of a stimulus until a response is initiated. The RT interval is thought to be a reflection of the time required for cognitive or central processing. Welford (1984) suggests that the slowing or impairment that appears with advanced age is the result of central rather than peripheral mechanisms. Therefore, researchers must manipulate cognitive motor processes and provide clues as to which central processes are most affected by advanced age.

Response Preparation. One manipulation, which has received a great deal of attention, is the provision of advance information to determine whether older adults fully prepare for an upcoming response. Gottsdanker (1980a, 1980b, 1982) has performed a variety of experiments to determine how response preparation is affected by age. In a simple RT task, Gottsdanker (1980a) found only small differences between younger and older adults in RT when preparation was easy. When preparation was difficult or impossible to attain, RT lengthened considerably among older adults (Gottsdanker, 1982).

Stelmach et al. (1987) studied response preparation using a pre-cuing technique. They attempted to determine whether the processes involved in the planning of a response could be responsible for the observed slowing in older adults. Subjects in three age groups (young, middle, older) received varying degrees of information about arm, direction, and extent of the parameters. The results, shown in Figure 4, indicate that older adults were disproportionately slower than young and middle-aged adults in specifying the individual movement parameters and that this increase was a result of the uncertainty associated with producing a response. The figure also indicates differences between groups in the slope of the regression lines due to uncertainty level and also indicates that all groups were able to use advance information since RTs were faster

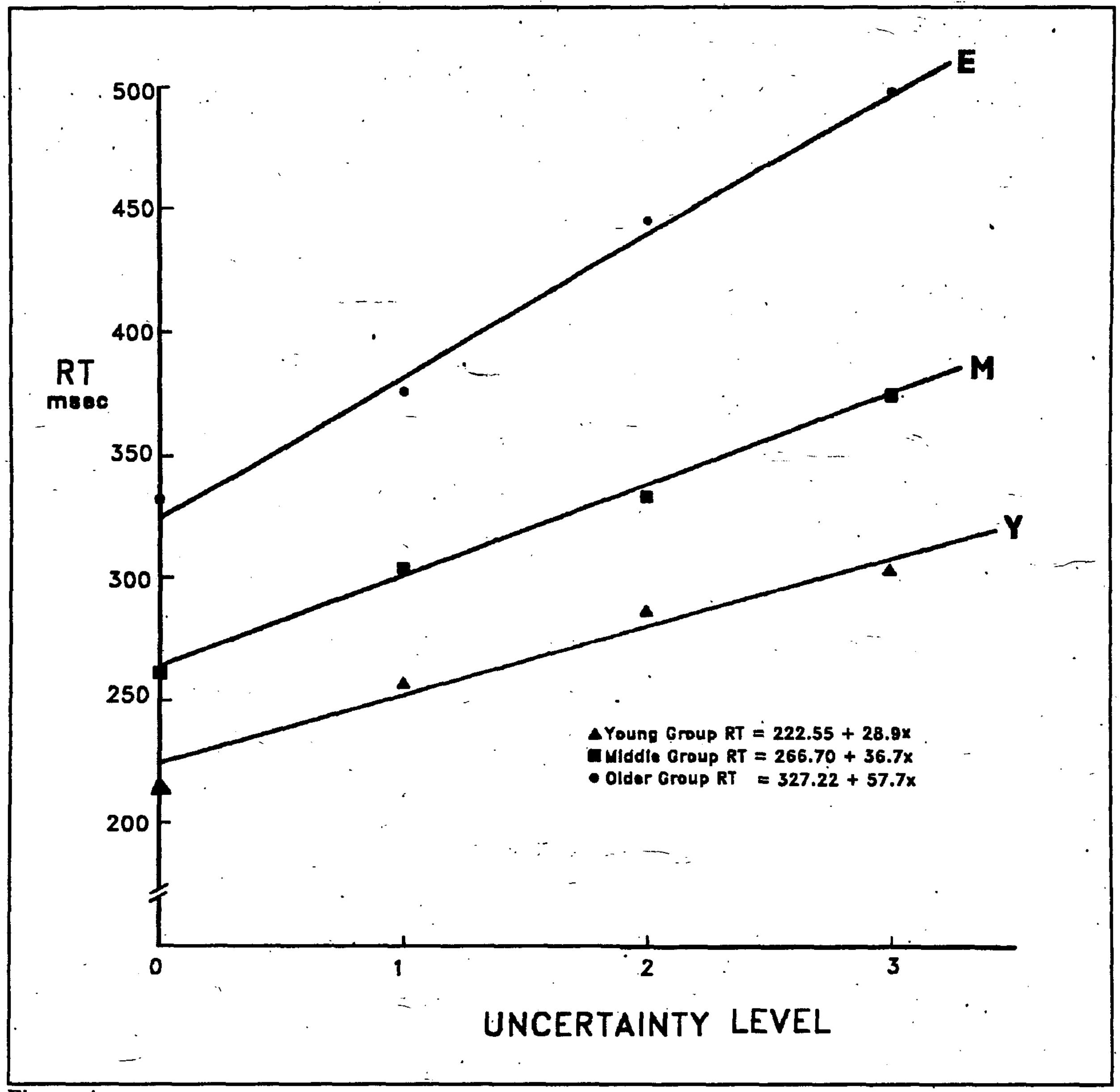

Figure 4

when full information was provided about the upcoming response. The authors concluded that the observed slowing in older adults is due to response uncertainty and response specification. Other studies have shown that the disproportionate slowing and higher error rate in older adults are due to the difficulty in maintaining control of preparation, that older adults have difficulty in maintaining optimal preparation over long preparatory intervals, and that the length of the pre-cue stimulus display and preparatory interval are critical in age-related experiments on movement preparation and planning.

Response Selection. Response selection is thought to reflect decision-making processes or capabilities. A second manipulation that can implicate central mechanisms in the observed slowing in older adults involves varying response selection processes. Simon and Pourghabagher (1978) conducted experiments indicating that older adults were significantly slower than young adults and that the primary locus of slowing in older adults is in response encoding processes rather than response selection processes.

Fozard (1981) claims that older adults require more time to identify the stimulus signal, to decide which response goes with which signal, or possibly to perform a combination of the two. Salthouse and Somberg (1982a) examined the slowing with age that is apparent in speeded tasks and concluded that the slowness that accompanies age is not isolated in one stage but is more general, with the entire central nervous system experiencing slowing. Strayer et al. (1987) conducted an experiment to determine what stage of the information-processing system is affected by advancing age and concluded that young and older adults did not differ in central processing speed or capacity but that the differences were due to slowing in perceptual-motor processes.

Response Programming. Another manipulation by which central mechanisms in age-related slowing can be elucidated is the study of the programming or reprogramming of movements. Larish and Stelmach (1982) and Stelmach et al. (1988a) conducted experiments to determine if young and older adults program and reprogram movements in a similar manner. In both experiments, subjects were provided advance information that was either accurate (programming situations) or inaccurate (reprogramming situations); subjects could prepare their movements in advance, but sometimes they had to change their planned movement at the time of the signal to respond. Larish and Stelmach (1982) found that older subjects were slower in both RT and movement time (MT), but did not find that older adults were more affected in the reprogramming conditions. They concluded that older adults' methods of planning, preparing, and reprogramming movements were similar to those of young adults and suggested that these processes are slower but remain intact with age. Stelmach et al. (1988a) found that older adults were proportionately slower in RTs when they had to reprogram a movement. However, if older subjects had to perform a slower movement, they were unable to prepare this type of movement as proficiently as young subjects. It was concluded that older adults show impairment at lower levels, such as preparing a specific movement parameter, but that higher level processes, such as reprogramming a movement plan, remain intact.

As the number of actions to be performed increases, the latency of response also increases. In traffic situations, incipient responses have to be overridden often. The older person is most vulnerable once he or she has committed to a particular action and must jettison the preparation for the action in order to perform a different action. Sudden skidding, for example, is much easier for the younger person to negotiate.

Response Complexity. One final manipulation thought to affect RT is the examination of response complexity, although there has not been a great deal of research in this area with older adults. Griew (1959) performed an experiment to examine stimulus choice (simple RT or choice RT), response complexity, and task continuity. The results indicate that response complexity has a differential effect on the RTs of older adults. Jordan and Rabbitt (1977) have suggested that complexity has a disproportionate effect on older adults only during the early stages of practice or learning. Falduto and Baron (1986) had young and older women perform card sorting and manipulated task complexity by increasing the number of stimuli as well as making the sorting procedure dependent on a second stimulus. The results indicated that older women were slower, with greater age differences as task complexity was increased.

Stelmach et al. (1988b) conducted an experiment to determine if older adults have deficits in coordinating two hands while performing a motor task. The results showed that older adults are more affected by the level of task complexity and display control problems in coordinating different movements. These findings have implications for steering wheel manipulations and manual controls.

Movement Execution Mechanisms

Motor control is also represented in terms of execution of movement. MT is defined as the interval from the initiation of movement to movement completion. The relationship between advancing age and MT has not received as much attention as the relationship between age and RT deficit largely due to the difficulty of providing appropriate manipulations.

Many studies suggest that older adults are slower in response execution. Figure 5 shows the findings of a number of these studies illustrating the overall slowing that occurs with advanced age in movement execution tasks. As shown, there is a dramatic increase in the time taken for a complex task such as handwriting as one ages, with performance of tapping increasing slightly. However, there is a lack of data beyond the fact that older adults are simply slower.

Speed-Accuracy Relationships. Numerous studies (e.g., Salthouse, 1979 and 1985; Botwinick, 1984; Welford et al., 1969; and Warabi et al., 1986) have been undertaken that address the relationship between aging and the speed-accuracy trade-off. These studies have manipulated the accuracy of a response to determin how MT is affected. It has generally been demonstrated that part of the slowing that occurs with advanced age is due to the emphasis older adults place on maintaining accuracy of response. This relationship is borne out in observations of fewer speeding

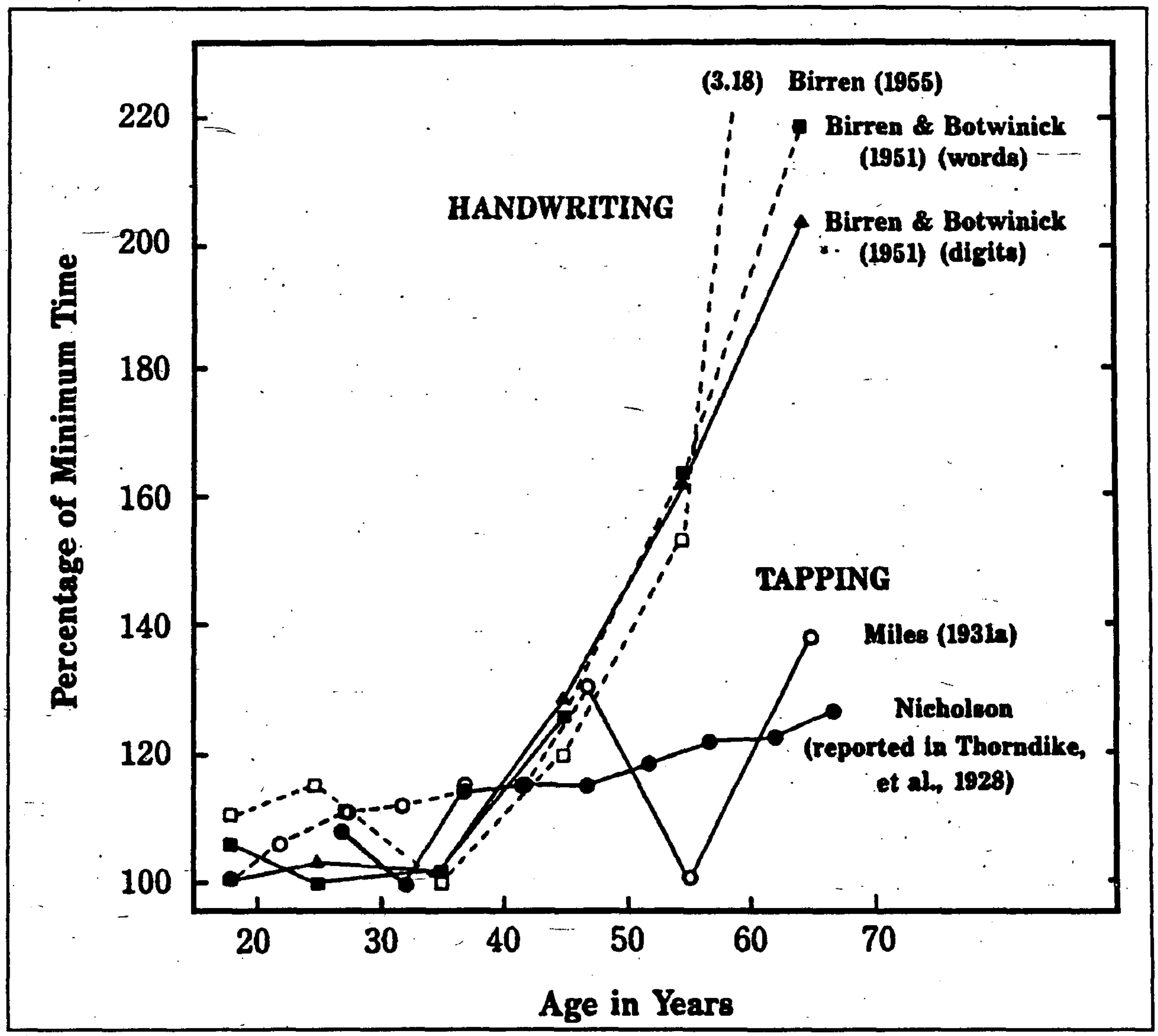

Figure 5

citations and typically slower driving speeds of the older driver.

Response Characteristics. It is quite possible that the movement patterns or response characteristics produced by older adults in executing a movement are very different from those of young adults. Murrell and Entwisle (1960) conducted an experiment based on the premise that normal movement is composed of three phases: an acceleration phase, a steady speed, and a deceleration phase. Two groups of subjects (ages 20 to 25 and 60 to 65) were required to make simple movements in a choice RT condition. The results indicated that older subjects accelerated less rapidly than young subjects and displayed a shorter negative deceleration phase even though there were no significant MT differences. Figure 6 displays a typical velocity and acceleration pattern of an older adult from the data in this study.Goggin and Stelmach (1989) performed an experiment to determine if movement corrections would occur "on-line" or while the movement was being performed as advance information was varied. Data indicate that older subjects were significantly slower in RT, and time to peak velocity. Figure 7 shows the difference between young and older drivers. More importantly, data from this study, with support

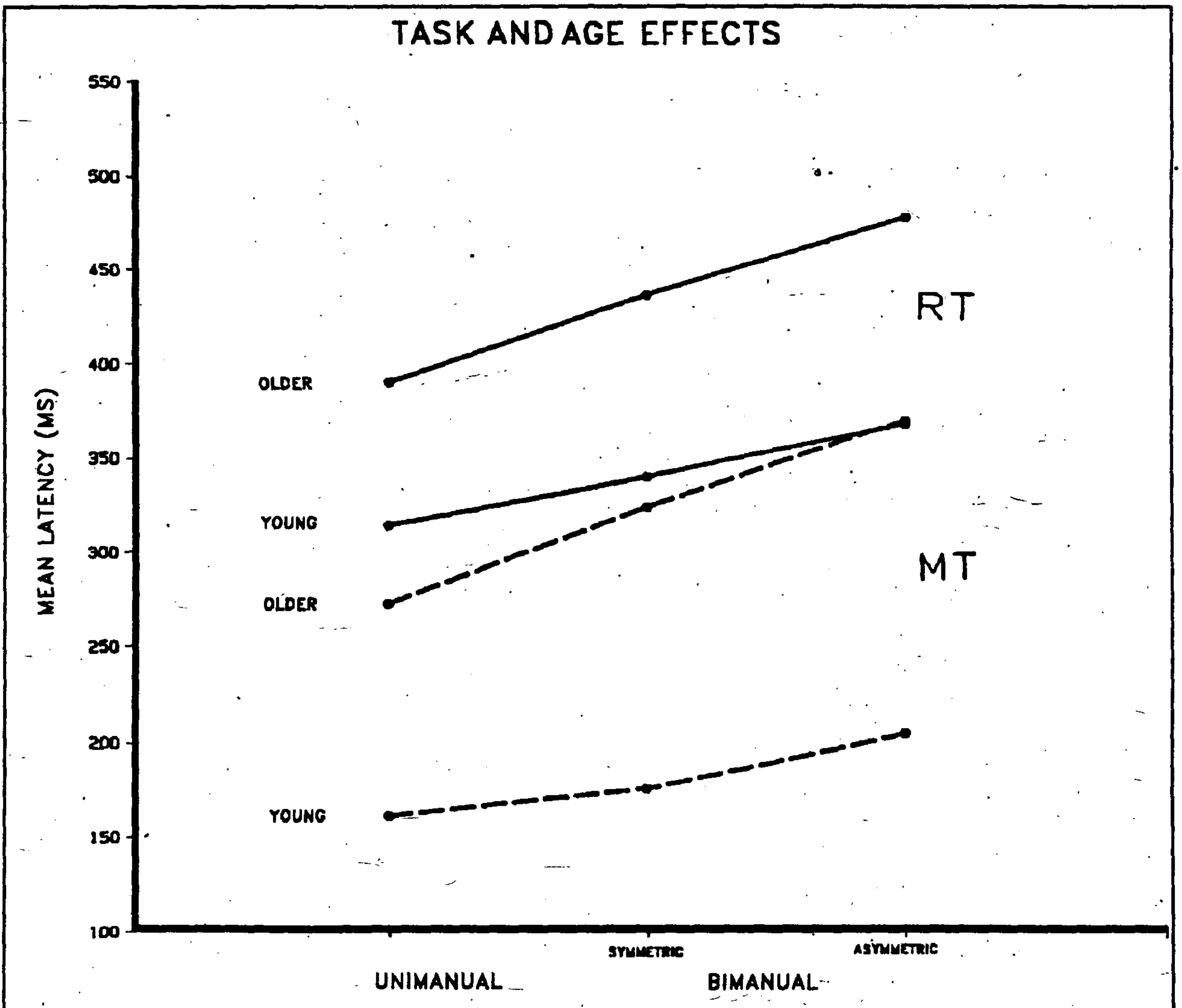

Figure 6

from other studies, suggested that older adults have difficulty in scaling velocity for long and short movements where amplitude is the only criterion of movement. This difficulty in scaling velocity to match movement amplitude may indicate a problem in controlling the amount of muscular force that an older adult is capable of generating.

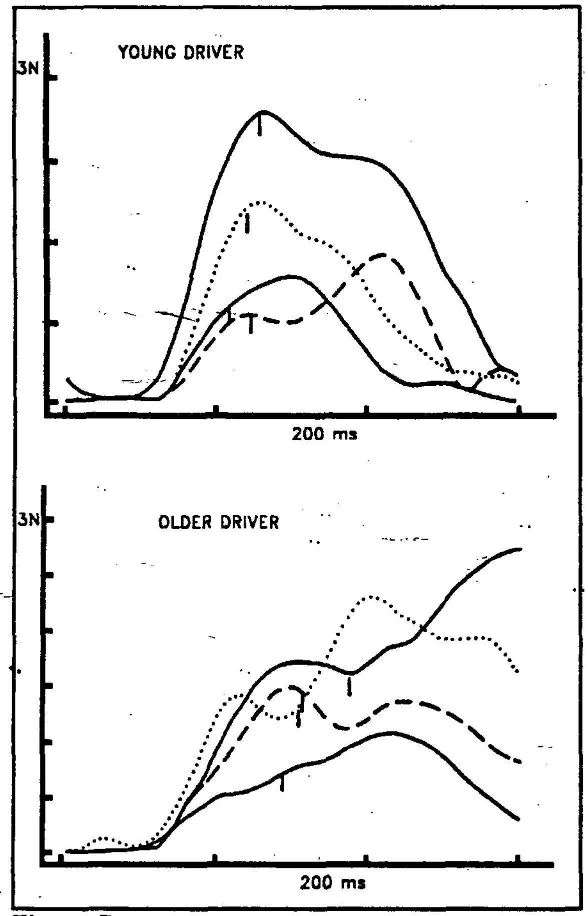

Figure 7

Vrtunski et al. (1984) found that older adults displayed less braking ability than young adults in the release segment of the button press and suggest that the synchronous relationship between agonist and antagonist muscles is poor in older adults. Stelmach et al. (1989) examined the relationship between force and force variability and found that older adults were more variable (9.4 percent) than young adults (8.4 percent) in relative peak force. This variability may have implications for difficulties in steering and difficult maneuvers.

Motor Control Deficit Hypotheses

Dr. Stelmach presented several hypotheses to account for some of the motor impairments that occur with advanced age. These hypotheses and theories suggest that older adults may set different criteria for responding or may adopt different strategies (e.g., emphasis on accuracy, cautionary behavior, monitoring of responses) from those of young adults to perform a movement successfully. It appears that the slowing in older adults is general in nature and linked to a specific deficit since many mechanisms show deterioration with age.

The data presented demonstrate that the deficits in cognitive-motor control of older adults are partially documented by slowness in RT and MT. Older adults display a slowing in response preparation, response selection, response programming, response complexity, and response execution. In addition, older adults display different response characteristics, such as velocity, acceleration, and force, from young adults. Thus, it is likely that central mechanisms are responsible for the slowing and that most of the slowing is general in nature and may not be linked to a specific deficit.

To fully understand the decline in motor performance that occurs with age, it is necessary to examine how physiological and psychological factors contribute to aging processes. Both the interaction of sen^Esory and motor factors as well as the tasks being performed must be considered.

Illness and Motor Control

Dr. Jette addressed the distinction between normative aging deterioration and deterioration caused by disease and illness, the effects of which may be reversible. Impairments are not necessarily caused by advancing age, and we must avoid misinterpreting these observed age differences as being caused by the aging process itself.

Aging is associated with a progressive decline in bone density in both males and females. Osteoporosis, a condition characterized by decrease in bone mass, afflicts 15 to 20 percent of older adults. As the proportion of persons age 65 and older continues to rise, the incidence of nontraumatic fractures due to osteoporosis is reaching epidemic proportions.

Age-related changes in bone density can be attributed to three separate causes:

1. Components of intrinsic aging (a decline in bone mass).

2. Components that are sex-specific (menopause).

3. Extrinsic factors (smoking, alcohol abuse, inadequate calcium intake).

Only the first two are aspects of aging and as such are generally irreversible. The impact of extrinsic factors, however, is not part of normal aging and in fact appears to account for a remarkable variance in bone density observed in the aging population. Knowledge of the cause of bone density loss has opened many fruitful new areas of investigation, including those of life-style and diet.

Arthritis, the inflammation of joints, is a leading cause of many motor control losses and may be one of the important external factors that can cause many of the observed different driving behaviors. Arthritis is a chronic, potentially disabling condition that is highly prevalent in the middle-aged and older driver. It ranks as the leading cause of social limitations in women and the second cause in men. Rates from health interview studies indicate that one-third of middle-aged women and over half of older women have arthritis. The rates for men are 40 to 50 percent lower than that for women in each age group. Arthritis has an important impact on driving behavior in ways that are potentially or at least partially reversible or preventable.

One of the most prominent of diseases, arthritis is one of the least studied. Data linking specific diseases like arthritis to change in motor control and consequent impact on driving and other activities of daily living are lacking. Dr. Jette noted that in the preponderance of completed studies, which were cross sectional, the impairments studied were not necessarily due to aging. The causes in observed age differences in motor control must be clarified before they can be addressed. It must be known why motor function decreases before appropriate interventions can be considered.

Compensatory Behavior

Compensatory behavior is a cardinal principle in motor control loss associated with aging. Older people trade speed for accuracy. Although it is clear that RT increases with advanced age, there are data that suggest that increases in RT can be reduced or even prevented. Spirduso (1982) has reported that practice is much more beneficial to the older adult, and Salthouse (1985) suggests that there is a decline in RT in older adults with extended practice. If older adults are allowed to make vocal—rather than manual—responses, the RT differences between young and older adults are not as disproportionate (Salthouse, 1985; Salthouse and Somberg, 1982b). Finally, Spirduso (1982) has found that physical exercise can minimize and/or slow the rate of decline in some cognitive and physiological functions. She found that older adults who were physically trained were much faster than age-matched adults who were untrained. Although these three areas have been shown to be beneficial to the older adult, the age differences in RT between young and older adults cannot be eliminated completely (Fozard, 1981).

Following Dr. Stelmach's review of research findings, Dr. O'Hanlon addressed factors that impair compensatory behavior. It may be that age-associated deficits in cognitive motor functions become important only when they are unrecognized by older drivers, when they lose the motivation to compensate for them (alcohol or medication), or when pressures force them to drive at times or under conditions when they would not normally drive. Very little is known about how older people actually perform the driving task. The underlying processes must be looked at: it cannot be known how compensatory factors fail unless the way they work is known.
Dr. O'Hanlon placed the cognitive motor deficits in the concept of the global descriptive model of driving behavior that has been developed and advanced by several other researchers. The model comprises three levels

of operation arranged in a hierarchy from the bottom up.

1. *The automatic control level* consists of information processing activities below the conscious level, processes that rely heavily on prior experience.

2. *The maneuvering level operations* are the rapid differential speed judgments. If a wrong decision is made, the driver must decide to cancel it, review alternative options, and reprogram.

3. *The strategic level* entails such activities as pre-trip planning.

The activities of these levels are most clearly seen when they break down, primarily as a result of drugs. Dr. O'Hanlon described a research program with which his group and two others have been involved for more than 10 years. It employs a standard on-the-road driving test that mainly measures the automatic control functions of the first level. The subjects operate a specially instrumented vehicle under the supervision of an expert who has access to dual control. The subjects attempt to maintain a constant speed and a steady lateral position between delineated boundaries of the slower traffic lane while traveling over a 60-mile circuit on a primary highway. Their road tracking error is measured automatically and continuously. Tracking error measure is one of the most sensitive indices of sedative drug effects. The project has been able to measure significant impairment in subjects who are operating with a blood alcohol concentration of 0.05, the level at which cognitive impairment generally begins. The study has found that tracking error increases with drug dosage. Automatic processes, control processes, and the risk of accident are affected. Dr. O'Hanlon stated that these results could not be explained in terms of current performance theory, and he was unable to use models of cognitive psychology because they deal with control or decision-making processes. He therefore used a model from control systems engineering. This model describes straight road tracking performance in an equation containing only two parameters: system gain (relationship of motor output to perceived error input) and pure time delay (the information transmission parameter). The latter is important because it is analogous to RT in a continuously running, closed loop, manually controlled system. If transmission delay increases due to the influence of a drug or as the result of normal aging, the phase shift between a perceived error and the compensatory response will increase. Unless a compensatory drop in gain occurs, there will be an increasing tendency for the driver to respond inappropriately when faced with the need for maneuvers requiring high-frequency steering.

In addition to other findings, the project revealed that subjects who show elevated tracking errors can generally do nothing about it. If the subject can achieve correction, it lasts only for a minute or two before the subject reverts to the previous impaired level of performance.

It is hoped that this work will produce predictively valid test batteries. But it is equally promising to see correlations between criterion variables (e.g., accidents) and actual driving performance that can be safely measured in a standard on-the-road driving test.

Researchable Issues

Current data document the motor deficits found in RT and MT measures in older adults. These data demonstrate deficits in both the motor preparation and the maintenance of preparation and difficulty in motor programming and restructuring. The research objective with regard to the older driver is to link motor control with driving behavior as well as aging. This objective can be met by addressing the following researchable issues:

- Determine which driving skills that are affected by loss of motor control can be maintained through compensating behaviors.

- Determine the differences between the young-old and old-old groups regarding their motor control deficits.

- Determine if motor control losses in cases of arthritis and osteoporosis are caused in part by extrinsic factors and if this loss is partially reversible.

- Conduct population-based prospective investigations of change in motor control conditions among different aging cohorts for whom extensive information on disease and life-style history is available.

- Determine if there are threshold levels of motor impairment at which injury or risk increases. Determine the rate of progression of motor impairment. Identify the principle determinant of the rate of change that can be observed.

- Determine the major causes of variability in motor impairment.

- Determine which of the identified determinants of motor impairment can be retarded or prevented through intervention.

- Collect data on long-term task performance. Skills increase and driving is a highly practiced skill.

- Clarify causes of observed age differences in motor control.

- Examine how physiological and psychological factors contribute to aging processes.

- Establish and utilize standard deviations in motor control research.

- Establish the discrete tasks of driving and determine which driving skills are affected by loss of motor control.

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Medication and Alcohol

The plenary session on Medication and Alcohol was chaired by Dr. James Fozard, Associate Scientific Director for the Baltimore Longitudinal Study of Aging, National Institute on Aging. The primary presenter was, Dr. Wayne A. Ray, Associate Professor of Biostatistics, Department of Preventative Medicine, Vanderbilt University. Dr. Ray provided a summary of the research findings linking the use of medications to driving. Unfortunately, he stated, research on driving and medications focuses exclusively on younger drivers. Consideration of these findings nevertheless provides a starting point for studies in older populations, since medication effects may be even more pronounced in older drivers. Dr. Ray reviewed the methodologies used in conducting research in this area and proposed the use of large data bases as a solution to some of the methodological problems.

Discussant Dr. Jerry H. Gurwitz expanded on pharmacologic changes occurring with aging that could lead to greater relative impairment in the driving performance of the older driver and described two epidemiologic studies that addressed the association between medication exposure and physical injury in the older population. Dr. Gurwitz, a specialist in clinical strategies at Harvard University, also described several data bases that might be used and discussed their limitations.

Alcohol is the only drug for which there is epidemiological data, indicating that use by the older driver produces a larger increase in accident probability than alcohol use in other driver age groups. Dr. Moskowitz—a researcher with some 30 years' experience in the fields of human factors and psychopharmacology and editor of *Alcohol, Drugs & Driving*—discussed the difficulties with obtaining epidemiological data that could permit similar analysis for the use of other drugs in the older driver. In addition, he described experimental studies demonstrating driving impairment produced by alcohol and drugs in the older driver.

Medications and the Older Driver

Medications produce central nervous system effects that potentially impair driving performance. Their adverse effects on driving safety may be more pronounced in older drivers as a result of the increasing prevalence of medication use, age-related changes in pharmacokinetics and pharmacodynamics, or the decline of compensatory mechanisms. Furthermore, the relative importance of medications as a risk factor may be increased for the older driver as use of alcohol decreases with age (Stephens and Schoenborn, 1988).

Dr. Ray described medications potentially thought to impair driving safety. They include the benzodiazepines, other psychotropic drugs, phenobarbital, antihistamines, narcotic analgesics, hypoglycemic, skeletal muscle relaxants, phenylbutazone, indomethacin, methyldopa, beta-blockers, and other anticholinergic medications. Table 3 shows the 1-year prevalence of these medications used by persons 65 years of age or older who are not residing in a nursing home. The prevalence rate was calculated for 1987 from records of reimbursed pharmacy prescriptions for persons in the Medicaid program in Tennessee. The most frequently prescribed medications were narcotic and reacted analgesics, benzodiazepines, other psychotropics, hypoglycemics, and antihistamines. For each of these medication classes, 15 percent or more of enrollees had filled a prescription in a 1-year period. These data are not ideal because they include medication use by non drivers and exclude use of over-the-counter medications. Nevertheless, they suggest that older persons frequently use medications that may impair driving and underscore the need for further studies to elucidate their actual effects on the safety of older drivers.

Nearly all hypnotic/anxiolytic drugs produce central nervous system depression and thus have the potential to impair driving performance. Cyclic antidepressants and antipsychotics have marked sedative effects, and there are data that suggest they may decrease driving performance (Hindmarch, 1986; Betts et al., 1986; and Hindmarch and Subhan, 1986). Many antihistamines are highly sedating, even at low doses, thus giving rise to concern that they decrease driving safety. Performance studies (Hindmarch, 1986) and controlled driving studies (Betts et al., 1986) suggest some impairment, which seems to be reduced with the newer nonsedating compounds (Betts et al., 1986; and de Gier et al., 1986). Narcotic analgesics have been shown to reduce performance on tests of driving-related skills (Starmer, 1986). Other medications that have been mentioned as potentially impairing driving because of either their pharmacologic properties or anecdotal data include hypoglycemic, skeletal muscle relaxants, phenylbutazone, indomethacin, methyldopa, B-blockers, and other medications with anticholinergic properties (Seppala et al., 1979; and Linnoila et al., 1986).

A member of the audience raised the question of pelotherapy (the simultaneous use of multiple drugs), which Dr. Ray acknowledged must also be considered in any study of drugs and driving.

Research on Benzodiazepines

The best data suggesting driving impairment are for benzodiazepines, which are used frequently among older adults. Dr. Ray described the research conducted on benzodiazepines by methodological approach used:

Table 3. Medication prevalence

Medication	Prevalence of use (per 100)
Benzodiazepines	
Long half-life	16.2
Short half-life	8.6
Other psychotropics	
Non benzodiazepine hypnotic/anxiolytic	9.2
Cyclic and related antidepressants	9.0
Antipsychotics	7.2
Lithium	0.1
Phenobarbita	13.0
Antihistamines (Includes antihistamines, promethazine, and prochlorperzaine)	15.3
Narcotic analgesics (Includes codeine, propoxyphene, and pentazocine)	27.3
Hypoglycemics	
Insulin	9.2
Oral hypoglycemics	10.0
Other	
Skeletal muscle relaxants	3.8
Phenylbutazone, indomethacin	4.4
Methyldopa	8.6
B-blockers	11.9
Other anticholinergics (ophthalmic preparations and Antiparkinsonian agents)	1.1

- Assessment of general central nervous system effects.
- Laboratory studies of medication effects on skills thought to be related to driving.
- Experimental studies of medication effects on driving under controlled conditions.
- Epidemiologic studies of the association between medication use and motor vehicle crashes.

General Central Nervous System Effects. Common side effects of benzodiazepines are related to depression of the central nervous system and include drowsiness and confusion, ataxia, dizziness, and impaired motor coordination (Greenblatt et al., 1983; American Medical Association, 1986; and Harvey, 1985). These side effects are particularly pronounced for older patients receiving drugs with a long-elimination half-life. In hospitalized patients prospectively monitored for adverse drug reactions, clinically significant drowsiness among users of diazepam and chlordiazepoxide increased from 4 percent for those 40 or younger to 11 percent for those older than 70 (BCDSP, 1973). The rate of morning confusion, drowsiness, or ataxia in persons receiving flurazepam the previous evening increased with both age and dose, reaching 39 percent for persons older than 70 who received 30 millegrams (mg) or more per day (Greenblatt et al., 1977). Healthy community-dwelling older subjects given 10mg of nitrazepam in the evening made significantly more mistakes on a psychomotor test the following day than did treated younger subjects or older subjects who received a placebo (Castleden et al., 1977). A clinical trial comparing 15mg flurazepam with 0.25mg triazolam in older insomniacs found that flurazepam users had increased daytime sleepiness and decreased vigilance (Carskadon et al., 1982). A randomized trial of 2 weeks of treatment with 6mg diazepam and 30mg oxazepam in healthy volunteers 60 years of age or older found that, at the end of therapy, the diazepam group had prolonged drug elimination and greater self-reported fatigue and sedation (Salzman et al., 1983).

Laboratory Studies of Driving-Related Skills. While the studies of general central nervous system effects suggest that benzodiazepines might impair driving safety, the relevance of nonspecific performance deficits such as drowsiness or confusion to driving may be questioned. Thus, there have been numerous controlled studies of the effects of benzodiazepines on more specific measures of psychomotor function that may be better indicators of driving performance, including laboratory studies of specific motor skills and studies of simulated driving.

In a review of an extensive literature, Hindmarch (1986) noted that commonly used benzodiazepines, including diazepam, chlordiazepoxide, and nitrazepam, decrease performance on the critical flicker fusion threshold and choice reaction time tests. Palva and coworkers noted 10mg diazepam given to healthy men younger than age 59 in a double blind crossover study produced mild impairment of visual stimulus detection, reaction time, and eye-hand coordination and suggested that the decreased baseline performance on these tests in middle-aged persons (relative to students 18 to 24 years old, might imply a reduced margin of safety for diazepam users in this age group who were driving (Palva et al., 1982). Seppala et al. (1986) tested the effects of anxiolytics with several measures of performance, including critical flicker fusion threshold, choice reaction time, body sway, eye-hand coordination, and a divided attention test. They found that either 10mg diazepam or 2.5mg lorazepam produced impairment, but 10mg buspirone did not. Moskowitz and Smiley (1982) found that 15mg diazepam impaired performance in a driving simulator test and that this persisted through 9 days of treatment. In contrast, no impairment was observed with 20mg buspirone. Similar results were obtained by Bond and Lader (1981), Erwin and Linnoila (1982), and Smiley et al. (1983). Arando and Mattila (1986) noted reduced performance in critical flicker fusion threshold and divided attention tests with use of 3mg lorazepam.

Driving Under Controlled Conditions. The driving performance data for benzodiazepines clearly indicate that these drugs, particularly those with long half-lives, impair driving performance under controlled conditions. Quality of driving under controlled conditions is thought to be an even better indicator of actual driving performance. Numerous studies have been conducted on the effects of benzodiazepines on performance in controlled driving tests, as reviewed in Table 4.

Although a variety of measures of driving quality have been used, there are several consistent findings. Virtually all of the benzodiazepines tested impair performance shortly after use, and this effect persists through several days of therapy. For some drug dose combinations, the impairment can be equivalent to that produced by moderate (0.10%) blood alcohol levels (Volkerts and O'Hanlon, 1986a; and Mortimer and Howart, 1986). Long half-life hypnotics consistently impair performance the next morning in a dose-related manner; for high doses, some impairment may persist into the afternoon (Volkerts and O'Hanlon, 1986a). The residual effects of short half-life hypnotics are either not detected or less than those of the long half-life drugs. Studies in persons formerly treated for insomnia or anxiety demonstrate that the performance impairment occurs only under active drug treatment.

Although these and other studies consistently find a performance deficit in benzodiazepine users who are young or middle-aged, most subjects were young volunteers and none included persons over the age of 60 or those with any illness. Therefore, the effects of benzodiazepines on the performance of older drivers or drivers with concomitant acute or chronic disease are unknown, although it would be expected that this group would be even more sensitive to the adverse effects of benzodiazepines on driving performance.

Epidemiologic Studies of Motor Vehicle Crashes. There have been several case-series studies of benzodiazepines and crashes. These have been restricted to fatalities or severe injuries. Positive serologic tests for benzodiazepines have been noted for between 5 and 10 percent of cases (Cowart and Kandela, 1985; Polen and Friedman, 1988; Seppala, 1979; and Fortenberry et al., 1986). Three case-control studies have found an increased risk of crashes among benzodiazepine users. Honkanen and colleagues (Honkanen, 1980) compared serum samples from 201 Helsinki drivers injured in automobile crashes and seenin the emergency room with those of 352 controls randomly selected from car drivers at 10 gas stations. Cases were significantly more likely to have diazepam detected than were controls. Skegg et al. (1979) used the Oxford record linkage system to identify 57 people in crashes resulting in hospital admission or death and 1,425 matched population controls. For persons

Table 4. Benzodiazepines and controlled driving studies

Study	Population (Age Mean/ Range)	Drug	Outcome	Effect on Performance
de Gier, Hart 1986 (nonexperimental study)	22 males (43)	Diazepam 5mg	Rated driving skill	↓
O'Hanlon 1982	9 males (24-34)	Diazepam 5mg Diazepam 10mg	Lateral position control, nighttime	None ↓
O'Hanlon 1986	11 female insomniacs	Nitrazepam 10mg Temazepam 20mg	Lateral position control next a.m.	↓ None
Volkerts & O'Hanlon 1986	Female insomniacs	Secobarbital 200mg Flurazepam 30mg Loprazolam 2mg Flurazepam 15mg Flunitrazepam 2mg Zopliclone 7.5mg Nitrazepam 5mg	Lateral position control next a.m.	↓↓ ↓↓ ↓↓ ↓ ↓ ↓ Not significant
Betts & Birtle 1982	12 females	Flurazepam 15mg Temazepam 20mg	Weaving, gap acceptance next a.m.	↓↓ ↓
Betts & Mortiboy 1986	40 female students, 16 students	Chlordiazepoxide 10mg Nitrazepam 5mg Triazolam .25 mg Loprazolam 1mg	Weaving, gap acceptance next a.m.	↓ ↓↓ ↓ ↓
Laurell & Tornros 1986	18 students (20-34)	Nitrazepam 5mg Triazolam 0.25mg Brotizolam 0.25mg	Emergency avoidance next a.m.	↓ None None
de Gier, Hart et al., 1986	18 patients with history of anxiety (36)	Lorazepam 1mg Bromazepam 1.5mg	Rated driving skill	↓, Not sig. ↓, Not sig.
Mortimer & Howart, 1986	14 (21-32)	Diazepam 7.5mg (Dose was 0.11mg per kg body weight)	Serpentine track, Evasive lane change	↓, Comparable to alcohol 0.08%

filling a prescription for a minor tranquilizer in the preceding 3 months, the relative risk of a crash resulting in a hospitalization or death was 4.9. McPherson and coworkers found that drivers in New South Wales with a positive breath alcohol analysis carried out as the result of a crash had a greater self-reported use of benzodiazepines than did other drivers with positive breath alcohol tests (McPherson et al., 1984). However, Jick and colleagues found no difference in prior hypnotic/tranquilizer prescriptions among drivers and passengers who were hospitalized after a crash in a health maintenance organization in the United States (Jick et al., 1981).

Drugs and Physical Injury

A number of studies have explored the association between exposure to psychotropic agents and the occurrence of physical injury (primarily falls and hip fractures) in older patients. Because these medications are among the agents of primary interest in relation to driving safety and motor vehicle accidents, Dr. Gurwitz added them to the list reviewed by Dr. Ray.

Tinetti et al. (1988) conducted an observational cohort study to investigate risk factors for falling among older persons living in the community. A sample of 336 persons at least 75 years of age were followed for 1 year. Information on falls and their circumstances was obtained through telephone calls made to study subjects every other month. Participants kept a diary to record fall events. The adjusted odds ratio estimating the independent contribution of sedatives (including benzodiazepines, phebnothiazines, and antidepressants) to the likelihood of falling was 28.3 (95 percent CI, 3.4-239.4). A similar study design could be employed to assess pharmacologic risks for motor vehicle accidents; however, self-report of mishaps involving the use of motor vehicles would probably be less complete than that for falls.

Ray et al. (1987) performed a case-control study of the association of hip fracture and the use of various psychotropic drugs in a population of older enrollees in the Michigan Medicaid program. The investigators determined that a significantly increased risk of hip fracture was associated with current use of hypnotics and anxiolytics with long-elimination half-lives (odds ratio 1.8), tricyclic antidepressants (odds ratio 1.9), and antipsychotics (odds ratio 2.0).

Pharmacology in Older Adults

Dr. Gurwitz added to the discussion of psychotropic drugs—especially the benzodiazepines—by pointing out their interaction with the aging process. Important issues in geriatric clinical pharmacology involve pharmacokinetics (what the body does to the drug) and pharmacodynamics (what the drug does to the body). The first aspect is the pharmacokinetics factor. Since the distribution of a drug in the body depends to a large extent on body composition, age-related increases in body fat at the expense of muscle can have important implications. Such changes in body composition lead to a greater volume of distribution and half-life for highly lipid-soluble medications such as the long-acting benzodiazepine hypnotics. Age-related changes in phase I biotransformation reactions in the liver (oxidation, reduction, and hydrolysis) can also prolong the half-lives of a number of medications (Montamat et al., 1989). Based upon these pharmacokinetics changes, it is not surprising that the half-lives of many commonly prescribed medications—including the long-acting benzodiazepine hypnotic, flurazepam—are substantially prolonged older adults (Greenblatt et al., 1981).

The second aspect is the pharmacodynamic factor. For reasons that are not completely understood, the aging process seems to be associated with an increase in sensitivity to many medications, including the benzodiazepines. One of the earliest studies describing such changes involved a sample of patients between the ages of 30 and 90 who were medicated with diazepam to undergo elective cardioversion (Reidenberg et al., 1978). The clinical end point used was the patient's inability to respond to a verbal stimulus. The serum level of diazepam at which this effect occurred was significantly lower in the older patients. Similar findings have been described in studies of other benzodiazepines and the opiates (Scott and Stanski, 1987).

Dr. Gurwitz also noted that, while Dr. Ray rightly places an emphasis on the psychotropic drugs—especially the benzodiazepines—it should be emphasized that use of these drugs in the community-dwelling population is greatest among "non-elderly" individuals 45 to 54 years of age (Koch and Campbell, 1980 and 1981).

Alcohol and the Older Driver

In the case of alcohol, there is epidemiological evidence indicating drug-age interactions. Dr. Moskowitz described the findings of a two-way analysis of age, blood alcohol concentration levels, and accident frequencies using data compiled in a Grand Rapids, Michigan, study (Zylman, 1968). The data on which the analysis was based were obtained by investigators rushing to the scene of most accidents in Grand Rapids over a 1-year period, and obtaining breath alcohol samples of the drivers involved. Breath alcohol samples were also obtained from randomly stopped nonaccident-involved drivers passing the same location in the same traffic direction at the same time of day on the same day of the week. By comparing the distribution of breath alcohol concentrations in accident-involved drivers with those in drivers not involved in accidents, it was possible to determine the relationship between alcohol level and accident probability. Information also was obtained from the drivers regarding a variety of personal factors including age. In the Zylman (1968) analysis, the data were segregated into four alcohol concentration levels: 0; 0.01 to 0.04 percent; 0.04 to 0.09 percent; and 0.10 percent and above. The data were then examined by age and accident probability. The results indicated that, in comparison with drivers age 25 to 55, the young (under 25 years) and older drivers (55+ years) showed a greater increase in accident probability with alcohol. The method of data collection served as a control for many factors that are important in accident production, such as time of day, traffic direction, weather, and area. Further, by questioning the driver, the researchers were able to establish the importance of age, race, marital status, economic status, and employment as factors affecting crash probability. Finally, a direct measure of the drug level determining behavior at the time of the accident was obtained by measuring the breath alcohol concentrations.

Dr. Moskowitz stated that he knew of no other epidemiological data that examined age interaction with another drug. The Grand Rapids study—the most well-known driving accident and alcohol interaction study—had 13,575 subjects, of whom 5,985 were involved in accidents and 7,590 were not. Despite this large number of tested subjects, attempts to break the data down for statistical analysis of accident probability by alcohol concentration versus other variables were limited due to the small number of subjects falling into some of the cells in the analysis.

Dr. Moskowitz cited a number of problems with epidemiological research on other drugs. First, in most cases, the studies compare users to nonusers because there is no measure of the drug effect level at the time of the accident. Obtaining blood samples to determine drug levels from a random group of nonaccident participants is difficult, especially in comparison to the breath samples needed for alcohol. Second, even if blood samples from accident and nonaccident subjects could be obtained in a study, the drug serum level, unlike alcohol, is typically not a good measure of the current impact of the drug on the central nervous system and behavior. There is no simple correlation between drug serum level and behavior.

For example, with marijuana, blood levels of delta-9 THC, the active element, dropped with 2 to 3 hours to a point at which most laboratories cannot even detect it. Yet, behavioral studies have demonstrated impaired behavior for more than 12 hours and possibly up to 24 hours.

Moreover, unlike some studies in the past, it is no longer possible to obtain a large sample size by assuming that all drugs in a drug category are similar in behavioral effects. For example, several previous epidemiological studies placed all antihistamines in one group and all minor tranquilizers in another group. Yet, antihistamines and tranquilizers are now marketed that have been specifically designed to avoid behavioral side effects. Future epidemiological studies thus would have to ensure that a specific drug within a category is identified in order to do an analysis. This would result in very small sample sizes except for a very few drugs. Most of the information to evaluate drug effects on older drivers therefore must come from laboratory experimental studies using driving-related behavioral measures.

Research Methodologies

Dr. Ray discussed two directions for research: (1) experimental studies on performance; and (2) epidemiological studies on crashes per se. He emphasized that it must be validated that performance indicators do predict crashes.

An epidemiologic study of crashes must define the population of older drivers, identify crashes, select comparable controls (in a case-control study), accurately determine medication use in study subjects, and control for other potential confounders. The availability of computerized driver license and crash data bases has greatly facilitated the first three steps. However, determination of medication use—particularly for older subjects—is difficult. In other epidemiologic studies, medications are ascertained by interview: intentional underreporting can markedly decrease the accuracy of their driver interviews. Honakanen and colleagues found that only 45 percent of drivers with positive serologic tests for benzodiazepines reported such use in an interview (Honkanen, 1980). Although assays of body fluids are generally the most reliable method for determining drug use, such testing may be unacceptable in many settings for controls not involved in crashes.

An alternative technique for determining medication use is the use of automated records of filled prescriptions. In health maintenance organizations or Medicaid programs (Ray and Griffin, 1989), computerized pharmacy files may be generated routinely. Enrollment files, which enumerate the membership and provide identifying and demographic information, can be linked with driving data bases to define the study population, identify cases, and select controls. This use of record linkage techniques offers the promise of performing epidemiologic studies of medication use and crashes in older drivers quickly and economically.

A potential limitation of this method is control for other factors that are associated with both medication use and risk of crashes. In younger populations, alcohol use might be one such confounder. However, a 1985 survey of behavioral risk factors in a probability sample of adults in the United States found that only 4 percent of men 65 years of age or older and 1 percent of women reported driving following alcohol use (Stephens, 1988), suggesting that alcohol is unlikely to be an important confounder in studies of the older driver.

A more serious limitation is lack of information on miles driven and indication for drug use. The former should generally be a conservative bias, as ill medication users should be likely to drive fewer miles than those in good health. However, for some medications, the magnitude of this bias might be sufficient to conceal large impairments in driving safety. In contrast, confounding by indication might produce spurious associations. For example, an association between anticonvulsant and crashes might reflect crashes resulting from breakthrough seizures.

The ideal system, Dr. Ray concluded, would consist of a record linkage system which permitted interview of selected subjects that would allow either demonstration that miles driven and drug indication were not confounders or appropriate statistical controls for these factors. Unfortunately, confidentiality issues have made the personal interview difficult in most record linkage systems. Perhaps a concerted effort by those interested in improving safety of the older driver will help convince data base gatekeepers of the pressing public health need to elucidate the role of medications in motor vehicle crashes in this vulnerable population.

Data Bases

In response to Dr. Ray's recommendation to use data bases, Dr. Gurwitz commented on the positive features and potential limitations of various data bases that could be considered for use.

Medicaid Claims Data. Medicaid claims data are being employed in an increasing number of descriptive and analytic epidemiologic investigations to study adverse drug effects (Bright et al., in press). In research relating to drug exposures in older patients, the demographic characteristics of Medicaid populations are a definite strength. For example, 18.3 percent of all Medicaid recipients in fiscal year 1983 were 65 years of age or older, a substantially larger proportion of older adults than in the general population (Health Care Financing Program Statistics: Medicare and Medicaid Data Book, 1986).

However, other characteristics of the Medicaid population may prove troublesome when designing a study to investigate safety in the older driver. Medicaid eligibility is tied primarily to poverty or poverty in conjunction with poor health. The high costs of owning an automobile and maintaining it on the road seem inconsistent with Medicaid eligibility. In addition, the institutionalization of a large proportion of older Medicaid recipients would generally preclude the use of an automobile (Health Care Financing Program Statistics: Medicare and Medicaid Data Book, 1986). Among older, noninstitutionalized Medicaid recipients, data from the 1980 National Medical Care Utilization and Expenditure Survey indicated that 70 to 80 percent reported a functional limitation, probably further limiting the number of car drivers available for study (Kasper, 1986). Although further information is necessary to assess adequately the usefulness of Medicaid data to study older drivers, current knowledge about older Medicaid recipients suggests important difficulties in using the data for this purpose.

Health Maintenance Organization Data. Large HMOs can provide another source of computerized prescription and diagnostic data which could be linked to driver license and motor vehicle accident data bases. The number of people now enrolled in HMOs exceeds 21 million (Hellinger, 1987). However, in contrast to Medicaid programs where proportions of older Americans exceed those in the overall U.S. population, HMO memberships tend to be skewed toward the younger age groups. For all HMOs combined, the proportion of members 65 years of age or older is 5.8 percent, far below the percentage of older people in the U.S. population—i.e., more than 12 percent (Hodges, 1989). The numbers of "old-old" (85 years of age or older) enrolled in HMOs are few. One notable exception is the Kaiser Permanente Medical Care Program (total membership of 5.4 million), which includes more than 200,000 members 85 years of age or older nationwide (Yamada, 1988). Unfortunately, data concerning these individuals would not be found in a single data base.

Another important point concerning HMO membership for older persons is the question of comparability with the general U.S. population in terms of health status. While the Medicaid older population is typified by poorer health overall, evidence suggests that the older HMO membership is healthier than the general population (Riley et al., 1989). Therefore, the use of HMO data would raise concerns for two reasons: (1) a potential problem with inadequate numbers of older subjects for study inclusion, especially the "old-old;" and (2) concerns about generalizability to the population of all older adult drivers. Alternatively, the healthier older HMO population could improve the feasibility of a study utilizing an HMO data base because a healthier population might include more drivers.

The "Catastrophic" Health Insurance Data Base. A national data base with information about medications and diagnoses for most if not all of the older population would provide the capacity to select a study group of adequate size that would be truly representative of the population of older drivers in the United States. Although such a data base sounds improbable at present, the provision of the catastrophic illness law extending coverage to outpatient prescription drugs might lead to such a data base. Under the provisions of the law, the Health Care Financing Administration apparently would provide every participating pharmacy with a communications device through which the pharmacy would transmit to a data bank information about all outpatient prescriptions dispensed to Medicare beneficiaries (Iglehart, 1989). Should the program go into effect, it would provide a valuable new source of information for research on a variety of issues including medications and the older driver. Unfortunately, the fate of catastrophic health insurance remains in limbo at this time.

Researchable Issues

Most studies conducted on drugs and medications have demonstrated performance deficits in subjects. Researchable issues that would contribute to knowledge in this area follow.

- Conduct experimental studies with subjects 65 years of age or older.
- Link computerized data bases with driver license and motor vehicle accident data bases. Determine if an appropriate data base currently exists for this research.
- Follow studies of performance with epidemiologic studies of crashes which corroborate the results of laboratory studies and can thus create a greater impetus for appropriate preventive measures.

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4. Planning Sessions

Upon completion of the six plenary sessions, the conference participants broke into smaller groups to attend seven concurrent planning sessions. At these sessions, participants worked in groups to identify future research directions in each of the following topical areas as they relate to older drivers:

1. General assessment.
2. Vision assessment.
3. Functional assessment.
4. Driver intervention.
5. Vehicle design.
6. Highway design.
7. Basic research.

The format for each planning session varied somewhat from the others. In general, however, each session was chaired by a session leader, who opened the discussion of the topic at hand, summarizing salient points and setting parameters as necessary. The leader distributed blank cards on which participants were asked to note preliminary research issues. Following this, the session leader presented the issues to the group for further discussion and refinement.

During this discussion, the leader drew on the relevant information provided in the foregoing plenary sessions, and encouraged and facilitated group discussion of this information. Each planning group left its session with a list of researchable issues.

This chapter presents the researchable issues that were developed in each planning session as well as a summary of the considerations behind these issues. A list of planning session participants is provided in Appendix D.

General Assessment

The General Assessment planning session was led by Dr. B. J. Campbell, director of the University of North Carolina Highway Safety Research Center. Dr. Campbell identified the following issues as the context within which the discussion was to be based.

- Who should be identified for assessment, older drivers in general or older drivers with specific characteristics?
- Should road testing be used for assessment? If so, who should be examined and what should the tests measure?
- Should physicians or other health care officials be required to report impairment of older drivers to the department of motor vehicles?
- Should attempts at reducing accidents be directed at reducing the number of accidents per unit of exposure or at limiting the amount of exposure?
- What driver controls should be used to trigger the assessment process, licensing procedures or convictions of violations?

Family members and health care officials are concerned about these issues because they have no guidelines for making an objective decision about the older driver's ability behind the steering wheel.

Assessment Population

The prevailing political philosophy in the United States calls for virtually universal access to the motor vehicle. The presumption in the testing procedure is that the great majority of applicants will pass. The purpose of testing is not to select a few highly capable drivers, but to delay licensing for a relatively small minority until they gain enough skill and knowledge to meet the State's standards. Typically, these standards require only minimal skill needed to operate the vehicle under safe conditions. Older drivers may have no difficulty passing even with cognitive deficits. Furthermore, because renewal processes generally do not require retaking a road test, an older person who may have been licensed many years before the onset of an impairment that represents a hazard on the road would generally not be detected during license renewal.

In general, the benefits of driving have been so great that authorities are reluctant to deny driver licenses. When older adults are restricted from driving, their quality of life may be greatly diminished. Either they must depend on others to transport them and perform their errands, or they are forced to rely on public transportation, which often requires physical mobility that older people do not have. On the other hand, although older adults represent only a small proportion of the driving public, they contribute to an inordinate number of accidents in relation to the number of miles they drive.

Most of the policies and procedures for driver licensing were formulated more than 50 years ago, in the 1930's. The driving population at that time was much smaller, and only a few of those drivers were older adults. This situation has since changed drastically; not only has the number of drivers and the amount of traffic greatly increased, but the proportion of older drivers has increased as well. Also, as life expectancy increases and the number of older adults within our population increases, the number of older drivers will continue to increase. These changing demographics and nature of the driving task should prompt us to reevaluate present licensing policies.

A policy has been proposed to require road tests every 5 years for drivers who are 55 or older. Although this procedure is possible at the policy level, it would require developing measurement parameters for driving skills that apply to all drivers. Otherwise, the policy could be seen as discriminatory against the older adult. Presently, only three States and the District of Columbia require routine road tests based on advanced age. In Illinois, drivers who are 69 or older must take a road test to renew their licenses. In Indiana, New Hampshire, and the District of Columbia, a road test is required for all renewing drivers who are 75 or older. These tests are repeated every 4 years as long as the driver holds a license. Studies have shown that the percentage of older drivers who renew their licenses declines at a greater rate in these States. States that require the driver to appear in person or to take a vision test have a smaller rate of decline in renewals. States with a mail-in renewal form have the highest rate of extensions. Perhaps requiring a road test would encourage older drivers themselves to evaluate their need to drive in light of their confidence in their driving abilities.

One panel member related the results of a survey asking older drivers if they felt that they should be retested for driver license renewal. Almost all responded positively, but disagreed totally as to the age when the retesting requirement should begin. They all felt that testing should begin for drivers a few years older than themselves. Most agreed that a vision test should be required, and some indicated that a medical examination would be needed. Only a few said a road test should be required. When asked if they would feel threatened by a road test, most said that they would not unless they were required to parallel park, which is the most difficult maneuver on the road test and the only one whose performance was shown to be a predictor of potential accidents in a North Carolina study.

The question of how to determine who should submit to reassessment for driver licensing presents a dilemma. Abilities vary greatly from one older driver to another; only a subgroup of older drivers contributes to the problem. Likewise, each driver's abilities can vary significantly from one day to the next. Furthermore, some of the driving problems may not always be due to diminished ability: they may reflect an uncooperative or defeatist attitude. The problem is twofold: (1) how to objectify and systematize what actions indicate that a person should not drive; and (2) how to identify the group that contributes to traffic problems so that preventive or corrective actions can be taken. This problem clearly requires research.

Road Testing

Current road tests are more suitable for youthful drivers, who are novices and are destined to improve their abilities. These tests do not screen out reckless drivers who handle driving mechanics well, but who nevertheless have a high risk of accidents. They also fail to reveal demented older drivers who could not respond to more complex situations.

Research on current road tests shows little correlation between scores on various aspects of the test and potential crashes, except in the case of parallel parking. However, older drivers typically object to this task on the grounds that it is not absolutely necessary. North Carolina licensing agencies dropped parallel parking from its road test because of these objections. At any rate, older adults who passed a road test including parallel parking are generally not required to take the test again, so that diminished driving abilities may never come to the attention of authorities. If this policy changes so that retesting on the road is required, new tests should be devised that reflect the need to evaluate accurately the older driver's ability to handle traffic situations.

A road test of this type must test the skills that are directly related to driving, just as a skills test for employment must directly reflect the job to be performed. Panel members agreed that—particularly for the impaired older adult—this type of test should start with simpler tasks. A hierarchy of complexities could then be introduced to identify individuals with unacceptable crash risks under realistic driving stresses. For example, making a left-hand turn at a controlled intersection is a more complex maneuver that could be considered a basic driving task. The panelists agreed that an important aspect of this test should be determining if the driver can adapt to and not disrupt the traffic flow. Someone driving too slow for conditions or stopping unexpectedly creates a hazard as surely as someone driving too fast. Older drivers should be able not only to control their own behavior, but also to judge how their behavior affects the traffic situation and to adjust it accordingly.

One of the panel members is currently devising such a test to be given in two parts. The first part takes place in a parking lot with no other vehicles present. The candidate must be able to identify vehicle controls and how to use them, fasten seat belts, turn right and left, and perform other very basic tasks. The second part involves traffic situations including left and right turns and negotiating a high-demand intersection. Some States—notably Pennsylvania and Michigan—have designed performance-based examinations including visual search and scan and judgment components that are evaluated in recognized traffic situations. However, these tests have not been fully implemented.

Once a test has been designed, the matter of scoring presents another problem. Research should determine if a detailed checklist or a subjective rating is a more effective device for evaluating driving skills. Some driving skills, such as maneuvering a left turn or staying within the traffic at certain speeds, are obviously more critical than others. Many tasks must be performed, but certain tasks must be performed *well*. One panel member suggested that the latter group of skills be given more weight. He advised that the driving tasks should be divided by function or type of maneuver and that a value for each function be determined. The driver would receive a figure-of-merit score based on his or her ability to perform the various functions. A minimum figure-of-merit score would be required to pass the license examination.

One panel member pointed out that an urban driving environment presents much greater demands upon the driver than does a rural environment. This variation of driving conditions presents a problem in designing a road test that will screen problem drivers adequately but will not deprive those who can perform in less stressful situations. One panelist recommended that tests may need to be repeated so that variations in driver performance at different times could be evaluated.

Considerable research and effort will be needed to devise a road test that meets these requirements and to determine the most effective way to evaluate driver performance.

Physician Reporting

Most States have various processes for reporting drivers with medical problems to their motor vehicle divisions. Though more research is needed in this area, one study that tracked cardiovascular patients who participated in a medical review board process showed promising results: those drivers had better driving records than patients who did not participate. However, in New York, for example, only 10 percent of older drivers' disabilities are reported. Some States require that physicians report these conditions to the licensing agencies; other States (such as New York) are implementing such requirements. In these latter States, a doctor could be held liable for damages for failing to report a disabling condition that later led to an accident.

Most health care providers are reluctant to report medical problems for various reasons. Such reporting is counter to the patient's right to confidentiality, and many physicians fear the legal consequences. Many States have granted physicians immunity against legal action on those grounds, but the rate of reporting still remains low. Physicians are also hesitant to report patients when they are personal friends or well known to the physician's family. They may also fail to report patients who are well-known in the community. Some people fear that physician reporting also may be biased in favor of the wealthy and that only the poor will be reported through such means. On the other hand, some physicians hesitate to report suspected disabilities because of the expense of medical examinations to confirm or disprove the disability. One panel member related the case of a hospital that gives a specialized driving test for older drivers. The test is too expensive for most patients, and is not covered under Medicare. Some physicians doubt that the division of motor vehicles will act upon their reports. A panelist cited one extreme case in which a patient with daily seizures continued to drive because cognizant hospital authorities could not have his license revoked until they convinced the licensing agent to come to the hospital to observe the patient.

Decisions for reporting are not always clear-cut. Many physicians fail to report physical impairments simply because they have no guidelines for determining which patients should be reported. The physician may not realize all the factors that are related to an increased risk of traffic accidents. In California, for example, physicians must report any older person who has a mobility problem, but since this type of problem affects all older adults to one degree or another, the physician is left to determine what degree of mobility problems should be reported.

As more States attempt to enact legislation in this area, more research will be needed on the effect of various medical conditions on driving ability and on the training physicians need to determine proper recommendations in all cases of impaired older adults.

Accident Reduction

One obvious way to reduce the number of accidents involving older drivers is to limit the amount of driving they do. However, as noted before, older drivers contribute to a higher number of accidents per number of miles driven than other driver age group. This fact demands that researchers study ways to reduce the number of accidents per unit exposure as well as reducing the number of miles driven.

Education may offer some potential in this regard. The older driver may respond favorably to information about new symbols on dashboards indicating vehicle safety features, the use of head restraints, and the benefits of wearing seat belts. Studies have shown that older drivers use seat belts less—particularly shoulder straps—because they find fastening them difficult. Older drivers could also benefit from education in how drivers acquire driving-related skills, which abilities—such as reaction time—diminish with age, and ways they can compensate for these diminished skills in the driving environment. They might be taught prompts or artificial portrayals of driving situations that allow them to regain these abilities to some extent. The goal is for older drivers to know which tasks are absolute requirements for driving and which ones must be done well, and to be able to perform them accordingly.

Some the research aimed at reducing accidents could be done with patients suffering from Alzheimer's disease because studies have shown that they have the same types of accidents as other drivers. Some national centers for Alzheimer's research are already conducting longitudinal driving studies, but many are no longer being funded. Further research could include specialized road tests and could study issues such as the relationship of a high number of accidents to the onset of dementia and the types of informal constraints family members impose on drivers as driving errors increase.. Reducing accidents also requires research in vehicle and highway redesign that considers problems unique to the older driver.

Driver Controls

Although physician reporting is one means of driver control aimed at improving safety for the older driver, that method is not adequate for screening potential problem drivers, nor should physicians be required to decide if a patient should drive or not. Research has shown that older drivers are self-victims, but do not often inflict harm to others; therefore, they may not always come to the attention of highway authorities. As a result, more measures are needed to enable highway authorities to identify the problems of older drivers.

One way to identify these problems would be to track crashes involving older drivers, particularly those above a certain age. These accidents are difficult to track, however, because not all of them have a related traffic violation or require a police report. Many fender benders may escape notice, particularly if they are not reported to the insurance agency.

Once a driver has been identified as a risk, the answer is not always to restrict his or her driving completely. Some drivers need only to restrict their driving location or distance: they would choose a restricted license. Alternatives to denying a driver's license, how these alternatives will be implemented, and methods of enforcement need to be explored.

Researchable Issues

The planning session revealed the following research issues related to driver assessment:

- Medical guidelines should be established for licensing older drivers. Research should identify specific conditions that indicate a potential driving risk. Health care officials and highway authorities should be aware of these guidelines.

- Drivers who participate in State medical review board programs should be tracked to evaluate program effectiveness in improving driving behavior.

- Research is needed to develop comprehensive assessment methods. This research should include designing a behind-the-wheel test based on dynamic task performance such as maintaining traffic flow. The validity and reliability of a gestalt-like performance evaluation and a micro checklist evaluation of driving abilities should be examined. A multitask assessment should be studied with a goal of establishing a figure-of-merit score for qualifying drivers.

- A major research effort should be directed at reducing the number of accidents per unit exposure instead of merely reducing exposure. Driver education should be a significant part of this research. Vehicle and highway redesign efforts aimed at this goal should be researched.

- Research should determine how and when to trigger post-licensing control procedures. Various methods such as age, referrals, traffic convictions, and accidents should be explored. Giving older drivers the option to restrict their own licenses should be considered.

- The characteristics of the subgroup of older adults who contribute most to traffic problems should be studied and correlations among these characteristics, if any, should be determined.

- Alternatives to denying driver licenses arbitrarily to older patients with limited disabilities should be explored. These alternatives might include driving only at certain hours, in certain locations, and for specified distances.

- Demented and healthy elderly patients should be used for driver research. Studies could be performed using patients with Alzheimer's disease for comparisons. One area of study might be the relationship between an increase in driving errors or crashes and the onset of dementia.

Vision

The planning session on Vision was led by Dr. Herschel Leibowitz. Dr. Leibowitz, who is with Pennsylvania State University's psychology department, started the session by asking the panel what research should be done in the field of vision as related to the mobility and safety of the older driver. He raised these questions: What is good driving performance, and how do we measure it in terms of vision? The discussion that followed centered on these two questions as they relate to the interactions among vision, cognitive function, and driving behavior as well as to vision tests currently used by State licensing agencies. The discussion concluded with a recommendation for standardized testing with a more complex two-tiered approach that would distinguish the driver of whatever age whose vision problems may lead to unacceptable driving performance from those whose vision is adequate to the demands of driving.

Behavioral Measurement

The panel members agreed that an operational definition for good driving performance should be derived. This definition should delineate satisfactory performance as opposed to optimum performance, which is generally used in the laboratory setting. Driving does not require optimum performance; therefore, research should be directed at defining the behaviors that may be hazardous to the driver, particularly the elderly driver.

This definition will be difficult to attain. Although driving involves many dependent variables, defining satisfactory driving behavior requires making specific difficulties observable in the experimental sense. The panel members discussed various ways to observe driving behavior. Their consensus was that current driving tests administered by State licensing agencies are not adequate: they have no standardization, they are too short, and they often do not reveal the driver's potential responses to various traffic situations. A trustworthy assessment of driving behavior may require observers in the car. Also, a reliable road test is needed to evaluate skills and explore these issues. Although Dr. Margaret Jones has designed such a road test, such a study would involve considerable space and cost, and funding is difficult to obtain. Some States may be willing to participate in this study, but they would, no doubt, require that the test be conducted by their own personnel, who would need lengthy training to perform the type of scoring needed to obtain accurate results.

Although a method of measuring good driving performance is needed before minimal vision requirements for driving can be established, the panel conceded that defining this method involves research beyond the scope of this planning session.

Minimal Vision Requirements

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

Conversely, the question of which visual attributes are required for satisfactory driving performance is debatable. Among likely candidates are improved field measures, such as "useful field of view," as referred to in Dr. Ball's discussion (see the discussion of the plenary session on Cognition in Chapter 3), peripheral and central angular movement, and movement in depth (see Shinar's 1977 report to the National Highway Traffic Safety Administration [NHTSA]), contrast sensitivity, and sensitivity to glare (Transportation Research Board [TRB] 1988 Report, chapters by Bailey and Sheedy and by Schieber) as well as dynamic visual acuity and low luminance performance. A realistic observation of the correlation between these visual measures and accidents requires isolating only those accidents that are directly vision related.

One strategy to determine the visual requirements for driving would be for a clinician to conduct further testing on drivers whose screening by licensing agencies indicated poor vision. More sophisticated visual tests could be administered to determine the relationship between higher level visual skills and driving performance. Drivers who might not receive a license based on their initial screening should be receptive to additional testing. After this testing, a decision could be made to allow, limit, or withhold driving privileges.

Another suggested approach starts with normal visual characteristics, then simulates one form of visual deterioration to determine which characteristics are important for driving. For example, to determine the effect of cataracts on driving performance, cataracts would be simulated in people with normal vision and differences in their driving performance documented. This approach does not consider that people who lose abilities naturally over a period of time adapt their behavior to compensate for the loss. Also, driving performance among drivers with the same visual deficiencies varies greatly.

Vision Testing

Just as there are no standards establishing minimal vision requirements for driving, there are also no standards for administering tests and applying the results of the tests. In some States, failure of the vision test means an automatic denial of driving privileges. In other States, a person who fails the vision test may still be granted a license if he or she passes the driving test. One panelist pointed out that the purpose of present screening is not to restrict driving completely for those who fail the test, but to identify those who need corrective measures such as eyeglasses to correct vision deficiencies.

Guidelines are still needed for standardizing testing from State to State. Also, the testing needs to be more sophisticated. Although testing acuity is a good place to start because it predicts other problems, a battery of tests should be designed that will predict performance in other visual areas including contrast sensitivity, visual search, low luminance performance, and glare measure. Acuity tests alone will not indicate the extent of the problems in other areas.

A panel member suggested that an operational visual acuity test could be devised and implemented in the field by quantifying the stimuli in the visual environment, then altering the number of stimuli to test the visual demands made upon the driver. Another panelist commented that, in England, visual testing is based on reading license plates. This type of test benefits drivers by giving them a clear indication of their visual ability in the driving environment. This feature is particularly relevant because drivers are often unaware that their vision is deteriorating.

Panelists agreed that vision testing at the division of motor vehicles should perform a public health service as well as screen applicants for drivers' licenses. Drivers who have difficulty with the vision screening should be referred to optometrists or ophthalmologists for further testing. This testing may, in turn, lead to referrals for other types of testing. Ophthalmologists and optometrists should follow up on those with weaker vision and make a recommendation on driving to the motor vehicle division. Such a recommendation should include an assessment of visual skills as well as assessment of disease. As part of this process, mechanisms should be established to keep doctors informed about visual standards and about changes in such standards.

The question is this: What further testing is necessary after the person is referred to practitioners? A second tier of visual testing could include behavioral testing, visual field-in-field testing with input from cognitive psychology, reaction time, motor response, attention response, and effects of stress such as prolonged performance on vision.

Two-Tiered Testing Recommendation

The panel concluded by recommending that vision screening for driver license applicants should involve a two-tiered approach. The first tier would be performed at the licensing agency. Appropriate characteristics to be researched for inclusion in this test are contrast sensitivity, visual fields, low luminance performance, glare measure, dynamic visual acuity, and peripheral and central angular movement.

Drivers who fail the first tier of testing should be referred to a practitioner for the second tier. Besides more sophisticated vision tests, appropriate attributes to be researched for possible inclusion at this level are behavioral testing, effective visual field test with input from cognitive psychology, reaction time measurement, motor response testing, attention response testing, and evaluation of the effects of stress on vision.

Researchable Issues

The panelists' discussion revealed several issues that require further research regarding the visual ability needed for driving. This additional research involves the following areas.

- Derive an operational definition of good driving performance as it relates to vision. Specific behaviors should be identified that either hinder or enhance driving performance.
- Evaluate the effects of the visual environment on driving performance. Research ways that the visual environment can be made more conducive to good driving performance.
- Study the implications of the different minimal vision requirements used from State to State. Determine realistic minimal vision requirements that would become the standard used in every State. These minimal requirements may relate to more visual attributes than the visual acuity measurements that are currently used.
- Design tests that will measure all visual characteristics that affect driving performance.
- Standardize visual testing in all States. The testing should use a two-tiered approach that begins with screening at the licensing agency. It should also include referrals to practitioners for further testing. Areas to be tested in this approach are listed in the foregoing recommendations of the panelists.
- Research the feasibility of maintaining vision-screening records and using them for follow-up information for public health services.
- Determine the training needed for personnel who will conduct first-tier testing and for practitioners who will conduct the follow-up, second-tier testing.

Functional Capabilities Assessment

The planning session on Functional Capabilities Assessment was led jointly by Dr. Patricia Waller, director of the University of Michigan Transportation Research Institute, and Dr. Sheldon Retchin, chair of the Division of Geriatric Medicine at the Medical College of Virginia. The session focused on assessment of driving tasks and research related to the various aspects of driving performance. It concluded with a range of researchable issues.

Driving Tasks and Driving Performance

The group unanimously agreed on the need for both an analysis that defines driving tasks and a validation of these tasks. Although the need for definitions in this area was heartily endorsed, some concern was expressed that this type of research might not be funded. The group emphasized that (1) direct observation is necessary to determine which behaviors are peculiar to older drivers, and (2) observational studies for older drivers' behaviors should be a priority.

Members of the group also endorsed an outcome analysis. While accidents and deaths were concerns for the group, a task analysis of specific outcomes that appear to be related to age was a high priority. These outcomes include various traffic violations such as disobeying signals, merging and changing lanes improperly, and executing left-hand turns inappropriately. The group felt that the tasks associated with these specific maneuvers needed both description and validity testing.

A common language and definitions for driving tasks, outcomes, health status variables, and methodologies are also needed.

Multi-Disciplinary Approach

A multi-disciplinary approach to research in this area is needed because results from previous studies cannot be generalized sufficiently to the field of the older driver. The group recommended that research projects linking function and performance use multi-disciplinary teams that include experimental psychologists, epidemiologists, clinicians, health care workers, public health officials, motor-vehicle division officials, and other policy-makers depending on the nature of the research.

State Standardization

The group expressed concern that no uniform structured data collection takes place at the State level and that there was tremendous variation among States in the evaluation of the data. Although the Federal Government is prohibited under the Truth in Information Act from collecting personal identifiers, it could ease public access to data pertinent to research.

The group discussed establishing a task force or committee to recommend greater standardization of data across States.

Dr. Retchin described the data base that the Centers for Disease Control (CDC) is currently setting up in cooperation with NCHS. This network, which will be operational in the next year and a half, will enable States and localities to calculate accident rates.

Designs, Distributions, and Biases

The group endorsed both cohort and case-control research designs. Because cohorts may be difficult to assess due to the rarity of significant outcomes (i.e., traffic violations, accidents, deaths), the group recommended that "piggyback" funding be encouraged for cohorts studies using "nested" investigations. Furthermore, the group also endorsed case-control designs that pursued specific outcomes, recognizing that care must be exercised to avoid significant bias. The group emphasized the need for the largest data base possible since the accident incidence rate is low.

The distribution of the tasks associated with driving should first be used to define the variables that are particularly predictive of poor driving performance. Therefore, the bottom portion of the distribution of performance should be emphasized. Data on psychomotor slowing, which shows that some older persons are particularly affected by slower reaction times, were cited. The group also emphasized that the older adults appear to be extremely variable in performance characteristics and that this variability should be taken into consideration for any mechanism of testing.

The group members discussed biases in the data both from a violation perspective—e.g., that police may not cite women and the older adults as readily as youngsters in sports cars—and from a health perspective.

Remediable and Asymptomatic Measures

Research related to driving should emphasize the identification of functional status and severity of illness variables that are remediable. Current research appears to show that older people reduce their driving frequency and practices according to many aspects of functional decline. Those functions and environmental variables (e.g., vehicle design) that can be modified should be a high priority.

The group felt that some functions are not easily identified by older persons, and that this issue should also be emphasized as a high research priority. Among these functions, mental status was highlighted. The group also discussed a need to research areas in which the individual is not aware of his or her limitations and to evaluate health and driving performance. Testing may be required to reveal deficits of which the driver is unaware, such as reduced visual field following a stroke. Diagnostic test batteries are needed to ascertain the progression of Alzheimer's disease, because victims become less aware of their limitations as the disease progresses.

High-Risk Situations

The group also considered a research focus on situations in which the older adults are at high risk and discussed the difficulty with this approach. Although physicians can produce lists of medical impairments involving driving accident risk, few conditions, outside of alcoholism (which is not a major problem for the older adults), are known to be risky in a definite way. Older drivers are not associated with speeding but are associated with failure to yield the right of way, improperly merging and negotiating intersections, and driving the wrong way on one-way streets.

There was some discussion of the role of situations involving stress and divided attention, such as a child running in front of the car and other passengers being in the car. The group felt that, even if such situations were modeled or simulated as part of a driving test, responses in the test would not be predictive of future behavior in the same or similar situations.
Dr. Retchin cited the need for examining the environment for older drivers when studying high-risk situations. He described the case in which a number of accidents were reported at a specific location, which consisted of a home for the older adults on one side of a broad street and a grocery store on the other side. Rather than any particular subgroup, all the older adults were at risk. Another case, reported at the CDC conference in San Antonio, occurred on Queens Boulevard in New York City. Many older people were killed on what was the widest street in the city. Some relatively minor changes in traffic control reduced fatalities and serious injuries by 40 percent.

Research Studies

Dr. Patricia Waller described assessment measures developed to indicate overall level of functioning. One such scale was the Abbreviated Injury Scale, developed by the American Association of Automotive Medicine (AAAM). This scale determines the extent of threat to life but does not correlate well with final outcomes.

Dr. Julian Waller has developed a scale known as the Functional Impairment Scale. Although this scale determines the extent of functional impairment, it does not take into account overcoming injury effects through compensation mechanisms. Scales that indicate driving ability have also been developed by Gatz, Rousseau, and McKnight; however, these scales fail to correlate with accident risk.

Dr. Retchin cited the difficulty in using what is known at the present time to predict risk over a licensing period 1 to 4 years from now. He emphasized the need for a system of predictive values. He also addressed normative aging and the difficulty a physician has in looking at the information available to him or her (basically physiological and pathological) at a point in time. From this limited information, the physician must determine not only which conditions are likely to impair an individual over the next 3 or 4 years, but also how to modify the effects of one condition when others are present.

The group also expressed concern that, even if the relative risk of crashing could be determined, the criterion for allowing an individual with high risk to drive would still have to be agreed upon and formulated into policy. Furthermore, even if the relative risk of crashing were an available measurement, it would still ignore factors of judgment and compensating behaviors that ultimately affect driving outcomes.

There was some discussion regarding the severity of illness model proposed by Dr. Retchin at the plenary session. Dr. Retchin emphasized that no one has yet developed a disability scale for driving behavior. Current scales only consider if the individual can drive; they do not address issues of highway safety and levels of risk. Current scales also lack the level of sophistication needed. Further work for a model that could be easily exported is needed in this area and case-control research may be the only way for initial studies to address this topic in the near future.

Dr. Adrian Ostfeld, a physician epidemiologist at Yale Medical School, described two studies that have recently been funded by NHTSA through the National Institute on Aging (NIA)-sponsored Established Populations for the Epidemiologic Study of the Elderly (EPESE). Dr. Ostfeld is the principal investigator on the New Haven EPESE, which is collecting data on driving behavior and driving records in an urban setting. Dr. Robert Wallace is the principal investigator of an EPESE in Iowa, which is collecting data on the driving behavior and driving records of two rural Iowa counties. These two EPESE have more than 8 years' medical condition and functional capability data on over 5,000 cohorts.

Dr. Marsha Wolf, of the Harborview Injury Prevention and Research Center, described a case-control study currently under way, sponsored in part by NHTSA, of older drivers injured in accidents who were group health enrollees. Crash reports were obtained from the police departments and State highway patrol. Medical records were obtained from health maintenance organizations (HMOs); driving histories were obtained from police departments and motor vehicle divisions. A mail survey is being conducted to further ascertain amounts of driving, when done, use of alcohol, use of seat belts, etc. All data were indexed to the year prior to the crashes, in 1987-1988. They have identified more than 300 cases, with two controls matched with regard to age, gender, and county, per case. Whether the older driver caused the crash was determined from the description of the crash and violation citations.

The issue of individuals with multiple accidents was considered. One member of the group described a study in which 6 to 7 percent of the population of a subgroup in North Carolina was responsible for 100 percent of the accidents in one year; the next year, another (different) small group was responsible for most of the accidents. Dr. Waller rose to defend the older driver, reminding the group that neither multiple crashes nor multiple violations are associated with older drivers.

Researchable Issues

Researchable issues evolving from the session were the following.

- Develop techniques to identify and correct remediable causes of performance impairment.
- Determine the effects of multiple interacting performance deficits that would be found more frequently among older drivers.
- Determine sets of minimal functional performance conditions under which older persons should stop driving temporarily or permanently.
- Conduct cohort analyses to relate crash rates to performance impairments in older drivers.
- Compare self-reports with observer reports regarding effects of age-related impairments on driving.
- Obtain data on driving with functional impairments from studies of handicapped drivers, particularly older drivers.
- Summarize all driving-related function performance characteristics and their specific limitations as found in older drivers.
- Compare functional performance of older drivers and older nondrivers.

- Determine age-related changes of driving-related functional performance.
- Determine the positive impacts of driver training, safety consciousness, and physical fitness on driving performance.
- Study decreases in cognitive abilities with normative aging, particularly relative to attention span, memory, divided attention, attention switching, symbol recognition, problem solving, and self-orientation in space and time.
- Compare performance functions of older drivers with dementia versus healthy older drivers.
- Evaluate current procedures for identifying older drivers with medical conditions.
- Identify diseases and handicaps of older adults that have potential for causing defective driving.
- Determine how medicine use is associated with increased crash risk as a function of age in older drivers.
- Study driving behaviors of patients in Alzheimer's centers.
- Study the effects and incidence of undetected, unsuspected, and incipient disease and their variations with age of older drivers.
- Determine the prevalence of functional impairments in older drivers.
- Determine the extent of functional impairments due to the most common diseases and conditions of older adults, including vision loss due to cataracts or glaucoma, ischemic heart disease, stroke, diabetes, alcoholism, dementia, arthritis, and osteoporosis, and due to the use of medications including polytherapy, as well as fatigue, stress, inattention, decreased tolerance to injury, physical or mental handicap, and frailty.
- Study crash sites where older drivers are disproporticnately involved to determine characteristics of the sites that increase crash risk.

Driver Intervention

The planning session on Driver Intervention was led by Raymond Peck, chief of the California Department of Motor Vehicles' Research and Development Section. Mr. Peck opened the session by stating that any consideration of research needs regarding older driver intervention should begin with a review of what is presently known about the effectiveness of intervention programs and a consideration of the larger context of the transportation system in which intervention programs are embedded.

Intervention Schema

To facilitate the discussion of the overall context of driver intervention, Mr. Peck distributed a conceptual schema to the group members. This schema, provided in Figure 8, illustrates how older drivers come to the attention of driver license authorities. The various ways are:

- At time of license application or renewal, poor performance on licensing tests (written, vision, road, psychomotor), or observed inappropriate behavior.
- Referrals and reports from physicians (e.g., voluntary reports, responses to State medical reporting laws, DMV referrals to physicians for vision and medical exams, etc.).
- Reports from relatives and others.
- Self-reports (e.g., answering "yes" to physical and mental questions in driver license renewal application) or personal request for re-examination.
- Reports from traffic police and traffic courts (e.g., police or court observation of disabilities, mental problems, and disorientation).

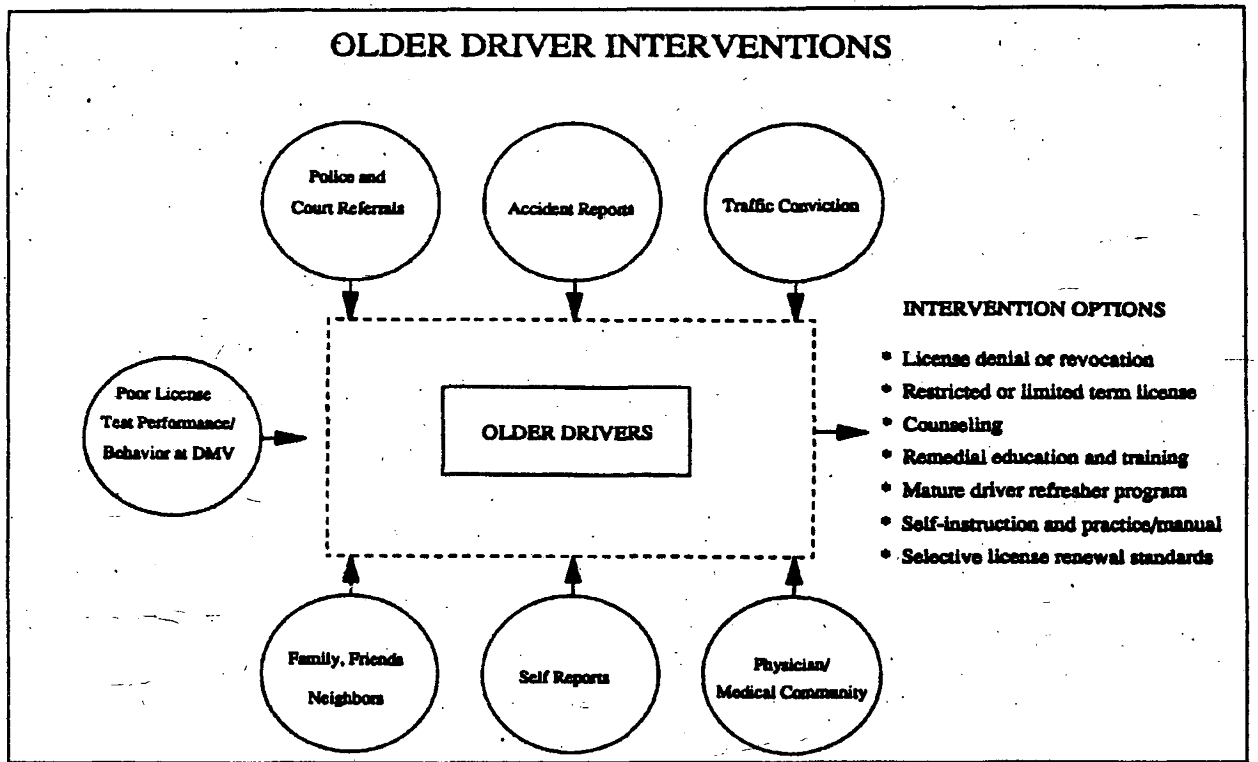

Figure 8

- Accumulation of accidents and traffic violations.

One caveat Mr. Peck gave was that interventions can't be fully separated from assessments because the assessment identifies the characteristics of the intervention.

Although State DMVs have been the major conduit for the delivery of interventions, other mechanisms do exist. For example, many States have established mature driver improvement programs such as the American Association of Retired Persons' "55 Alive" for which older drivers may volunteer and receive insurance premium reductions. The National Safety Council (NCS) offers a defensive driving course (DDC), and various private, community, and insurance-sponsored programs are available. Finally, pertinent articles also appear from time to time in various publications likely to be read by the older driver.

Mr. Peck completed his background material by reminding the group that a comprehensive identification of research and development needs should consider all components of the older driver/risk management process: (1) accident risk level; (2) characteristics of the identified deficiencies; (3) reliability and validity of the problem assessment; (4) effectiveness of the intervention in reducing accident risk and improving driver competency; and (5) older driver transportation needs and availability of alternative transportation mechanisms.

Current Interventions

The following types of actions and interventions are currently used by some or most States as methods of controlling age-related driving problems:

- Denial of license privilege to older drivers unable to pass the prescribed tests.

- Use of license restrictions (area, time of day, etc.) for older drivers exhibiting marginal performance.

- Issuing licenses for limited terms based on evidence of declining skills or other functional abilities.

- Selective renewal requirements (e.g., passing additional tests, exclusion from renewal-by-mail programs, periodic medical examinations).

- Voluntary enrollment in driver improvement programs (e.g., 55 Alive, DDC program, etc.).

- Informative materials in brochures, driver's licensing handbooks, mass media campaigns, newspapers, etc.

- Influence of community support groups and "significant others" that lead to self-restriction and voluntary surrender of license.

- Insurance premium reductions for those who restrict their driving.

Current Intervention Research

Research on renewal testing requirements for the older driver has been inconclusive. California (Janke and Kelsey, 1981) has shown that drivers aged 70 or older receiving license extensions by mail had significantly fewer accidents than their age peers in a regular renewal testing control group over a 2-year period. A later California evaluation (Kelsey et al., 1985) covering 4 years of driving found no significant difference for the original older adult sample (who had undergone an intervening in-person renewal). Before release of the Kelsey report, renewal policy had changed restricting renewal by mail to those younger than 70 and allowing those under 70 to obtain successive 4-year extensions. A recent unpublished report (Janke, 1988) on persons not tested for 12 years revealed few health problems, but about 27 percent of those aged 55 or older had new vision restrictions (corrective lenses or daytime only) placed on their licenses. (This is not to say that they were previously unaware of their vision problems or that these problems had not already been corrected.) A study in Israel (Zaidel and Hocherman, 1986) found that only about 7 percent of drivers over 64 who wore glasses stated that they had learned about their vision problems as a result of the license renewal vision test procedure. These authors conclude that Israel's elaborate renewal process for older drivers had no impact as a screening device and "has no proven diagnostic-remedial value."

Several studies have shown license withdrawals to be effective in reducing accident risk. Although these studies largely involve younger and more deviant drivers, it seems safe to conclude that older drivers would be less likely to violate license suspension. Therefore, license suspension should considerably reduce the risk of accidents involving older drivers. Retrospective pre-post statistical studies of drivers revoked for lack of skill or for physical disability (groups largely comprised of older drivers) show strong evidence of fewer accidents when license revocation is enforced in these cases. (Janke et al., 1978). Popkin et al. (1983) also reported substantial reductions in accident rates when medical interventions are implemented.

Studies of driver counseling programs as an intervention method have shown somewhat promising results. Evidence from a well-controlled study by Helander (1985) shows that accident avoidance counseling sessions are effective countermeasures for drivers contacted on the basis of an accumulation of accidents. An older driver counseling program was instituted in Oregon to assist drivers in evaluating their skills and preparing for their upcoming renewal test. A very preliminary evaluation revealed that substantially more drivers in the experimental group voluntarily surrendered their driver licenses.

Stylos and Janke (1989) conducted a prospective statistical evaluation of California's mature driver program. Program graduates had significantly fewer fatal or injury-related accidents and traffic convictions both prior and subsequent to the program. Inclusion of the prior record and other variables as covariates reduced—but did not eliminate—the differences in subsequent records. Although the authors were very guarded in their interpretation, the study can at least be considered suggestive of a positive effect.

Future Research and Development Needs

Existing research focuses solely on the question of program effects on subsequent accident rates. A more fundamental question relates to the validity and scope of methods currently employed to identify and diagnose problem older drivers, and to deliver intervention programs tailored to their specific needs. There are currently no incidence or prevalence data on the proportion of older drivers exhibiting disabilities of various types nor any established method of testing for drive-task-relevant decrements caused by functional aging. The number of drivers identified through the various sources listed above is also not known.

A pivotal question concerns the extent to which older drivers are aware of their deficiencies and adopt appropriate compensatory mechanisms. It has been commonly assumed that substantial adaptation occurs, and the fact that the amount of driving, amount of high-risk exposure, and vehicle speed decreases with the driver's age lends credence to this hypothesis. The results of the California study by Janke and Kelsey (1981) provide additional support.

However, it would seem prudent to subject this issue to empirical test. Assume that three groups would emerge: (1) those who are largely unaware of their deficiencies; (2) those who are largely aware and compensate; and (3) those who are largely aware but do not compensate. Under such a scenario, efforts could be primarily directed toward the first and third groups. The first group might be responsive to informational feedback, whereas the third group would be more likely to require license control actions.

Recent NHTSA statistics gathered from six States (Illinois, Indiana, Michigan, Minnesota, Ohio, and Wisconsin) indicate that the proportion of the older population who are licensed declines gradually to about the age of 75 and declines steeply after age 80. Nevertheless, even at age 80+, over 40 percent of the population holds valid licenses (for California, the figure is 38.6 percent). In the two States requiring a road test at age 75 (Indiana and Illinois), the licensing rates declined more steeply than in the other States. Based on California data, it is safe to conclude that most of the reduced licensure occurs voluntarily—i.e., the driver decides not to renew his or her license. However, concern over the renewal tests and the prospects of taking a road test are frequently cited by older drivers as reasons for the decision. One question raised by these data is whether the reduced licensure is a desirable objective and whether it is justified to impose added age-related requirements and hurdles to achieve this end. The answer to this question is not now known.

Researchable Issues

The participants identified 14 research needs pertaining to older driver intervention. Some of these recommendations relate to driver assessment. This linkage reflects the participants' belief that many intervention strategies are inextricably linked to some form of the problem identification process. The research recommendations follow.

- Evaluate the characteristics of older drivers who fail the current motor-vehicle division driving test or who otherwise drop out of the system. Determine if the right drivers are being failed.
- Determine the extent to which providing feedback from diagnostic testing, physicians, driver training, and counseling results in appropriate compensation and self-restriction.
- Develop and evaluate the effectiveness of age-tailored educational manuals and audiovisual self-assessment kits in improving older driver performance. Include information on alternative transportation features and restraint systems.
- Evaluate the utility and legality of driver record information (accidents and traffic convictions) in triggering diagnostic, remedial, and license control actions for older drivers. Such an evaluation should include an

assessment of whether the types of actions and point-count thresholds should be different than for younger drivers.

- Develop and evaluate a functionally anchored diagnostic and counseling protocol for use by physicians in advising older driver patients.

- Develop and evaluate an older driver graduated licensing system in which the driver's license terms and restrictions are tied to the driver's functional performance level, mobility needs, and other relevant characteristics. This research should include an evaluation of the array of restrictions, such as driving to and from a given destination during specific hours.

- Evaluate current procedures for identifying older drivers with medical conditions. Develop and evaluate an optimum system for communication among physicians, patients, DMVs, and medical advisory boards.

- Develop and evaluate a part-task driver simulator for assessing functional performance decrements and providing remedial training.

- Determine the extent to which older drivers are aware of, and appropriately compensate for, decrements in skill. Develop and validate appropriate interventions for those who are either not aware of decrements or who are aware but do not compensate.

- Develop and evaluate knowledge, vision, and driving tests tailored to the specific problems of older drivers.
- Determine if the tests should measure ability and impart information to improve subsequent driving or if they should screen out incompetent drivers.

- Conduct basic research aimed at determining if various age-related deficits in performance and in task-relevant information processing skills can be modified. Potential modifications in driver deficiencies should include driver factors, vehicle factors, and highway factors.

- Do a controlled experimental evaluation of the effectiveness of current and alternative mature driver program curricula. Determine if periodic refresher courses are needed and the optimum time period between these.

- Develop a driver test that is functionally related to accidents and age-related skill deficits. Determine the validity of the test as a screening device for driver license renewal.

- Develop and evaluate training and licensing programs tailored to the needs and problems of the novice (first-time) older driver.

References

In preparing his presentation to the planning session on Driver Intervention, Dr. Peck referred to several published resources. Set out below are selected citations.

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Vehicle Design

The planning session on Vehicle Design was led by Dr. Anthony Yanik, whose research focuses on the study of the older driver as he or she interfaces with the vehicle. Dr. Yanik identified the session's primary challenge as determining the research needed to expand vehicle design and engineering parameters that will encompass the needs of older drivers. To meet this challenge, research initially must establish the effects of the aging process relative to vision, hearing, cognition, and tolerance to injury as they apply to the driving task. Dr. Yanik then provided an overview of vision, hearing, cognition, and injury tolerance, and the research issues related to each.

Vision Impact

The earliest and most widespread changes that affect the aging driver vision changes. For example, the onset of presbyopia may make it difficult for drivers in their mid-40's to perceive controls and displays within near vision. So too, does gradual reduction in visual acuity, contrast sensitivity, and lens light transmission, which initially manifest in the early 50's. Color perception may determine how well defined the control displays appear: certain colors seem to have better definition than others. Steady declines in the visual field may impede the older driver's view of the road. Adaptation to the dark becomes prolonged. Low lens light transmission and a sensitivity to glare from oncoming traffic or from light reflected in rearview mirrors has been cited as the most significant reason why older adults reduce their driving at night.

New research to improve vision in the vehicle might include the following:

- Determine the relative eyes-off-the-road time that aging drivers can sustain when they switch focus to vehicle controls and displays.
- Determine an optimum mounting height for headlamps or investigate other means of controlling headlamp glare from following vehicles, especially from trucks, buses, and motor pool vehicles.
- Determine whether the average low-beam headlamp pattern is sufficient to meet the need of older drivers and explore technologies that would increase low-beam visibility without undue increase in glare.
- Acquire a better understanding of the older person's ability to learn to operate control systems representing a new technology, one that might make new demands upon memory and divided task competency.
- Investigate the effects of windshield tinting and other forms of glazing upon nighttime visibility and determine if there should be any change in the minimum threshold for a windshield's light transmittance.
- Study the effects of aging upon accommodation and convergence and determine its importance to the driving task. Explore the feasibility of devising technologies to meet any needs discovered.

- Determine the extent to which vehicle systems no longer can offset the declines in driving capability experienced through the aging process.

Hearing Impact

Hearing loss is a chronic condition of aging that is realized initially in the third decade of life. Usually the decline experienced is one of a sensitivity to high-frequency sounds and pure tones. One concern has been that of an older driver's ability to discern warning sounds either inside or outside the vehicle. Very few studies have attempted to establish the relationship between hearing loss and driving safety.

Research of hearing loss might answer the following questions:

- Determine whether hearing loss affects the driving capability of older adults.

- Determine whether it would be practical, safe, and effective to determine a means of detecting and communicating the sound of emergency vehicle warning systems (ambulances, police, fire trucks, etc.) within the vehicle.

Cognition Impact

The driver is called upon to respond to a continually changing series of events in the cognitive or decision-making process of driving. After each event is perceived, an appropriate response must be decided upon and made. The driving task is also complicated by secondary tasks such as operating the radio, the heater/air conditioning system, the wiper/washer system, or other controls.

Research has documented the latency in response times that develop as drivers age, the increased difficulty they experience with divided task operation, the effects of aging upon vigilance and judgment, and even the role of memory in habitual response operations. Little has been done, however, to study the effects of cognitive aging upon the driving task itself.

Relative to the role of cognitive aging within the vehicle environment, research that might be considered would be to:

- Evaluate the significance of control location expectancy upon the older driver's ability to respond quickly in a complex driving situation.

- Determine the precedence that older drivers give to secondary control systems such as the radio and heater/air conditioner during the driving task and evaluate the divided task capability of different age groups.

- Determine the extent to which different age groups are able to accept, learn, and operate new vehicle control systems.

- Determine the effectiveness of vehicle route guidance systems upon older drivers, especially those who are in the early stages of dementia.

Injury Tolerance

Evidence suggests that aging reduces a person's tolerance to crash forces, not only in terms of bone fracture, but in other forms of trauma as well. Research is needed that will relate aging differences to injury patterns, not just to fatalities. Such efforts might lead to a reevaluation of the motor vehicle safety standards that apply to occupant protection. Perhaps a compromise is needed between a standard's performance characteristics that are modeled upon high-energy collisions involving occupants with a high-injury tolerance and those based on lower energy collisions involving persons with low-injury tolerance.

The following research might be useful to vehicle engineers in providing occupant protection for older persons.

- Study the injury tolerance levels of persons in different older age groups such as 45 to 54, 55 to 64, 65 to 74, 75 to 84, and 85+.

- Apply the foregoing results to a study of the effectiveness of vehicle safety standards related to the protection of older occupants.

- Study the relative effectiveness of different restraint systems with older occupants.

- Study the trade-offs between mandating side impact performance requirements modeled upon high-energy impact tests involving dummies with high tolerance to injury characteristics, and performance requirements modeled upon lower energy impact tests involving dummies with lower tolerance to injury characteristics that are more representative of the older population.

- Study optimum mounting locations for hardware associated with active and passive safety belts to address changed physical structures in older adults.

A goal of meeting all the needs of both older and younger adults within the same vehicle may be neither possible nor desirable. On the other hand, many vehicle refinements designed with older drivers in mind also would enhance the vehicle environment for everyone, regardless of age. Seeking out such refinements should be this conference's initial goal since it holds the most promise. Whether vehicles should be designed specifically for older persons, however, is a question that can be answered only when more is known about these issues.

Researchable Issues

After discussing the panorama of potential issues, the group decided that the first priority of new research should be to determine the specific capacities and limitations of mature drivers. To this end, group members proposed that research develop a design driver that would represent each of the different older age groups (e.g., 50 to 60, 61 to 70, 71 to 80, and 80+) or a combination thereof. This design driver would provide information on the mature driver's motor strength, anthropometry, hearing capability, cognitive ability, tolerance to injury, attention levels, response to fatigue, and need for security. This information, in turn, would provide industry with the human factors data necessary for the following development programs:

- Making controls and displays more accessible and legible.

- Communicating vehicle status information correctly.

- Making seats that are more comfortable and less fatiguing.

- Providing occupant protection more suitable to an aging population.

- Providing improved handling.

- Improving nighttime driving visibility via headlighting and appropriate windshield and other glazing surface transmittance values.

Also, the group suggested that a concept or corrective car should be developed in which the human factors, determined through research on the different age groups, could be demonstrated.

The above recommendations were developed from a list of research priorities that were suggested in the morning planning session. These priorities are divided into two parts: research that would be more appropriate for industry to conduct, and research that would be more appropriate for government to conduct.

Industry Issues. Researchable issues developed in the session that would be appropriate for industry to conduct relative to the mature driver follow.

- Investigate mirror designs to improve indirect visibility.

- Develop parameters for improving seat comfort and convenience.

- Research the means for improving restraint accessibility and performance.

- Investigate stowage of mobility aids (wheelchairs, walkers, etc.).

- Study the effects of windshield angle upon light transmittance.

- Study the effects of aging upon the use of controls and displays.

- Establish the parameters for good display design.

- Develop measures to improve nighttime visibility by investigating the feasibility of such technologies as polarized lighting, midbeam headlamps, etc.

- Determine the importance of nighttime security functions to older people, such as an automatic delay of lights-off functions, etc.

Government Issues. Researchable issues that the group felt would be appropriate for government to conduct relative to the mature driver are the following.

- Develop quantitative data on the basic driving-related physical and mental processes of older adults by age groups.

- Study the behavioral and physiological correlates or indices that would indicate the attention levels of mature drivers.

- Study the effects of fatigue on the capabilities of the mature driver and the relationship of fatigue to accidents.

- Develop ways to improve audibility of sounds such as horns, sirens, emergency warning systems, etc.
- Determine the informational needs of the mature driver.

- Study the need for nighttime driving.

- Study the effects of road and traffic glare on the driving task.

- Determine the thresholds of tolerance to injury among the different age groups.

- Provide a quantitative measure of the at-risk mature driver's accident avoidance capabilities.

Highway Design

The planning session on Highway Design was led by Dr. Mark Freedman, whose major research concentration is on the application of human factors principles to transportation, engineering, and traffic safety issues. Dr. Freedman began by identifying several issues that he felt should be addressed involving older adults' driving performance and how that performance relates to highway design. He then surveyed the group on all potential issues, reviewed completed research relating to these, and distilled the group's ideas for final researchable issues.

Potential Issues

Dr. Freedman noted that although research has addressed the performance envelope of older drivers, that envelope is not fully quantified. Even when all key aspects of driver performance become known, significant gaps will still exist in the knowledge of problems specific to older drivers. There is not yet a general understanding of the relationships between the set of performance variable levels and driving safety, crashes, and violations. Dr. Freedman proposed that an extensive longitudinal study, of the type often used in biostatistical or epidemiological research, be performed to better understand the relationship between health performance levels and safety. The study would relate physical health and capability to driving safety in much the same way that eating habits, exercise, and life-style relate to cardiovascular wellness.

Several members of the group suggested approaching older drivers directly to get their perspectives on the factors that constrain their mobility. The fact that older drivers are self-selecting indicates that they are perceiving problems at certain times such as at night or during rush hour. Better identification of these problems could lead to solutions that would extend the driving period. While some members of the group recommended efforts toward enabling night driving, others expressed concern about putting the older driver in a situation that might not be in his or her best interests. The group briefly discussed the moral implications of night driving, considering that it might put older people in a threatening environment, which would still restrict their mobility and would make the situation worse.

Many group members brought up the need for design homogeneity, both in roadway geometry and in integrated traffic control guidance systems. They described a heterogeneous population being forced to use a roadway that perhaps was designed for a vary narrow subset of the population and that does not satisfy the needs of a much broader subset of the population. Older drivers are more highly compromised than younger drivers in safely and efficiently performing the driving task because of design discontinuities and the inadequacies of maintenance in keeping the system up to or close to its optimal characteristics. The basis for accommodating older drivers is the same as the basis for accommodating any other driver on the road: the driver's expectations should not be violated. Current roadways continually violate driver expectations.

There was much discussion in the group on the need for standards. One person emphasized a need for standards to be in the Manual on Uniform Traffic Control Devices (MUTCD), the "green book," the Federal regulations, and other documents that are often used by engineers. These documents govern how and when Federal monies are applied, and engineers are responsive to them. One group member stated that there are very few standards and very few mandatory characteristics that all jurisdictions have to observe in the highway design and traffic engineering environment. For example, the Code of Federal Regulations mandates that every State highway should have a skid-resistant surface; yet there are no standards for skid resistance on the nation's highways. There is also a need for a common terminology to bring engineers and social scientists together. No commonality of a tight construction framework exists in which to discuss the topic.

One group member stated that there is no specific targeted safety evaluation standard for any safety construction program activity in the Federal aid program; i.e., the majority of Federal aid projects involving reconstruction/rehabilitation do not need to meet any specific thresholds or performance standards. Dr. Freedman responded that a great deal of current research addresses many of these problems, and that much of this research is conducted to provide input to the standards recommended by the Office of Traffic Operations (OTO). He also pointed out that OTO is becoming more specific in the MUTCD and other kinds of documents that provide direct operational and design guidelines for the traffic engineering design community.

A group member brought up the fact that models for highway capacity do not currently address age distribution. Signal timing is primarily a volume- and delay-based simulation procedure, and intersection capacity is primarily speed- and delay-based. Dr. Freedman commented that even if the effect of driver age distribution were to be studied beginning now, it would be years or more before there is a version of the capacity manual with driver ages as a variable.

The group identified some specific older driver behaviors or diminishing abilities that could be addressed in highway design research. Dr. Freedman noted that a left turn at a complex intersection is the greatest documented problem for older drivers. However, the issue of vehicular traffic signals was conspicuously absent in the TRB 218 Report. There was also no mention of traffic signal brightness, size, or color. Although color does not seem to be a problem, color sensitivity shifts among older drivers should be addressed.

One group member spoke to the need for determining which signs need to be larger and which need to be redundant. Another member spoke to issues of luminosity and contrasts of brightness. Speed variance was also nominated as a potential issue. It was noted that the Federal Highway Administration has done some work on speed variance, but had not targeted older drivers as a group. Some operational measures such as separating trucks may have special benefits for older drivers. A group member mentioned that a study of visual complexity in nighttime driving revealed that lower spatial frequencies were important in getting a pathway for a driver to follow. This study may have implications for how roadways ought to be delineated. Optimal markings might be defined for the lane itself or contrasted with shoulder treatments or adjacent lanes. Larger spatial frequency treatments are resistant to visual degradation in situations such as rain and blurred vision and might alleviate any problems. A greater use of medians is another possibility. However, one group member voiced concern that many recommendations—including TRB recommendations—do not match accident characteristics. For example, single vehicle accidents such as running off the road are thought to be a problem, but older drivers have few problems with delineation and only minimal problems with signs. Yet the need for signs is continually pointed up. Research and recommendations need to be more closely tied to what accident data identify as the problems.

The group also touched on research in the area of deceleration, particularly stopping versus maintaining control of the vehicle. A 50-feet-per-second stopping rate is easy to achieve, but there is a good chance of swerving: the driver is always making a trade-off between those two factors. Some of the research in this area has been questionable, because much has been based on a worst-case design scenario without clearly stating that assumption. The issue is whether the near-panic stop is a comfortable stop or a complete panic stop. There is a similar issue in acceleration and start-up delay time. The scenario needs to be better defined.

Congestion is a concern of traffic engineers in places such as Phoenix and Florida where there is a disproportionate number of older drivers in the traffic stream. There is a ground swell of activity among policy-makers and the auto industries to alleviate congestion. No data are available to specify how older driver behavior contributes to congestion.

A member of the group introduced the problem of determining the effectiveness of highway design changes in measures other than safety. He stated that even if all changes that the group and TRB 218 recommended were implemented, he doubted there would be a significant decrease in highway fatalities. And if outcome measures are not based on safety measures, there is even greater difficulty with measures of effectiveness.

The group briefly discussed "trailblazing," a term recently used for the concept of navigating in traffic. Many older drivers perform pre-trip planning before going somewhere new. Before they leave the house, they write a sequence of directions, which they then place in the car next to them. They use these directions instead of a map. This situation leads to problems in navigation. One new approach to this difficulty enables anticipation of problems before they occur. This approach is an in-vehicle navigation system—probably a visually based system, although there may be some auditory components as well. It is hoped this system will consider the needs of the older driver. It is expected to become operational in the year 2000 and beyond when the older population will increase. At least initially, older drivers will have some problems with accommodation considering the displays that are being offered. These issues seem to be vehicle design but are highway related, too. A device of that type could be used for two purposes: to help determine the driver's performance envelope and to help evaluate traffic control device design changes.

A member of the group noted that young drivers, not older drivers, pose the greatest problem. This member also noted that there are other priorities for the nation's roadways: bridges are falling apart, roads are crumbling, sewers are exploding. Another member pointed out, however, that these needs translate into vast amounts of money for which there is much competition. He emphasized that recommendations for research and standards must be evaluated in terms of how they can aid everyone, and not just the older driver.

Completed Research

Following the discussion of potential issues, Dr. Freedman surveyed the group to identify completed research of which the group members were aware. He asked the group to consider what research is taking place and to what end it is directed and also to identify research that has been completed but has not been applied to the potential issues identified.

One member described a recently completed project that studied what States are doing with older driver pilot projects. States had been instructed to make improvements for older drivers, and the study was to evaluate these improvements and report on the results to Congress. Since only three projects were reported, additional information was requested. The responses indicated two facts. At first, State officials didn't think there was a problem until the TRB report was released. They then realized the validity of older driver needs. As a result of that report, activities are beginning in several States. However, States will not make changes until the problem gains national attention.

One member of the group asked about the research that NHTSA is currently involved with and if it is addressing the needs of older drivers. Another member reported that the Federal Highway Administration has a request for proposal out now involving traffic maneuvers, and—which specifically addresses problems of older drivers. He stated that NHTSA is also currently involved in a survey querying older drivers about a number of issues that concern them, including driving factors such as lights and brightness.

The same group member also described current projects that are examining building specifications for traffic control requirements. A controlled field study tested certain basic driving maneuvers on a closed highway section with a large sampling of older drivers. This study provided an initial knowledge base on maneuvers such as stopping from various speed levels, changing lanes, and adjusting speed. This study is encouraging, because it gives a rational basis for the assumption that a specific amount of time and distance are required to make a lane change from 55 mph. This evidence will indicate the mean distance and variability within age groups. Evidence of this type can be used as a basis for future design recommendations.

A model based on contrast has been developed that focuses on work done by Blackwell. Contrast sensitivity is the ability to detect fine detail at a particular contrast level as a function of age. Visual acuity is a subset of contrast sensitivity. The CIE model describes the basic visual process and has been incorporated into a broader highway model to predict the brightness requirements of traffic control devices. The validation that this model needs before it can be used as a general design tool is under way now.

The group also discussed simulators as a device for screening and testing. One member of the group cautioned against crediting simulators with more than they can do. He emphasized that an inexpensive simulator with a fuzzy 16 millimeter image cannot test driving performance in a way that is predictive of future behavior in the real world. Simulators are very effective in aviation and railroad operations and in the astronaut training program, where they are used—not for screening and testing—but for training. The group agreed that simulators that can accurately predict driving behavior will not be available for many years to come.

One group member also addressed the need for making research available to other research communities besides the traffic operations community. This conference has demonstrated the need for a better distribution of research because significant parts of most studies are focused on targeted areas. Geriatric and medical specialists have a great deal of knowledge about how older adults function and about their response capabilities, but they are not familiar with much of the design and function research that has been done.

Researchable Issues

Dr. Freedman surveyed the group members for issues warranting further research, and asked them to categorize the issues as either basic or applied research.

The researchable issues that the group considered to be basic research issues were the following.

- Develop a methodology to determine the design driver that will be useful to highway design policy-makers, based on trade-offs in economics, capacity and flow, and safety.

- Determine the limits of the performance envelope of the design driver for each of the parameters needed by highway designers and traffic operations analysts.

- Determine an understanding of the relationship between the proportional occurrence of the design driver in traffic and resulting highway capacity. For example, an expansion of the *Highway Capacity Manual* could be used with the driver age percentile level as a variable.

- Conduct a large-scale longitudinal study of the relationship between driver health and performance levels and highway safety as measured by traffic crashes and violations.

- Determine the incidence of unsafe and erratic driving behavior by older drivers exhibited within a range of roadway situations such as intersections, channelized areas, curves, and decision points, and determine the behavior's impact on traffic operations.

Dr. Freedman then directed the group to identify applications of current knowledge, specifically knowledge of sensory mode capabilities and decrements as applied to highway design standards and recommendations. Applied research recommendations included:

- Develop specifications for the family of traffic control devices that will satisfy the known performance limitations of older drivers and pedestrians; these include signs, signals, and delineations.

- Develop useful navigational aids ranging from highway information signs to pathfinder systems to advanced on-board navigational aids. These navigational aids should guide the driver into and out of destinations and should all be based on older driver performance limits.

- Attempt to eliminate inconsistencies in highway and vehicle design standards, which are regulated by separate agencies and are sometimes conflicting.

- Develop techniques to reduce speed variability and optimize operational parameters that describe traffic flow.

- Develop improved highway design criteria to better accommodate night driving.

- Develop an information dissemination network to inform all researchers and practitioners of primary and secondary research objectives and findings as well as data bases generated as a result of research in the medical, sociological, and highway design and safety areas.

Basic Research

The planning session on Basic Research was led by Dr. Alphonse Chapanis, President of a professional association providing human factors consulting services. Dr. Chapanis opened the session with a review of various remedies to reduce highway traffic accidents, such as highway and vehicle design, restricting various kinds of drivers, restricting the conditions under which some drivers are allowed to drive, and training the driver. He also reviewed the influences on an older person's need to drive, such as housing, organization of cities, availability of fuel, and the costs of alternative transportation. Dr. Chapanis then opened the session to a group discussion of basic research concerns.

Basic Research Concerns

The group agreed that preliminary research objectives should be to establish baseline measures of driving, perform a task analysis of driving, and study person-systems interactions (e.g., to judge older drivers' competence in relation to the driving environments in which they perform).

However, there are major obstacles to meeting these objectives. For example, task analysis of driving has failed in the past because it has been based on crashes, which reflect poor outcome measures. Some possible ways around the obstacles are to consider new methodologies for task analysis (e.g., Card, Moran, and Newell), to use the automatic-controlled distinction (see the discussion of the planning session on Cognition [Fisk] in Chapter 3), and to broaden the outcome measures to include self-reporting, collateral reporting, simulation, and standard driving tests (seeking convergent validity). Even with new methodologies and broadened outcome measures, however, the group agreed that the development of any matrix for what is safe driving is extremely complex.

Studies should also include the identification of driving behavior specific to the life-styles of different groups of older adults and longitudinal changes in driving patterns. Changes brought about by circumstance (e.g., retirement, change of residence) should be distinguished from changes brought about by self-restriction. (Work has already been done in this area by Ysander in Sweden and is noted in the TRB 218 Report.)

Health Issues

Current statistics on driving need to be broken down, not simply by age but by drug use, dementia, experience, etc. The interaction of vision and cognition in older adults and the relevance of this interaction in driving must be determined. Progress in this area hinges on obtaining valid measures of driving competence. With reference to psychomotor processes, the effects of peripheral and central changes should be separated. Also, arthritis must be separated into different classes of disease, each of whose effects on driving must be assessed. A lcose classification of arthritis on survey instruments will lead to unusable data. A greater understanding of the effects of arthritis on older adults and their driving behavior needs to be developed.

Drug and Alcohol Use

The group could not agree on the merits of a large-scale prospective epidemiological investigation of the effects of prescription drugs. Such a study has the unique advantage of providing baseline data on drug use and relating it to patterns of driving. However, the incidence of reported accidents involving drug use is extremely small. The data are therefore too limited to determine whether drivers in those accidents were taking the drugs in the doses prescribed.

A validated driving test is key in this research area. Drug effects on skilled versus unskilled drivers need to be evaluated. More research is needed and should be encouraged on drugs that lack behavioral toxicity. The study of polypharmacy effects (multiple drug interactions) is crucial for older drivers. There was considerable discussion about an appropriate methodology for investigating drug effects. The group did agree that further work along the lines of O'Hanlon's is sorely needed in the older adult population.

Group members also recognized the need to chart the effects of alcohol consumption on older drivers, taking into account the fact that absorption rates differ by age and that—to a limited extent—the effects of alcohol may also interact with skill level. Are older adults aware of the relatively prolonged effects of their alcohol consumption?

Recreational drug use is not seen to be a problem in the current population of older drivers. However, future cohorts may show different patterns given the (presumed) overall age distribution of drug use at this time.

Methodological Issues

The group discussed several methodological issues that arose during the session. Methodological needs and issues follow.

- Clarify the role of cross-sectional versus longitudinal studies as a way of understanding the dynamics of accidents and also of structuring a research agenda.

- Determine if large prospective studies should be conducted, considering the tremendous cost and sample size as well as the lack of scientific consensus on which baseline measures are most important.

- Determine if the endpoints in driver function can and should include near misses and accidents caused by, but not involving, the index driver.

- Focus on immediate areas of payoff such as medication use and accident risk.

- Distinguish between long- and short-term goals of modeling driver transportation modes. Long- versus short-term goals may differ with respect to understanding interactive systems, and vehicular, environmental, and traffic situations.

Researchable Issues

The session concluded with the identification of specific researchable issues. These were:

- Develop a model of the transportation needs of older persons, including mega-trends such as the availability of the automobile, the environmental consequences of fossil fuels, urban design, and family structure.

- Study spatial clustering of the activity centers to which the older adults need to drive and how to structure centers to reduce accident risk.

- Study the dynamics of the driver in a social context including the role of other passengers in the vehicle, the social reasons for the driving activity, and the costs and consequences of removing or restricting driving behavior.

- Study the trade-offs to society of alternative or decreased transportation for older people. Determine the budgetary costs of ill health due to accidents and the alternative uses of these funds.

- Study the specific functions of driving, particularly with respect to the person-machine interface.

- Identify the basic skills and tasks of driving and develop simulator methodologies and closed course driving procedures to test them.

- Establish comprehensive baseline measures by testing cohorts, including basic tests in driving simulators, and follow these cohorts to relate these baseline measures to accident risk.

- Study the relation of "stress" to accidents, that is, stress due to unfamiliar environments or vehicles or to restrictions in the use of such vehicles.

- Conduct a study to track changes in the older person's perception, cognition, and motor control.

- Measure the combined psychological and sensory systems simultaneously, e.g., study the relationship of vision and cognition function in accident risk. (Most research studies isolate the specific elements.)

- Determine the role of self-reports and collateral reports in understanding the dynamics of an accident.

Appendix A: Conference Agenda

RESEARCH AND DEVELOPMENT NEEDED TO IMPROVE SAFETY AND MOBILITY OF OLDER DRIVERS

AUGUST 23-24, 1989

BETHESDA, MARYLAND

AUGUST 23

8:30 a.m.	**OPENING SESSION**		
	Welcome	Adele Derby, Associate Administrator NHTSA Plans and Policy	
	Keynote	Patricia Waller, Director University of Michigan Transportation Research Institute	
9:00 a.m.	**PLENARY SESSIONS**		
	General Medical	Julian Waller, Presenter Robert Wallace and Sheldon Retchin, Discussants	
	Dementia	Alfred Kaszniak, Presenter Marilyn Albert and Penelope Keyl, Discussants	
	Cognition	Arthur D. Fisk, Presenter Lorin Staplin, Karlene Ball, and Leonard Ross, Discussants	
	Vision	David Shinar, Presenter Ronald Klein, Cynthia Owsley, and Frank Schieber, Discussants	
6:30 p.m.	**DINNER ADDRESS**		
	Introduction	Caryll Rinehart, Staff Committee on Public Works and Transportation U.S. House of Representatives	
	Address	Carlton C. Robinson Highway Users Federation	

AUGUST 24

8:00 a.m.	**PLENARY SESSIONS** (cont'd.)	
	Motor Control	George Stelmach, Presenter Alan Jette and James O'Hanlon, Discussants
	Medication and Alcohol	Wayne Ray, Presenter Jerry Gurwitz and Herbert Moskowitz, Discussants
11:00 a.m.	**PLANNING SESSIONS** (Seven Concurrent Sessions)	
	General Assessment	B.J. Campbell, Leader
	Vision Assessment	Herschel Leibowitz, Leader
	Functional Assessment	Patricia Waller and Sheldon Retchin, Leaders
	Driver Intervention	Raymond Peck, Leader
	Vehicle Design	Anthony Yanik, Leader
	Highway Design	Mark Freedman, Leader
	Basic Research	Alphonse Chapanis, Leader
1:00 p.m.	**LUNCH ADDRESS**	
		Matilda White Riley, Associate Director Behavioral and Social Research, National Institute on Aging
3:00 p.m.	**PRESENTATIONS OF RESEARCHABLE ISSUES**	
4:15 p.m.	**ORDERING OF RESEARCHABLE ISSUES**	
		Richard Pew Bolt Beranek and Newman Laboratories, Inc.
4:45 p.m.	**CLOSING REMARKS**	
		Richard Waxweiler Division of Injury Epidemiology and Control Centers for Disease Control

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Appendix C: Planning Session Attendees

General Assessment

Leader: Campbell

Baum, Blatt, Brown, Bylsma, Cerrelli, Cole, Cook, Cox, Hawley, Hyman, Jacobus, Kaszniak, Laux, Luchter, McPherson, Michaels, Monaco, Odenheimer, Oldak, Phillips, Radcliff, Ross, J., Staplin, Stelmach, Tarrants, Vegega, Wolfson

Vision Assessment

Leader: Leibowitz

Allen, Boffa, Briggs, Contee, Good, Harsh, Hertz, Higgins, Keeney, Klein, Kosnik, Owsley, Pain, Scheiff, Schieber, Sheedy, Shinar, Sturr, Szlyk, Waller, J., Whitener

Functional Assessment

Leader: Retchin/Waller, P.

Conte, Doege, Eberhard, Fozard, Gianutsos, Hadley, Hall, Hunt, Jacobs, Jette, Keyl, Lanze, Morris, Ostfeld, Ross, Sattin, Shipp, Sterns, Waxweiler, Wolf

Driver Intervention

Leader: Peck

Anderson, Ball, Blow, Boffa, Chorba, Christensen, Cushman, Derby, Fisk, Ganikos, Gurin, Gurwitz, Hale, Hedlund, Humphrey, Jonah, Kenel, Mancil, McKnight, Meadows, Ostrow, Ray, Rebok, Schnitzer, Smith, G., Smith, M., Stiles, Sweedler, Tannahill, Teed

Vehicle Design

Leader: Yanik

Albert, Beard, Bhise, Cheimets, Jeng, Knaff, Laster, Olson, Peacock, Perel, Pew, Pike, Quatrano, Richard, Smith, B.D., States, VanCott, Viano

Highway Design

Leader: Freedman

Dewar, Donaldson, Ehrlich, Fegan, Lerner, Lunenfeld, Mast, Nowakowski, O'Hanlon, Rodwell

Basic Research

Leader: Chapanis

Alicandri, Barr, Deal, Dickman, Gold, Hancock, Havlick, Howie, Jones, McCaig, McCullough, Moskowitz, Plude, Riley, M., Rinalducci, Tarrants, Temple, Wallace

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NRD-40